DETERMINATION OF COMBUSTION CHARACTERISTICS OF DENSIFIED BIOMASS FUELS FROM AGRICULTURAL AND DOMESTIC WASTES

Abstract

The combustion characteristics of two carbonized biomass briquettes fuels samples (sample A and B) from two bio-wastes have been presented. Sample A is comprised of Agro-waste (residues) mainly rice husk, groundnut shell, corn cob, bagasse, rice straw, coconut coir, branches, wheat straw, maize husk, grass from the field, cassava stem while Sample B comprised of decaying domestic wastes material from wastes disposal/collection points mainly garbage, vegetables/fruits, protein, groundnut shell, maize cob, waste papers, all sorts of discarded foods etc. Analysis of briquettes fuels samples in terms of proximate analysis, ultimate analysis and calorific values were necessary to determine suitability of such material as reliable and sustainable energy sources. These parameters analyzed are unique fundamental code that characterizes and determines the properties, quality, potential applications and environmental problems related to any fuel. The result of the analysis placed sample B above sample A in terms of heating value. The proximate analysis indicated that the sample B had a better ignition characteristic at 77% volatile matter against 44% of sample A. Also, sample B have better heating value with fixed carbon 32% against 21% of sample A. This was also confirmed by ultimate analysis where sample B recorded a higher value of percentage Carbon and percentage Oxygen at 47.04% and 41.6% respectively. The bulk densities were in the range of 499kg/m^2 to 502kg/m^2 which is very good in terms of handling and transportation of the fuels.Moreso, calorific value of both samples were appreciably high at 18704 KJ/Kg for sample A and 18901.3 Kj/Kg by sample B. The ratio FC:VM for sample A is 0.477 which is higher than that of sample B, indicating that sample A will have a better yield and formation of biochar. Therefore the carbonised biomass briquettes are of good quality and exhibited good combustion properties as an alternative energy feedstock for domestic and industrial applications. It is a better source of energy for cooking, replacing fuel wood (firewood) and it is eco friendly.

Keywords: *densified biomass; briquettes; fuel wood; pyrolysis; calorific value; proximate analysis, ultimate analysis, agro-waste; municipal solid waste.*

1.0 INTRODUCTION

1.1 BACKGROUND

The ever growing concern that fossil fuel resources are largely depleted and tending towards exhaustion coupled with its rising cost and its negative effect on the environment in form of pollutions, greenhouse gas emissions and general environmental imbalance are current topical issues that demand urgent intervention and concerted efforts of all stakeholders towards finding new, sustainable and alternative energy sources

Biomass is organic, which implies it is made of material that comes from living organisms, such as plants and animals. The most common biomass materials used for energy are plants, wood, and waste. These are called biomass feedstocks. Biomass energy can also be a non-renewable energy source.

Biomass sources for energy include:
forest resources- wood and wood wastes,

- Agricultural crops and waste materials- corn, soybeans, sugar cane, switchgrass, woody plants, and algae, and crop and food processing residues
- Organic waste from municipal waste - paper, cotton, and wool products, and food, yard, and wood wastes
- Animal manure and human sewage

Fig 1 is a pictorial representation of types of biomass for energy.

