EVALUATION OF THE COMBUSTION CHARACTERISTICS OF RICE HUSK AND COCONUT SHELL BRIQUETTES.

Abstract

Combustion characteristics of rice husk and coconut shell briquettes have been investigated with a view of establishing its suitability as an energy source. The husk and shell were collected and carbonized in a furnace as rice husk charcoal (RHC) and coconut shell charcoal (CSC). These were further down sized and sieved to 2.5 mm particle size. The RHC and CSC were mixed in proportions of 50:45, 60:35, 70:25, 80:15, and 90:5% by weight respectively, and 5% cassava starch used as binder for all the compositions. The briquette samples were formed by thorough mixing and compaction in a metallic mold and extruded for drying and labelled 1A, 2A, 3A, 4A and 5A respectively. Physical and mechanical as well combustion tests were performed to confirmed the viability of the briquettes. The results indicate that sample 1A had the highest calorific value (4886 cal/g). The other properties such as water content, ash content, density of briquettes also indicate their suitability as energy source.

Key words: Rice husk, Coconut shell, Carbonization, Briquettes, Calorific value, Rice husk charcoal, Coconut shell charcoal, Ash content, Ignition time, Burning time.

1 INTRODUCTION

The decreasing availability of fuel like wood, coupled with the ever-rising prices of kerosene and cooking gas, has drawn global attention to the need to consider alternative source of energy for domestic and cottage level industrial use. As rightly noted by Naziri [1] noted that a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria. Renewable energy are energy sources that are naturally replenished on human time scale. An attempt to develop renewable energy from Rice husk biomass or waste material from rice production is of great importance. The waste has a low economic value and residual material after the main parts of this product are taken for use. Converting this raw material as a residual material into fuel as Bio-briquettes can make this material more economically profitable [2]. Rice husk is available in a sustainable manner. As biomass products, rice husk and coconut shell combustion have neutrality of carbon emission. This carbon can be reabsorbed without any challenge, hence, these are not just advantageous for environmental and economic sustainability, but also a long-term sustainable social-political stability [3]. Rice husk and Coconut shell are biomass based on carbon polymer compound named lignocelluloses consisting of three main parts; cellulose, hemicelluloses, and lignin Table 1. Converting rice husk into fuel requires a process called carbonization, and the process evaporates the water content and breakdown the cellulose, hemicelluloses, and lignin leaving carbon in the form of charcoal as a raw material for making bio-briquettes [4]. Rice husk briquettes can be produced by adding a certain amount of coconut shell charcoal as a substitute for wood charcoal which is no more economically and environmentally profitable. Rice husk briquettes formed using gum Arabic as binder has less superior combustion properties compared to fire wood [5]. Carbonization of Rice husks and synthetic starch as binder produce char with low heating value [6]. Cassava starch is used as a binder for quick burning and for the production of high calorific value briquettes. These materials are abundantly available and relatively cheap aside other useful characteristics such as ferrous sulfate or sodium hypophosphite [7].

Cassava has many other remarkable characteristics including, high paste viscosity, high paste clarity and high freeze-thaw stability.

Table 1: Composition of Rice husk and Coconut shell.

Mineral content (%)	Rice husk	Coconut shell
Cellulose	32.67	26.6
Hemicelluloses	31.68	-
Lignin	18.18	29.4
Extract solvent	-	4.2
Urinate anhydrous	-	3.5
Ash	11.88	0.6
Pentose	-	27.7
Water	-	8.0

Source: [8]

Traditionally, wood in form of fuel wood, twigs and charcoal have been a major source of renewable energy in Nigeria accounting for about 51% of the total annual energy consumption [9]. It is in line with this that this study seeks the utilization of rice husk and coconut shell to produce an energy source. Nigeria is a major rice producing and processing country with large quantity of rice been produced annually across different milling centers within the country [10]. When Rice and Coconut are harvested, the husks and shell are removed, and they are considered as waste materials and are dumped. There are heaps of these rice husk in several states across the country. The problems associated with Rice husk and Coconut shell disposal can be greatly reduced if they can be effectively utilized as a source of energy. Attention should be focused on converting these wastes into briquettes to address the environmental consequences and health hazards associated with the use of solid fuels (wood and charcoal).

