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DETERMINATION OF THE ENERGY CONTENT OF SOME SELECTED BIOMASS WITHIN KUTIGI METROPOLIS

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Abstract

Biomass remains one of the most important renewable energy sources for domestic and small-scale industrial applications in developing countries. In Nigeria, fuelwood constitutes a significant portion of household energy consumption due to limited access to modern energy infrastructure. Wood waste if well harnessed is a potential alternative source of energy. This study investigated the energy content of selected wood species commonly used as fuel within kutigi metropolis in Niger State, Nigeria. This research paper aims to determine and compare the energy parameters of some selected wood biomass. Six commonly available wood species were selected for the study, namely, Iroko, African walnut, Eucalyptus, Shea, Mango and Neem. The wood samples were collected, prepared and analysed in the laboratory following the procedure of the American Society Standard Test Method. The result of characterization of the wood samples showed a range of values for the volatile matter (74% to 84.60%), ash content (0.4% to 4.62%), fixed carbon (3.97% to 19%) and moisture content (2% to 13%). Eucalyptus tree had the highest volatile matter and the lowest ash content. This indicates that the quantity of hydrocarbon in the wood samples was high and hence would have high energy content. Furthermore, to

Key Words: Biomass energy, calorific value, fuelwood, renewable energy, torrefaction, Kutigi

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increase the heating value of the woods, torrefaction was carried out. The torrefaction result shows that eucalyptus tree had the highest calorific value of 22300KJ/kg when treated with heat between 260 – 290°C. Generally, the calorific value of the wood fuels increases with temperature, but decreases as from a higher temperature range of 290 – 350°C. The findings indicate that eucalyptus wood possesses the highest energy potential among the species studied and is therefore more suitable as fuelwood. The study provides valuable data for biomass energy utilization and contributes to sustainable energy planning in rural communities.

Introduction

Biomass energy refers to energy derived from organic materials such as wood, agricultural residues, and animal waste. It is considered renewable because it can be replenished through natural biological processes. Biomass resources have significant potential to contribute to sustainable energy systems, particularly in countries with abundant agricultural and forest resources (Ukoba et al., 2024). According to the International Energy Agency, biomass contributes significantly to global renewable energy supply, accounting for a large share of renewable heat and power generation. Food and Agriculture Organizations, (2022) stated that, in many African countries including Nigeria, biomass provides up to 70–80% of the total domestic energy demand, particularly in rural communities. Fuelwood, charcoal, and agricultural residues are the most commonly used forms of biomass energy.

Biomass energy constitutes a major component of the national energy mix. Fuelwood, charcoal, and agricultural residues are widely used for cooking and heating purposes, especially in rural and semi-urban communities. The availability and affordability of wood fuel make it one of the most commonly used energy sources for domestic applications (Adeleke et al, 2021).

The energy content of biomass is usually expressed in terms of calorific value or heating value which represents the amount of heat released when a unit mass of biomass is completely combusted. The heating value of biomass depends on several factors including moisture content, ash content, and chemical composition such as cellulose, hemicellulose, and lignin content. Biomass with higher lignin content typically exhibit higher calorific values compared to those with higher cellulose content. Studies have shown that the calorific value of wood biomass generally ranges between 15 and 22 MJ/kg depending on the species and moisture content, making them sustainable for domestic