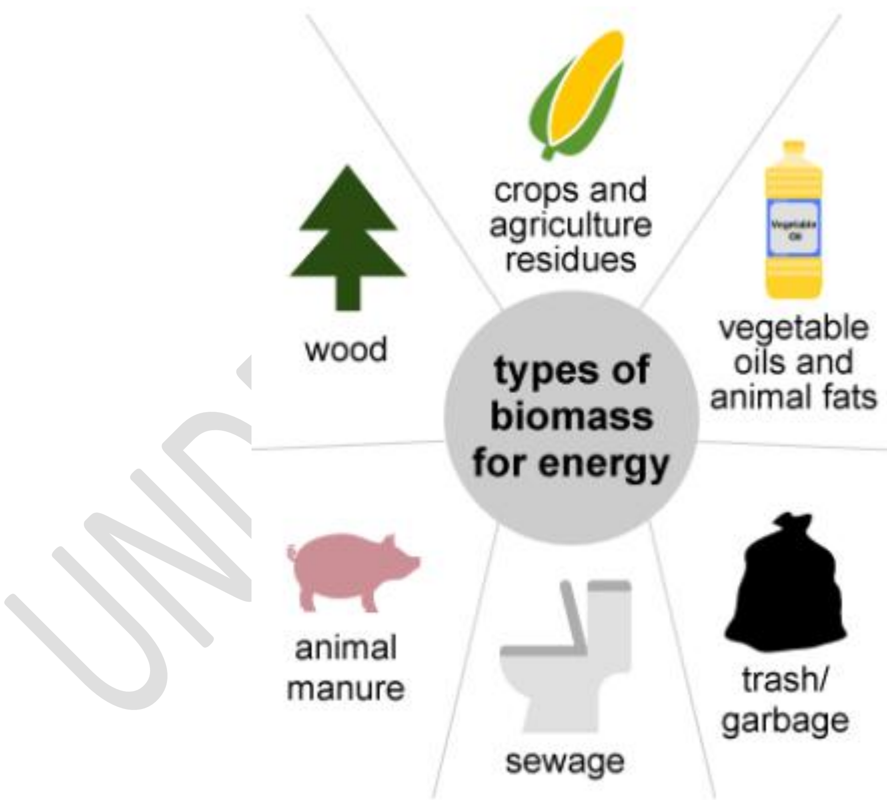

Fig 1. Types of biomass for energy

In 2021, biomass provided about 4,835 trillion British thermal units (TBtu), or about 4.8 quadrillion Btu and equal to about 5% of total U.S. primary energy consumption [1]

Nigeria has an ideal environment for biomass production due to its geographical location and its agricultural production. In terms of record, the country biomass generation capacity is over 2 billion tons with a potential to generate about 62 Mtoe (2.6 billion GJ) of energy from its biomass resources [2]. This energy resource is abundant and it is capable of replacing fuel wood, charcoal and most especially coal.

Biomass Resource	**Quantity (billion kg/year)**	**Estimated energy potential (PJ/year)**
Crop residues	153.76	2,033.85
Perennial crop residues	2.35	28.88
Forest residues	19	362.95
Municipal solid wastes	4.51	21.36
Animal wastes	17.69	106.39
Human wastes	2.87	28.83
Overall total	200.18	2,582.26 (61.67 Mtoe)

Table 1: Previous estimate of bioenergy potential in Nigeria **[2-3],**

Rural population is mainly dependent on the biomass as a traditional fuel, which is utilized inefficiently and generates greenhouse gases [3]. There is a great need to develop suitable technologies to utilize the abundant biomass resource available after harvest, from the environment and from domestic waste. Moreso, the knowledge of properties of biomass (which vary with geographical locations) is essential **[2, 4].**

Table 2: Biomass energy utilization in Nigeria

Sector	**Oil Products Mtoe (EJ) %**	**Coal Mtoe (EJ) %**	**Natural gas Mtoe (EJ) %**	**Biofuels/Waste Mtoe (EJ) %**	**Electricity Mtoe (EJ) %**
Industry	0.40 (0.02) 5.26	0.00(0.00) 0.00	2.60(0.11) 34.21	4.20(0.18) 55.60	0.40(0.02) 5.26
Transport	8.40(0.35) 100	0.00(0.00) 0.00	0.00(0.00) 0.00	0.00(0.00) 0.00	0.00(0.00) 0.00
Household/Others	2.70(0.11) 2.62	0.00(0.00) 0.00	0.00(0.00) 0.00	98.70(4.14) 95.64	1.80(0.08 1.74
Non-energy use	0.00(0.00) 0.00	0.00(0.00) 0.00	1.40(0.06) 100.00	0.00(0.00)	0.00(0.00) 0.00

				0.00	

Table 2 also shows that 96% of biomass energy is utilized by the household sector in Nigeria [5].

