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PRODUCTION OF BRIQUETTES FROM A BLEND OF RICE HUSKS AND PALM KERNEL SHELLS AS AN ALTERNATIVE SOLID FUEL

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ABSTRACT

In this study, composite briquettes were produced from agricultural waste (rice husks and palm kernel shells) using a manually operated 20-ton air hydraulic press fabricated for this purpose.

This research addresses the environmental and economic challenges posed by current fuel sources by developing an alternative solid fuel from agricultural waste. The current energy poverty in Nigeria, occasioned by increasing energy demand, insufficient grid electricity supply, increasing costs, and shortage of fossil fuel resources, are currently topical issues that require interventions. This is because the attendant effects on the environment in the form of pollution, greenhouse gas emissions, and general environmental imbalances are issues that still remain unresolved. The concern that fossil fuel resources are tending towards exhaustion requires concerted efforts by stakeholders to find new, sustainable, and alternative energy sources.

Biomass fuel briquettes have received global acceptance as a better replacement for fuel wood (firewood) and charcoal for heating, cooking, and other industrial applications in urban and rural areas. The rice husk and palm kernel shell samples were ground into powder and sieved with a 1 mm sieve mesh. Thereafter, rice husk (RH) and palm kernel shell (PKS) samples were thoroughly mixed to obtain a uniform and homogeneous mixture. The mixtures were prepared at rice husk: palm kernel shell weight ratios of 90:10, 80:20, 70:30, 60:40, 50:50, 100:0, and 0:100, and compacted under a pressure of 110 bar using 25% gelatinized starch as a binder. A comprehensive investigation was conducted into the densities, proximate analysis, and calorific value of the produced briquettes. The experimental results showed that the compressed and relaxed densities of the fuel briquettes ranged from 0.84 to 1.09 g/cm³ and 0.54 to 0.68 g/cm³, respectively. Proximate analysis of the briquettes showed that the percentages of moisture, ash, volatile matter, and fixed carbon ranged from 4.18 to 5.57%, 12.48 to 19.32%, 74.39 to 81.38%, and 0.05 to 2.11%, respectively. The results for higher heating value (HHV) ranged from 16.92 to 19.19 MJ/kg, which compared well with the standards set by the American Society for Testing and Materials (ASTM). The briquette at a 50:50 ratio of rice husk to palm kernel shell recorded the highest HHV of 19.19 MJ/kg, implying it has a higher heating advantage over the remaining samples and is therefore recommended as an alternative fuel to conventional fuels (charcoal and firewood).

Keywords: Briquettes, Rice Husks, Palm Kernel Shells, Proximate Analysis, Calorific Value, Solid Fuel

INTRODUCTION

Every year, millions of tons of agricultural waste are generated, which is either destroyed or burned inefficiently, causing air pollution. This waste can be recycled to provide a renewable source of energy by converting biomass fuel into high-density fuel briquettes (Garrido *et al.,* 2017). The current energy poverty in Nigeria, occasioned by increasing energy demand, insufficient grid electricity supply, increasing costs, and shortage of fossil fuel resources, are topical issues that require intervention. This is because the attendant effects on the environment in the form of pollution, greenhouse gas emissions, and general environmental imbalances are issues that still remain unresolved. The concern that fossil fuel resources tend to be exhausted requires concerted efforts by stakeholders to identify new, sustainable, and alternative energy sources (Ayuk *et al.,* 2020).

Biomass fuel briquettes have received global acceptance as a better replacement for fuelwood (firewood) and charcoal for heating, cooking, and other industrial applications in urban and rural areas (Mwamlima *et al.,* 2023). Biomass briquettes are considered superior alternatives to traditional fuels due to their higher energy efficiency, lower emissions, and sustainability. They have higher energy density, resulting in longer burn times and greater heat output per unit compared to raw biomass or traditional wood fuels. Additionally, biomass briquettes produce fewer emissions, including lower levels of particulate matter, sulfur oxides, and nitrogen oxides, contributing to improved air quality and reduced health risks. Furthermore, the use of agricultural waste for briquetting promotes environmental sustainability by reducing deforestation and managing waste effectively.

