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PRODUCTION AND EVALUATION OF BIOMASS BRIQUETTES FROM PALM KERNEL SHELL AND COCONUT HUSK

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Abstract
This study investigates the production and evaluation of biomass briquettes derived from palm kernel shell (PKS) and coconut husk (CH), with cassava starch as a binder. The raw materials were carbonized at 400°C for PKS and 250°C for CH, mixed in different ratios, and compressed into briquettes. Five samples (A–E) were formulated and evaluated based on their physical and combustion properties. Parameters such as density, moisture content, volatile matter, ash content, fixed carbon, and calorific value were analyzed. Among the samples, Sample D (20% PKS, 70% CH, 10% binder) exhibited the highest calorific value of 465.28 J/g, making it the most efficient formulation. This research demonstrates the potential of agro-waste briquettes as a sustainable alternative energy source for domestic use.

Keywords: *biomass, briquette, palm kernel shell, coconut husk, calorific value*

Introduction

HThe rising demand for sustainable and eco-friendly energy sources has intensified research into renewable alternatives such as biomass. In Nigeria and other developing countries, the abundance of agricultural waste presents an opportunity to convert these materials into biofuels. Recycling of biomass, which is simply to burn to ash for disposal, has seen a sharp increase, posing a serious social problem for our society and a major challenge in the protection of environment and natural resources (Swapan and Shalini, 2017). Briquetting is one such technique that enhances the handling and combustion properties of agro-wastes. Koleola *et al*. (2022), focus research on the need to convert agricultural wastes to useful and viable source of alternative energy for domestic and industrial purposes has been very rife in recent developments. Palm kernel shell (PKS) and coconut husk (CH) are two abundant by-products often left unused or burnt openly, contributing to environmental degradation. Previous studies have shown the potential of various biomass materials for briquette production, yet limited attention has been given to combining PKS and CH. Olugbade and Mohammed (2015), researched on the recycling of agricultural waste products into useful products is rarely practiced in developing countries such as Nigeria to meet the high demand of low-cost energy in running daily domestic needs, especially cooking. Baffour-Awuah *et al*., (2021), state palm kernel (PK) is one type of tree that has various benefits for the life of humanity. Its varieties are often identified as palm oil producer or oil palm fruit. The use of PKS briquette as high-grade solid fuel can reduce considerably both environmental pollutions emanating from wastes as well the energy crises in most developing countries (Adeniyi *et al.*, 2014). The reuse of waste material reduces operation costs, negative environmental effects and dependency on conventional fuels. Utilization of oil palm waste is used in mill boilers to produce steam, and electricity through a back pressure turbine (Aris *et al.,* 2005).

Coconut husk, a lignocellulosic biomass, as a promising engineering material for non-wood paper production. Plant fiber classified as environmentally friendly material is a promising renewable engineering material rich in lignocellulose that can be employed in the pulp and paper industry as a substitution to wood which has been entailing negative environmental impacts due to acute deforestation (Pratima and Nausheen, 2021). Stelte *et al.* (2023), The global production of coconut, mainly for food and oil production, exceeds 62 million tonnes per annum. Large quantities of coconut husk remain unutilized after industrial processing, giving rise to environmental problems. Traditional products such as textiles, mats, and brushes made from coir are increasingly being joined by new, high-value, non-traditional uses. The coconut industry generates a relatively large amount of coconut shell and husk biomass, which can be utilized for industrial and environmental purposes. Pyrolysis, gasification and selfsustained carbonization are among the production technology discussed to convert this biomass into carbon-rich materials with distinctive characteristics (Azrine *et al.,* 2022). Wolfgang *et al.* (2023) gave explanation of coir from coconut processing waste as a raw material for applications beyond traditional uses. It exploits the potential presented by the extraction of coir, which could have numerous applications. This study aims to produce briquettes from these materials; Palm kernel shell (PKS) and coconut husk (CH) and assess their suitability as domestic fuel based on combustion characteristics. Senchi and Kofa (2020), the excellent selection of agro-waste briquettes for domestic and industrial cottage application typically depends on the fuel properties such as proximate and combustion characteristics.