Environmentally, biomass is considered as an environmentally friendly fuel and has some advantages over fossil fuels such as coal, petroleum and natural gas. Biomass contains little sulfur and nitrogen. Biomass can also be co-fired with coal in a steam in steam turbines. Co-combustion has significant positive SO2 reductions of up to 75%. Moreover, most of nitrogen in biomass is converted to NH products such as ammonia NH3 during combustion. Growing plants for use as biomass fuels may also help keep carbon dioxide levels balanced. Plants remove carbon dioxide as one of the greenhouse gases from the atmosphere when they grow. Moreover, thermal utilization of biomass can contribute to the reduction of CO2 emissions since the same amount of CO2 is extracted from the air during thegrowth period of the plants as it is released by combustion CO2 balance.

The two main sources of biomass are the purpose-grown energy crops and wastes. Energy crops include woody crops and agricultural crops. Wastes include wood residues, forestry residues; temperate crop wastes, tropical crop wastes, sewage, municipal solid wastes and animal wastes.

2.2 Composition of biomass"The identification and characterization of chemical and phase compositions of a given solid fuel is the initial and most important step during the investigation and application of such fuel. These compositions are a unique fundamental code that characterizes and determines the properties, quality, potential applications and environmental problems related to any fuel. For that purpose, well-known physical, chemical, petrographic, mineralogical and geochemical studies were used for characterization of solid fuels. Authors used data from: (1) structural analysis, (2) proximate analysis, (3) ultimate analysis, (4) ash analysis, (5) petrographic analysis, (6) mineralogical analysis, (7) separation procedures, and (8) other analyses of fuel, low-temperature ash (LTA) or high-temperature ash (HTA) to characterize specific solid fuels. Identical or similar analyses are also applicable for biomass characterization despite some peculiarities and limitations"**[6]**

2.0 METHODOLOGY

2.1 SAMPLE PREPARATION

It involved the collection of agro-residues and domestic waste respectively, dried, carbonize and densified each on a 15Mpa briquetting machine. Finally carryout analysis by standard methods.

Several biomass from different sources are collected and grouped into two; sample A and Sample B. Sample A comprised of Agro-waste(residues) mainly rice husk , groundnut shell , corn cob , bagasse , rice straw , coconut coir , branches, wheat straw , maize husk, grass from the field, cassava stem while Sample B are basically kitchen or food market generated wastes such as garbages, vegetables, leaves, protein, groundnut shell ,maize cob, waste papers, discarded foods etc. The biomass samples were simultaneously dried in the oven at 105^{o}C and cut into a small size of 12 mm (approx.), and grind/densified using 15Mpa briquetting machine. The densifiedbiomss fuel known as briquettes Samples were analyzed, to determine their potential as boiler feedstock, and to determine the thermal properties of both sources of bio fuels. The binder (gelatinized cassava peel) at 20% of the total mass of the materials were used for the respective agglomerate samples **[7].**Fig 2 show the carbonized densified biomass fuels (briquettes) from the different biomass sources, representing Samples A and B respectively.

Fig 2: Carbonized biomass briquettes Samples

3.0 EXPERIMENTATION

3.2 Proximate analysis of biomasses

"The proximate analysis was completed for the biomasses using methods recommended for coal and sparkling fuel. It involved the determinations of volatile matter (V.M.), fixed carbon (F.C.) and ash content on a moisture-free basis" [8]. The muffle furnace and hot air oven along with the electronic balance were used to complete the analysis.

3.2.1 Volatile matter content

Samples A and B were measured and placed in a crucible of known mass. It was then oven-dried to constant mass. After, the samples was heated in the furnace at a temperature of 905 °C for 7 min and weighed after cooling. The volatile matter ($V\,m$) was then be evaluated as the percentage loss in mass of the sample using Eq. (1) expressed as follows **[9]** :

$$V_m(\text{ wt\% }) = \frac{B-C}{B} \times 100\% \qquad (1)$$

Where B is the weight of the oven-dried sample and C is the weight of the furnace-dried sample.

3.2.2 Ash content These samples were placed in a crucible of known mass and heated in the furnace at a temperature of 500 °C for 5 hours and will be weighed after cooling. The ash contents were then estimated from the percentage loss in respective masses of the samples A and B using Eq. (2) **[10]** :

$$Ac\ (\text{wt\%}) = D/B \times 100\% \quad (2)$$

where*Ac* is the percentage ash content, *D* is the weight of ash (furnace dried), and *B* is the weight of the oven-dried sample.