The Nigerian Conservation Foundation (NCF) reported that Nigeria lost almost all of its original forest due to deforestation, which is partly attributed to the use of fuel wood and charcoal for energy (Mong *et al.,* 2022). Most rural dwellers (about 70% of people in Nigeria) and almost all farmers heavily depend on wood fuel for all their domestic and other commercial activities that require heat (Mohammed *et al.,* 2018). The energy crisis in Nigeria is exacerbated by the overreliance on traditional energy sources like firewood and fossil fuels, which are increasingly unsustainable and environmentally harmful. Biomass briquettes offer a viable solution to this problem by providing an alternative, renewable source of energy that can alleviate the pressure on existing resources and reduce environmental degradation.

Rice husks (RH) are the protective outer coating surrounding rice grains that are separated during milling. In rice-producing countries such as Nigeria, rice husk is a waste material containing 30-50 % organic carbon and 17–23 % ash (Masilan *et al.,* 2023). Included in this composition are cellulose (50 %), lignin (30 %), silica (SiO3) 16-20 % and moisture, 10-15 % (Pharm *et al.,* 2019). Palm kernel shells (PKS), also known as palm kernel expeller (PKE), are the hard endocarp of the palm kernel fruit that surrounds the palm kernel seed of the oil palm tree (Elaeis guineensis). PKS is a by-product produced when the kernel is crushed to remove palm seeds after the production of palm kernel oil. PKS is rich in proteins and fibers. It has high energy value, low ash content, and low water content, making it suitable for energy purposes (Kahar *et al.,* 2022).

Biomass briquetting is the densification of loose biomass materials to produce compact solid composites of different sizes under the application of pressure (Sa'ad and Bugaje 2016). The process of converting rice husks and palm kernel shells into briquettes not only addresses waste management issues but also provides a sustainable energy source that can contribute to alleviating Nigeria's energy crisis. The advantages of biomass briquettes, such as improved combustion efficiency, reduced emissions, and utilization of agricultural waste, underscore their potential impact.

A review of existing literature reveals a range of studies focused on the production and evaluation of biomass briquettes from various agricultural residues. For instance, Tembe *et al.,* (2014) explored the use of groundnut shells, rice husks, and sawdust for briquetting, achieving favorable density and combustion properties. Ibitoye *et al.,* (2023) investigated corncob and rice husk briquettes, reporting results comparable to the present study in terms of density and heating value. These studies highlight the potential of different agricultural residues for briquetting but indicate a gap in comprehensive evaluations involving rice husks and palm kernel shells combined with cassava starch as a binder.

In this research work, the evaluation of the physicochemical properties of briquettes from rice husk and palm kernel shells was carried out using cassava starch as a binder with the application of pressure, to determine the compressed and relaxed density, proximate analysis, and calorific value of the briquettes. The study aims to address Nigeria's energy challenges by providing an affordable alternative fuel for households and industries. By focusing on the combination of rice husks and palm kernel shells, this research seeks to fill the gap in literature and demonstrate the potential of these materials in producing high-quality biomass briquettes.

Despite the promising benefits, producing and using biomass briquettes also present certain challenges. Issues such as material handling, binder efficiency, and market acceptance need to be addressed to ensure the widespread adoption of briquettes. Additionally, the variability in the quality of agricultural residues and the consistency of briquette production are potential limitations that require attention. Acknowledging these challenges provides a balanced view and sets realistic expectations for the study's contributions.

The scope of this research includes investigating specific research questions related to the physicochemical properties of the briquettes: What are the compressed and relaxed densities of the briquettes produced from rice husks and palm kernel shells? How do the moisture content, volatile matter, ash content, and fixed carbon vary among different briquette compositions? What is the higher heating value of the briquettes, and how does it compare to conventional fuels? By addressing these questions, the study aims to provide valuable insights into the potential of biomass briquettes as an alternative energy source in Nigeria.

