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Burning Rate and Water Boiling Testsfor Differently Composed Palm Kernel Shell Briquettes

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Abstract:*In this work, we have produced and determined some physical and combustion characteristics of biomass briquettesmade with palm kernel shell (PKS) as the major component of interest. We considered four briquette samples. Samples I and II were produced with different compositions of PKS, sawdust, and cement dust which was the binder source. Samples III and IV were composed of only PKS and soaked wastepaper. In this group, the later though also flammable, was the binder source. A fifth sample (Sample V), common firewood from unidentified wood, was used as a control. We conducted burning rate test and water boiling test for the briquettes to determine their suitability as cooking fuel. It was found that the briquettes produced from PKS and wastepaper compared very well with firewood, while those produced with PKS, sawdust and cement also performed well but burnt without flame and with much smoke as the composition of PKS is increased at the expense of sawdust (from Sample I to Sample II). We observed that even though this group of briquettes (PKS/Sawdust/Cement) may not boil water readily, they are suitable for slow cooking and food smoking, as they ensure slow and steady release of heat energy without flame.*

Keywords:*Biomass briquettes, Palm kernel shell, Briquette binders, Water boiling test, Burning rate test.*

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I. Introduction

In most rural communities of developing countries such as Nigeria, forest resources are the predominant source of cooking fuel. This often leads to indiscriminate and unregulated felling of trees whose various parts are used as firewood upon drying. Such activities may eventually lead to deforestation which impacts adversely on the environment. Protecting the environment by limiting deforestation can be achieved by making briquettes from forest and agricultural waste.

Briquettes from agricultural waste (biomass) contribute significantly to the energy mix. The advantage of being able to transform biomass, which in its raw form, has low density, low heating value and high moisture content, to highly efficient fuel briquettes has been of research interest. A variety of sources have been used and newer ones are being explored. Interests are geared towards using locally available materials peculiar to various countries. For instance, in Uganda, groundnut shell and bagasse have been investigated (Lubwama & Yiga, 2017); Coffee husks and pulp in Ethiopia *(*Merete *et al*, 2014)and rice straw in Thailand (Rahaman & Salam, 2017). Here in Nigeria, Onukak*et al* (2017), Nwabue*et al* (2017), Onuegbu*et al* (2011), Davies and Davies (2013), Mbamala *et al* (2015)and many other workers have used various materials to produce briquettes for fuel. All these authors strive to show the role of briquettes in meeting rural energy requirement. In this work we focus on production of briquettes from palm kernel shell (PKS).

Palm kernel shells have been traditionally used as solid fuel for domestics cooking, supplementing other primary fuel sources such as firewood. In recent years, fuel briquettes have been produced from shells (including coconut shell) which usually involved partial or total carbonisation of the material. Generally they use pyrolysis method at temperatures well above 280^{o}C to carbonize the shells. The resulting charcoal further goes through the process of pulverization before briquetting(Adeniyi *et al*., 2014; Ugwu & Agbo, 2011). If the heat energy input in pyrolysis is greater or comparable to the heat energy output of the briquette produced, then the gain in briquetting is greatly diminished.

In this work, we want to make briquettes from palm kernel shell without the energy and time cost of carbonizing the shell and pulverizing the charcoal. We use selected binders to densify the shells into convenient shapes. The briquettes produced can then be stored and used in the same convenient manner conventional firewood is used as primary fuel source. This process is simpler and more cost effective.We investigate four sample briquettes produced with different compositions of PKS and with two different binder sources, namely cement dust and paper (wastepaper). In samples I and II, PKS was mixed with sawdust and cement. Sawdust is introduced to embed the PKS as it will be difficult achieve a stable PKS briquette without pulverizing it. In samples III and IV, the composition was PKS and soaked mashedpaper. The paper served as binder and also to embed the PKS.

