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Energy Evaluation of Various Compositions of Biomass Waste Briquettes

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Authors' contributions

This work was carried out in collaboration between all authors. Author ACU designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors CHA and JLC managed the analyses of the study. Author CHA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study focused on evaluation of energy values and performance of briquettes prepared from biomass wastes such as sawdust, rice husk and their composites using two binders (starch and clay) when fired in briquette stove. The briquettes produced are composed of locally sourced bio-wastes of uniform grain sizes (0.5 mm) and two binders in percentage composition of 90:10 which were sun-dried, prepared and compressed. Combustion-related properties (%volatile matter, % ash content, % fixed carbon and calorific value of raw materials) were determined for the sample materials (sawdust, rice husk and starch). Performance tests on 12 different briquettes which included water boiling time, burning time, ignition time, heating rate, fuel consumption rate and cooking efficiency test were carried out. The briquettes were subjected to energy evaluation tests using a bomb Calorimeter. The mean bulk densities of the briquettes produced from the different samples were determined. The test results show that the calorific value of mahogany sawdust, gmelina, oak, composite of mahogany/gmelina/oak, rice husk and gmelina/rice husk briquettes with binder starch were 4.516 kcal/g, 4.1487 kcal/g, 4.4312 kcal/g, 3.8614 kcal/g, 4.0531 kcal/g, 4.067 kcal/g respectively and with clay as binder were 1.9003 kcal/g, 1.5331 kcal/g, 1.8156 kcal/g, 1.2458 kcal/g, 1.4375 kcal/g, 1.4451 kcal/g respectively. The ignition time of 0.206 min, boiling time of 18.1 min, fuel consumption rate of 33.2 g/min and burning time of 42.21 min of mahogany briquette with

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starch binder is less than the values obtained for other briquettes while its cooking efficiency of 45.8% is greater than those of other briquettes. This therefore shows that it has better energy efficiency than other briquettes considered.

Keywords: binders; biomass waste; briquettes; calorific value; energy; heating rate; volatile matter.

1. INTRODUCTION

Biomass waste is a general term given to all organic wastes and dry plant materials and is characterized by a variety of conversion and end use. It has found its way as one of the favourable means of creating a cleaner environment, waste recycling to valuable products, renewable energy and inexpensive energy conversion etc. [1,2]. Examples of these include; sawdust, rice husk, palm kernel shell, groundnut shell, sugarcane bagasse etc. Again, the use of biomass fuel such as composite sawdust briquette has been found to be a good source of renewable energy for domestic cooking [3]. In the seventeenth century, the rural poor often burnt dried cow dung because of the acute shortage of wood fuel and widespread deforestation. The conversion of Agricultural by-products, wood waste and coal dust to high energy value briquettes for cooking and drying has been investigated and found to be feasible [4].

Furthermore, the importance of sawdust and rice husk as sources of fuel cannot be over-emphasized as it is readily available and cheap. Most often, it is usually dumped or burnt off at sawmill sites in Nigeria thus a lot of energy is being wasted and uncontrolled heat generated. Over the years, sawdust has been used for the production of heat and power in gasification plants and for domestic cooking [5,6]. This possibility raises the issue of how best to utilize this economical waste. Moreover, the production of biomass briquette contributes to income generation for microenterprises or any entrepreneur who produces them for sales. In this way, more money stays within the community rather than being exported for foreign fuels.

Briquetting can be defined as a process of converting loose biomass residue such as sawdust, straw or rice husk into high-density solid blocks that can be used as a fuel. Briquetting can be of two types - high-pressure briquetting and low-pressure briquetting. High-pressure briquetting uses a power-driven press to raise the pressure of dry, powdered biomass to about 1500bar (150Mpa) [7]. This in effect raises the temperature of the biomass and as a result melts the lignin in the woody (sawdust) material. Low-pressure briquetting can be used for materials with a low amount of lignin, such as paper and charcoal dust [8]. In this process, the powdered biomass is mixed into a paste with a binder such as starch or clay, and water. A press is used to push the paste into a mould or through an extruder or can simply be shaped by hand. The best materials for high-pressure briquetting are sawdust and woody residues because they contain a high proportion of lignin. However, most dry agricultural residues can be used if they are ground into a coarse powder [5,9].

Thus, this work seeks to investigate the energy values of different compressions of sawdust and rice husk briquettes using a bomb calorimeter. However, before measuring the energy values of the sawdust briquettes, binders for different briquettes were reviewed.

2. MATERIALS AND METHOD

2.1 Materials

The materials used are Sawdust (Gmelinaarborea, Mahogany, Oak) and Rice Husk. These samples were obtained from two major sources namely; Timber wood market, and Ugboka Rice Mill, both in Enugu, Nigeria respectively. The binders used were cold water starch and clay.

