DOI: 10.56892/bima.v8i1.586

Determination of Combustible Properties of Palm Kernel Shell and Palm Fiber Mixture for Heat Generation

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ABSTRACT

This research investigates the potential of palm kernel shell (PKS) and palm mesocarp fiber (PMF) as alternative energy sources for rural community. Using a Bomb Calorimeter, the calorific values of agricultural waste materials in both raw and briq form. The results reveal that briquet forms have higher calorific values, with palm kernel shell at 27.35MJ/kg and palm mesocarp fiber briquettes at 25.92MJ/kg, compared to their raw counterparts at 24.04MJ/kg and 22.97MJ/kg, respectively. Based on the results of physical properties like moisture, ash, and volatile matter content. Majority of the parameters meet the minimum standard for calorific value (10MJ/kg – 35MJ/kg), indicating that these materials are viable for energy production. Palm kernel shell shows superior qualities, with a higher mass (25.5g) compared to palm mesocarp fiber (5.08g), and better FBR and SFC values. By using these agricultural wastes as energy sources, the dependency on fuel wood can be reduced, thereby mitigating deforestation, soil degradation, and the impacts of climate change.

Keywords: Briquette, Palm kernel shell, Palm Mesocarp Fiber, Agricultural waste, calorific value.

INTRODUCTION

The escalating demand for energy, driven by increased car ownership, industrial growth, and reliance on various energy-dependent devices, has become a crucial factor in countries development and economic stability, particularly in the context of global energy challenges. This situation is especially critical in developing countries like Nigeria, where the predominant use of fossil fuels and fuel wood has led to deforestation and significant carbon emissions, exacerbating global warming concerns (Boye et al., 2007).

In response to these challenges, biomass renewable energy emerges as a sustainable alternative, offering a viable solution to mitigate the depletion of fossil fuels and their adverse environmental impacts (Dutta et al., 2013). Biomass resources, characterized by their renewable nature, present a sustainable option, with the potential for long-term utilization without significant resource depletion (Akhator et al., 2017). Nigeria, rich in underexploited renewable energy sources including biomass, solar, wind, and hydro resources (Akinrinola et al., 2014), faces an increasing demand for conventional fuels for heating, spurred by economic and population growth in the developing world. This demand coincides with a decrease in firewood availability, a consequence of rapid deforestation and insufficient reforestation efforts (Adegoke et al., 2014).

The over-reliance on firewood in developing countries has led to substantial deforestation, with Nigeria losing over 464 square miles of forest annually due to human activities (Quartey, 2011). Most rural populations depend on bioenergy for basic needs like heating and cooking, often employing

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inefficient methods (Akinrinola et al., 2014). This reliance has also spurred interest in greener heating alternatives, leading to the exploration of biomass materials such as palm kernel shell (PKS) and palm mesocarp fiber (PMF), which are less competitive with food and industrial resources.

Briquetting technology is identified as a key approach to enhance the heating value of biomass (Wilaipon, 2007). This involves densification, where biomass residue is compacted into solid fuel briquettes, yielding a product with higher density, energy content, and lower moisture than its raw form. Various techniques, with or without binders, can be employed in this process (Sotannde et al., 2010). Kuti (2009) highlights the importance of briquettes in augmenting biomass utilization for heat and power generation, suggesting that domestic use of biomass fuel, including briquettes from sawdust, palm shell, and agricultural by-products, is an efficient renewable energy source (Kuti & Adegoke, 2008). Such practices could significantly contribute to climate change mitigation and reduce the encroachment into forest plantations.

The health implications of using biomass, particularly in rural areas where palm kernel shells are used for cooking, cannot be overlooked. This practice produces substantial smoke, posing health risks (Quartey, 2011). Studies suggest that modest pyrolysis could reduce smoke-producing chemicals in biomass (Adetogun et al., 2017; Chen & Kuo, 2010; Musa, 2007; Akinbami, 2001). The primary aim of this study is to facilitate access to cleaner energy sources for impoverished populations, focusing on palm kernel shells and palm mesocarp fruit fiber as sustainable, less industrial alternatives.

MATERIALS AND METHODS

Palm Materials

Palm kernel shells and palm fiber mixture were collected from modern market area, along Mobile Barrack road and the University of Agriculture Makurdi Village (UAM) in Makurdi Local Government Area of Benue State, Nigeria.