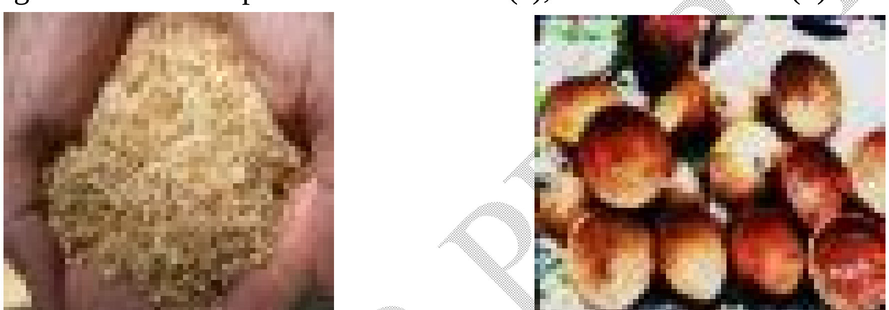
Processing rice husk charcoal into bio-briquettes is in one-way an effective way of packaging of Rice husk for charcoal briquettes and can be stored for energy use. Energy content of the rice husk charcoal briquettes can be increased by adding other kinds of biomass with high calorific values of energy [11]. Improving the quality of briquettes can be done at the preparation stage of charcoal such as carbonization, grinding, formulating the optimum composition and the addition of appropriate adhesive material in appropriate levels.

Charcoal is a light weight black carbon residue from wood, coconut shell, peat, and petroleum (or other animal and plant materials), by strong heating in minimal oxygen to remove all water and volatile constituents. In the traditional version of this pyrolysis process, called charcoal burning, the heat is supplied by burning part of the starting material itself, with a limited supply of oxygen. The material can also be heated in a closed retort. The use of charcoal as a source of energy or electricity is typically concealed in some regions because it is overshadowed by other dominant energy sources such as coal and gas in the energy mix. Charcoal utilization and consumption is often linked to lack of modern alternatives but globally electrified regions are still using charcoal as a source of energy [12]. Coconut shell charcoal is super stiff, hard and resistant. Most manufacturers base the quality of activated coconut shell charcoal on the absorption capacity that is directly related to the contact area. Coconut activated carbon is composed of 70 to 80% carbon, is practically pure, and the ash content varies between 5-10% [13]. Charcoal generally, produces more heat than coal, and it is cleaner than coal. Coal is basically a result of fossil fuel that is formed over many years, whereas the source of charcoal is slow burning carbon woods, and is considered as a non-renewable natural resource [14]. Once coal is mined out and used, it cannot easily be regenerated. Aside energy source, charcoal has several other benefits and uses, such as in water and air purification, deodorization, removal of organic substances, solvent recovery and as a catalyst and also treatment of acute poisoning.

Cassava, as a crop is second to potato as the most important starchy root crop of the tropics used for food and industrial purposes [15]. The current drive towards earning foreign exchange from cassava product had raised more awareness on the importance of the crop [14]. Cassava derives its importance from the fact that its starchy thick tuberous roots possess valuable calories. This product is just drained off without any thought for their utilization. The abundant availability of waste rice husk, coconut shell and cassava starch drives the need to evaluate the combustion characteristics of rice husk and coconut shell briquettes, with the utilization of cassava starch as a binding material (adhesives).

2.0 MATERIALS AND METHOD

The raw materials used for this experiment include rice husk as the base compound, coconut shell as energizer, cassava starch as binder, and water as a processing material. The rice husk was collected from Wurukum rice mill, and the coconut shell from Railway market, both in Makurdi, Benue State. Figure 1 shows samples of the rice husk (a), and coconut shell (b).