Materials and Methods

Materials

Palm kernel shells (PKS) and coconut husks (CH) were collected from local sources in Nigeria. Cassava starch was used as a binder due to its availability and adhesive properties.

Plate 1 shows the palm kernel shells (PKS), derived from ***Elaeis guineensis*** species (Dura and Tenera varieties), by-product of palm kernel (PK) processing. For this study, the PKS were sourced from Ilesha, Osun State of Nigeria and subjected to superheating at 400 °C.

Plate 2 shows the coconut husk (Cocos nucifera), a waste product obtained from coconut plant. For this study, coconut husk (CH) was sourced from Awule, Akure, Ondo State of Nigeria and superheated at 250 °C.

Plate 3 shows the cassava starch, sourced from the local market at Euwveri, Ughelli, Delta State of Nigeria. The cassava starch was processed and used as the binder.

Methods

Palm kernel Methods used for the production of briquettes in this project research involves several stages. This includes; sample collection, pyrolysis

Plate 1: Palm kernel (Elaeis guineensis) shells as received

Plate 2: Coconut (Cocos nucifera) husk as received

Plate 3: Dry powder cassava starch as received

Plate 4: Carbonization furnace housing the saggar

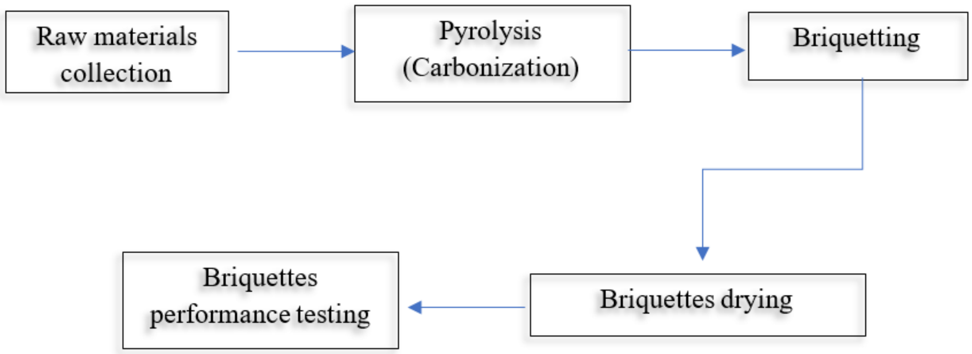

Figure 1: Research methodology flow diagram

process, briquetting process and evaluate briquettes. Figure 1 shows the research methodology flow diagram.

Carbonization
The biomass materials were collected from the local sources in Nigeria, the PKS from Imo, Ilesha, Osun state, the CH from Awule, Akure, Ondo state and the cassava starch from Euwveri, Ughelli, Delta state. After which, PKS and CH were sun-dried for 14 days, then carbonized using a locally fabricated drum kiln. PKS was carbonized at 400°C and CH at 250°C for uniform carbon content.The sun-dried PKS and CH were placed in a saggar, inside a carbonization furnace separately. The sun-dried CH was required to be crushed into smaller pieces before carbonization (placing in a saggar inside a carbonization furnace).

Plate 4 shows carbonization furnace housing the saggar, the pyrolysis process occurred in the furnace which is designed for carbonizing a variety of biomass materials, including palm kernel shell, sawdust, wood chips, bagasse, coffee grounds, bamboo, and coconut husks, among others (approximately for this study, 400 °C for PKS and 250 °C for CH). The furnace was designed to have a rectangular shape with a height of 1200 mm, 5 mm thick metal wall made of mild-steel lined internally with refractory brick insulations with an internal area of 0.5974 m^2. The combustion chamber is approximately 0.4037 m^3 in volume. Facilities for measurement such as 12 points channel temperature recorder, gas analyzer, and airflow meters were used. To ensure quality air-fuel mixture required for good combustion, a split air supply system was employed.