Sample Preparation

Palm kernel shells and palm mesocarp fiber were air-dried for ten days to reduce moisture, then crushed using a pestle and mortar and sieved through 1.18mm, 2.00mm, and 3.5mm meshes for size uniformity. For starch preparation, cassava tubers were cleaned, peeled, ground, and squeezed. The extracted liquid was filtered and left to settle for two hours for starch separation. The supernatant was discarded, and the starch was sun-dried for five days to decrease moisture.

Preparation of the Briquette Samples

The PKS and PMF were finely ground and sieved to a 1.18mm particle size. For the binder, 20 grams of cassava flour were mixed with 40 mL of cold water, followed by adding 100 ml of boiling water, stirring to form a smooth paste. Then, 135 grams of ground palm kernel shell charcoal were blended into this gel to create a thick, black mixture. This mixture was manually shaped into cylindrical molds and sun-dried for 7 days to lower moisture and increase density. Post-drying, various tests were conducted on the briquettes.

Proximate Analysis

The moisture content, ash content, volatile matter, and fixed carbon of the carbonized PKS were measured according to the ASTM D-3173 standard.

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Determination of Moisture Content

To measure moisture content in Palm Fiber and Oil Palm Residues, 10g samples were oven-dried in porcelain containers at 110°C for about 3 hours, until constant weight was reached. Moisture percentages on both wet and dry bases were calculated using Equation (1) and (2) (Onochie et al., 2017).

$$x_{0w} = \frac{w_1 - w_2}{w_1} x100 \qquad (1)$$

Where X_{0w} = moisture content on a wet basis
W_1 = Initial mass of the sample
W_2 = Final mass of the sample after drying

$$x_{0d} = \frac{w_1 - w_2}{w_2} x100 \qquad (2)$$

Where, X_{0d} =Moisture content on dry basis
W_1 = Initial mass of the sample
W_2 = Final mass of the sample after drying

Determination of Ash Content in the mixture of Palm Kernel Shell and Palm fiber

To determine the ash content in PKS and PMF mixtures with additives (Al2O3, CaO, MgO), the procedure adhered to ASTM E1755-01 standards. A 2% sample was oven-dried at 105°C in a 50 ml crucible to remove moisture and achieve Oven-Dry-Weight (ODW), then cooled in desiccators. The sample was burned on an ash burner until smoke ceased, followed by placement in a muffle furnace at 575˚C for 24 hours, with careful handling to avoid loss. After cooling in desiccators for 1 hour, it was returned to the furnace for heating to constant weight. ODW and ash percentage were calculated using specific equations.

Determination of Volatile Content of Palm Shell and Palm Fiber

To ascertain Volatile Content (VC), around 2 grams of air-dried biomass (W1) were heated in a semi-enclosed porcelain crucible to 900°C for seven minutes, following BSI standards, in a furnace. Post-heating, the crucible cooled in desiccators, and the weight of the residual content was determined using equation 2.

Determination of Fixed Carbon Content of Palm Shell Palm Fiber

The fixed carbon content was calculated by subtracting the sum of the moisture (MC), volatile matter (VC), and ash contents (AC) from 100%, as illustrated in Equation 3 (UNEP, 2006).

$$FC = 100 - (MC + VC + AC) \qquad (3)$$

Determination of calorific value

To measure moisture content, 1 gram of fuel was weighed in a crucible with a Nickel fuse wire between electrodes, touching the fuel. 2 ml of water was added to absorb Sulphur and nitrogen combustion products. The bomb, filled with oxygen at 25 atm, was placed in a calorimeter containing a known amount of water. After connection setup and stable temperature recording, the fuel was ignited, and temperature monitored at 30-second intervals to peak. The bomb was then opened, pressure released, and contents weighed. The water and calorimeter absorbed combustion heat. Gross heat of combustion was calculated for each residue using a bomb calorimeter, as per CEN/TS 14918:2005.

$$CV = C\,\Delta T - \frac{e_1+e_2+e_3}{m} \quad (4)$$

Where C = Heat capacity of the bomb calorimeter
ΔT = Change in temperature variation
e_1 = Correction of heat of neritic acid
Nitrite acid was flushed in the bomb calorimeter using oxygen to remove nitrite acid formation in the calorimeter Hence $e_1 = 0$
e_2 = Correction of heat formation of sulphuric acid
Percentage (%) of Sulphur in sample X 57.54(J/g) X mass of sample (g)
e_3 = Correction of heat of formation fuse wire (Length of fuse wire consumed in (Cm) X 9.66(J/cm)

