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Evaluation of physical and combustion characteristics of briquettes of palm fruit fibre and maize chaff using cassava extract as binder

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Abstract

The selection or choice of agro-waste briquettes for domestic and industrial cottage applications depends on the fuel properties. In this work, Palm fruit fibre (PFF) and maize chaff were separately sun dried for seven days to remove moisture. The dried materials were separately ground using electric milling machine. They were then reduced to mesh sizes of 1.18, 1.70, 2.36 and 3.35 mm respectively. Filtered liquid extract of cassava was collected and dried for five days to form the binder. Different concentration of biomass materials were prepared by blending palm fruit fibre at 20, 40, 60 and 80% concentrations with maize chaff. Shattering index, ignition time, water boiling time, burning rate, specific fuel consumption, percentage ash content and calorific values of PFF and maize chaff briquettes were investigated. Results showed that shattering index reduced with increase in particle size and increased with reduction in particle size. Highest and lowest durability were obtained at particle sizes of 1.18 and 3.35 mm respectively. The ignition time decreased with increase in particle size of briquettes. 1.18 mm particles give the highest ignition time (54.88 sec.) and 3.35 mm particles gave the lowest ignition time (24.24 sec.). Therefore, increasing the particle size increases the ignitibility of the briquettes. It was observed that the ignition time increases with increase in percentage composition of palm fruit fibre in the briquette samples with a maximum ignition time of 29.66 seconds at 80% PFF. The specific fuel consumption, shows that there was an initial increase from 50.0 g/ltr to 55.0 g/ltr, after which it decreased continuously with increase in particle size. Water boiling time, showed an inverse relationship with particle size. However, water boiling time between 2.36 and 3.35mm particle size has a more pronounced variation in comparison with preceding values. Higher calorific value 31,514.05 and 31,004.30 kJ/kg of PFF and maize chaff briquettes were recorded.

Keywords: Evaluation; Briquettes; Binder; Palm fruit fibre; Maize chaff; Particle size; Percentage Composition

1. Introduction

Lack of adequate power supply has been a long standing problem in Nigeria and this is associated with the country's slow development. Energy is a necessary requirement for everyday life. Its application ranges from domestic cooking, local and industrial food processing, household warming and other commercial applications. The combination of the power output from to national grid and energy sources is below 3000 MW (Okafor, 2009). This quantity is considered highly insufficient in view of the growing population of the country.

Energy and specifically oil and gas has contributed over 70% of Nigeria's government revenue (Sambo, 2009).The situation in the rural area of the country is that most end users of energy depend on fuel wood. Fuel wood is used by over 60% of Nigerians living in rural areas. Nigerians consume over 50 million metric tons of fuel wood annually (Rotimi *et al.,* 2013). Increasing pressure on forest resources for energy has led to what is termed "Other Crisis of Wood fuel" [Adeggbulugbe, 1994; Energy National Commission, 1998; and Akinbami). This has led to environmental degradation, deforestation and misuse of our forests. The uncontrolled level of cutting of wood for firewood and charcoal for domestic and industrial use is now a serious problem in Nigeria. One major way of reducing deforestation and protecting

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the environment is by briquetting of flammable materials. Briquetting is the process of conversion of agricultural waste by densification or compression, into uniformly shaped solid flammable materials to be used as fuel (“Briquettes”,http://en.wikipedia.org, 2013). It is the process of binding together pulverized carbonaceous matter, often with the aid of binder (Martin *et al*., 2008). Coal briquettes and biomass briquettes are common forms of briquettes. Agricultural wastes constitute a major source for biomass briquettes. The enhancement of the utilization of alternative energy source is achieved by conversion of biomass to briquettes and subjecting it to thermal process. The particle must bind properly during compression, otherwise the briquette might easily crumble. Heat, pressure, moisture and size reduction are considered in the process of making good briquettes [8].

The Binding material can be organic or inorganic agents. Heavy crude oils, starch and molasses are example of organic binders. while clay, sodium silicate and cement are inorganic binders. The binder type, amount of binder agent and water addition have significant effect on the combustion of briquettes (Altun *et al.,* 2003)].