2.2 Method

2.2.1 Raw materials preparation

The lignocelluloses waste (sawdust) and rice husk used for the production of briquettes were randomly collected from sawmills located in Timber, Enugu and Ugboka, Enugu Nigeria. The moisture content (MC) of each sample before briquetting was 15% and 20% respectively. They were flash dried to reduce the moisture content to 5% at a temperature of 50ºC – 100ºC for 50 minutes. The sawdust and rice husk samples of different grain sizes were sieved for the experiment. The samples were measured out for the different woods, rice husk and binder with percentage weight of 90% (woods, Rice husk) and 10% (binder). The moisture content (MC) of each sample before briquetting was 15% and 20% respectively. Finally, a total of twelve samples were set for the experiment, six (6) samples (Melina, mahogany, oak, Melina/mahogany/oak, rice husk, rice husk/Melina) for each binder. The samples with starch as binder were tagged Group A, while the samples with clay as Group B.

2.2.2 Characterization of the raw materials

(a) Proximate Analysis of the Raw Materials: The PA analysis test was done following JIS 8812 standard method to evaluate the percentage of moisture, ash, volatile matter, fixed carbon contents. The fuel samples for the PA analysis were prepared by grinding them into powder form. The fuel test was repeated three times, and average value was recorded. The samples were weighed on a digital balance and recorded.

(b) Determination of the Moisture Content of the Raw Materials: Collected samples were placed in airtight drying oven to prevent gains or losses in moisture from the atmosphere. An aluminum pan of known weight was placed in a drying oven for 3 hrs at 105ºC. The aluminum pan was then transferred into a desiccator to cool. The aluminum pan was reweighed and the weight recorded. 1g of the sample was then measured out. The sample and aluminum pan were placed in a drying oven set at 105ºC and left for 6hrs. The pan and its contents were removed and placed in a desiccator, allowed to cool to room temperature and reweighed. This was repeated until the weight after cooling was constant. To reduce the possibility of errors, each experiment was repeated three times and an average value was determined.

$$\%MC = \frac{W_{i-}W_f}{W_{i-W_c}} \times 100 \quad (1)$$

Where;

W_i = initial weight of the sample plus crucible, W_f = final weight of sample plus crucible after oven drying, W_c = weight of the empty crucible.

(c) Determination of the volatile matter in the samples: The volatile matter contents of the samples were determined using the Meynell method. The residual dry sample from moisture content determination was preheated at 250ºC in a furnace for 2 hrs to drive off the volatiles. The resulting sample was further heated at 470ºC for 2 hrs just before the materials turn black (i.e. before it ashes). The weight of the samples were measured and recorded.

$$\%Volatile = \frac{W_{rd-}W_{ds}}{W_{st}} \times 100 \quad (2)$$

Where;

W_{rd} = weight due to removal of volatile matter, W_{ds} = dry sample after heating, W_{st}= weight of sample taken.

(d) Determination of the ash content of the raw materials: Ash is the inorganic solid residue left after the fuel is completely burned. 1 g each of samples in crucible porcelain were placed in the muffle furnace at about 815ºC for about an hour. After removing from the furnace samples were cooled in the desiccator and weight recorded. Experiment was repeated for each of the three samples and average value noted down. The following formula was used to determine ash content.

$$\%ASH = \frac{W_{b-W_c}}{W_{od}} \times 100 \quad (3)$$

Where;

W_b = weight of the crucible and ash, W_c = weight of the empty crucible, W_{od} = oven dry weight of the sample

(e) Determination of the fixed carbon content of the raw materials: The fixed carbon content of the samples was calculated using equation (4). The solid carbon in biomass remaining after de-volatilization process is represented as fixed carbon.

$$\%FC = 100\% - (\%MC - \%AC - \%VM) \quad (4)$$

Where;

MC = Moisture Content, AC = Ash Content, VC = Volatile Matter Content.

(f) Proximate Analysis of Binder Starch: The varieties of cassava root used for this study were obtained from State Ministry of Agriculture farm Igbariam, Anambra Nigeria. They were transported to the PRODA laboratory, Emene, Enugu Nigeria. The cassava tubers were peeled to rid of the two outer coverings. The peels were collected, sorted and washed severally with water to remove sand and other dirt particles. The samples were sun dried to remove the initial moisture and carefully spread out on a laboratory tray and dried in a moisture extraction oven at 105^{0}C until it was dry enough to be ground. The dried samples were milled in a blender to obtain smooth powdery samples. The powdery samples were collected and weighed using an electronic balance. These were packaged in three different labeled dry sample bottles for further analysis. The proximate analysis of these cassava waste peels was carried out by the method used in saw dust and rice husk. Moisture was determined in a thermostatic oven at the temperature of 105ºC until constant weight was obtained; Ash was determined in a muffle furnace at 550ºC for 15 hours; Crude protein by kjeldahl method (NX 6.25); the lipids were extracted with petroleum ether using soxhlet extractor while the carbohydrate was determined using same method.

2.2.3 Briquette production and quality evaluation

The sawdust and rice husk were loaded into a flash dryer to reduce the moisture content to 5% at 250ºC–300ºC for 50 minutes for both samples.