MATERIALS AND METHODS

Materials

The raw materials used for this experiment include rice husk as the base compound, palm kernel shell as energizer, cassava starch as binder, and water as a processing material. The raw rice husks were collected from Bida and Kontagora rice milling companies, and palm kernel shells were sourced from Etsu Yahaya palm oil mill at Bida. Cassava starch was purchased from the Kontagora market, both in Niger State, Nigeria. Figure 1 shows the samples of rice husk (a) and palm kernel shell (b).

Figure 1: Samples of (a) Rice husk, (b) Palm kernel shell (source: www.indiamart.com)

Method

Material Preparation

The handpicking technique was employed for the initial removal of unwanted materials from raw rice husk and palm kernel shell samples. The leftovers were ground into smaller particles and sun-dried in an open place for 7 days to remove their extrinsic moisture content. The rice husk and palm kernel shells were ground into a powder and sieved using a 1 mm sieve. The particle size before grinding was approximately 2-3 mm. The drying environment maintained an average temperature of 35 °C and relative humidity of 25%. The samples were prepared, weighed, and mixed for characterization and briquette production.

Preparation of starch gel

One liter of water was put into a pot and brought to a boil using a local charcoal stove; 400 g of starch was mixed with cold water (0.5 L) in a separate container to form a paste, making it easier to incorporate into hot water. Once the water boiled, the paste was poured into the boiling water and continuously stirred for approximately 15-20 minutes until it became thick and cloudy. The starch solution was allowed to cool to room temperature for 2-3 hours before use. The mixture was then gradually poured into a binder-to-raw-material ratio of 25:75 wt of 300 g.

Figure 2: Starch gel

Production of briquettes

The briquettes were produced at the Physics Department, Federal University of Technology, Minna, Niger State, Nigeria. Samples of rice husk (RH) and palm kernel shell (PKS) were thoroughly mixed to obtain a uniform and homogeneous mixture. The mixtures were prepared at the following weight ratios of rice husk to palm kernel shell: 90:10, 80:20, 70:30, 60:40, 50:50, 100:0 and 0:100, with the addition of 25% cassava starch gel as the binder. The mass of water mixed with the raw material was 400 ml while the mixing time of the composite materials (rice husk, palm kernel shell, and binder) was 10 minutes. In each case, the mixture was hand-fed into a briquette machine and compacted using a manually operated 20-ton air hydraulic piston press with a pressure gauge to obtain the compressive pressure at room temperature and relative humidity. The compressive pressure used in this study was 110 bar. A dwell time of 1-2 minutes was used for each bio-residue consolidated in the mold after loading and compaction to prevent spring-back. Twelve (12) briquettes were produced per batch. The average time taken by two people to produce 12 briquettes from loading to removal was 18 minutes. The briquettes were cylindrical with a 1.0 cm diameter placed in the center to create a hole in the middle of the briquette. The holes help to increase the porosity and oxygen supply, thereby improving briquette combustion.

Figure 3: Sample of fuel briquettes produced from rice husk and palm kernel shell

Densities

Compressed density of briquettes

The compressed density (density immediately after compression) of the briquettes was determined immediately after ejection from the molds as the ratio of the measured weight to the calculated volume. The mass was measured using a digital weighing balance and the volume was calculated from the external diameter and height of the briquettes using a Vernier caliper.

Compressed density = $\frac{Mass\ (g)}{Volume\ (cm^3)}$,

Where volume = $\frac{\pi\, d^2 h}{4}$ (1)

Relaxed density of briquettes

The relaxed density (density determined when dried) and relaxation ratio (ratio of compressed density to relaxed density) of the briquettes were determined under dry conditions after approximately 31 days of sun drying to a constant weight. The relaxed state was calculated as the ratio of the briquette weight (g) to the new volume (cm^3).

Shatter Index Resistance

The shatter index resistance was determined as described by Law *et al.,* 2018).

The sample was dropped onto the concrete floor from 2metre height for 3 times continuously.