In this work, Palm fruit fibre and maize chaff were reduced to particle sizes of 1.18, 1.70, 2.36 and 3.35 mm, cassava binder was used to produce briquettes of 40, 60 and 80 percent composition of palm fruit fibre and maize chaff. The influence of different particle sizes and percentage compositions on the physical and combustion characteristics of palm fruit fibre and maize chaff briquettes were considered. Properties like shattering index, water boiling time, burning rate, ignition time, percentage fuel consumption and calorific values were investigated. Palm oil plants are mostly found in Central and southern parts of Nigeria. The oil palm has a wide range of applications. The kernel is a major source of palm oil for cooking, the leaves provide brooms for cleaning the environment, the seed is a major source of oil used in the pharmaceutical and cosmetic industries. In oil palm processing the solid waste are; empty fruit bunches (EFB), palm fruit fibre (PFF) and palm kernel shell (PKS). Maize or corn is a cereal crop that is grown widely throughout the world in a range of agroecological environments. More maize is produced annually than any other crop (www.iita.org/maize, 2012). It is the most important cereal crop in sub-Saharan Africa and an important staple food for more than 1.2 billion people in sub-Saharan Africa and Latin America. Although grown more in the Northern part (Adamawa, Bauchi, Borno, Yobe, Jigawa, Gombe, Taraba, Plateau, Sokoto, Kebbi, Katsina, Nasarawa, Niger and Zamfara), maize finds its highest production in Nigeria. The national demand for maize starch in Nigeria is 800, 000 tons/ annum while the current national supply is 350, 000 tons/ annum. Two types of maize are grown in Nigeria—the yellow and white varieties. Due to its rate of adaptability maize is not a seasonal product. All parts of maize can be used for food and non-food products (www.foramfera.com/index.php, 2015). Maize chaff is the waste product of, usually disposed of by local farmers, gotten when maize peeled before being ground for food. This chaff burns easily because of its low moisture content. As a result, it is used for briquette production, either alone or as composite with other biomass material. Carbonizing and briquetting of blends of PFF and maize chaff will make for efficient and sustainable use of the product. This work is to harness blends of PFF and maize chaff to make a reasonable energy mix.

2. Material and methods

2.1. Materials

The materials used for fuel briquetting include:

- Agricultural waste like Palm kernel fibre and maize chaff (b) Cassava binder and
- Hand Mould

2.2. Preparation of Briquettes

The biomass materials for production of PFF and maize chaff briquettes were collected in large quantity from places where they were produced in large quantities. The production process begins with drying, size reduction and compaction. The raw PFF and maize chaff were sundried for 7days. The dried raw materials were reduced in size using a hammer mill. The particle size distribution was achieved using a Particle size distribution equipment consisting of sieve shaker and Tyler’s sieves of various diameters or particle size openings. This equipment forced the particles through the meshed screen by vibration. For this equipment, mesh sizes of 1.18, 1.70, 2.36 and 3.35 mm were used. Each of the compositions of PFF and maize chaff were measured and 20 % by weight of cassava binder was added to each of the samples after mixing with 100 cm^3 of water to form a paste. Agitating process was carried out in an electric mixer to enhance proper blending after which 5 cm^2 mould was used as seen in figure 1. The blends were briquetted under ambient condition and dwell time of 5minutes in a manually operated hydraulic power press having capacity of 196.2 N. Each particle size had briquette prepared for the four percentage compositions as represented in figure 2.