II. Materials and Methods

Materials

The materials used in the production of the briquettes include:
(i) Palm kernel shell
(ii) Sawdust
(iii) Binder sources --- (a) Cement dust and (b) Soakedwastepaper
(iv) Manuel briquette mold.

Palm kernel shells (PKS)

Palm kernel shells are the shell fractions left after the nut has been removed after crushing in the Palm oil mill. Large and small shell fractions are mixed with dust-like fractions and small fibres. A sample of PKS is shown in Figure 1. PKS is relatively in high demand. It is used by farmers to cover the top soil to check weed, especially in pineapple orchards. A 100kg bag of PKS was purchased for one thousand naira (about USD 2.80) from an oil mill in Owerri, Nigeria.

Figure 1:A hip of palm kernel shell.

Sawdust

Sawdustis a by-product of cutting, grinding, drilling, sanding or otherwise pulverizing wood with a saw. It is in abundance in all timber saw mills and can be obtained at no cost.

Binder: Cement dust

Cementis a substance commonly used in building construction. Itsets, hardens and adheres to other materials, binding them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together to produce various end products, such as concrete. Cement is readily available and sells for about fifty naira(USD 0.14) per kg in Nigeria. A recent study of briquette production with sawdust and cement showed that only a little quantity of cement is required in briquettes making(Mbamala, 2018).

Binder: Soaked paper

A large quantity of waste papers was obtained from the Department of Physics, Federal University of TechnologyOwerri at no cost. When paper is soaked in water, left for some time and mashed, it releases the chemical binders used in making the paper, making the suspension slurry and starchy.

The Briquette Mold

Two types of simple steel molds were used --- cylindrical and rectangular shaped, similar to and operated as the common manual building block molder. The idea is to have the briquettes look like firewood. The details of the construction of the molds have been discussed elsewhere(Mbamala *et al,* 2015).

Methods

Sample I

Sample I is composed of sawdust, palm kernel shell and cement dust. They were mixed in the ratio of 14:7:1 respectively by volume (not by mass). The volume of sawdust is twice that of PKS.Sawdust is introduced here to have a biomass into which the PKS will be embedded. This is similar to introducing sands when making a concrete of gravels or chippings. The components were mixed thoroughly with an appropriate amount of water before molding.

Sample II

This sample has the same components as in Sample I but with the volume of PKS increased. The ratio of sawdust to PKS to cement dust is 10:10:1

Sample III

Sample III is composed of palm kernel shell and soaked paper. Here sawdust is not included because the soaked paper serves as binder and embedder. Some quantity of wastepaper was soaked in water for several days and then mashed until it became slurry and slimy like starch. The slurry was then mixed thoroughly with PKS, poured and compressed in the mold to form the briquettes. The ratio of the palm kernel shell to the paper slurry for Sample III is 4:3 by volume.

Sample IV

This sample is similar in composition as in Sample III but again with the amount of PKS slightly increased. Here, the ratio of PKS to the mashed paper slurry is 4:2 by volume. Although the density of the mashed paper was not determined, it was the same as used in Sample III.

Sample V

Sample V is a bundle of common firewood of unknown mixture of forest wood. It is included here as a control.They were cylindrical in shape.

All the briquettes produced were left to dry under the tropical harmattan wind (December to January). Previous tests on some of the briquettes produced and dried in the same period showed the briquettes having negligible moisture content(Mbamala, 2018). The sample firewood were also very dry.

Physical and combustion characterization

Biomass briquettes are usually characterized in term of their dry densities, percentage moisture content, percentage volatile matter, percentage ash content, percentage fixed carbon and gross calorific values. We will however focus mainly on results from water boiling test (WBT), burning rate and ignition time as they are more accessible to the common end users of the briquettes.