The shatter resistance of the briquettes was calculated using the following equations, whereby the weight of the sample briquettes was recorded before and after shattering; thus, the percentage of shatter resistance can be calculated as:

$$\text{Weight loss } (\%) = \frac{W_1 - W_2}{W_1} \times 100\ \% \qquad (2)$$

Shattering Resistance (**%) =** 100 - Weight loss (%)

Where W_1 and W_2 are the initial and final briquette weight (g), respectively.

Proximate analysis

Proximate analysis were carried out to investigate the parameters of moisture content (MC), volatile matter (VM), ash content (AC) and fixed carbon (FC).

Moisture Content

1 g of well-prepared samples (i.e., reduced to powder form using a laboratory mill and sieved to obtain up to 250 µm grain sizes according to ASTM D2013-86 Standard method) were introduced into pre-weighed aluminum dishes and passed to the preheated oven at 105 °C for one hour. The weight was recorded after cooling in a desiccator. The moisture content was calculated and expressed in %.

$$\%\ \text{Moisture content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (3)$$

Where W_1= Empty crucible weight,
W_2 = Crucible weight and biomass sample before oven drying,
W_3 = Crucible weight and biomass sample after oven-dried

Volatile Matter

One gram of well-prepared sample was introduced into pre-weighed crucibles, covered with lids, and placed into the furnace at 105 °C to determine the weight and then at 950 °C according to ASTM E872-82 and procedures maintained at that temperature for about seven (7) minutes. The weight was recorded after cooling in the desiccator, and the volatile matter was calculated and expressed in %.

$$\%\ \text{Volatile matter} = \frac{W_2 - W_3}{W_2} \times 100 \qquad (4)$$

Where
W_2 is the weight after subjecting it to 105 °C,
W_3 is the weight after subjecting to 950 °C

Ash Content

Ash content of the samples was determined according to ASTM E1755-01 standard method. 1 g of sample was weighed into a pre-weighed standard crucible and then incinerated at 760 °C until complete ash content or white grayish matter was attained. The crucible was then allowed to cool in a desiccator, and the ash content was determined as:

$$\text{Ash}\ \% = \frac{W_3 - W_2}{W_2 - W_1} \times 100 \qquad (5)$$

Where
W_1 = previous weight of empty crucible,
W_2 = crucible weight and sample before incineration, and
W_3 = crucible weight and sample after incineration

Fixed Carbon

Fixed carbon content was calculated using the equation below:

$$FC = 100 - (\%Mc + \%Ash + \%VM) \qquad (6)$$

Where FC= Fixed carbon content,
%Mc = Percentage moisture content,
%Ash=Percentage Ash Content,
%Vm = Percentage Volatile Matter.

Higher Heating Value (Calorific Value)

The HHV of the samples was measured using a bomb calorimeter according to the ASTM D2015 standard method. 0.5 g sample was weighed into a clean crucible, and the weighed crucible and sample were inserted into the crucible holder of the outside electrode, ensuring that the firing cotton touched the sample. The electrode assembly (Lid Assembly) was inserted into the vessel body. The vessel was then filled with 3000 kPa of oxygen. After stabilizing for approximately 1 minute, the prepared vessel was inserted into the well of the e2k bomb calorimeter, the lid was closed, the vessel was fired, and the results were displayed automatically.

RESULTS AND DISCUSSION

Compressed and Relaxed density

The results of the compressed and relaxed density of the briquette samples are presented in Figure 4. Sample E (50RH:50PKS) recorded the highest compressed and relaxed densities of 1.09 g/cm³ and 0.68 g/cm³, respectively. These results are compared to values from other studies. For instance, Tembe et al., (2014) reported compressed and relaxed densities of 1.0 g/cm³ and 0.55 - 0.84 g/cm³ for briquettes made from groundnut shells, rice husks, and sawdust. Ibitoye *et al.*, (2023) found compressed and relaxed densities of 2.1 g/cm³ and 0.82 g/cm³ using corncob and rice husk briquettes.

The differences in densities might be attributed to the variations in the biomass materials and binder used, as well as the specific compaction pressures and moisture content in each study. Our findings for sample E (50RH:50PKS) demonstrate favorable physical and combustion properties, making it a suitable alternative fuel.