(a) (b)

Figure 1: Samples of (a) Rice husk, (b) Coconut shell.

2.1 Materials preparation

The Rice husk and coconut shell were properly washed separately with clean water to remove dirt and sun-dried for 3 days to reduce the moisture content. Samples of the rice husk and coconut shell of 25 kg each in a steel crucible were separately carbonized in a furnace. This was done by gradually raising the temperature to 250 ^{o}C and maintaining it for 24 hours. This is the decomposition temperature at which the water content evaporates and the cellulose, hemicelluloses and lignin breakdown to leave carbon in form of charcoal. These were then collected and allowed to cool under normal condition and used for the production of the bio-briquettes.

2.2 Production of Bio-briquettes

The carbonized products were collected and separately crushed in a steel mortar. A 2.5 mm diameter sieve size was used to sieve out the fine particles which were then properly stored separately in desiccators. The cassava starch was prepared by boiling 3 liters of clean water in an aluminum steel pot.

The cassava flour/powder was first properly dissolved and mixed with a very small quantity of cold water in a plastic container. The boiled water was gradually poured into the plastic container with the dissolved mixture and stirred continuously until it becomes gelatinized and gradually coagulates. This starch was then allowed to cool in the plastic container preparatory for use.

2.2.1 Formulation and blends of the briquettes

The bio-briquette samples were with proportions by weight of rice husk charcoal (RHC), coconut shell charcoal (CSC), and cassava starch (CS), as shown in Table 2. The samples were labeled 1A, 2A, 3A, 4A, and 5A respectively.

Table 2: Proportions by weight of Rice husk, Coconut shell charcoal, and Cassava starch for the samples.

RHC (%)	CSC (%)	CS (%)	SAMPLE ID
50	45	5	1A
60	35	5	2A
70	25	5	3A
80	15	5	4A
90	5	5	5A

The respective RHC and CSC compositions were added into a container and properly mixed with the CS which was kept constant at 5% for all the samples. They were properly stirred to blend together forming a solid mass, and was loaded into a cylindrical hollow (20 mm internal diameter and height of 50 mm) metallic mold as shown in Figure 2(a) and compacted using a hydraulic press. The compacted samples were then extruded as shown in Figure 2(b) from the mold using a metallic plunger. These were labeled accordingly for proper identification as shown in Figure 2(c). The briquettes were then weighed and allowed to dry (cure) in air for 3 days preparatory for further tests.

(a) (b) (c)

Fig. 2: Briquettes mold (a), Extrusion process (b), and Sample Identification (c).

2.3 Combustion tests

The Chinese water boiling protocol 2008 as applied by Kers et al. [16] was adopted. A cooking stove with a combustion chamber in place was positioned with a wire mesh grid resting on two supporting fire bricks stands. The cooking stove was placed directly beneath the mesh with free flow of air around the briquette. The briquettes were stacked in the combustion chamber of the stove. 2 liters of water in a steel pot was the placed on the stove. The initial temperature of water in the pot (T_1) was measured using dry a bulb thermometer and the initial weight of the briquettes in the combustion chamber (w_1) was also measured using digital a weighing balance.

2.3.1 Ignition and burning time test.

The stove was lit and allowed to produce a blue flame until the entire bottom surface of the briquettes were simultaneously ignited. Draught was avoided to prevent flame spread in the transverse direction. The stove was left on till the briquettes were in steady state burn phase. The ignition time taken to light up the briquettes was recorded as t_1, while the burning time (t_2) was taken as average time taken for the briquettes to burn into ash after ignition until the water boiled.

2.3.2 Water boiling test

The briquettes were lit and allowed to candle to blue flame, as the ignition time was taken using stop watch. The water in the steel pot earlier placed on the mesh over the combustion chamber of the stove was allowed to boil. The starting time and boiling time at 100 ^oC were noted as (t_1) and (t_2) respectively.

