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Preparation of Environmental Friendly Bio-coal Briquette from Groundnut Shell and Maize Cob Biomass Waste: Comparative Effects of Ignition Time and Water Boiling Studies

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ABSTRACT
To maximize the efficiency and to avoid environmental hazards it is necessary to blend the coal, which is highly used in Nigeria for energy purposes. In present investigation, we have prepared an environmentally friendly bio-coal briquette from groundnut shell and maize cob biomass waste through blending with coal. In preparation of briquette the ratio of coal to agricultural wastes used were 100:0, 90:10, 85:15, 80:20, 75:25, 70:30. The mixture was treated with calcium hydroxide which serves as a desulphurizing agent before briquetting. The moisture content, ash content, volatile matter/fixed carbon, calorific values and carbon contents of raw materials were analyzed. The ignition time and water boiling tests of the briquettes prepared by blending coal and different biomasses were compared. Ignition time and water boiling tests of the bio-coal briquette decrease with increase in agricultural wastes load. Briquettes blended with maize cob have shorter ignition time and burning rates. The results of the briquettes blended with maize cob were better than that of groundnut shell. Biomass increases the burning efficiency of briquettes, ignites faster and produces fewer pollutants. The obtained results showed that the bio-coal briquette used in this study was environmental friendly and useful in real applications.

Key words: Bio-coal, ignition time, water boiling test, coal, briquette, agricultural wastes

INTRODUCTION
In recent years, Nigeria and other sub-Saharan countries were facing forest degradation problems due to clearing of land for agricultural and industrialization purposes, over grazing, drought, deforestation and increased in the consumption of fuel wood, etc. (Jean and Owsianowski, 2009). About 80% of Nigerians live in the rural or semi-urban areas and they depend solely on fuel wood for their energy needs. Fuel wood accounts for about 37% of the total energy demand of the country (ECN, 2009) and a report showed that out of the total wood demand from the forest, 90% goes to fuel wood. At present Nigeria reportedly consumes about 43×10^9 kg of fuel wood annually (ECN, 2009) and it is increasing annually. Meanwhile, it was reported that the total forest cover of Nigeria is still less than 10% of the land area, which is far below the 25% recommended by the United Nation Development Programme (UNDP) (Philip, 2007). Furthermore, in the recent years, global warming caused by green house gasses has become an international concern. It was shown

that increased emission of CO_2 in the atmosphere in the recent time has exacerbated the global warming (Okonkwo and Eboatu, 2002). This is because the forest resources which act as major absorbers of CO_2 have been drastically reduced due to the fact that the rate of deforestation is higher than the afforestation in the country.

Apart from environmental effects, the use of fuel wood for cooking has health implications especially on women and children who are disproportionately exposed to the smoke (Onuegbu, 2010). In some areas, the exposure is even higher especially when the cooking is done in an unventilated place or where fuel wood is used for heating of rooms. Generally, biomass smoke contains a large number of pollutants which at varying concentrations pose substantial risk to human health. Among hundreds of the pollutants and irritants are particulate matters, carbon monoxide, formaldehyde and carcinogens such as benzo[α] pyrene, 1, 2-butadiene and benzene (Schirnding and Bruce, 2002). Also, consistent evidence revealed that exposure to biomass smoke increases the risk of a range of common diseases both in children and in adults. The smoke causes Acute Lower Respiratory Infection (ALRI) particularly pneumonia in children (Smith *et al.*, 2000; Ezzati and Kammen, 2001a). Among the women, it causes chronic bronchitis and Chronic Obstructive Pulmonary Diseases (COPD) (Progressive and incompletely reversible air ways obstruction) (Bruce *et al.*, 2000; Ezzati and Kammen, 2001b). Eyes irritation (sore, red eyes, tears) from the smoke is also a common experience in the use of fuel wood. An experiment carried out on animals which showed that biomass smoke is capable of damaging eye lens Ezzati *et al.* (2000).