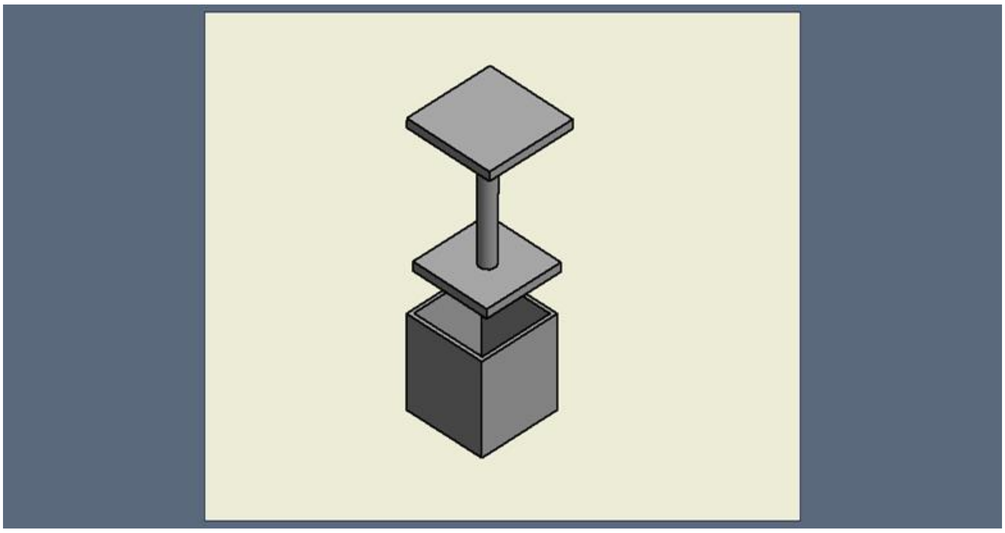

Figure 1 5cm[2] Mould Used for Briquette Production

Figure 2 Briquette Samples

The shattering index is a measure of the durability of the briquettes (Shuaibu *et al.,* 2015). The briquettes shattering index was measured according to ASTM D44086 (2002) of drop shatter developed for coal. After two weeks of briquettes formation, a set of briquettes of known weight (W_1) was placed in a plastic polythene bag. The bag was thrown onto concrete floor three times from a height of 2 m after the dropping; the briquettes and fractions were placed on top of a 35mm square mesh screen and sieved. The durability rating for each type of briquette was expressed as the ratio of weight of weight of material retained on screen (W_2) to weight of briquette before dropping (Shuaibu *et al*., 2015).

$$\text{Shattering index} = \frac{weight\ of\ briquette\ retained\ on\ the\ screen\ after\ drooping}{weight\ of\ briquette\ before\ dropping}$$

2 g of the briquette sample was weighed into a crucible and transferred into the furnace set at 55 ^{o}C and left for 4 hours. By this time, the sample had turned to white ash. The ash was removed and weighed after cooling to room temperature. The percentage ash content (PAC) was determined using the formula:

$$\text{PAC} = \frac{weight\ of\ ash}{original\ weight\ of\ sample} \times 100$$

The ignition time was determined following the method used by Onuegbu *et al,* (2010). Each briquette sample was ignited at the base with a cigarette lighter in a drought free environment. The time required for the flame to ignite the briquette was recorded as the ignition time using stop watch.

Water boiling test was carried out to compare the cooking efficiency of the briquettes. It measured the time taken for each set of briquettes to boil an equal volume of water under similar conditions. 100g of each briquette sample was used to boil 100cm^3 of water using domestic briquette stove.

During this test, burning rate was also determined. Burning rate is the ratio of the mass of the fuel (in grams) burned to the total time (in minutes) taken.

$$\text{Burning rate} = \frac{mass\ of\ fuel}{total\ time\ taken}$$

The specific fuel consumption is the ratio of the mass of fuel consumed (in grams) to the quantity of boiling water (in litres).

$$\text{SFC} = \frac{mass\ of\ fuel\ consumed}{quantity\ of\ boiling\ water}$$

The percentage volatile matter (PVM), percentage fixed carbon (PFC), and heating value (HV) were determined in accordance with the method adopted by Emerhi (2011). To determine the PVM, 2g of pulverized briquette sample in a crucible were placed in the oven until a constant weight was obtained. The briquettes were now kept in the furnace at a temperature of 550^{0}c for 10 minutes and weighed after cooling and the PVM was determined with the formula:

$$\text{PVM} = \frac{B-C}{B} \times 100$$

Where B is the weight of oven dried sample and C is the weight of sample after 10 minutes in the furnace at 550^{0}c. The PFC was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) from 100.