Group A: Each sample of both the sawdust, rice husk and their composites were fed into a bowl and mixed with a binder (starch) in percentage compositions of 90:10, respectively. The agitating process was done in a mixer to enhance proper blending prior compaction. A steel cylindrical crucible (die) of dimension 14.3 cm height and 70mm in diameter was used. The die was freely filled with known amount of weight (charge) of each sample mixture and positioned in the briquetting press machine for compression. The piston was actuated for 20 oscillation counts of hammer head with respect to piston movement to compress the samples. Compaction pressure was kept at 9.0MPa. After pressure was applied for a dwelling time of 45 seconds to the material in the die, the briquette formed was extruded.

Prior to the release of applied pressure, the process was repeated on other samples according to the level of process variables. The briquettes produced were allowed to dry in the sun for two days and then ready to be assessed for their energy content.

Group B: Same samples of the sawdust, rice husk and their composites were fed into a bowl and mixed with a binder (clay) in percentage compositions of 90:10, respectively. The same procedure for Group A was utilized for Group B in making the briquettes.

2.2.4 Performance analysis of briquette

(a) Determination of Ignition Time: The briquette was placed on gauze and a Bunsen burner was used to ignite its base from under the gauze. A stopwatch was used to record the time the base of the briquette ignited.

(b) Determination of Burning time: Burning time was obtained by observing the mass changes recorded on mechanical balance and also by using a stop watch. It is time taken for the briquette combustion to be complete.

(c) Water boiling test: This 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. 100 g of each briquette sample was used to boil 100 cm^3 of water using a small stainless cup and domestic briquette stove. During this test, other fuel properties of the briquettes, like burning rate and specific fuel consumption were also determined. The level of smoke evolution was equally observed.

$$T_S = \frac{T}{W_b} \quad (5)$$

Where;

T_S = Boiling time (i.e. total time spent in boiling water) (min/kg), w_b = total weight of boiled water

(d) The fuel sample outputs analyzed include:

(i) Cooking efficiency: This is given by [10];

$$\eta = \frac{M_W h_i}{M_F c_f} \quad (6)$$

Where,

η = Cooking efficiency (%), M_w = mass of water evaporated (0.01 kg), h_i = heat evaporation of water at atmospheric pressure and temperature of 100ºC (2260 kJ/kg), M_f = Amount of fuel burnt (kg), C_f = heat value of fuel used (MJ/kg).

(ii) Burning Rate: this was determined by dividing the equivalent dry briquette consumed by the time of the test [10];

Burning rate = mass of fuel consumed (g) / total time taken (min) (7)

(iii) Fuel Consumption Rate: The rate at which briquettes of various fuel samples were burnt was determined using equation (8);

$$M_f = \frac{w_{i} - w_f}{t} \quad (8)$$

Where;

W_i = initial mass of fuel before consumption (kg), W_f = final mass of fuel after consumption (kg), t = total cooking or boiling time (min).

(e) Data Collection: The length, mass, diameters of the briquettes were determined. These measurements were used to compute the volume and density of each of the twelve (12) samples of briquettes produced. Data were also collected on the physical properties of briquettes produced from the sawdust.

2.2.5 Measurement of the energy content of the briquettes

In determining the calorific value of the briquettes, the Bomb Calorimeter was used. First, the samples of the briquettes produced were allowed to dry naturally in the sun for 2 days, after which the average mass of the sample group was gotten. The bomb calorimeter was placed and tightly screwed in position. The thermocouple was plugged into the bomb until the pressure rose to 25 bars. The light spot index was set to zero using the galvanometer zero knob ensuring a stable temperature before the firing knob was depressed and released to ignite the bomb. Heat was released, and the maximum deflection of the galvanometer scale was recorded after which the burnt gases were released from the apparatus with the aid of the pressure release valve.

The maximum deflection obtained in the galvanometer was converted to the energy value of the briquette material by comparing the rise in galvanometer deflection with that obtained when a sample of known calorific value of benzoic acid is combusted. The process is repeated to determine the energy value of the different compressions. The energy values of all the samples burnt were recorded.

(a) Heat Value: The heat value of the samples was determined using a Bomb calorimeter. Each sample of the briquette from each group was weighed and placed in the crucible before covering it tightly. The bomb was closed and charged in with oxygen up to 400 Psi. The bomb was fired up by depressing the ignite switch to burn the sample in excess of oxygen. The maximum temperature rise in the bomb was measured with the thermocouple and galvanometer system. The energy value is given by the relation in equation (9);

$$\text{G.E. (Kcal/g)} = \frac{\text{G.meter deflection x calibration}}{\text{weight of sample.}} \quad (9)$$

Where; G.E is the Energy value.

(b) Moisture Content: One of the main parameters in determining briquette quality is moisture content of the sawdust/rice husk used as the input material. The most durable briquettes of bio wastes are of the moisture content of 5%. The moisture content of the bio wastes studied is 5% which ensured production of good quality briquettes. This lower moisture content of briquettes implies higher calorific value. Moisture content more than 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 fuel may not also be stable in storage.