Calorific Value

Utilizing the fixed carbon, volatile matter, and ash content obtained from the proximate analysis, the calorific value was determined using the High Heating Value (HHV) formula as proposed by Parikh et al., 2005. The HHV is calculated with the formula;

$$HHV = 0.3536FC + 0.1559VM - 0.0078AC \text{ (KJ/g)}, \quad (5)$$

Where FC is the fixed carbon,
VM is the volatile matter, and
AC is the ash content.

Ignition Test

The briquette sample was lit from the bottom, and the time it took for the flame to ignite the briquette was measured as the ignition time using a stopwatch.

Combustion Test

A briquette sample was ignited on a domestic stove. 100 ml water at room temperature was added to an iron container and heated. The time to boil was timed with a stopwatch, and the briquette mass used was measured. Specific fuel consumption and burning rate were calculated during the test (Kuti, 2009).

RESULTS AND DISCUSSION

The result of the proximate analysis and physical characteristics of the palm biomass are presented in Tables 1, 2 and 3 respectively.

Table 1: Proximate Analysis of raw residues and fuel briquettes

Residues	(%) Moisture	% Ash	% Fixed Carbon	% Volatile Matter
Raw Residues				
Palm Kernel Shell, PKS	9.23	3.04	11.62	76.11
PMF Palm Fibre,	9.97	5.08	9.26	75.69
Briquettes Fuel				
Palm Kernel Shell, PKS	7.90	1.02	6.36	84.72
Palm Fibre, PMF	8.42	2.80	4.38	84.40

Table 2: Physical characterization of Raw, PKS and PMF Briquetted

Properties	**Palm Fiber (PF)**	**Palm kernel shell (PKS)**	**PF Briquettes**	**PKS Briquettes**
Moisture content	9.97	9.23	8.42	7.90
Volatile matter	75.69	76.11	84.40	84.72
Ash content	5.08	3.04	2.80	1.02
Fixed carbon	9.26	11.62	4.38	6.36
HHV	22.97	24.04	25.92	27.35

DOI: 10.56892/bima.v8i1.586

Figure 1: Palm Mesocarp Fiber

Figure 2: Palm kernel shell in coarse and powder

Figure 3: Palm Mesocarp Fiber Briquettes

Figure 4: Palm Kernel Shell Briquettes Coarse Aggregate

Table 3: Combustion and Ignition Test Result on Palm Kernel Shell (PKS) and Palm Mesocarp Fiber (PF) Briquette

Test	**Data on PMF briquettes**	**Data on PKS briquettes**
Total weight of fuel at the start of the test (g)	155.36	500.56
Total number of fuel at the start of the test	7 lumps	6 lumps
Average weight of each fuel (g)	22.19	83.43
Total weight of fuel after water boiled (g)	85.63	289.49
Initial volume of water in pot /temperature (mL/30^{o}c)	100	100
Final volume of water in pot after boiling/ temperature (mL/100^{o}c).	78.09	90.07
Physical appearance	Brown color at start-up	Black color at start-up
Density (g/mL)	26.5/10= 2.67	135/110.5 =1.22
Time for water to boil	12.00min	9.00min
Ignition	Kerosene burns in 1min and lumps of fuel turned red and then ash produced	Kerosene burns in 8 mins and several lumps of fuel turns red and produced no ash
Odor	Smoky odor	No odor
Spark	No spark	No spark
Cleanliness	Turn cooking pot black	Cooking pot remains neat

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Moisture content (%)	8.42	7.90
Specific fuel consumption	3.48g/ml	20.05g/ml
Fuel burning rate	Initial mass=18.26g Final mass=13.18 Mass of burnt matter=5.05g 0.42g/mins	Initial mass=135g Final mass=109.48g Mass of burnt matter=25.52g 2.84g/mins
Smoke	Produced smoke	Without smoke
Mass of kerosene used	5.05g	25.56g

DISCUSSION

Proximate Analysis of Raw and Briquetted Palm Kernel Shell and Palm Mesocarp Fiber