In the whole, it was summed up that the total deaths attributed to the use of fuel wood in Nigeria are about 79,000. Also nearly 45% of the national burden diseases are related to solid fuel use, according to a WHO Survey (Philip, 2007). Again, combustion of raw coal has equally been reported to have detrimental effects on both environments and the health of the people. Transition to electricity or gas would have been the healthiest solution to these problems but the likelihood of a complete transition in the poorer urban and rural communities in the near future is minimal. Therefore, it is pertinent that other intervention measures especially ones recommended by WHO (Schirnding and Bruce, 2002) should be adopted to mitigate these health risks to the lowest possible level and equally to relieve the forest resources from pressure mounted on it. Therefore, it is imperative that concerted efforts are needed to address this situation; the reduction in the use of fuel wood will drastically reduce the pressure mounted on the forest in search of wood.

Researches showed that a cleaner, affordable fuel source which is a substitute to fuel wood can be produced by blending biomass (agricultural residues and wastes) with coal. Nigeria has large coal deposit which has remained untapped since 1950's, following the discovery of petroleum in the country. Also, million tons of agricultural by-products are generated as wastes every year in Nigeria. These agricultural wastes accumulated during clearing of land for farming or processing of agricultural produce are usually burnt off. By this practice, not only that the useful raw materials are wasted, it further pollutes the environment and reduces soil fertility. Fire affects soil below ground biodiversity, geomorphic process and volatilizes large amount of nutrients and carbon accumulated in the soil organic matter (Owsianowski, 2009). Again, burning of agricultural wastes can lead to bush fire, thereby destroying further the forest which has suffered much from the hand of wood seekers if not properly controlled. Forest fire is one of the major environmental problems in Nigeria and it destroys the fresh saplings, seedlings and arrest regeneration of native species (Owsianowski, 2009).

The main purpose of this study was to compare the ignition time and water boiling test of coal briquette blended with groundnut shell and maize cob.

MATERIALS AND METHODS

Sub-bituminous coal was obtained from Onyeama mine, Enugu, Enugu State, Groundnut shell and maize cob were collected from waste stream from Nnamdi Azikiwe University, Awka, Anambra State, Nigeria, while calcium hydroxide was procured from BDHL, England.

Preparation of materials: The coal was sun-dried for three days to reduce its moisture content and was broken into small particles using hammer. It was then ground into fine powder using electric milling machine and sieved to obtain coal of particle size of 1 mm in diameter. The agricultural wastes were sun dried for one week, milled with electrical milling machine and sieved to obtain materials of particle size of 3 mm in diameter and stored in polyethylene bag as shown in Fig. 1.

Cassava tubers (source of starch) collected were washed, peeled, crushed and pressed to extract the liquid content. The liquid was filtered and the filtrate was allowed to stay for sometimes so that the starch would separate from the mixture. After that, upper liquid layer was carefully decanted. The starch was air-dried for five days to reduce the moisture content.

Proximate analysis of the raw materials: The following parameters were carried out on the raw materials using standard methods: moisture content (Aina *et al.*, 2009), ash content (Ekpunobi and Onuegbu, 2012), volatile matter/fixed carbon (Onuegbu *et al.*, 2011), calorific values and carbon content (Sharma, 2006).

Bio-coal briquette formulation: Bio-coal briquettes were formulated using different percentages of coal and biomass. The ratio of coal to biomass made were 90:10, 85:15, 80:20, 75:25 and 70:30. The quantity of calcium hydroxide used was 5% of the quantity of coal used and that of starch was 20% of the whole briquette as shown in Table 1.

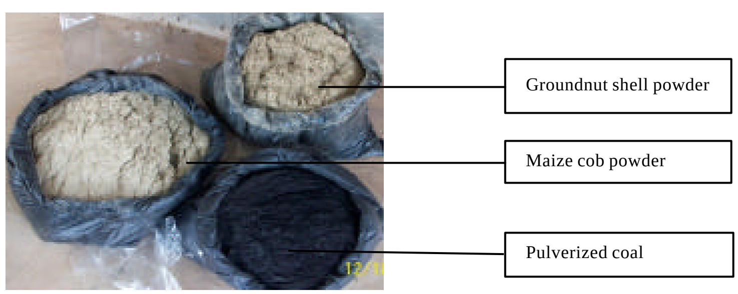

Fig. 1: Prepared raw materials

Table 1: Formulation of briquette samples

	Coal:biomass					
Raw materials	100:0	90:10	85:15	80:20	75:25	70:30
Starch (g)	70.0	70.0	70.0	70.0	70.0	70.0
Coal (g)	280.0	252.0	238.0	224.0	210.0	196.0
Biomass (g)	0.0	28.0	42.0	56.0	70.0	84.0
$Ca(OH)_2$ (g)	14.0	12.6	11.9	11.2	10.5	9.8
Water (mL)	250.0	250.0	250.0	250.0	250.0	250.0