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and industrial application (Olabisi et al., 2023; Ajayi & Ajanaku, 2020). Wood species with higher lignin content generally produce higher heating values because lignin contains more carbon and hydrogen compared to cellulose (Adebayo & Ojo, 2022). Two types of calorific values are commonly used in energy analysis. The Higher Heating Value (HHV), which represents the total heat released when fuel is completely combusted, including the heat recovered from condensing water vapour while the Lower Heating Value (LHV) excludes the heat recovered from water vapour condensation and is usually lower than HHV. (Demirbas, 2007; Adebayo & Ojo,2022). Recent research on biomass fuels has emphasized the importance of determining thermochemical properties such as calorific value, ash content, volatile matter, and fixed carbon in order to evaluate the suitability of biomass materials for energy applications (Yunusa et al., 2024). Research carried out on Nigerian wood species indicates that hard wood species generally possess higher calorific values compared to softwood species due to their higher density and carbon content. Understanding the calorific values of locally available wood species helps in selecting efficient fuel materials and improving biomass energy utilization (Adeleke et al, 2021).
Kutigi metropolis in Niger State is surrounded by vegetation that provides several wood species commonly used as fuel by residents. Despite the widespread use of these wood species, limited scientific information exists regarding their energy potential. Therefore, determining the calorific values of commonly used fuelwood species is essential for identifying efficient fuel sources and improving biomass utilization. Thus, the objective of this research work is to determine the energy content of selected species of wood commonly used in kutigi metropolis to ascertain their potential for energy production. Several analytical methods are used to evaluate the energy characteristics of biomass materials. In this study, the bomb calorimetry which is the most common method was used to determine the calorific value of the selected wood species. The proximate and ultimate analysis was also carried out to provide information for utilization of their fuel potential properties.

Sample Collection

The woods of different species of trees were collected from Kutigi metropolis located in Niger State, Nigeria. Kutigi lies within the Guinea Savannah vegetation zone where several indigenous tree species are available and widely used as fuelwood for domestic cooking and small-scale processing activities.
Six commonly used wood species were selected for the study. They include Iroko tree, African walnut tree, Eucalyptus tree, Shea tree, Mango tree and Neem tree.

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Sample Preparation

The wood samples were cut into smaller pieces and sun-dried to reduce to minimum the moisture content. The dried samples were then ground into fine particles using a grinding machine and thereafter it was sieved to obtain uniform size particles and it was then stored in airtight containers prior to analysis.

Proximate and Ultimate Analysis

Proximate analysis was carried out to determine the **moisture content, volatile matter, ash content, and fixed carbon** of the selected wood species. These parameters are essential for evaluating the combustion characteristics and fuel quality of biomass materials. Proximate analysis of the samples was conducted following standard procedures recommended by the ASTM International. The ultimate analysis was carried out using an elemental analyzer to determine the amount of Carbon (C), Hydrogen (H), Nitrogen (N) and Sulphur (S). The Oxygen composition was calculated by difference i.e., by subtracting the sum of Carbon, Hydrogen, Nitrogen, Sulphur and Ash composition from 100. The fixed carbon was determined by subtracting from 100 the sum of volatile matter (VM), moisture content (MC), and ash content (AC).

Torrefaction of Wood Biomass

The torrefaction of the species of woods was investigated under six different temperature levels ranging from 200 - 350 °C, at the heating rate of 30 °C/10min. In each run, two (2) kilograms of ground wood biomass was subjected to torrefaction (at atmospheric pressure) at the six different temperature severities. A muffle oven modified to accommodate a gas inlet and outlet, fitted with a one-way valve system was used. The torrefaction process was carried out in an inert atmosphere using nitrogen gas, at a constant flow rate of 50 l/h for a constant gas flush. Prior to commencing the torrefaction process, the system was purged for 20 minutes to remove air from the oven. The oven was then heated at a heating rate of 10°C/min to the desired torrefaction temperature.

Determination of Calorific Values

The Calorific value was estimated using an Oxygen Bomb calorimeter. 3g of wood sample was placed in crucible inside the bomb, which was filled with oxygen under a pressure above 25 atm. The heat released during combustion increased the temperature of surrounding water, which was used to calculate the calorific value of the sample. Bomb calorimetry is widely used for determining the energy potential of biomass fuels due to its accuracy and reliability (Ahmadu et al., 2024).