PFC = 100 – (PVM+ PAC) ………………………………………….. (9)

Heating value (HV) or calorific value was calculated using the formula:

HV = 2.326(147.6C + 144V) ……………………………………… (10)

Where C is the percentage fixed carbon and V is the percentage volatile matter (Bailey *et al,* 1982).

3. Results and discussion

Figure 3 shows the variation of shattering index and burning rate of briquette samples with particle size. The trend clearly indicates that the higher the particle size of the sample, the lower the shattering index or durability. 1.18mm particle size gave the highest durability (0.852 or 85.2 %) while 3.35mm particle size gave the lowest durability (0.544 or 54.4 %). Variation of shattering index and burning rate with percentage composition of biomass is represented in figure 4. Shattering index increased with increase in percentage composition of PFF and maize chaff. Maximum shattering index of 0.916 at 60% PFF with maize chaff was observed. The shattering index then tends to decrease with increase in composition up to 80% PFF with maize chaff. The range of values of durability obtained from this study compares favourably well with values of 45 to 85 % obtained by Shuaibu *et al,* (2015) for briquettes of sawdust residue, and 60 to 95 % obtained by Davies and Abolude, (2013) for water hyacinth briquettes.

The trend in Figure 3 shows that burning rate increased with increase in particle size. A maximum value of 1.89g/min at 3.35mm particle size. The trend could be as a result of briquettes with larger particle sizes having higher porosity because the higher the porosity the higher the rate of infiltration of oxidant and outflow of combustion/pyrolysis products during combustion and the higher will be the burning rate of the briquettes (Onuegbu *et al.,* 2010).

It can be seen Figure 4, that the rate at which the briquettes are used up with respect to percentage composition of PFF with maize chaff is sinusoidal in nature. 2 % and 60% PFF gave the lowest values of 0.84 and 0.85g/min while 40% and 80% PFF gave the highest values of 1.61 and 1.64g/min respectively. The values of burning rate obtained from this study are in slight deviation from values of 1.6 to 3.3 g/min. obtained for briquettes of coal and spear grass composite by Onuegbu *et al.,* (2010) and values of 3.7 to 4.35g/min. obtained for briquettes of empty fruit bunches (Kenechukwu and Kevin, 2013). This may be due to the fact that palm fruit fibre and maize chaff briquettes have lower volatile matter than spear grass briquettes.