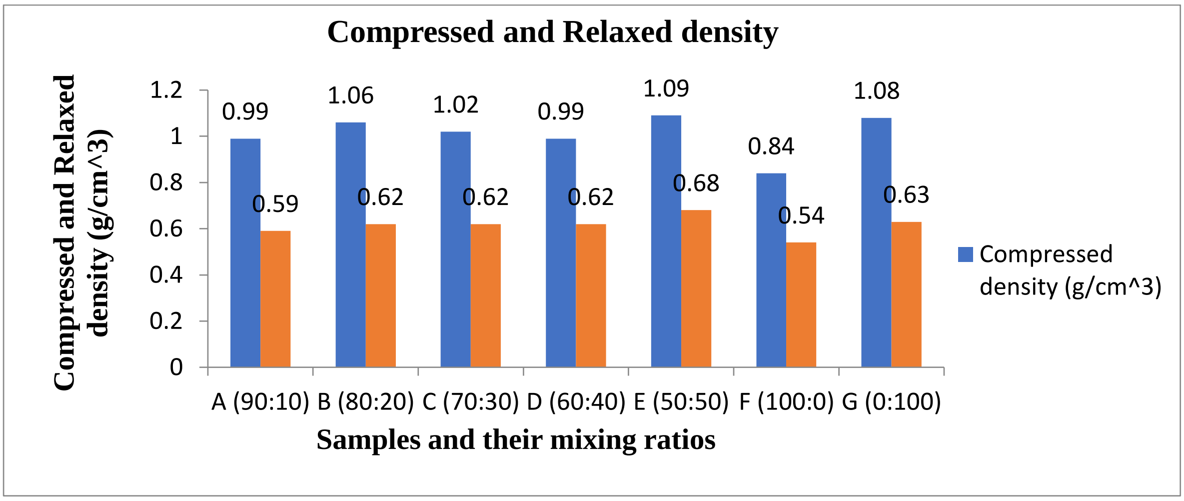

Figure 4: Compressed and relaxed density

Shatter index

The results of the shatter index of the briquette samples are shown in Figure 5. Shatter index resistance tests are a direct means of gauging the mechanical strength of briquettes for the purpose of handling, transportation, and storage. Results showed sample E (50:50 RH: PKS) had the highest shatter index of 97.24%, while sample F (0:100 RH: PKS) had the lowest of 84.36%. These findings align with Sunnu *et al.*, (2023), who reported a shatter index of 96.93%, and Kpalo *et al.*, (2020), also recorded the results of shatter index between

98.28% and 99.08% using corncobs (CC) and oil palm trunk bark (OPTB) briquettes. However, using cassava starch as a binder enhances material agglomeration, resulting in strong particle bonding (Mohd *et al.*, 2016). Therefore, higher shatter index values indicate better briquette quality and durability. Thus, the briquettes produced in this study are suitable for transportation and storage.