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Calculation of Calorific Value

Heat released by fuel sample = $W_f.C$

Heat received by water and calorimeter = $(W_w+W_e).\ c.\ [\ (t_2-t_1) + t_c]$

By energy balance;

$W_f.C = (W_w+W_e).\ c.\ [\ (t_2-t_1) + t_c]$

Where;

W_f = weight of fuel sample, kg

W = weight of water, kg

c = specific heat of water

C = calorific value (higher) of fuel, kJ/kg

W_e = water equivalent of calorimeter (kg)

t_1 = initial temperature of water and calorimeter

t_2 = final temperature of water and calorimeter *source:* Jain, 2009

Proximate Analysis

Proximate analysis provides information on the combustion characteristics of biomass by determining moisture content, volatile matter, ash content, and fixed carbon. These parameters are essential in evaluating the suitability of biomass as a fuel (Yunusa et al., 2024).

Table 1: Proximate Analysis for Selected Wood Species

Wood Species	Moisture content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)
Walnut tree	13.0	80.93	2.01	4.06
Shea tree	6.2	74.0	0.8	19.0
Neem tree	8.2	82.41	1.8	7.59
Mango tree	7.8	76.68	0.87	14.65
Iroko tree	9.0	82.41	4.62	3.97
Eucalyptus tree	2.0	84.60	0.4	13.0

The moisture content of the selected wood species ranged from 2% to 13%. The percentage moisture content of walnut tree was the highest, while that of eucalyptus was the least. This indicates that Eucalyptus will give the highest fuel calorific value (i.e., best fuel property) amongst the other wood species considered in this work. Also, it will be the one with the highest durability value in terms of them being stored. Moisture content is an

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important factor affecting combustion efficiency because higher moisture levels reduce the effective heating value of biomass fuels.

The **volatile matter content** of the wood species varied from 74.02% shear tree to 84.60% Eucalyptus, thus with Eucalyptus having the highest value and shea tree the least. The volatile matter content of a biomass material when high indicates that during the process of combustion, most of it will volatize and burn as gas. This indicates that the quantity of hydrocarbon in the wood samples was high and hence would have high energy content. High volatile matter facilitates easier ignition and rapid burning of biomass fuels (Olabisi et al., 2023).

The **ash content** of the samples ranged from 0.4% for Eucalyptus to 4.62% for Iroko. The high ash content of Iroko indicates that it has high mineral matter. The ash content of the various wood species used in this study was lower than 5%, which is relatively low and desirable for fuelwood. Low ash content improves combustion efficiency and reduces slagging and fouling during burning (Ahmadu et al., 2024). Hence, it is likely that when species like walnut tree, shea tree, neem tree, mango tree and Eucalyptus tree are used as fuel, slagging would not occur. On the contrary, slagging might occur when wood species like Iroko are used as biomass fuel.

The **fixed carbon content** ranged from 3.97% (Iroko) to 19% (shea tree), indicating moderate char formation during combustion The higher the fixed carbon, the more the heating value, and thus the result agrees with that presented by Huhtinen (2009) where the fixed carbon of certain biomass was in the average of 16%. The high fixed carbon content indicates that the biomass will require a long combustion time. Fixed carbon contributes to sustained burning and heat generation after volatile components have been released.

According to Chakradhari & Patel, (2016), Proximate analysis is the method most commonly used to characterize biofuel and an important consideration in proximate analysis which influences the energetic value is the volatile material that is released when organic substances are heated at high temperature. These findings are consistent with previous studies which reported that biomass fuels with high volatile matter and low ash content tend to exhibit better combustion characteristics (Yunusa et al., 2024).

Ultimate Analysis

Ultimate analysis determines the elemental composition of biomass, including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). These elements influence the energy content and combustion behavior of biomass fuels.

