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Utilization of Groundnut Shells for the Production and Characterization of Bio-Briquettes for Household Cooking

Zaka A. Galadima, Momoh Shaibu, Zakari S. Mohammed, Emmanuel Onoja and Abdullahi A. Samaila
Department of Science Laboratory Technology, Federal Polytechnic, Kaura Namoda, Zamfara State, Nigeria
E-mail: momohshaibu3@gmail.com
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Abstract - **Agricultural waste, such as groundnut shells, can pose environmental pollution, fire hazards, and soil degradation if not properly managed. Therefore, recycling groundnut shells into briquettes as an alternative energy source for households may help mitigate these problems. This research aimed to utilize groundnut shells for the production and characterization of bio-briquettes for household cooking. Groundnut shell samples were obtained from a groundnut milling site in Kuriya, Zamfara State. The results obtained using standard analytical methods were as follows: density (1.2 g/mL), moisture content (3.650 ± 0.048%), volatile matter (11.60 ± 0.004%), ash content (1.840 ± 0.029%), fixed carbon (45.740 ± 0.031%), and calorific value (4984.730 ± 0.169 kJ/g). Combustion properties such as ignition time were 4 minutes and 53 seconds, with no emission of smoke or odor; red sparks were also observed. The boiling time was 14 minutes and 23 seconds, with a burning rate of 1.5 g of briquette per minute during combustion. The physical and combustion properties show that the briquette produced from groundnut shells is effective, affordable, and environmentally friendly compared to firewood and charcoal. Bio-briquettes can be adopted as an alternative energy source for domestic cooking.**
Keywords: **Groundnut Shell, Bio-Briquette, Recycling, Energy Source**

I. INTRODUCTION

Agricultural waste, such as groundnut shells and rice husks, can be recycled into energy sources for domestic and industrial uses [1]. Agricultural waste recycling refers to the process of converting agricultural waste materials into valuable products, such as bio-briquettes. This, in turn, reduces the environmental impact of disposing of groundnut shells into the environment. For decades, many rural households and some urban residents have relied heavily on charcoal and firewood as their main sources of energy for cooking [2]. However, charcoal and firewood have a tremendous effect on greenhouse gas emissions, as their production results in deforestation. Deforestation is the permanent destruction of forests as a result of human activities [3].

Global warming has become a serious issue worldwide. Carbon dioxide, identified as the main greenhouse gas, contributes significantly to global warming. Research has demonstrated that rising emissions of this gas have been exacerbated by deforestation for energy production, outpacing the nation's afforestation efforts [4].

Biomass, especially agricultural waste such as groundnut shells and rice husks, is one of the most promising prospective energy sources for developing nations like ours [4]. The demand for firewood and wood charcoal has prompted researchers to focus on utilizing agricultural wastes efficiently to reduce the impact of deforestation. The significance of these wastes as fuels for domestic and commercial heating applications has increased based on the findings of various researchers.

Certain agricultural wastes, such as coconut shells and wood debris, can be used directly as fuels. Biomass, which includes rice husks and groundnut shells, is a major agricultural waste that is often burned during the processing of agricultural produce, contributing to environmental degradation. The majority of these wastes are either burned, which pollutes the environment, or left to decay [5].

A briquette is defined as a fuel block composed of charcoal dust, biomass, or compressed coal used to start and maintain a fire. The compression method is used to shape tiny particles of biomass into the desired form [6]. Traditionally, the briquette process has focused on converting agricultural waste into smokeless solid fuels using various methods. The most popular technique employs a roller press with a binder and moderate pressure, followed by drying for use in household cooking or industrial applications if produced in large quantities [7].

However, various techniques have been adopted by different researchers [8]-[11] for the additional processing of biomass into briquettes before they can be utilized directly as fuel. This is due to high moisture content and density, which can lead to issues during handling, storage, and transportation.

Even though several studies [11]-[13] have demonstrated that agricultural wastes, such as groundnut shells, rice husks, and other materials, can be recycled to produce smokeless briquettes, bio-coal briquettes, and biomass briquettes, they have not been fully utilized. These briquettes have the highest potential as suitable alternatives to coal and fuelwood for thermal applications and domestic purposes but remain underutilized among the available energy resources in Nigeria.

Therefore, the objectives of this research are to evaluate the feasibility and efficiency of using groundnut shells as a renewable source to replace firewood and charcoal, as well as to investigate the technical specifications required for the production and utilization of bio-briquettes for household cooking.

II. MATERIALS AND METHODOLOGY

A. Sample Collection

Groundnut shells were obtained from a groundnut shell milling site in Kuriya, Kaura Namoda, Zamfara. Kuriya is an area located in the Kaura Namoda local government, where groundnut farmers mill their groundnuts, and the shells are dumped, causing environmental issues such as unpleasant odors. The groundnut shell samples were filtered to remove sand and stones before being sun-dried.

B. Production of Bio-Briquette

A starch powder was prepared by using boiled water at 100°C to form a gel and allowed to cool. After 50 g of the dried groundnut shell was weighed, it was divided into five crucibles and heated to a temperature of 1200–1250°C in a muffle furnace. The ash remains were allowed to cool in the absence of air. A uniform paste was formed by weighing and combining 25 g of the ash samples with 4 g of the produced starch. The paste was then compacted into a solid form and allowed to dry [16].