3. RESULTS AND DISCUSSION

Fig. 1. shows the graph of moisture content of the entire sample which was reduced to 5% to have a uniform value, though the highest initial moisture content (20.92%) was found in wood sawdust sample while rice husk was 15.90%. The highest moisture content in the wood sawdust may be due to the climatic condition and may have absorbed some moisture in storage. High moisture content affects the calorific value of biomass fuels since some energy is lost for vaporizing the moisture in the fuel. So, to reduce moisture content in biomass they should be dried by natural means i.e. sunlight for at least 48 hours.

Fig. 2. shows the graphical results of different samples tested in the lab. The figure clearly depicts mahogany sawdust a better option for high volatile matter (83.1%) followed by gmelina

(82.6%), oak (81.6%) and rice husk (73.4). Hence the higher the volatile matter of the fuel, the faster the combustion process and the higher the temperature of the flame.

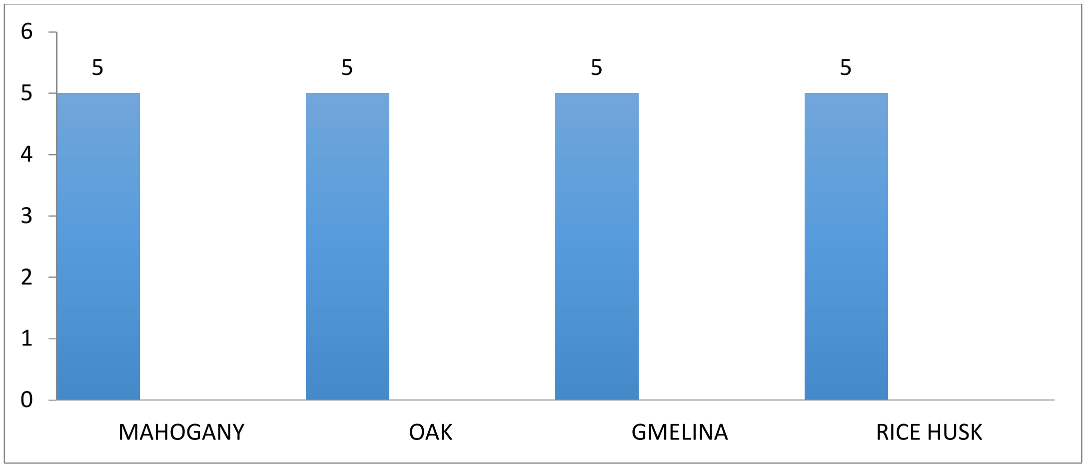

Fig. 1. Plot of samples against % moisture content

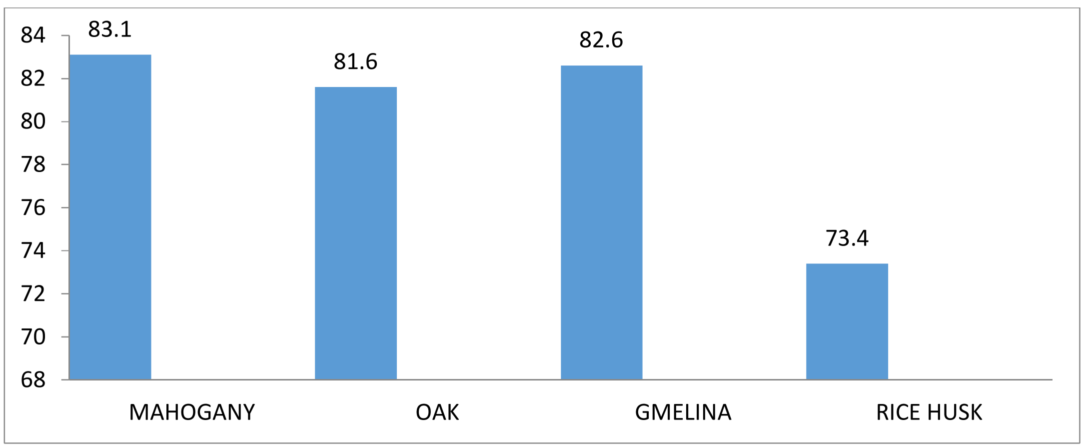

Fig. 2. Plot of samples against % volatile matter

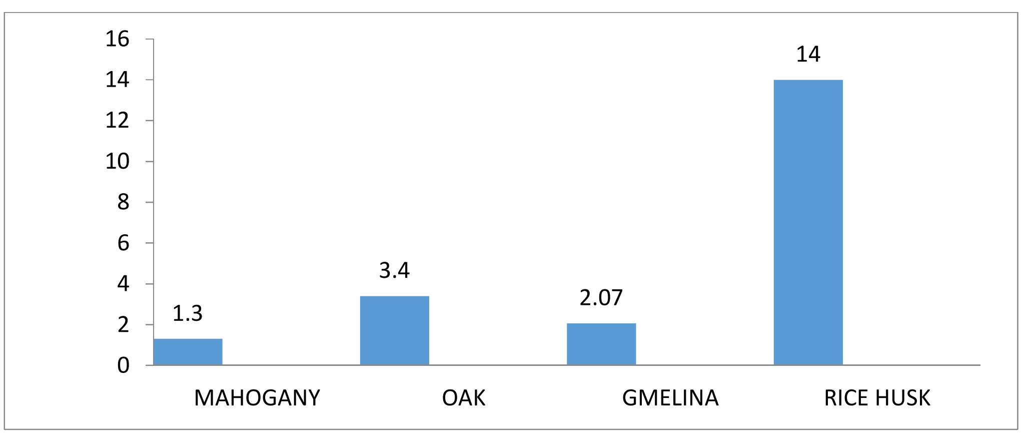

Fig. 3. Plot of samples against percentage ash content

Fig. 3. shows the graphical representation of the ash content of the sample materials. The highest ash content (14%) was found in rice husk sample. Similarly, oak sawdust showed approximately 3.4%, Melina sawdust (2.07%) and mahogany sawdust had lowest as 1.3% ash content respectively. The highest ash content in biomass has effect of disposal of ash from the gasifier system.