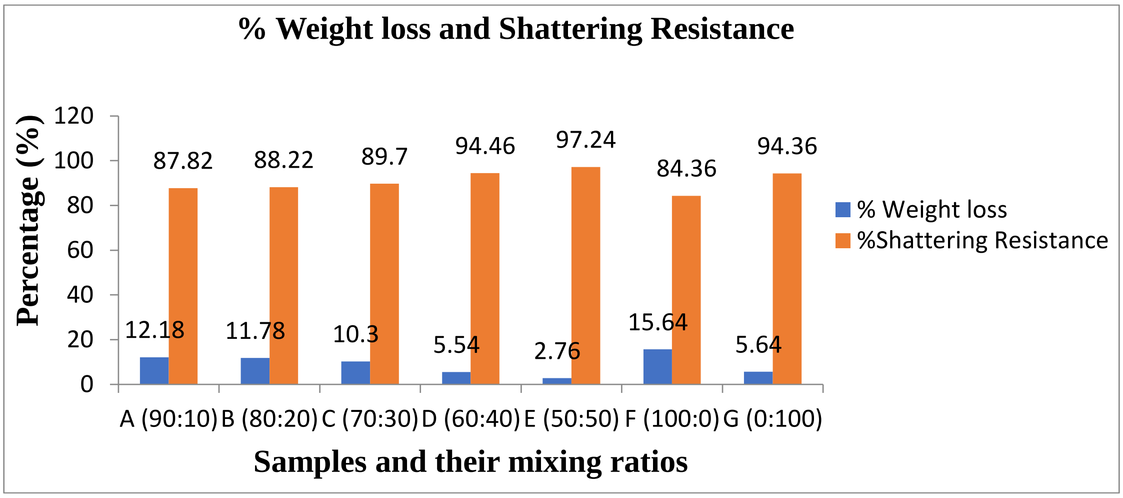

Figure 5: % Weight loss and Shattering Resistance

Proximate Analysis

Moisture Content

The moisture content of the briquette samples is presented in Figure 6. Sample A (90RH:10PKS) exhibited the lowest moisture content at 4.18%. Low moisture content is crucial as it enhances ignition and calorific value. This result is consistent with Akowuah *et al.,* (2012), who reported similar moisture content in sawdust charcoal briquettes, but significantly improved over the 28.01% to 42.97% moisture content obtained by Kayode *et al.,* (2021) for rice husk and wheat husk briquettes.

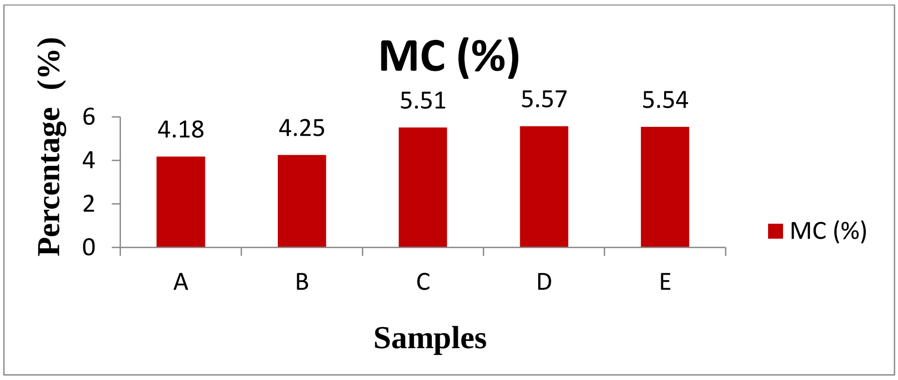

Figure 6: Moisture content (%) of different compositions

Volatile Matter

The volatile matter content of the briquette samples is shown in Figure 7. Sample E (50RH:50PKS) had the highest volatile matter at 81.38%, while Sample A (90RH:10PKS) had the lowest at 74.39%. High volatile matter indicates greater emissions during combustion, which can be a disadvantage. Our results align with findings from other studies, suggesting that lower volatile matter is preferable for higher quality briquettes.