"Significant differences in combustion properties of biomass is observed on the basis of their ash composition"**[11].**"The composition of biomass ash is strongly dependent on the species and part of the biomass plant. The available nutrients, soil quality, fertilizers and weather conditions have significant impact on the contents of potassium, sodium, chlorine and phosphorus especially in agro-biomass ashes" [12]

3.2.3 Fixed carbon

The percentage fixed carbon of each sample of briquette were estimated using the relation in Eq. (4) **[13]** :

$$F c\ (\text{wt\%}) = 100 - (V m + Mc + Ac) \quad (3)$$

where*F c* is the (wt%) fixed carbon obtained for each briquette sample, *V m* is the (wt%) volatile matter obtained for each briquette sample, *Mc* is the moisture obtained for each briquette sample and *Ac* is the (wt%) ash content obtained for each briquette sample.

3.3Ultimate analysis and associated properties of biomasses

The ultimate analysis was done determined the elemental percentages of carbon, hydrogen and oxygen along with the ash content (which was determined through proximate analysis mentioned previously. The analysis ignored the determination of nitrogen and sulphur as their values are negligible **[14-15].**

3.3.1 Elemental composition

Based on the result of the proximate analysis, the elemental composition of common organic elements such as carbon (*C*), hydrogen (*H*), and oxygen (*O*) for the briquettes were estimated using Eqs. (7) , (8) and (9) ,respectively. These were evaluated at an estimate of 95% confidence level **[16]:**

$$C = 0.637\ F c + 0.455\ V m \quad (4)$$

$$H = 0.052\ F c + 0.062\ V m \quad (5)$$

$$O = 0.304\, Fc + 0.476\, Vm \qquad (6)$$

All the analyses followed the American Standard Testing Method (ASTM) for biomass fuel analyses.

Table 3: American Standard Testing Methods (ASTM) for biomass fuel analysis

Experiment	**ASTM**
Heating value (MJ/kg)	D 2015, E 711
Proximate analysis	
Moisture	E 871
Ash	D 1102, E 830
Volatile matter	E 872, E 897
Fixed carbon	By difference
Ultimate analysis	
Carbon, Hydrogen	E 777
Nitrogen	E 778
Sulfur	E 775
Chlorine	E 776
Oxygen	By difference
Ash elemental analysis (Si, Al, Fe, Ca, Mg, Ti, Na, K, P)	D 3682, D 2795
Ash fusion temperature	D 1875
Bulk density	E 873
Fuel size	E 323

3.4 Bulk densities and calorific values of biomasses

The samples; A and B were subjected to the determinations of bulk densities through the standard method. **[8, 18**]. Bulk density was determined using the following formula:

Bulk density = (Wd/Vd) × 1000 kg/m^3 (7)

where Wd is the weight of the biomass (g) and Vd is the volume of packed biomass (cm3).

The briquettes samples were also tested for their calorific values using a bomb calorimeter. A high calorific value of the fuel is always advantageous. A very low heating value sometimes makes the agro-residues totally unsuitable and may require some pre-treatment for enriching the fuel.

Also the calorific values of the briquettes samples were compared to results obtained using this model developed by **[19]**.

H H V (MJ / kg) = 0.1846 V m + 0.0352 F c (2)

4.0 RESULTS AND DISCUSSIONS

4.1 PROXIMATE ANALYSIS OF BRIQUETTE

	VM (%)	FC (%)	FC/VM	Ash (%)
Sample A	44	21	0.477	18.12
Sample B	74	32	0.41	9.0

Table 4: Proximate analysis result

The volatile matter of Composite Sample A is 44% while composite sample B recorded a higher volatile matter of 74%. Higher volatile matter suggests that the briquettes B (sample B) will ignite better than sample A, with appropriate flame [20].

Fixed Carbon determines fuel briquettes' heating value. Sample A recorded a fixed carbon value of 21% while sample B recorded 32%. This suggests that sample B will generate a better heating value compared to A.