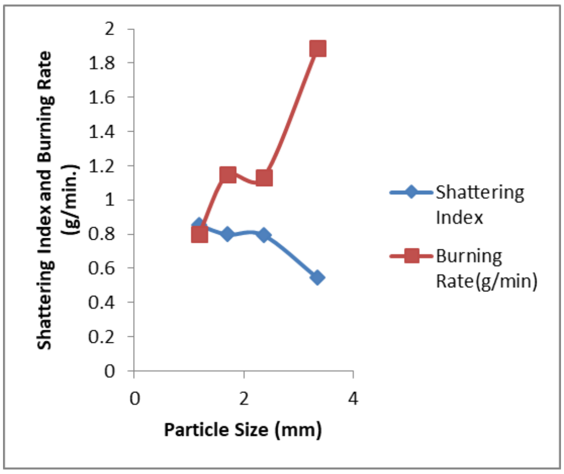

Figure 3 Shattering Index and Burning Rate against Particle Size

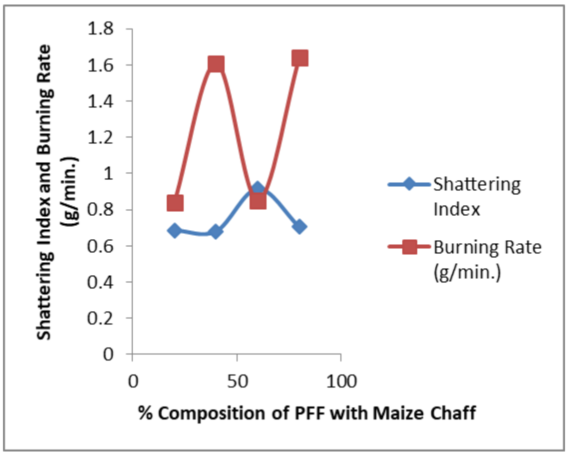

Figure 4 Shattering Index and Burning Rate against Percentage Composition of PFF

Figure 5 shows that ignition time decrease with increase in particle size of briquettes. 1.18mm particles gave the highest ignition time of 54.88 sec and 3.35mm particles size gave the lowest ignition time of 24.24 seconds. Therefore, increasing the particle size will definitely increase the ignitibility of the briquettes. It was observed in Figure 6 that ignition time increases with increase in percentage composition of palm fruit fibre in the briquette samples except for the decrease in ignitibility observed between 40% and 60% composition of PFF with maize chaff, after 60%, ignitibility continues to increase with composition of PFF up to maximum value of 29.66 seconds at 80% PFF. In Figure 5, the specific fuel consumption showed an initial increase from 50.0 g/ltr to 55.0 g/ltr, after which it decreased continuously with increase in particle size and the highest value of 55g/ltr was recorded by particle size 1.70mm. Figure 6 shows a somewhat sinusoidal progress of specific fuel consumption with percentage composition of palm fruit fibre and maize chaff. Briquettes of 3.35 mm particle size and 60% PFF will produce optimum fuel efficiency because they take lesser time and quantity to boil water than other samples. The range of values obtained from this study differs from 0.28 to 0.46 g/ltr for coal and spear grass composite briquettes by Onuegbu *et al,* (2010).

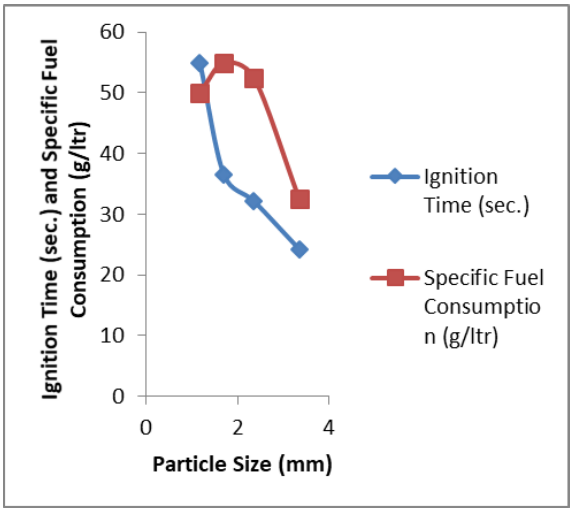

Figure 5 Ignition Time and Specific Fuel Consumption against Particle Size

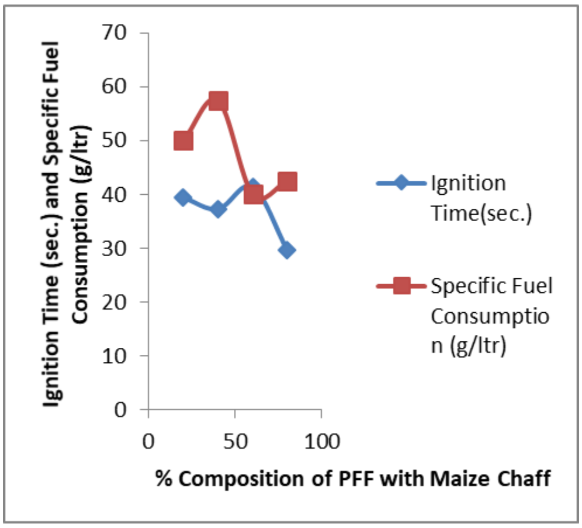

Figure 6 Ignition Time and Specific Fuel Consumption against % Composition of PFF