Fig. 4. presents a graph of the sample materials fixed carbon. The fixed carbon for the case of mahogany sawdust (10.6%) is higher compared to other samples like oak sawdust (10%), gmelina sawdust (10.33%), and rice husk (7.6%). This suggests that further solid combustion takes place in case of mahogany sawdust. Thus, further Combustion of mahogany sawdust generated a significant amount of ash compared to other tested fuels, which indicates that this fuel is highly reactive and has high carbon conversion efficiency.

3.1 Physical Characteristics of the Briquettes

The briquettes were produced using a screw press briquetting machine. The outer surface of the briquettes was carbonized and solid with no holes at the center. The average weight of the briquettes made with starch is approximately 75g while that made with clay as binder is 84 g. The average length and diameter are 35 mm and 70mm respectively. The average volume is 110cm^3 while the briquettes from both samples of the sawdust and rice husk assumed a brown coloration.

In Fig. 5 the densities of the samples were shown considering the binders. The difference between the two densities was found to be 0.032 g/cm^3 and has been uniformly through for all the samples. This can be attributed to the heavy nature (weight) of clay present in the samples. Starch is quite lighter than clay and the

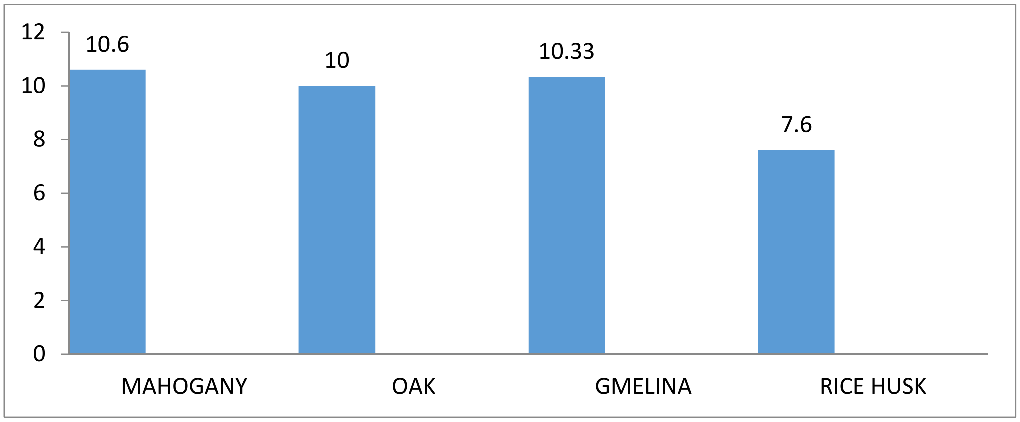

Fig. 4. Plot of samples against % fixed carbon

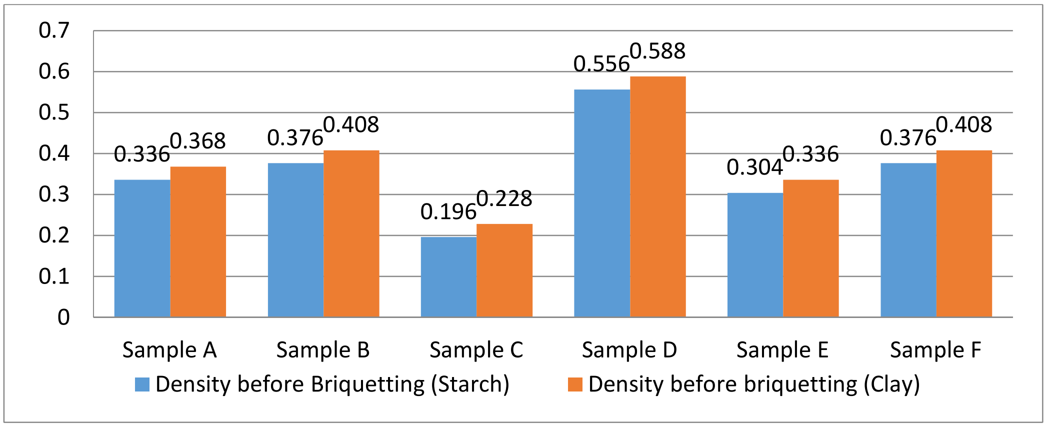

Fig. 5. Plot of samples vs density before briquetting

samples with starch as binder have lower densities as compared to those with clay.