Table 2: Ultimate Analysis for Selected Wood Species

Wood Species	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Walnut tree	47.2	4.0	43.2	0.4	0.02
Shea tree	47.1	7.0	43.4	2.3	0.06
Neem tree	43.4	8.0	43.0	1.3	0.03
Mango tree	45.5	6.0	43.0	2.0	0.05
Iroko tree	43.2	5.8	43.0	1.2	0.06
Eucalyptus tree	50.2	4.3	45.2	0.2	0.01

The ultimate analysis results indicate that **carbon content** ranged from **43.2% to 50.2%,** with eucalyptus tree having the highest carbon content. Higher carbon content is directly associated with higher calorific value because carbon is the primary energy-yielding element in biomass (Oyerinde et al., 2025). The **hydrogen content** ranged from **4.0% to 8%,** contributing to the heating value of the biomass. Hydrogen enhances combustion by producing additional heat when oxidized. The **oxygen content** ranged from **43% to 45.2%.** Biomass materials generally contain high oxygen content, which reduces their heating value compared to fossil fuels (Olabisi et al., 2023). The **Nitrogen and Sulphur contents** were found to be very low, which is environmentally favourable. Low nitrogen and sulpfur content reduce the emission of harmful gases such as nitrogen oxides (NO_x) and sulphur oxides (SO_x) during combustion (Ahmadu et al., 2024).

Table 3: Calorific Value of Selected Wood Species

	Time	Calorific Value (kJ/kg)					
Temp. °C	(min)	Mango	Neem	Iroko	Shea	Walnut tree	Eucalyptus
170-200	30	4000	4300	6200	7700	4135	7000
200-230	40	6000	7000	8700	13800	5700	14700
230-260	50	9000	12300	13100	19900	10000	20400
260-290	60	13000	19000	18800	18200	17900	22300
290-320	70	16000	15300	16100	16100	17900	18100
320-350	80	16000	13000	14500	14300	11135	14000

Calorific value is fundamental to evaluating a fuel from the point of view of its energetic value, as well as providing an idea of its flammability or its potential to generate and propagate fires. The result obtained herein shows the calorific value of torrefied wood biomass in relation to heat applied in the process. Torrefaction improves the heating effect of organic solid fuel. From Table 3, it shows that Eucalyptus tree recorded the highest calorific value of 22300KJ/kg when treated with heat between 260 - 290 °C,

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suggesting that it has greater energy potential compared to the other species. The variation in calorific values among the wood species may be attributed to differences in density, lignin content, and elemental composition. Generally, the calorific value of the wood fuels increases with temperature, but decreases as from a higher temperature range of 290 – 350°C. The results of proximate and ultimate analyses collectively explain the variation in calorific values observed among the wood species. Wood species such as Eucalyptus, which exhibited low moisture content, high volatile matter, low ash content, high carbon and hydrogen content also recorded the highest calorific value. This confirms that both physical properties (proximate analysis) and chemical composition (ultimate analysis) play a crucial role in determining the energy potential of biomass fuels.

CONCLUSION

This study was conducted to determine the energy content of selected wood species within Kutigi metropolis. The results obtained from the analysis revealed that the wood species differ in their moisture content and calorific values. The proximate analysis shows an average volatile matter of 76.34% and a low ash content of 0.9%, indicating that all the selected wood samples possess good potential as biomass fuels. Among the species studied, Eucalyptus tree recorded the highest volatile matter content, the lowest ash content and the highest calorific value of 22300KJ/kg when treated with heat between 260 – 290 °C while Mango tree recorded the lowest calorific value. Based on the results obtained, it can be concluded that **Eucalyptus tree is the most suitable fuelwood among the species studied due to its high calorific value and relatively low moisture content.** The study therefore highlights the importance of evaluating the energy potential of different wood species in order to promote efficient utilization of biomass resources.

RECOMMENDATION

Based on the findings of this study, the following recommendations are made:

1. Further studies should investigate additional indigenous wood species to expand the database of biomass energy resources in Nigeria.
2. Wood species with higher calorific values such as Eucalyptus should be encouraged for fuel use due to their higher energy efficiency and sustainable management of fuelwood resources should be promoted to prevent environmental degradation and deforestation.
3. Improved biomass conversion technologies should be adopted to enhance energy utilization.

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