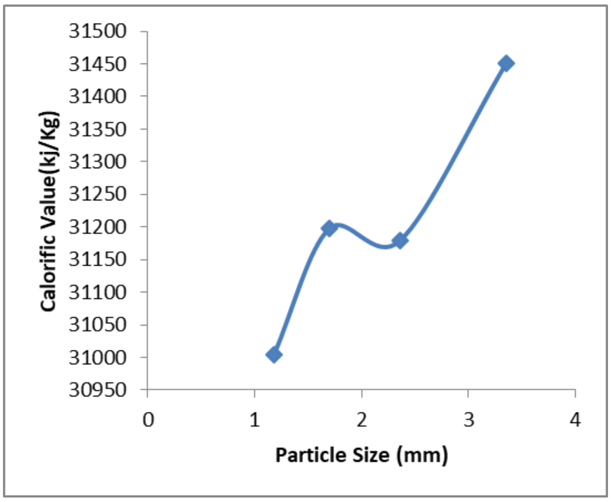

Figure 7 Calorific Value against Particle Size

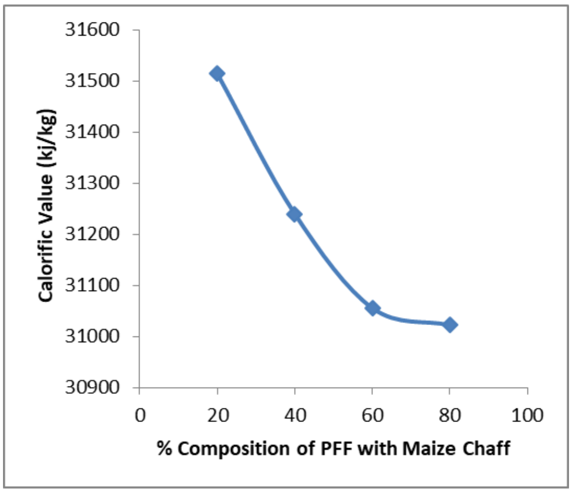

Figure 8 Calorific Value against % Composition of PFF

This could be as a result of higher cooking efficiency of coal compared to palm fruit and maize chaff composite briquette. However, values from this study shows a higher cooking efficiency of palm fruit fibre and maize chaff briquettes when compared to 202.5 to 460g/ltr obtained by Onuegbu *et al*, (2010) for briquettes of elephant grass and coal.

Figure 8 shows an inverse relationship between PAC and particle size, while Figure 9 indicates that the higher the percentage composition of PFF in the briquette, the higher the PAC. These relationships favour larger particle sizes (particularly 3.35mm) and lower composition of PFF (particularly 20% PFF). This clearly shows that higher percentage of maize chaff of larger particle sizes in the briquette produces lesser ash. The mean value of ash content obtained in this study is far higher than 0.7% minimum ash content recommended by DIN 51731 (Emerhi, E.A., 2011) but less than that obtained for briquettes of coal and spear grass by Onuegbu *et al*, (2010).

Briquette produced with particle size 2.36mm had the lowest ash content of 1.06%, 6.30mm had a moderate ash content of 1.20% while 4.75mm had the highest ash content of 1.23% (Adetogun *et al.,* 2014).

4. Conclusion

Briquettes were produced from mixture of Palm fruit fibre and maize chaff using starch as binder. the effects of particle size and percentage composition on the durability, ignition time, water boiling time, burning rate, specific fuel consumption, percentage ash content and calorific value of PFF and maize chaff briquettes was studied. Sequel to the results and findings of the research, the following conclusions were made:

Particle size and percentage composition have effects on all the parameters measured. Durability decreases with increase in particle size and percentage composition of PFF. Burning rate increased with particle size but oscillates with increase in composition of PFF. Ignition time, water boiling time and specific fuel consumption decrease in value with increase in particle size and percentage composition of PFF, except for specific fuel consumption values which fluctuates as composition of PFF increases. Percentage ash content of the briquettes decreased with increase in particle size but increased with increase in percentage composition of PFF. Calorific value is favoured by increase in particle size but decreased with increase in concentration of PFF in the briquettes. From all the particle sizes investigated, 3.35mm briquettes gave the best performance. 20% composition of PFF gave the optimum calorific value and percentage ash content, while 60% PFF offered the highest durability and cooking efficiency compared to other compositions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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