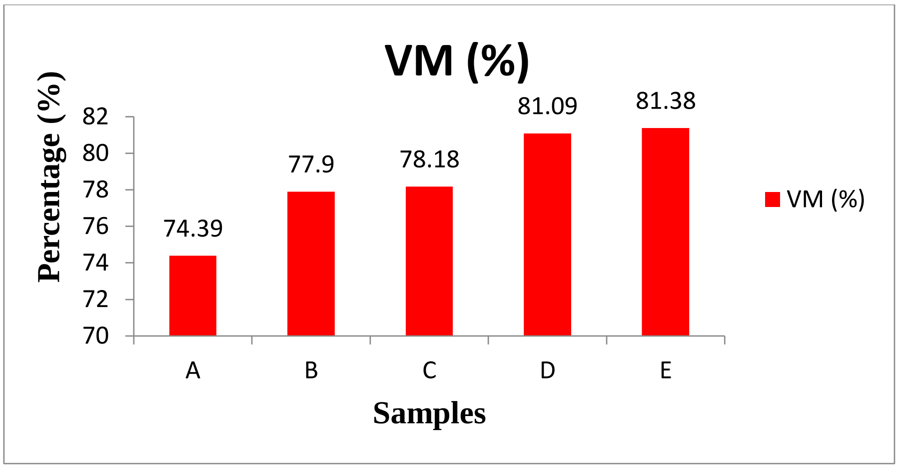

Figure 7: Volatile matter (%) of different compositions

Ash Content

Ash content results are presented in Figure 8. Sample E (50RH:50PKS) had the lowest ash content at 12.48%, while Sample A (90RH:10PKS) had the highest at 19.32%. Low ash content is desirable as it correlates with higher calorific value and reduced emissions. These findings are consistent with Kayode *et al.*, (2021) and show improvement over the 28.01% to 42.97% ash content reported by Tanko *et al.*, (2020) for rice husk and coconut shell briquettes.

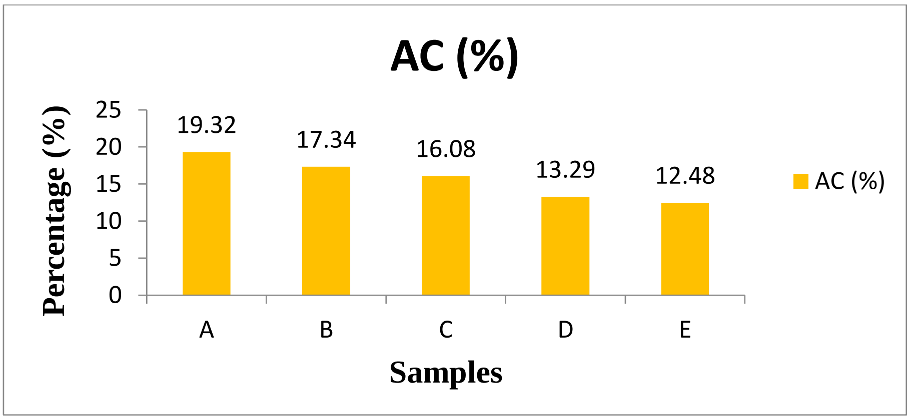

Figure 8: Ash Moisture content (%) of different compositions

Fixed Carbon

The fixed carbon content of the briquette samples is shown in Figure 9. Sample A (90RH:10PKS) had the highest fixed carbon at 2.11%, indicating good suitability for domestic applications due to its higher calorific value. This result aligns with findings from Imran *et al.*, (2020) and Pallavi *et al.*, (2013). The values obtained for moisture content, volatile matter, ash content, and fixed carbon in this study fall within the range reported by other researchers for biomass briquettes.

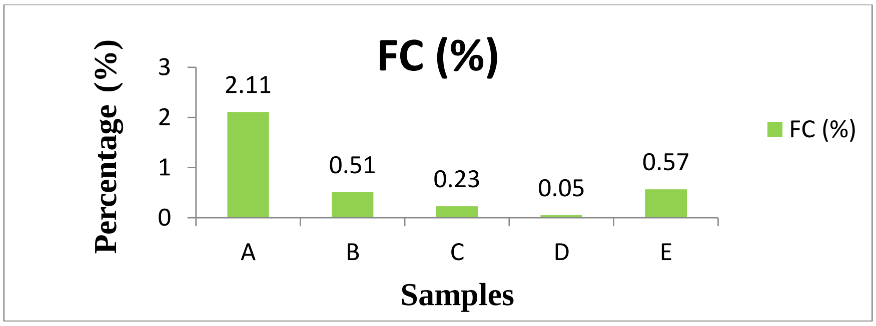

Figure 9: Fixed carbon (%) of different compositions

Higher Heating Value (Calorific Value)

The higher heating value (HHV) of the briquette samples is presented in Figure 10. Sample E (50RH:50PKS) had the highest HHV at 19.19 MJ/kg, indicating superior energy content compared to other samples. This value is higher than those reported by Kayode *et al.*, (2021), Akam *et al.*, (2024), and Tanko *et al.*, (2020), which ranged from 16.51 MJ/kg to 18.60 MJ/kg. A higher HHV means that the briquettes can generate more heat per unit mass, making them more efficient for heating and cooking applications. Therefore, the 50RH:50PKS ratio briquettes are recommended for use as an alternative to conventional fuels.