The ratio of percentage fixed Carbon to percentage volatile matter FC:VM was highest in sample A at 0.477 whereas, sample B recorded 0.41. Higher FC:VM implies better Biochar formation as well as lower formation of gases during thermochemical conversions in Pyrolysis and gasification chambers respectively [8]. Therefore, sample A will generate more biochar as well as briquettes than sample B.

In terms of Ash content, sample A recorded a higher ash content of 18.12% while sample B ash value is 9.0%. High ash content is inimical to combustion and biochar formation. It promotes catalytic activity; an undesirable activity that entraps combustible matter thereby, suffocating the combustion. Low ash enhances combustion rates [20].

4.2 ULTIMATE ANALYSIS

	C (%)	H (%)	O (%)
Sample A	46.20%	4.39	30.67
Sample B	47.04	5.68	41.61

Table 5: Result of ultimate analysis

The ultimate analysis results of briquettes are shown in table 5. The results showed that samples A and B have reasonably, high percentage of Carbon and Oxygen which confirm the potentials of this biomass, as well as, their briquettes in energy generation applications. The both samples recorded percentage Carbon in the range 46-47% and percentage Oxygen of 30.67% for A and 41.6% for B which are good enough energy source.

These results are in agreement with general percentage Carbon range for Biomass which is 43-54% . A good quality, biomass fuel behaves like a low quality coal. The percentage Carbon content for coal ranges between 65-85% [12].

Therefore, high percentage of fixed Carbon and Oxygen in sample B is an indication of higher heating value.

4.3 Bulk densities and Calorific Values

Table 6 : Bulk densities and Calorific Values in both samples

	Bulk Densities (kg/m^2	**Calorific Value (Kj/Kg)**
Sample A	502	18704.1
Sample B	499	18901.2

The bulk densities were in the range of 499kg/m^2 to 502kg/m^2 which is very good in terms of handling of the fuel. The result is in line with Mong et al (2023) which placed such result as a great improvement from 80 to 100 kg/m^3 range of bulk density for loose biomass.

Calorific value of fuel briquettes indicates their gross heating values. Sample A generated a better calorific value at 18704.1 Kj/Kg while sample B had a calorific value of 18901.3 Kj/Kg. Although both results are a bit lower than the reported value for wood fuels in Iyer et al (2002), but they are far better than minimum heating value for briquette production [20-21]. Sample B has a higher calorific value when compared to sample A as well as a better combustion characteristics.

5.0 CONCLUSION

The combustion characteristics of two carbonized biomass briquettes fuels samples (sample A and B) from two bio-wastes have been determined. Sample A is comprised of Agro-waste(residues) mainly rice husk , groundnut shell , corn cob , bagasse , rice straw , coconut coir, branches, wheat straw , maize husk, grass from the field, cassava stem while Sample B comprised of decaying domestic wastes material from wastes disposal/collection points mainly garbage, vegetables/fruits, protein, groundnut shell, maize cob, waste papers, all sorts of discarded foods etc.

Analysis of briquettes fuels samples in terms of proximate analysis, ultimate analysis and calorific values were necessary to determine suitability of such material as reliable and sustainable energy sources. The result of the analysis placed sample B above sample A in terms of heating value. The proximate analysis indicated that the sample B had a better ignition characteristic at 77% volatile matter against 44% of sample A. Also, sample B have better heating value with fixed carbon 32% against 21% of sample A. This was also confirmed by ultimate analysis where sample B recorded a higher value of percentage Carbon and percentage Oxygen at 47.04% and 41.6% respectively. The calorific of both samples were appreciably high at 18704 KJ/Kg for sample A and 18901.3 Kj/Kg by sample B. The ratio FC:VM for sample A is 0.477 which is higher than that of sample B, indicating that sample A will have a better yield and formation of biochar. These parameters analyzed are unique fundamental code that characterizes and determines the properties, quality, potential applications and environmental problems related to any fuel. Therefore the carbonised biomass briquettes are of good quality and exhibited good combustion properties as an alternative energy feedstock for domestic and industrial applications. Refuse Derive Fuels such as briquettes may become one of the major sources of thermal energy in the future, complimenting the ever depleting fossil fuels.

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