Fig. 6 shows a quite different result of densities after briquetting. For sample A, there is a great margin between the two densities with a difference of 0.136 g/cm^3. But for other samples, the densities having starch as binder were found to be slightly above those with clay for samples B, C and D with differences of 0.23 g/cm^3, 0.11 g/cm^3 and 0.26 g/cm^3 respectively while those for samples E and F have differences of 0.5 g/cm^3 between the densities.

Fig. 7 shows the calorific values of the samples for both binders. The samples with starch as binder have higher calorific values than those with clay as binder. The differences between the calorific values are significantly high. This means that samples with starch binder have better ability to burn and retain heat.

3.2 Performance Analysis of Briquettes

Fig. 8. shows the ignition time for the sample briquettes produced. From the results it can be seen that ignition time for oak sawdust blend with starch and clay respectively has the lowest ignition time (0.117 mins and 0.118 mins) compared to others, and similarly shows that ignition time of briquettes made from sawdust blended with starch and clay respectively have lower values than those of rice husk and its composite. A combustible material should be

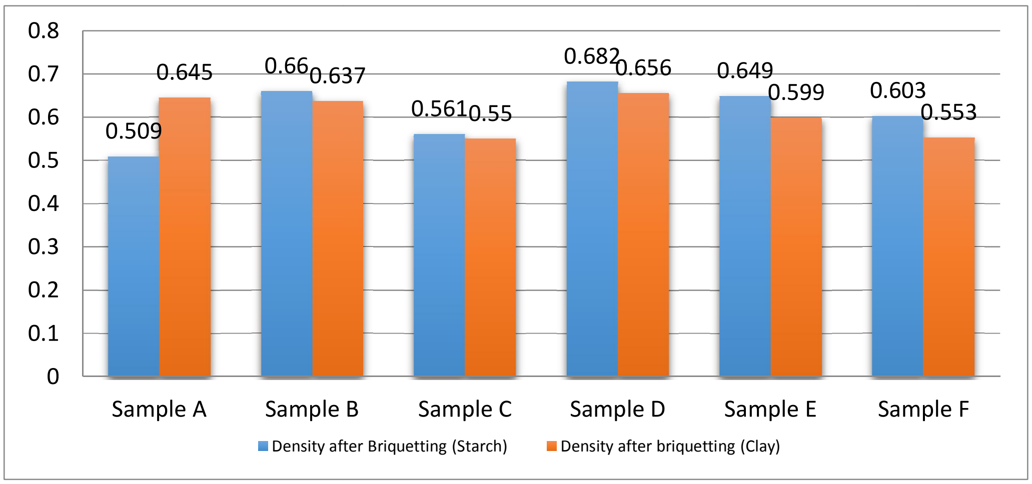

Fig. 6. Plot of samples vs density after briquetting

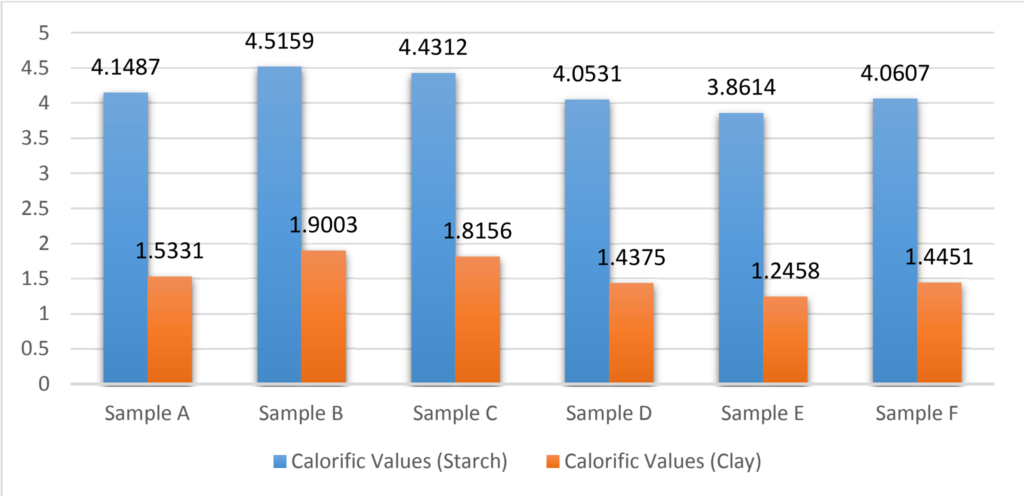

Fig. 7. Plot of samples vs calorific values

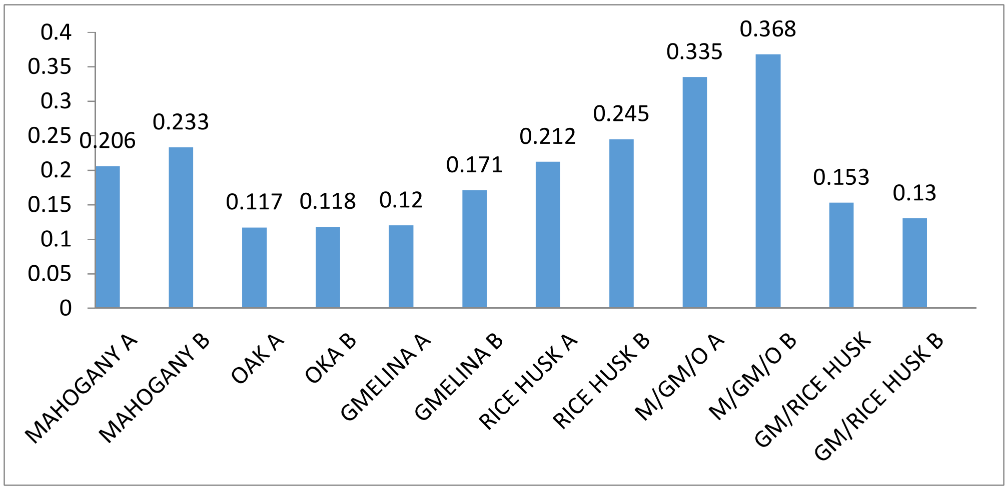