2.3.3 Ash content (Ac)

After boiling the water, the stove was put off and allowed to cool and the burnt briquettes were shake out and collected on the ash tray. The unburnt part of the briquettes was weighed and recorded as (w_1), and the burnt ash after cooling was again weighed and recorded as (w_2). The ash content was determined using equation 1.

$$\% \, Ash \; Content = \frac{W_2}{W_1} \times 100 \quad (1)$$

where W_1= weight of the in combustible part of the burnt briquettes and W_2= weight of the burnt ash after cooling

2.3.4 The calorific value (CV). The initial temperature of the briquettes before burning was measure as (T_1), and the burning temperature taken to boil water was measured as (T_2). The useful heat generated Q was obtained using a bomb calorimeter, while the mass (m) of the briquette was determined. The calorific value (CV) was calculated using equation 2.

$$\mathrm{CV} = \frac{\Delta \mathrm{T} - \mathrm{Q}}{\mathrm{m_b}} \quad (2)$$

where CV = calorific value, ΔT = Resulting temperature change from the object, m_b = mass of the briquette, and Q = quantity of heat generated as a result of burning.

2.4 Physical/ Mechanical test

2.4.1 Density

The density test was carried out using ASTM C693 where the mass of the sample was obtained using a digital balance. The briquette samples were immersed in water in a vessel and the volume of water in it) representing the water displaced by the sample and the volume of water displaced by the sample and the volume of the sample (v) determined. By Archimedes principle the density (ρ), of the sample was obtained using equation 3.

$$Density\ (\rho) = \frac{mass}{displaced\ Volume\ (v)} \quad (3)$$

where ρ = density (kg/m^3), m = the mass of the test sample (g), and v = the volume (m^3).

2.4.2 Shatter index test

This test was carried out in accordance with ASTM C234. The specimens were weighed on a digital weighing balance and recorded as (WBS). The specimens were then wrapped in a polyethylene bag and dropped on the face of an anvil from a height of 1.8 m. The percentage weight retained on a 4 mm diameter sieve was recorded as (WAS). The shatter index (S.I) was determined using equation 4.

$$Shatter\ index\ (\mathrm{SI}) = \frac{WAS}{WBS} \times 100 \qquad (4)$$

where WAS = weight after shatter and WBS = weight before shatter.

2.4.3 Water resistance test

Water resistance test (WRT) was carried out in conformity with ASTM C693. The weight of each briquette was measured and recorded as (wt_1). The samples were then immersed in cold water for 1 hour, and then removed and allowed to drain for 15 seconds and wiped with a damp cloth, and then weighed again as (wt_2). The percentage of water resistance was calculated using equation 5.

$$\%\,WR = \frac{Wt_2 - Wt_1}{Wt_1} \times 100 \qquad (5)$$

where Wt_1 = Initial weight of sample before immersion, and Wt_2 = Final weight of sample after immersion.

3.0 RESULTS AND DISCUSSION

3.1 Combustion tests

3.1.1 Ignition time

The mean results of ignition time for the briquette samples is presented in Table 3. The result of ignition time against sample composition for all the samples briquettes produced indicate that sample 5A had the least Ignition time of 69.48 s while sample 1A had the highest Ignition time of 111.40 s. As the RHC increases there was remarkable decrease in the ignition time. This could be attributed to the fact that CSC which has low calorific value which tend to reduce that of RHC when in combination. Also, the RHC and the Cassava starch contain some substantial amount of ferrous sulfate which improves its tendency to ignite [3].

Table 3: Combustion characteristics

Sample ID	IT (sec)	WBT (min)	AC (%)	CV (cal/g)
1A	111.40	14.40	32	4886
2A	110.52	16.15	30	4786
3A	96.18	20.09	28	4578
4A	76.18	21.50	26	4326
5A	69.48	23.22	22	4124

3.1.2 Water boiling time

The mean results of water boiling test are presented in Table 3. The water boiling time was within the range of 14-26 minutes. However, the results indicated that as the RHC increases the water boiling time also increases. RHC has higher caloric value than CSC but tend to hold burning longer, thereby extending the boiling time [6]. Other factors that could be responsible for burning rate of briquettes are chemical composition, volatile matter content and geometry of the briquettes [17].