Fig. 2: The manual hydraulic briquetting machine

Fig. 3: The briquettes produced

Preparation of briquette samples: Measured quantity of starch, biomass, coal and $Ca(OH)_2$ were weighed out using a triple beam balance into a 1000 mL plastic basin. They were mixed thoroughly until a homogenous mixture was obtained and water was added to give a paste that can agglomerate. The paste was poured in the moulds and covered with lids of the hydraulic press and pressure was applied to briquette the mixture. The manual hydraulic press briquette machine (Fig. 2) exerts pressure up to 10 MPa. The briquettes were removed from the mould by using the long lever arm to jack up the briquettes, after the hydraulic jack had been released. The briquettes were put in an oven set at 100°C, for about 1 h, so that the raw starch will cure and also to reduce the moisture content. They were then removed from the oven, sun dried and stored as shown in Fig. 3.

Characterization of the briquette samples

Ignition time: Ignition time is the time taken for a flame to raise the briquette to its ignition point. The briquette sample was ignited at the base and was adjusted to give a steady light as described earlier (Onuegbu *et al.*, 2006).

Water boiling test: Water boiling tests were conducted under similar conditions using 100 g of each briquette sample (Onuegbu *et al.*, 2011). To start up, few pieces of wood chips and kerosene were used to ignite the briquettes in a domestic stove, immediately the briquette started burning, the remaining unburnt starting material (wood chip) was carefully removed. Then, 100 cm^3 of water at room temperature was added in a small stainless cup, covered and placed on the stove. The time taken for the water to boil was noted using a stop watch. Also, the mass of the fuel used during the test was recorded.

Burning rate (R): Burning rate indicates the mass of fuel burnt per minute during the boiling phase. The formula in Eq. 1 was used to calculate the burning rate:

$$R = \frac{\text{Mass of fuel consumed}}{\text{Total time taken (min)}} \quad (1)$$

Specific fuel consumption (SFC): Specific fuel consumption indicates the mass of fuel required to produce one liter of boiling water. It was calculated using the following formula:

$$SFC = \frac{\text{Mass of fuel consumed (kg)}}{\text{Total mass of boiling water (L)}} \quad (2)$$

RESULTS AND DISCUSSION

The results of the proximate analyses, carbon content and calorific value of the raw materials used for the production of the briquettes are presented in Table 2. Carbon contents (%) analyses gave the following results coal (64.30)>groundnut shell (32.10)>maize cob (26.00) while that of the calorific values (kJ g^{-1}) are, coal (21.2563)>maize cob (16.4047)>groundnut shell (14.4037). The values for fixed carbon (%) are, coal (56.90)>maize cob (29.90)>groundnut shell (29.00). From Table 2, it is shown that maize cob (12.20%) has the highest value of moisture contents, followed by groundnut shell (10.30%) and then coal (6.10%). From literature, the moisture content of biomass lies between 10-15% so that there will be complete combustion of the briquettes (Maciejewska *et al*., 2006). Low moisture contents of the biomass also helps in their storage (prevents rotting and decomposition).

It can also be seen clearly from the Table 2, that groundnut shell has the highest value(54.70%) of volatile matter, followed by maize cob (54.60%), then coal (23.00%) which is in line with work reported (Maciejewska *et al*., 2006). The ash contents results show that coal has the highest ash content value (14.00%), followed by groundnut shell (6.00%) and then maize cob (3.30%). From literature, typical biomass contains fewer ashes than coal and their composition is based on the chemical components required for plant growth, whereas coal ashes reflect the mineralogical composition (Maciejewska *et al*., 2006).