A saggar is used to ensure controlled combustion, with the bottom perforated using a nail (diameter 2.11, and length 31.25 mm) to facilitate slow burning and even heat distribution. A 150 mm diameter hole was made at the top of the saggar's cover using a knife, and a two-way open cylindrical container (200 mm in length, and 14.9 mm in diameter) was inserted to act as a chimney. During the combustion, the temperature was maintained at approximately 400 °C for PKS and 250 °C for CH. After the end of combustion, the air inlet is closed, and after one to two hours of ventilation, the exhaust hole is sealed. Following 48 hours cooling period (this is to prevent oxidization), after the saggar is emptied, and the carbonized materials (palm kernel shell and coconut husk) is crushed. Plate 5 shows the CH and PKS physical look after pyrolysis. The carbonization process ensures that the palm kernel shell and coconut husk are well dried.

Briquette Formation
Charred materials were crushed and sieved to uniform particle sizes. Five different ratios of PKS and CH (Samples A–E) were prepared, each containing 10% binder by weight. The mixtures were compressed into cylindrical molds and sun-dried for 3 days. Plate 6 shows the briquetting machine used to produce the various briquette samples.

Performance Evaluation

- **Density**: Measured using volume and mass of each briquette.

Density as expressed in Equation (1) is a physical property defined as the ratio of a substance's mass to its volume and its typically represented by the symbol "ρ" (rho) and its units of mass per unit volume. It's an important property in science and engineering, as it can help identify substances and determine their properties, such as buoyancy and stability.
Density formula of briquette sample,

$$\rho = m/V \quad (1)$$

Where m is mass of cylindrical briquette sample (g), V is volume of cylindrical briquette sample, $V = \pi(D/2)^2 h$ (mm^3 or cm^3), D is diameter of cylindrical briquette sample (mm or cm), h is height of cylindrical briquette sample (mm or cm).

- **Proximate Analysis**: Conducted to determine moisture content, volatile matter, ash content, and fixed carbon (AOAC, 2000).
- **Calorific Value**: Determined using a bomb calorimeter (ASTM D5865-04).

Proximate analysis is an important tool for evaluating the quality and properties of briquette, helping to ensure the briquette meet the desired standards for energy production, and environmental impact. Moisture content is the amount of water present in the briquette, and the Ash content is the residual material left after combustion, which can affect the quality of the briquette. Volatile matter refers to the number of gases released during combustion, which can affect the burning characteristics, and the Fixed carbon is the amount of carbon remaining after volatile matter has been released, which affect the energy content.

Ultimate analysis provides a more detailed understanding of the elemental composition of the produced briquettes. Helping to evaluate energy content and combustion characteristics, assess environmental impact (e.g. NOx, SO2 emissions), determine suitability for domestic cooking in households at low cost, with little or no smoke and optimize briquette manufacturing processes. Ultimate analysis is typically performed on a dry, ash free basis to ensure accurate results using test in line with the American Standards for Testing and Materials (ASTM). Calorific value is the amount of energy released when the briquettes are burned, typically measured in Kilocalories per Kilogram (kcal/kg) or British Thermal Units per Pound (BTU/Ib).

Plate 5: CH and PKS physical look after pyrolysis

Plate 6: Briquetting Machine

Results and Discussion

Sample Briquettes

Using palm kernel shell and coconut husk as material for briquetting, five different ratios were prepared, each containing 10% binder by weight. Sample A; 90% PKS + 10% Binder, Sample B; 90% CH + 10% Binder, Sample C; 70% PKS + 20% CH + 10% Binder, Sample D; 20% PKS + 70% CH + 10% Binder, and Sample E; 45% PKS + 45% CH + 10% Binder, having 32 briquettes moulded. Plate 7 show typical the briquette samples produced.