Fuel Dry Density

The Fuel dry density (FDD) is the ratio of the mass, m_0(in grams) of the air dried briquette sample to the volume, V (in cm^3) of the briquette.

$$FDD = \frac{m_0}{V} \qquad (1)$$

The Fuel Burning Rate

The fuel or briquette burning rate was determined according to the method used by others (Davies & Davies, 2013; Onukak et al., 2017). A protective heat insulator was placed on a balance; a Bunsenburner was placed on the insulator;a tripod stand was placed over the burner; and a wire gauze wasplaced on the tripod stand. The combined mass of the insulator, stand and gauze was recorded from the balance. Briquette sample of known mass (100 g) was placed on the wire gauze and the burner ignited. As the briquette burnt, its mass was recorded every 30 seconds until the sample was completely burnt out and constant mass attained. The Fuel burning rate (FBR) is the ratio of the mass of burnt matter to the total time taken, i.e.

$$FBR = \frac{M_i - M_f}{t}, \qquad (2)$$

where M_i(in grams) is the initial mass of the sample briquette, M_f (in grams) is the final mass of the burnt briquette (charred remnant and ashes) and t(in minutes) is total time to attain constant burnt briquette mass.

Water Boiling Test

The Water boiling test (WBT) was carried out to determine the cooking efficiency of the briquettes. We measured the time taken for each set of briquettes (Samples I to IV) to boil an equal volume of water under similar conditions. An approximately equal quantity of each sample briquette was used to boil about 1 liter of water using a cooking pot on a traditional tripod stove. During this test, some fuel properties such as specific fuel consumption and water evaporation rate were determined. Other observations like the ignition time and level of smoke evolution were also made.

Specific Fuel Consumption

The specific fuel consumption (SFC) is the ratio of the mass of fuel consumed to the volume of water evaporated:

$$SFC = \frac{M_{f1} - M_{f2}}{V_{w1} - V_{w2}}, \qquad (3)$$

whereM_{f1} and V_{w1} are respectively, the mass of fuel briquettes and volume of water in the pot before boiling, and M_{f2} and V_{w2} are the mass of briquette remnants and volume of water after boiling respectively. V_{w1}andV_{w2} were calculated from the measured mass of water before and after boiling. Here, we give SFC in grams per milliliter (g/ml).

Water Evaporation Rate

The water evaporation rate (WER) is the ratio of the volume of evaporated water to the time taken for water to boil, t_b in ml/min:

$$WER = \frac{V_{w1} - V_{w2}}{t_b}, \qquad (4)$$

Where V_{w1} and V_{w2} are as define in eq. (3).

III. Results and Discussions

We present results of the quantities defined in equations (1) to (4) and use them, along with other observations to discuss the physical and combustion characteristics of the sample briquettes produced. As a refreshment Table 1 shows a summary of the composition ratios for the four samples. Samples I & II are composed of sawdust, palm kernel shells and cement, while Samples III & IV are composed of palm kernel shells and wastepaper.

Table 1: Biomass/Binder Composition

Sample	Sample composition	Ratio by Volume
I	Sawdust/PKS/Cement	14:7:1
II	Sawdust/PKS/Cement	10:10:1
III	PKS/Wastepaper	4:3
IV	PKS/Wastepaper	4:2

Figure 2 showsa sample stack of briquettes produced from sawdust, palm kernel shell and cement; and Figure 3 shows another stack produced from palm kernel shell and soaked wastepaper only according to the procedures outlined in section 2.

Figure 2: A stark of briquettes produced from sawdust, palm kernel shell and cement.

Figure 3: A stark of briquettes produced with palm kernel shell (PKS) and soaked mashed paper.

Table 2 is a summary of the physical and combustion characterization of the four briquette samples analyzed.

Table 2: Summary of the Physical and combustion characterization of the briquette samples: FDD (Fuel dry density), FBR (Fuel burning rate), SFC (Specific fuel consumption) and WER (Water evaporation rate. Here Sample V represent arbitrary firewood as control.