It can be seen that the ash contents of groundnut shell and maize cob are less than that of coal, the lower the ash content, the better the quality of the fuel. Hence maize cob will produce a better fuel than the others. Maize cob has the highest fixed carbon content, followed by groundnut shell

Table 2: Proximate analysis of the raw materials

Parameter	Coal	Groundnut shell	Maize cob
Moisture content (%)	6.1000	10.3000	12.2000
Volatile matter (%)	23.0000	54.7000	54.6000
Ash content (%)	14.0000	6.0000	3.3000
Fixed carbon (%)	56.9000	29.0000	29.9000
Carbon content (%)	64.3000	32.1000	26.0000
Calorific value (kJ g^{-1})	21.2563	14.4037	16.4047

and then coal. This shows that maize cob contains more quantity of carbon that can be burnt by a primary current of air drawn through the hot bed of it, than others. As expected, the carbon content of coal is higher than that of the biomasses, with that of groundnut shell being higher than that of maize cob (Table 2). During combustion, coal will release a higher percentage of gaseous pollutants such as carbon (II) oxide and carbon (iv) oxide than the other two. The carbon content of maize cob is very low compared to that of coal and groundnut shell. Therefore, maize cob will emit small quantity of these gaseous pollutants during combustion.

From Table 2, the calorific value of coal is higher than that of the biomasses, with that of maize cob being higher than that of groundnut shell. This indicates that during combustion, coal will produce more heat and energy, followed by maize cob and then groundnut shell. From the results, it was observed that briquettes prepared using maize cob have a higher calorific value than those prepared using groundnut shell. This is because; maize cob has a higher calorific value than groundnut shell. It was also observed that for both bio-coal briquettes, as the quantity of biomass incorporated into the coal increases and the quantity of coal decreases, their calorific value also changes. This shows that biomass alters the calorific value of coal and depending on the biomass used, (the bio-coal briquettes have higher calorific value than coal briquettes).

Also, the calorific value of the maize cob-coal briquettes is higher than that of the coal briquette, while the calorific value of the coal briquette is higher than that of the groundnut shell-coal briquette. This is as a result of the low calorific value of groundnut shell. Therefore, during combustion, maize cob bio-coal briquettes will release more heat and energy, than coal briquettes, followed by groundnut shell-coal briquettes. It was also observed that the calorific value of coal alone is higher than that of coal briquette. Since the briquette contains only cassava starch (which is combustible) and $Ca(OH)_2$, it means that it is as a result of the presence of calcium, implying that calcium is not combustible.

Ignition time and water boiling tests of the briquette samples: The results of ignition time and water boiling tests of the briquette samples are shown in Fig. 4-6. From Fig. 4, it is observed that the presence of biomass reduces the ignition time of the briquettes which is in support of earlier reported (Onuegbu *et al.*, 2010a, b, 2011). This shows that the biomasses have shorter ignition time and will catch fire easily than coal. As the percentage of biomass increases, the ignition time becomes shorter. It is also observed that maize cob-coal briquettes have shorter ignition time than groundnut shell-coal briquettes. Therefore, it can be said that corn cob has shorter ignition time than groundnut shell. This is surprising because maize cob