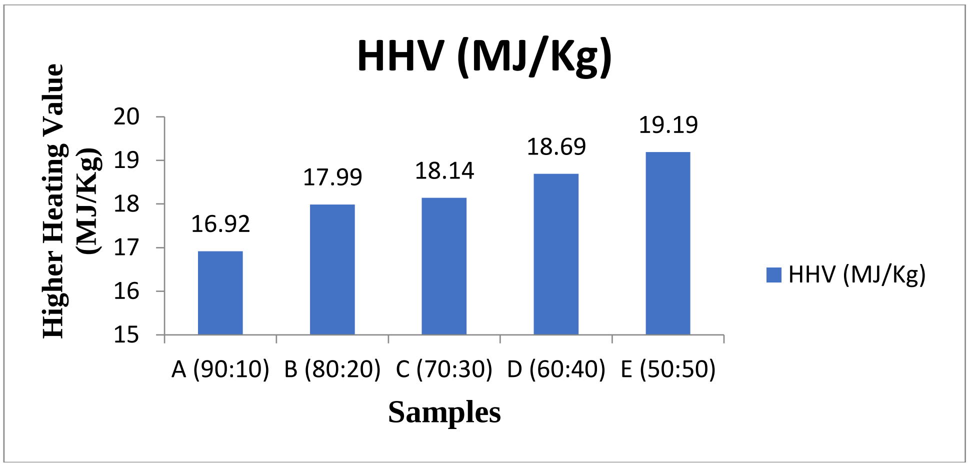

Figure 10: Higher Heating Value (Calorific Value)

CONCLUSION

This study evaluated the potential of composite briquettes made from rice husks (RH) and palm kernel shells (PKS) as an alternative solid fuel. The briquettes were produced and tested for various physical and combustion properties, including density, moisture content, volatile matter, ash content, fixed carbon, and calorific value.

The experimental results indicated that the briquette sample with a 50:50 ratio of rice husk to palm kernel shell (RH: PKS) exhibited the highest calorific value (HHV) of 19.19 MJ/kg, demonstrating superior heating efficiency compared to other samples. This value aligns well with other studies; for instance, Tembe *et al.,* (2014) reported a calorific value range of 16.51 to 18.60 MJ/kg for briquettes made from groundnut shells, rice husks, and sawdust, while Kayode *et al.,* (2021) obtained a calorific value of 17.54 MJ/kg for rice husk and wheat husk briquettes.

In terms of density, the 50RH:50PKS sample also showed the highest compressed and relaxed densities of 1.09 g/cm³ and 0.68 g/cm³, respectively. This is consistent with findings from Ibitoye *et al.,* (2023), who reported similar density ranges for corncob and rice husk briquettes, and Sam *et al.,* (2022), who found compressed and relaxed densities of 2.1 g/cm³ and 0.82 g/cm³, respectively, for similar biomass compositions.

The proximate analysis revealed that the 50RH:50PKS briquette had favorable characteristics, including low moisture content (4.18%), high volatile matter (81.38%), low ash content (12.48%), and fixed carbon content (2.11%). These properties contribute to efficient combustion and reduced emissions, comparable to the results obtained by Sukarta (2023) for wood and coffee skin briquettes, and significantly better than the high moisture and ash contents reported by Tanko *et al.,* (2020) for rice husk and coconut shell briquettes.

Overall, the findings confirm that the 50RH:50PKS briquettes possess excellent physical and combustion properties, making them a viable alternative to conventional fuels such as charcoal and firewood. The high calorific value and favorable proximate analysis results suggest that these briquettes can effectively meet energy needs while reducing deforestation and managing agricultural waste.

RECOMMENDATION

This work also recommends that Government and non-governmental organisations (NGOs) should support small-scale briquette production to create jobs, reduce deforestation, and manage agro waste.

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