Proximate analysis

The proximate analysis includes moisture content (MC%), ash content (Ash %), volatile matter (VM%), fixed carbon (FC%), fat and crude fibre (FCF%). These proximate analyses are essential for assessing the physical and chemical properties of the briquettes and their potential as a fuel source. Figure 2 shows the proximate analysis chart of the five briquette samples produced and Table 1 shows proximate and ultimate analysis of previous work compared. The Moisture Content (M.C.) of the briquettes ranges from 4.66 to 5.91 %, with Briquette D having the lowest moisture content at 4.66 %. Low moisture content is desirable for fuel briquettes as it reduces the risk of microbial growth and improves storage stability. The Ash Content of the briquettes varies from 6.22 to 7.20 %, with Briquette C having the highest ash content at 7.20 %.

Ash is the inorganic residue remaining after the organic matter has been burned off. High ash content can reduce the calorific value of the fuel and increase the amount of residue left after combustion. The crude fiber content of the briquettes ranges from 0.16 to 0.92 %, with Briquette C having the highest crude fiber content at 0.92 %. Crude fiber is the portion of plant material that is resistant to digestion by human enzymes and includes cellulose, hemicellulose, and lignin. While crude fiber is not directly related to the fuel properties of the briquettes, it can provide information about the raw

Plate 7: Typical briquette samples produced

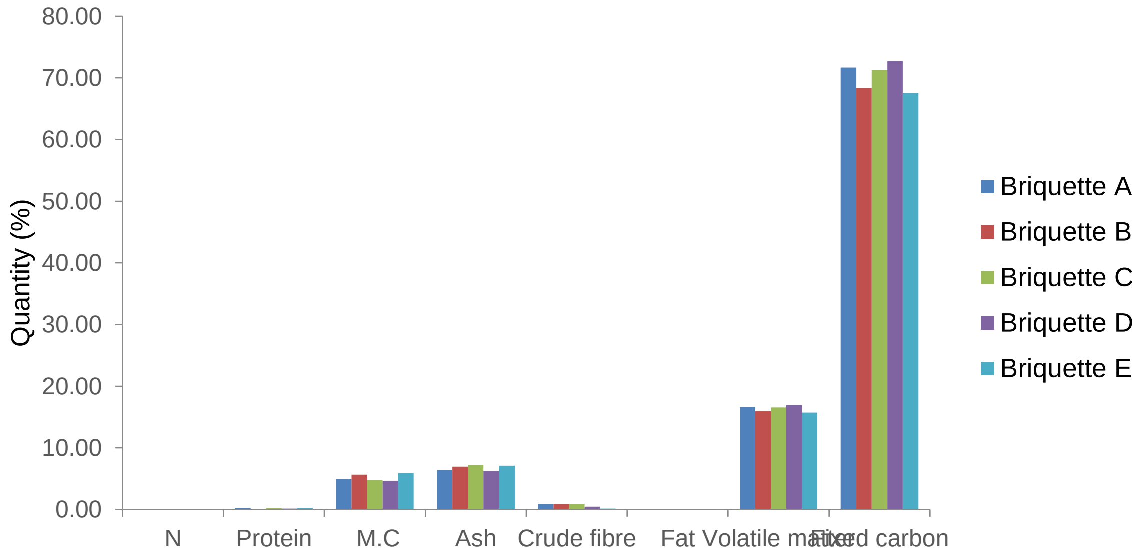

Figure 2: Proximate analysis chart of the produced briquette samples

materials used in their production. The fat content of the briquettes is negligible, with most samples having 0 % fat and only Briquette B and Briquette D having a trace amount of 0.01 %. Fat is not a significant component of fuel briquettes and is not expected to contribute to their combustion properties. The volatile matter and fixed carbon the briquettes range from 15.72 to 16.91 %, with Briquette D having the highest volatile matter content at 16.91 %.

Volatile matter is the portion of the fuel that is released as gases during combustion. The fixed carbon content, which is the portion of the fuel that remains after the volatile matter has been driven off, ranges from 67.60 to 72.70 %, with Briquette D having the highest fixed carbon content at 72.70 %. Fixed carbon is a measure of the fuel's ability to burn with a steady flame and produce heat. The Nitrogen and Protein Content of the briquettes ranges from 0.01 to 0.04 %, with Briquette B having the lowest nitrogen content at 0.01 % and Briquette C and Briquette E having the highest at 0.04 %. The protein content, calculated by multiplying the nitrogen content by 6.25, ranges from 0.08 to 0.24 %, with Briquette B having the lowest protein content and Briquette C and Briquette E having the highest. Nitrogen and protein are not directly related to the fuel properties of the briquettes but can provide information about the raw materials used in their production.