Sample	FDD (g/cm^3)	FBR (g/min)	SFC (g/ml)	WER (ml/min)	Other Observation
I	0.460	1.28	3.21	8.50	Required regular fanning to flame with some smoke
II	0.586	1.19	---	---	Required vigorous fanning; Hardly flamed; Very smoky
III	0.572	1.38	3.27	8.63	Required occasional fanning to flame with smoke
IV	0.591	1.42	2.92	11.20	Required a little fanning to flame; Less smoky
V	0.625	1.37	3.14	10.26	Ignited easily; Flamed without smoke and fanning

Table 2 shows clearly that the investigated parameters for the briquettes, namely, the FDD, FBR, SFC and WER are comparable to those of the common conventional firewood (Sample V). We note however, that Sample II which has cement as binder and has more palm kernel in composition than Sample I performed poorly. Even though its dry density (FDD) is closest to that of firewood (Sample V), it has the lowest burning rate (FBR), has no values for SFC and WER because it could not generate enough flame and heat to boil (100^oC) the liter of water (See Figure 4). It was observed that Samples I and II burnt slowly and steadily with lots of smoke until the entire fuel is reduced to ashes. This is however, a desirable attribute if the intention is to use the briquettes for smoking such as fish drying where flame is not desired.Figure 4, obtained from the Water boiling test (WBT) further shows that Samples III and IV which have soaked wastepaper as binder performed closer to common firewood. Sample IV was the quickest in boiling water (6 minutes) while Sample II could not bring the water to boil.

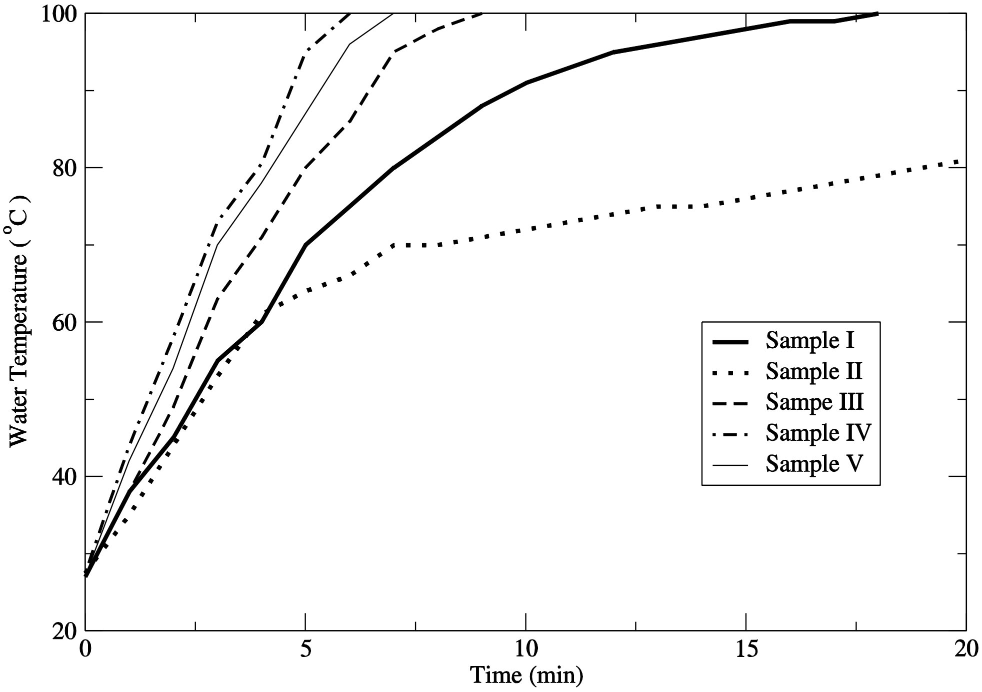

Figure 4: Water Boiling Test showing the temperature of 1 liter of water with time for the Briquette Samples I - IV and Firewood (Sample V)

The fuel burning rate (FBR) calculated from eq. (2) and shown in Table 2 can be said to be the average values because Figure 5 which is the plot of the mass of a 100g sample burning briquette with time shows the burning rate is not linear and therefore not uniform. One can obtain the instantaneous burning rate by determining the slope of the curve at any time.