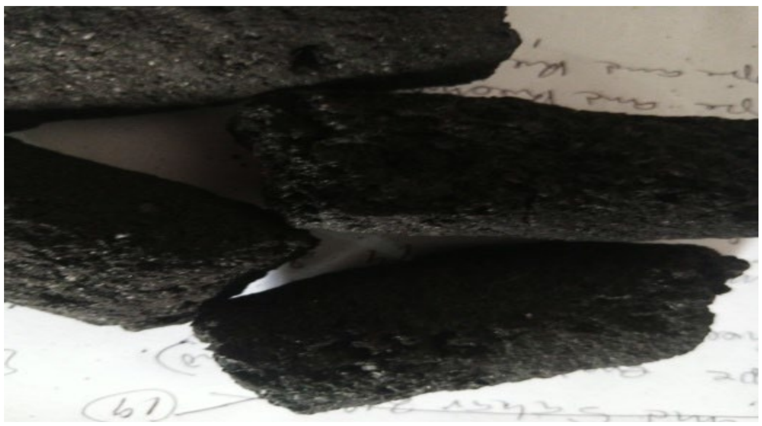

Fig. 1 Bio-briquette produced

C. Characterization of Bio-Briquette

1. Proximate Analysis of Briquette

a. Moisture Content: After 3 g of the samples were weighed and placed in a cleaned crucible with a known weight (designated as W1) and another crucible containing samples (designated as W2), the oven was set to 110°C for two hours. Following removal and cooling in desiccators, the crucible was weighed once again. The percentage of moisture was calculated based on the percentage of weight loss.

$$\text{Moisture content (\%)} = \frac{\text{X1} - \text{X2}}{\text{X1}} \times 100$$

Where X1 is the initial weight, X2 is the final weight of the sample

b. Volatile Matter

A moisture-free STEM method was used to calculate the volatile matter. Three grams of the samples were weighed into a cleaned, sealed crucible and heated to 920°C for seven minutes before being cooled. The weight loss of the volatile materials in the crucible was measured and reported as a percentage. The formula below was used to compute the volatile matter (in percent).

$$\text{Volatile matter (\%)} = \frac{\text{Dry weight} - \text{final weight of smple}}{\textit{oven druied weightt}} \times 100$$

c. Fixed Carbon

The amount of carbon in the material that remains after the removal of unwanted materials is known as the fixed carbon content. This differs from the final carbon content because some of the carbon is lost as hydrocarbons along with the volatile matter. Fixed carbon was calculated by subtracting the mass of volatile matter found from the sample's initial mass. The following formula was used for the calculations.

$$\text{Fixed carbon (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

Where, W_3=final weight
W_1=weight of VM crucible
W_2=weight of VM crucible+1g of sample.

d. Ash Content

The non-combustible residue that remains after burning a sample is called the ash content of the material. During ignition, carbon, oxygen, sulfur, and water are removed, leaving behind the mineral content. One gram of the material was burned at 800 ± 5 °C in open silica crucibles for approximately an hour in a muffle furnace to determine the ash content. The following formula was used for the calculation:

$$\text{Ash content(\%)} = \frac{Weight\ of\ Ash}{Dry\ weight} \times 100$$

The amount of heat energy contained in food or fuel is known as its calorific value, which is calculated by fully burning a given quantity of fuel under normal, constant pressure conditions. The energy content of the bio-briquettes was evaluated using the LECO AC-350 model bomb calorimeter.

2. Bio-Briquette Combustion Test

To replicate typical cooking conditions, the combustion test was conducted by boiling water (water boiling test) using a bio-briquette, two liters of water in a kettle, and a conventional tripod stove. The characteristics of combustion were analyzed as follows [15].

a. Ignition Time: The amount of time it takes for a flame to raise a briquette to its ignition point. This was measured using the standard test method for determining material ignition and flame spread properties [15]. The briquette was fully ignited before the ignition time was recorded with a stopwatch, ensuring that the entire bottom surface was ignited simultaneously using a Bunsen burner set to a blue flame.

b. Smoke: The color of smoke produced during the combustion of the briquette was recorded as minimal, dense, black, or white. Minimal smoke is preferred, as it indicates cleaner combustion [15].

c. Boiling Time: This refers to the amount of time needed for a 100 g sample of briquettes to boil a given amount of water. This metric helps determine which briquette sample will cook meals more quickly. The briquette samples were lit in a briquette burner after one liter of water was added to a kettle. The time taken by each briquette sample to bring the water to a boil was measured and documented [15].

d. Burning Time: This refers to the total time the briquette burns, from ignition to total burnout. The burn period is a crucial component as it dictates how long the briquette can sustain combustion.

e. Rate of Fuel Burning: The result of the water boiling test was used to calculate the fuel burning rate, as stated by [15]. The following formula was used:

$$\text{Fuel Burning rate} = \frac{intial\ mass\ of\ briquette - final\ mass\ of\ burnt\ briquette}{Time\ (mins)}$$

f. Flame: These are the characteristics of the flame produced by the briquette, including its color, height, and steadiness. A steady and uniform flame is preferred for optimal heat output and safety [15].

g. Odor: This includes any smells released by the briquette, as well as those created during combustion. Strong or unpleasant odors may indicate the use of improper materials or contaminants during the briquette's manufacturing process [15].

h. Spark: During ignition and burning, the briquette was observed for the presence of sparks or popping noises. Sparks can pose a safety risk, particularly in enclosed or indoor areas, and may indicate the presence of foreign materials in the briquette [15].