Ultimate analysis

Ultimate analysis, which evaluates the elemental composition of briquettes in terms of Carbon (C%), Hydrogen (H%), Nitrogen (N%), Oxygen (O%), Sulphur (S%), and Ash %, was conducted. The results of the analysis are as shown in Table 2.

The ultimate analysis of the briquette samples provides valuable information about their elemental composition and potential environmental impact. The Carbon Content of the briquettes ranges from 78.61 to 84.53 %, with Briquette D having the highest carbon content at 84.53 %. Carbon is the primary element in organic compounds and is a key component of fuel briquettes. The high carbon content suggests that these briquettes have a high energy content and could be suitable for combustion applications. The Hydrogen Content of the briquettes ranges from 2.45 to 5.00 %, with Briquette E having the highest hydrogen content at 5.00 %. Hydrogen is a minor element in fuel briquettes but is essential for the formation of organic compounds. The hydrogen content, along with the carbon content, contributes to the calorific value of the fuel. The Nitrogen Content of the briquettes ranges from 0.81 to 1.11 %, with Briquette A having the highest nitrogen content at 1.11 %. Nitrogen is a minor element in fuel briquettes and is not directly related to their combustion properties.

However, the nitrogen content can affect the formation of nitrogen oxides (Nox) during combustion, which are air pollutants. The Sulphur Content of the briquettes ranges from 0.11 to 0.23 %, with Briquette B having the highest sulphur content at 0.23 %. Sulphur is a minor element in fuel briquettes and is not directly related to their combustion properties. However, the sulphur content can affect the formation of sulphur oxides (Sox) during combustion, which are air pollutants.

Table 1: CH and PKS physical look after pyrolysis

Author (s)	% N	% Protein	% M.C	% Ash	% Crude Fibre	% Fat	% Volatile matter	% Fixed carbon
Adeniyi *et al.* (2014), Torrefied PKS	----	----	0.33 - 0.83	2.44 - 6.50	----	----	64.56 – 73.15	----
Edmund *et al*. (2014), PKS for Materials Reinforcement and Water Treatment	----	----	6.11	8.68	----	----	----	----
Ojaomo *et al.* (2022), Grain Size Effects of Palm Kernel	0.66	----	5.88	37.49	----	----	28.58	28.05
Azrine *et al.* (2022), Coconut Shell and Husk Biochar	----	----	7.50	0.92 - 5.30	----	----	82.94 – 85.30	14.70 – 16.14
Betty *et al.* (2020), Charcoal Briquette from PKS	----	----	16.00	2.04	----	----	80.50	1.46

Author (s)	% N	% Protein	% M.C	% Ash	% Crude Fibre	% Fat	% Volatile matter	% Fixed carbon
Adeniyi *et al.* (2014), Torrefied PKS	----	----	0.33 - 0.83	2.44 - 6.50	----	----	64.56 – 73.15	----
Edmund *et al.* (2014), PKS for Materials Reinforcement and Water Treatment	----	----	6.11	8.68	----	----	----	----
Ojaomo *et al.* (2022), Grain Size Effects of Palm Kernel	0.66	----	5.88	37.49	----	----	28.58	28.05
Azrine *et al.* (2022), Coconut Shell and Husk Biochar	----	----	7.50	0.92 - 5.30	----	----	82.94 – 85.30	14.70 – 16.14
Betty *et al.* (2020), Charcoal Briquette from PKS	----	----	16.00	2.04	----	----	80.50	1.46