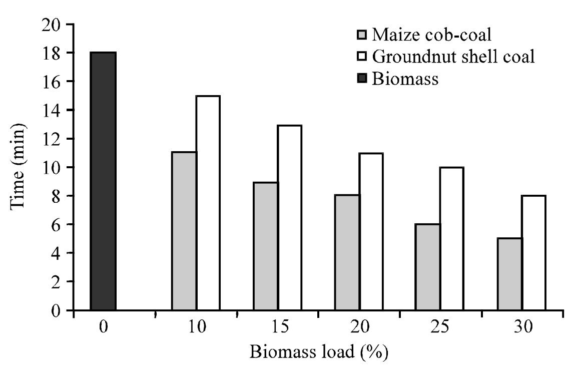

Fig. 4: Ignition time of the briquette samples

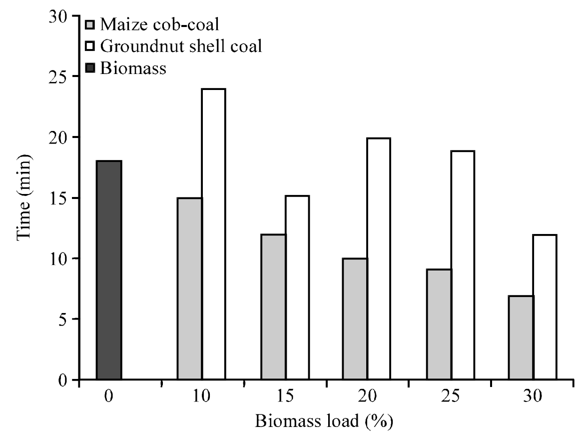

Fig. 5: Water boiling test of the briquette samples

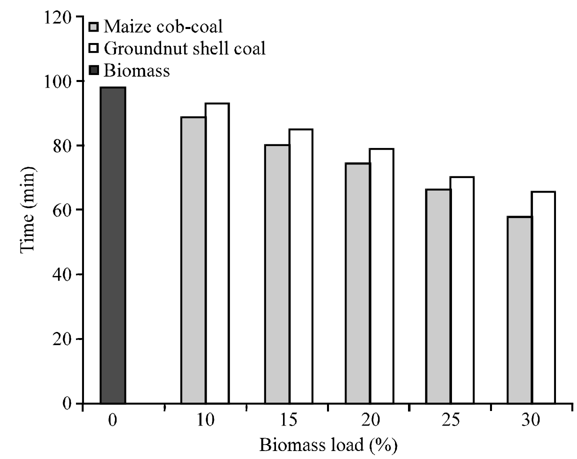

Fig. 6: Burning time of the briquette samples

has higher moisture content than groundnut shell. The reason for this short ignition time may be as a result of the fibrous nature of maize cob. The coal briquette has the highest ignition time because of its mineral constituents which takes time to ignite. In the bio-coal briquettes, part of the coal is substituted by biomass; therefore, shorter time is required for its ignition.

The results in Fig. 5 indicated that biomass reduces the time required for the briquettes to boil a specific quantity of water (i.e. 1 L) which was earlier reported (Onuegbu *et al.*, 2011). Water boiling tests was carried out to compare the cooking efficiency of the bio-coal briquettes of varied biomass composition with a coal briquette. It measures the time required to stimulate cooking as well as other fuel characteristics of the briquettes such as the burning rate and the specific fuel consumption during the boiling phase (Owsianowski, 2009). The groundnut shell-coal briquettes take longer time, followed by the coal and then the maize cob-coal briquettes. This is as a result of the low calorific value of the groundnut shell-coal briquettes as compared with maize cob-coal briquettes. Hence, incorporation of groundnut shell into the coal (slightly) reduces the calorific value, while incorporation of maize cob into the coal increases the calorific value. The higher the calorific value of the briquettes, the higher the heat and energy released and the lesser the time required to boil water.

It also indicated that biomass reduces the burning time of the briquettes (Fig. 6). The coal briquette has the highest burning time. It was also observed that the maize cob-coal briquettes have shorter burning time than groundnut shell-coal briquettes. This is also surprising since maize cob contains more moisture than groundnut shell. Hence, the reason for this is because the maize cob-coal briquettes are more porous (because of the particle nature). Therefore, air passes through the briquettes making them to burn faster than the relatively fine textured groundnut shell which is less porous. The coal briquette produced an ash or grey coloured ash, the maize cob-coal briquettes produced white ash, while the groundnut shell bio-coal briquette produced light ash coloured ash. These colours may be due to their mineral constituents. Also, the quantity of ash produced is much for the coal briquette and groundnut shell-coal briquette and few for the maize cob-coal briquette. This is as a result of the low ash content of maize cob-coal briquettes, compared to the groundnut shell and coal briquettes.

CONCLUSION

From the results of these tests and analyses carried out, the following conclusions can be drawn on the possibility of using maize cob and groundnut shell as biomass in the production of bio-coal briquettes:

- The biomasses enhance the burning properties of coal briquettes
- Biomass increases calorific value and burning efficiency and reduces the ash content, cooking time, ignition time, exhaust gas and smoke emission of coal briquettes
- Therefore, bio coal briquettes take less time to boil water and cook food than coal briquette
- Under similar conditions they burn smoothly with very little generation of smoke and harmful exhaust gases and are easier to ignite.

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