III. RESULTS AND DISCUSSION

TABLE I RESULT OF THE PROXIMATE ANALYSIS OF BRIQUETTE PRODUCED FROM BIOMASS

Proximate analysis	**Biomass Briquette**
Moisture content (%)	3.65±0.048
Volatile matter (%)	11.65±0.004
Ash content (%)	1.84±0.029
Fixed carbon (%)	45.74±0.031
Calorific value (kJ/kg)	4984.73±0.169

The result was expressed in mean± standard deviation

According to [16], the moisture content of biomass briquettes, as recorded in Table I, was 3.65±0.048%, which falls within the acceptable range for cooking fuel moisture content. This value is comparable to that reported in [17]. Cooking fuel typically has a moisture level of 8–12% [18], so the moisture content found in the current research is within the standard range. This is considered crucial for efficient and sustainable burning, which impacts the fuel's energy value [19]. This conclusion aligns with [14], which reported that fuel wood with high volatile matter content, such as charcoal, ignites and burns more quickly.

Ash content in biomass is often considered a complex issue due to its effects on ignition time and burning time. The amount of ash depends on the content of organic and inorganic matter and possible impurities present in the samples. Ash content may vary based on the sampling point, harvesting time, and harvest conditions [16]. The calculated ash content in biomass briquettes was 1.84±0.29%. Biomass briquettes have a low ash concentration, consistent with [20], which indicated that higher ash values are detrimental to boiler operations. Furthermore, [21] noted that many industries view biomass briquettes as excellent fuel for boilers due to their low ash, potassium, and chlorine content, which reduces ash agglomeration. During burning, it was also observed that fixed carbon is the primary source of heat.

The fixed carbon percentage in the biomass briquette was 45.74±0.031%. There is a significant relationship between heating value and fixed carbon that affects the time it takes for water to boil in the combustion test. With a calorific value of 4984.73±0.169 kJ/kg, biomass briquettes are an excellent fuel for burning (Table II).

TABLE II RESULTS OF THE COMBUSTION TEST OF BRIQUETTE PRODUCED FORM BIOMASS

Combustion Test	**Biomass Briquette**
Physical appearance	The observed color of the briquette was black
Density (g/ml)	1.2g/ml
Ignition time (minutes)	4 minutes 53 seconds
Smoke	no emission of smoke
Water boiling time	14 minutes 34 seconds
Fuel burning rate	Initial mass of briquette = 30.00 g Final mass = 12.48 g Mass of burnt matter = 17.52 g 1.95 g/min
Odor	no odor
Flame	Reddish in color
Spark	burnt with sparks

Water boiling tests were conducted to assess the suitability of the briquette as a fuel source for domestic and industrial use [20]. According to the ignition test results (Table 2), the briquettes did not ignite immediately; it took 4 minutes and 43 seconds for ignition. This delay may be attributed to the hardness of the groundnut shells. The observed ignition time for the biomass briquette (4 minutes and 53 seconds) did not match the 8 minutes reported by [22].

No smoke was released from the briquette upon ignition. The absence of smoke makes the biomass briquette a favorable option for residential cooking fuel, as smoke is well-documented as harmful to both the environment and human health [21]. The briquette burned with an odorless flame and a crimson hue.

During ignition and burning, sparks and popping noises were observed. Sparks may indicate the presence of foreign materials in the briquette and pose a safety risk, particularly in enclosed or indoor areas [21]. The water boiling time of 14 minutes and 23 seconds was used to calculate the briquette's fuel burning rate. According to the results (Table II), the fuel burning rate was 1.95 g of briquette fuel per minute during combustion. This value was lower than the 3.20 g/min obtained by [22], which could be due to variations in calorific value, briquette density, and raw materials.

Groundnut shell residues used in their raw form for cooking are considered somewhat unsuitable due to their high smoke production [22]. Therefore, biomass briquettes are a more sustainable and effective alternative to fuel wood and charcoal.

IV. CONCLUSION

Based on the findings, it was possible to produce biomass briquettes using groundnut shells. The study noted that these biomass briquettes were less costly to produce and less harmful to the environment. After manufacturing, the physical and combustion characteristics of the biomass briquettes - such as fixed carbon, moisture content, ash content, volatile matter, and calorific value—were found to be within acceptable ranges. Experimental results and observations related to combustion analysis indicated that, although the biomass briquettes took longer to ignite, they burned for a longer duration without producing any ash. Due to their low smoke emissions, the briquettes are considered to have adequate combustion qualities for household use.

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