Table 2: Ultimate analysis of the produced briquette

SAMPLE	% CHO	% C	% H	% N	% O	% S	% Ash
Briquette A	87.46	83.37	2.54	1.11	1.56	0.18	6.45
Briquette B	86.49	79.52	4.99	1.00	1.99	0.23	6.93
Briquette C	86.80	82.85	2.45	1.09	1.50	0.17	7.20
Briquette D	88.53	84.53	2.95	0.95	1.05	0.11	6.22
Briquette E	86.61	78.61	5.00	0.81	3.00	0.13	7.08

Table 3: Caloric value of the produced briquette

SAMPLE	Caloric value (J/g)
Briquette A	458.84
Briquette B	437.66
Briquette C	456.03
Briquette D	465.28
Briquette E	432.67

The Oxygen Content of the briquettes ranges from 1.05 to 3.00 %, with Briquette E having the highest oxygen content at 3.00 %. Oxygen is a minor element in fuel briquettes and is not directly related to their combustion properties. However, the oxygen content can affect the formation of carbon monoxide (CO) during combustion, which is a toxic gas. The Carbohydrate Content of the briquettes, calculated by difference, ranges from 86.49 to 88.53 %, with Briquette D having the highest carbohydrate content at 88.53 %. Carbohydrates are a major component of fuel briquettes and contribute to their energy content.

Plate 8: Sample D; 20% PKS + 70% CH + 10% Binder

Calorific Value

The energy content of briquettes is determined by their calorific value, which measures the total amount of heat released. This parameter is crucial for evaluating the efficiency and suitability of briquettes as a fuel source. See result has shown in Table 3, the calorific value of the briquettes ranges from 432.67 to 465.28 J/g, with Briquette D having the highest calorific value at 465.28 J/g. The calorific value is a measure of the energy content of a fuel, and it is an important factor in determining its suitability for combustion applications. Compared with calorific value of Olugbade and Mohammed (2015); 14,250 J/g, 13,890 J/g, and 13,540 J/g, respectively, with 14,250 J/g as the highest heating value. Adeniyi *et. al.* (2014) calorific value; 18,990 J/g, 19,610 J/g, and 19,980 J/g, respectively, with 19,980 J/g as the highest heating value. Ugwu and Agbo (2011); 23,603.28 J/g, Ojaomo *et. al.* (2022); fine particle 11,794 J/g and coarse particle 16,542 J/g, Betty *et al.* (2020); 20,270 J/g. It also compared well to most biomass energy obtained in the previous work. For examples, corncob = 20,890 J/g, groundnut shell briquette = 12,600 J/g, cowpea =14,372.93 J/g, rice bran = 12,000 to 15,000 J/g and soybeans =12,953 J/g. Comparison with Other Fuels; Charcoal: 29,000 J/g, Coal: 24,000-35,000 J/g, Kerosene: 46,200 J/g, Liquefied Petroleum Gas (LPG): 46,400 J/g, the calorific values of the briquettes are significantly lower.

Physical Characteristics

Sample D as showed in Plate 8 presented the highest density (0.61 g/cm³), indicating better compaction and energy content per unit volume. Plate 8 shows sample D; 20% PKS + 70% CH + 10% Binder.

Proximate Analysis

- **Moisture Content**: Ranged from 4.37% to 6.28%. Lower moisture in Sample D improves combustion efficiency.
- **Ash Content**: Lowest in Sample D (6.91%), suggesting minimal non-combustible residue.
- **Volatile Matter**: Highest in Sample D (20.22%), enhancing ignition and combustion.
- **Fixed Carbon**: Sample D again led with 70.74%, confirming its superior combustion potential.

Sample D recorded the highest calorific value of 465.28 J/g, followed by Sample B. This aligns with its high fixed carbon and low ash content. Comparative analysis with conventional fuels showed improved performance over firewood and cow dung, though lower than LPG.

Conclusion

This study confirms that palm kernel shell and coconut husk, when properly carbonized and mixed, can produce briquettes with desirable combustion properties. Sample D, with 20% PKS and 70% CH, demonstrated optimal performance in all tested parameters. These briquettes offer a viable alternative to traditional fuels, promoting environmental sustainability and waste-to-energy practices.

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