The proximate analysis of raw and briquetted palm kernel shell (PKS) and palm mesocarp fiber (PMF) depicted in Table 1 reveals critical fuel properties. The moisture content of raw PKS and PMF registered at 9.23% and 9.97%, respectively, while briquetted forms showed slightly reduced levels at 7.9% and 8.42%. These figures fall below the 10-15% range suggested by Wilaipon (2008) for high-quality briquettes and are marginally lower than those observed by Ladapo et al. (2020). Such moisture levels are conducive for complete combustion and stability against rot and decomposition, contrasting with higher moisture content (32.72% to 60.24%) reported by Noah et al. (2019). The ash content in raw PKS and PMF was 3.04% and 5.08%, respectively, which reduced to 1.02% and 2.8% in briquettes. This is in line with Garcia et al. (2012), who posit that good quality briquettes typically have lower ash contents, between 5-20%. High ash content is undesirable in fuels as it hampers combustibility (Sadiku et al., 2016). Comparative studies like Emerhi (2011) and Sotannde et al. (2010) show varying ash contents in different biomass briquettes.

Regarding fixed carbon, vital for fuel's energy content, raw PKS and PMF contained 11.6% and 9.26%, respectively, with a reduction in briquettes to 6.3% and 4.38%. This reduction impacts the biological conversion efficiency of the fuel. Volatile matter, crucial for ease of ignition and smooth burning, was high in both raw and briquetted forms (76%-84.7% for PKS and 75%-84.4% for PMF), aligning with findings by Sotannde et al. (2010) and Falemara et al. (2018) in similar studies. The calorific value, a key indicator of fuel quality, showed PKS briquettes with the highest value (27.35 MJ/kg), followed by PMF briquettes, raw PKS, and raw PMF. These values suggest that briquettes, especially from PKS, are superior alternatives to raw biomass. However, the slightly elevated ash content in briquettes, as shown in Table 2, indicates the need for pre-treatment to optimize their quality.

In summary, producing efficient fuel briquettes from palm biomass involves balancing moisture, ash, volatile matter, and fixed carbon content. The briquettes in this study generally met the criteria set by Asamoah et al. (2016), except for ash content. Thus, the study underscores the potential of PKS and PMF briquettes as viable alternatives for heat generation, with an emphasis on the refinement of ash content.

Physical Composition of Palm Biomass

Table 2 highlights that palm kernel shell (PKS) briquettes yield higher heat (27.35 MJ/Kg for briquetted PKS and 24.04 MJ/Kg for raw PKS) compared to palm mesocarp fiber (PMF) briquettes (22.97 MJ/Kg for raw PMF and 25.92 MJ/Kg for briquetted PMF). This higher heat output is due to PKS's lower moisture, higher fixed carbon, and volatile matter content, which enhance heat generation. PKS briquettes' greater hardness and fewer pore spaces, as opposed to the finer PMF, contribute to their superior heat production. These characteristics also result in a faster combustion rate for PKS briquettes, leading to higher heat yield. Additionally, the study analyzed the moisture, ash, volatile matter, fixed carbon, and calorific values of these biomass briquettes to compare with the quality standards for good biomass briquettes set by Asamoah et al. (2016). The findings, illustrated in Figures 5-9, showed that the produced biomass briquettes, especially from PKS, have a higher energy potential than traditional wood fuel and other agricultural waste biomass briquettes.