Fig. 8. Plot of samples vs ignition time

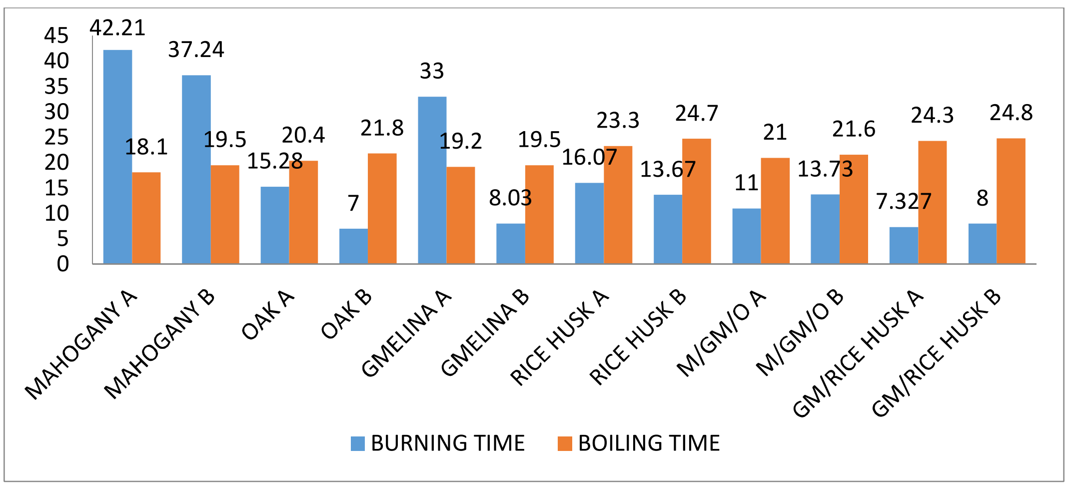

Fig. 9. Plot samples vs burning time and boiling time

easily ignitable, particularly for household domestic purposes.

Fig.9 shows the burning time and boiling time which indicate that the burning duration of mahogany sawdust with starch and clay have the highest values (42.21 and 37.24 mins) respectively and is as a result of their chemical constituents or composition. They are followed by Gmelina blended with starch (33mins) while oak with clay as binder and composite of Gmelina and rice husk with clay have the lowest values of (7mins and 7.2mins) respectively. The higher the burning time the better the briquette because less briquette will always be needed to start and maintain fire for domestic use. The graph also shows that mahogany sawdust with starch as binder has the lowest boiling time (18.1mins) than others which is a good performance for a material for use in making good briquette while rice husk with clay as binder and its composite with Gmelina sawdust also with clay as binder gave the highest value of boiling time (24.7 and 24.8) respectively. The lower the boiling time, the better the briquette produced.

In Fig.10 burning time of the various fuel samples were estimated using equations above with data obtained from the WBT. The average burning rates values for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering) were obtained. The burning of the briquettes was steady and it produced red