3.2.2 Ash content

The mean results of ash content of the briquette samples are presented in Table 3. The result shows that as the CSC decreases, the ash content equally decrease (from 32-22 %). Sample 5A had the least Ash content of 22%. Ash is a metallic oxide in charcoal composed of minerals that cannot evaporate in the carbonization process. The ash content is very influential to the quality of briquettes produced and is an incombustible material that will partake in the chemical reaction in the combustion process. These results agree with the findings of Nazari [1]. The higher the ash content in briquettes the lower the heat that will be produced [18].

3.2.3 Calorific value

The mean results the calorific value are presented in Table 3. The results show that Sample 1A had the highest calorific value of 4886 cal/g, while Sample 5A had the lowest of 4124 cal/g. The results indicate that as the RHC increases, the calorific value also decreases. Moisture contained and the introduction of starch as binder also affects the calorific value of the briquettes considerably. The high silica levels lead to increase in water content because the silica absorbs water so that the briquettes become hygroscopic [19].

3.3 Physical / Mechanical properties

3.3.1 Shatter Index

Shatter indices are direct means of gauging the strength of briquettes for the purposes of handling, transportation and storage. The mean results are presented in Table 4. The shatter index of the briquettes fall within the range of 94-99%. This is largely due to the cassava starch used as binder material. The addition of cassava starch as a binder is responsible for the agglomeration of the materials and result in a strong bonding of particles. When briquettes are bonded, the shatter index is greatly minimized [20]. Also, higher ratio or composition of RHC resulted in a higher percentage of shatter resistance of briquettes [11, 21].

Table 4: Mechanical/Physical test results

Sample ID	Shatter index (%)	Density ($\times 10^2$ g/cm^{-3})	Water resistance test (%)
1A	94.67	0.43	86.21
2A	94.33	0.40	90.12
3A	92,56	0.38	90.61
4A	98.22	0.36	93.09
5A	96.91	0.35	95.61

3.3.2 Density

The mean results of density are presented in Table 4. The results show that as the RHC increases the density decreases. Density is an important parameter for briquette handling. The higher the density of the briquettes the higher the energy/volume ratio with longer burning time [22]. Onchieku et al. [23] in their work reported the density of briquettes as ranging from 0.30 - 4.5 g/cm^3. Also, Antwi-Boasiako and Acheampong [24] stated that briquette density is affected significantly by the raw material particle size, and finely ground materials make very dense briquettes. This was confirmed by Kumar et al. [25], suggesting that raw material with finer particles provide larger surface area for bonding, which results in the production of briquettes with a higher density, owing to the tendency of not absorbing water.

3.3.3 Water Resistance

The mean results of density are presented in Table 4. From the results, it was observed that as the percentage RHC increases and CSC decreases, and water resistance for the briquettes increases. This could be as a result of the presence of cassava starch as binder during the production of the briquettes. Deshannavar et al. [26] in their study recommended water resistance for charcoal briquettes to be > 70%. It is important that briquettes display high resistance to water penetration to avoid decay and growth of fungi during storage, particularly if the feedstock is agricultural residues [13].

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the experiments and the result obtained, the best compositional mixture in terms of the property is that of Sample 1A (50% RHC and 50% CSC) with the Calorific value of 4886 cal/g. This shows that waste rice husk and coconut shell can be used to produce briquettes as energy sources, and to provide better alternative to wood, charcoal, fossil fuels, and eco-friendly solid fuel that can be used for domestic heat applications. Agricultural waste is produced in large quantities and is disposed indiscriminately most especially in the rural areas of developing countries, thereby causing a health hazards. The increased use of this wastes in producing briquettes will also help in solving disposal problem and the extraction of useful energy. The briquettes from a blend of rice husk and coconut shell could bring about significant environmental and socio-economic benefits to rural communities of developing countries including Nigeria.

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