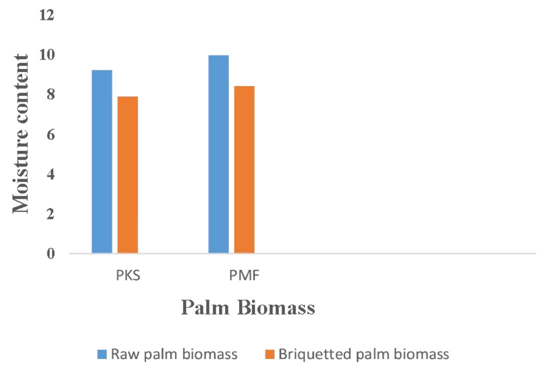

Figure 5: Moisture Content of a Raw and Briquetted Palm Biomass

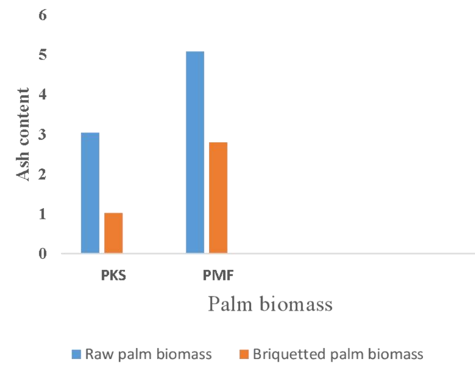

Figure 6: Ash of Raw and Briquetted Palm Biomass

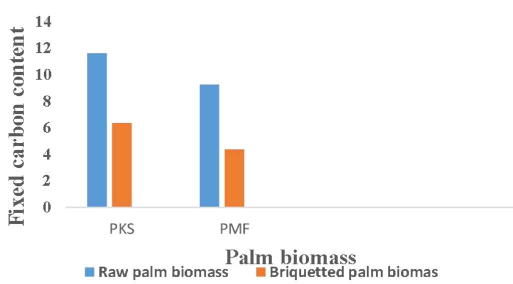

Figure 7: Fixed Carbon Content Raw and Briquetted Palm Biomass

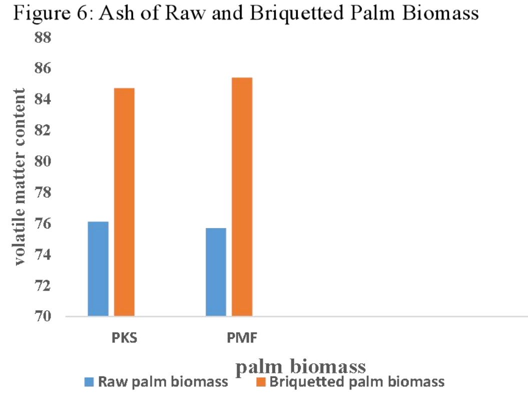

Figure 8: Volatile matter content of a raw and briquetted palm biomass

DOI: 10.56892/bima.v8i1.586

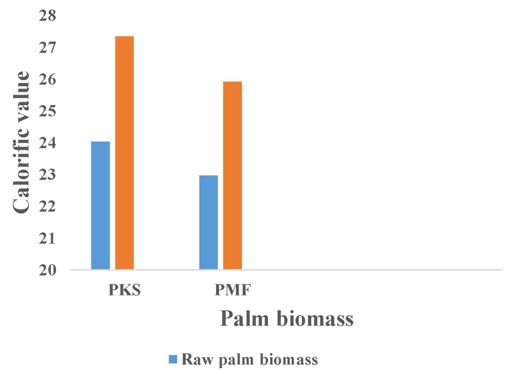

Figure 9: Calorific value of raw and briquetted palm biomass

Combustion Test for the Biomass Briquettes

Water boiling tests, as recommended by Oladeji, (2010), assessed the briquettes' suitability for household use. Table 3 reveals that palm kernel shell (PKS) briquettes were challenging to ignite, requiring significantly more kerosene compared to palm mesocarp fiber (PMF) briquettes. While PMF ignited with just 0.08g of kerosene, PKS needed 25.05g, indicating its harder nature. The ignition time for PKS was 8 minutes, consistent with Kuti's (2009) observations.

CONCLUSION AND RECOMMENDATION

Moisture content in palm biomass decreases from raw PMF to briquetted PKS, all within standard limits. Briquetted PKS and PMF have higher heating values than their raw forms. Calorific values rank as: briquetted PKS > briquetted PMF > raw PKS > raw PMF. Calorific values are 24.04 MJ/Kg for raw PKS, 22.97 MJ/Kg for raw PMF, and higher at 27.35 MJ/Kg for briquetted PKS, 25.92 MJ/Kg for briquetted PMF, meeting standards.

Recommendations from this research are: Use oil palm biomass (PKS and PMF) with calorific values of 27.35MJ/Kg and 25.92MJ/Kg, respectively, for domestic and industrial heating, as they meet standard requirements. Further investigate pre-treatment methods to reduce ash content before densification. Utilize palm kernel shell (PKS) for heat generation in agriculture and environmental applications, despite its slower ignition, due to higher heat output compared to palm mesocarp fiber (PMF). Conduct additional research on smoke emissions during the combustion process. Explore methods to enhance ignition of samples without relying on kerosene.

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