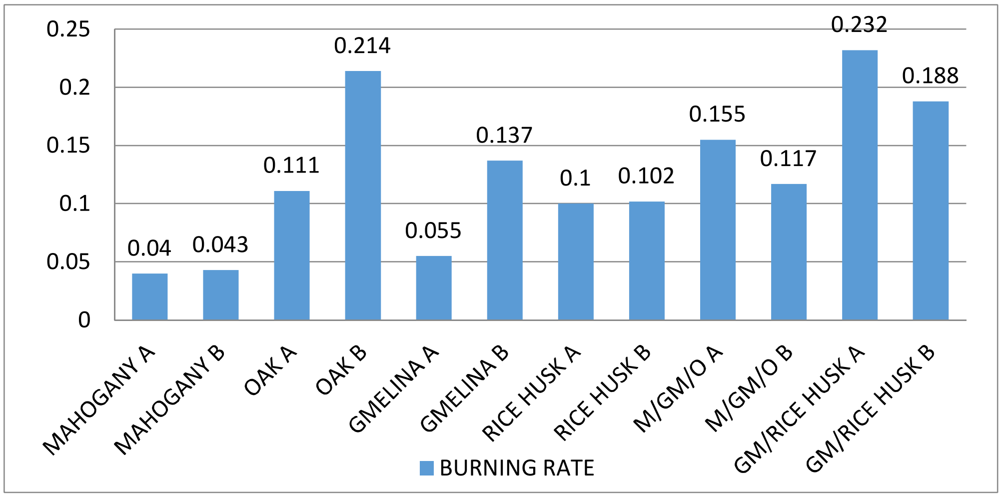

Fig. 10. Plot of samples vs burning time

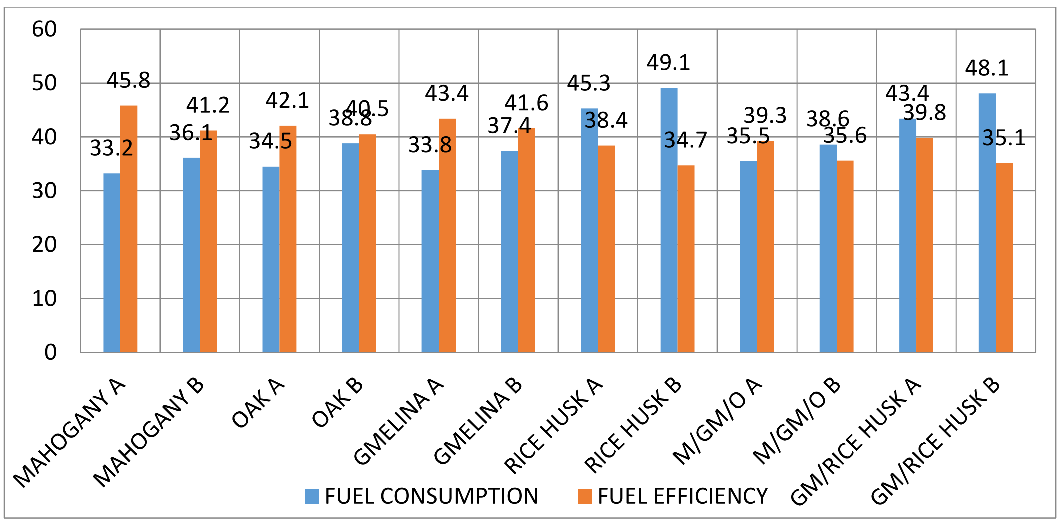

Fig. 11. Plot of samples vs fuel consumption and cooking efficiency

hot charcoal. Comparison of the performance of the average burning rates of the briquettes shows that mahogany briquette with starch as binder (0.04 kg/min) has the lowest burning rate followed by gmelina briquette with starch as binder (0.055 kg/min) while composite of gmelina and rice husk with starch as binder has the highest burning rate of (0.232 kg/min). The variation of the burning rate values of samples could be attributed to porosity exhibited between inter and intra–particles which enable easy infiltration of oxygen and out flow of combustion products from briquettes.

Fig.11 shows the fuel consumption values and the cooking efficiency. It could be noted that the lower the fuel consumption the better the cooking efficiency of the briquette. This is because less amount of fuel would be consumed and that helps to improve the efficiency of the briquette. The graph shows that briquette from mahogany sawdust with starch as binder has low fuel consumption (33.2%) in comparison to other briquettes and that helps to give it a higher cooking efficiency (45.8%). However, rice husk with clay as binder gave the highest value of fuel consumption and with less efficiency (i.e. 49.1% and 34.7% respectively).

4. CONCLUSION

Generally, briquettes of biomass show a lot of promise as a potential source of fuel. This work was carried out to examine the combustion related properties and efficiency of briquettes when tested in briquette wood stove. It was observed that the mahogany sawdust has higher percentage fixed carbon (10.6%) and volatile mater (83.10) but, Rice husk has lower fixed (7.6%) and volatile mater (73.40). The Calorific value of mahogany sawdust briquette was found higher than other eleven briquettes. The mahogany sawdust briquette with binder starch gave higher efficiency of 45.7% whereas, rice husk briquette with clay as binder gave lower efficiency of 34.7%. The test results show that the calorific value of mahogany sawdust, gmelina, oak, composite of mahogany/gmelina/oak, rice husk and gmelina/rice husk briquettes with starch as binder were 4.516 kcal/g, 4.1487 kcal/g, 4.4312 kcal/g, 3.8614 kcal/g, 4.0531 kcal/g, 4.067kcal/g respectively and with clay as binder were 1.9003 kcal/g, 1.5331 kcal/g, 1.8156 kcal/g, 1.2458 kcal/g, 1.4375 kcal/g, 1.4451 kcal/g respectively. Therefore, this shows that starch is a better bonding material than clay. The briquetting technology has a great potential for converting waste biomass into a superior fuel for household as well as industrial applications in affordable, efficient and environment friendly manner. Recycling of biomass can be significantly helpful in alternate fuels.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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