What we conclude from these results is that good and stable briquette can be made from palm kernel shell, but it needs supporting flammable materials like in this study, sawdust or paper in an un-arbitrary proportion to give it the desired combustion characteristics.

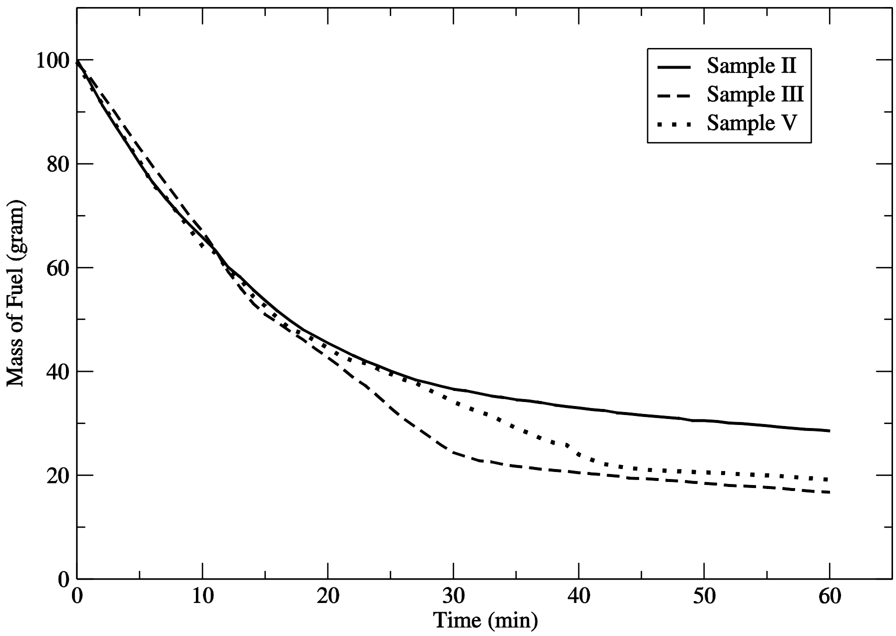

Figure 5: Plot of Mass of the burning Fuel versus time for some selected sample -- Sample II (pks/sawdust/cement); Sample III (pks/wastepaper); Sample V is firewood.

IV. Summary and Conclusion

Briquettes from agricultural residues (biomass) contribute significantly to the energy mix. Making briquettes from biomass can significantly reduce deforestation caused by the quest for firewood. We have produced and determined some physical and combustion characteristics of biomass briquettes with palm kernel shell (PKS) as the major component. We considered four briquette samples: Sample I has 14, 7 and 1 parts by volume of sawdust, palm kernel shell and cement respectively-- cement was the binder source. In Sample II, the composition of PKS was increased at the expense of sawdust, i.e. 10:10:1. Samples III and IV were composed of only PKS and soaked wastepaper in the ratios of 4:3 and 4:2 respectively. In this group, soaked paper, though also flammable (when dry), was the binder source. Again, in Sample IV, the composition of PKS was increased at the expense of soaked paper. The briquettes were produced in such shapes and sizes so as to be stored and used like common firewood in various wood stoves. Thefifth sample (Sample V), firewood from unidentified wood, was used as a control. We showed that the dry densities of the briquettes, though different from one another are comparable to that of the firewood (Sample V). We conducted burning rate and water boiling tests for the briquettes to determine their suitability as cooking fuel in most traditional wood stove – the tripod. It was found that the briquettes produced from PKS and wastepaper compared very well with firewood, while those produced with PKS, sawdust and cement equally performed well but burnt without flame and with much smoke as the composition of PKS is increased. We observed that even though this group of briquettes (PKS/Sawdust/Cement) may not boil water readily, they are appropriate for slow cooking and food smoking, as they ensure slow and steady release of heat energy without flame.

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