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Experimental Analysis of Combustion Properties of Tropical Wood Waste for Energy Production in Nigeria

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ABSTRACT

Renewable energy is becoming more and more well-known, with a focus on how it could replace fossil fuels. In Nigeria, sawmills that sell wood produce a lot of wood waste. This study, therefore, will focus on the experimental analysis of combustion properties of tropical wood waste for energy production in Nigeria. Okwen (Barchystegia spp.), danta (Nesogordonia paraverifera), afara (Terminalia superba), yukumo (kiranico), and altonia (Alstonia spp.) were collected from a sawmill in Benin, Edo State, and used as the samples. The moisture content, calorific values, and combustion analysis of the wood samples were determined. The findings indicated that the wood samples have a percentage moisture content that ranged from 7.26% to 7.70%. Similarly, the samples were also found to have high calorific values, the values being 30,516.81 kJ/kg to 30,738.38 kJ/kg. Besides, the combustion performance of the samples also revealed that the amount of carbon (IV) oxide released to the atmosphere during combustion is extremely low (18% to 22%). Therefore, rather of being disposed of, which could contaminate our environment, the wood waste samples produced in sawmills around Nigeria could be used to generate energy.

1. Introduction

Biomass is a renewable resource that may be used as fuel to produce heat and electricity. It is usually made from wood and other plant materials. It is plentiful and can be utilized to create biofuels, thermal energy, and electricity [1]. The Nigeria's total biomass potential, which included wood, agricultural, and animal waste, was 1.2 PJ [2]. Oladipo [3] also reported that Nigeria has 1,160 established forest reserves that cover 10% of the country's total geographical area. In rural Nigeria, wood fuel is the most use domestic energy source, and also among the low-income urban populations [4]. The country currently utilizes about 80 million cubic meters of fuel wood annually for domestic and culinary applications, with each person using 0.5 to 1.0 kilograms of dry fuel wood on average per day [5]. Just 5% to 12% of the 6.0 x 10^9 MJ of energy contained in the firewood being used is profitably used for cooking and other household purposes [6]. Energy supply and solid waste management are also two of Nigeria's most pressing problems at the moment [7, 8]. In Nigeria, biomass, a sustainable energy source that can replace the burning of fossil fuels that cause global warming, produces a lot of waste. Fiber [9], palm kernel shell [10–14], wood debris [15–21], and other combustible trash [22–25] are a few examples of biomass. Regretfully, the country has not been able to produce all of its energy from biomass waste [26–29]. Millions of tons of wood, agro-industrial, and forest biomass are collected each year for use in chemical products, boards, pulp, paper, cardboard, and fuels. The value-adding of biomass waste proves to be a critical issue in view of current concerns about sustainability and the ecological footprint of both materials and energy. Besides, a sizable portion of wastes in tropical nations like Nigeria cannot be recycled, reused, or utilized to make compost because of their diverse industrial infrastructure and socioeconomic circumstances [30]. Open burning activities and effluent emissions into open spaces or water have resulted from this [31, 32].

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Furthermore, wood waste can be recovered by mechanical conversion, biochemical conversion, and thermochemical conversion [33-35]. The most appealing option is thermochemical conversion due to its higher efficiency, versatility, and shorter reaction time required to treat large amounts of raw matter. The three most prominent thermochemical processes at the moment are combustion, gasification, and pyrolysis. The operating parameters (temperature range, heating rate, oxygen presence or absence), the need to dry feed the material, and the final product are what distinguish these processes from one another [16]. In addition, combustion occurs when fossil fuels such as biomass wood waste react with atmospheric oxygen to generate heat, which can be used for industrial processes. As fossil fuels are hydrocarbons, their primary constituents are hydrogen and carbon. Carbon dioxide (CO_2) and water (H_2O), which are produced from the reactants carbon and hydrogen in the fuel and oxygen (O_2) in the air, are the primary chemical byproducts of burning fossil fuels. When the reaction is balanced, there is only one CO_2 molecule and two H_2O molecules, and this energy release results in heat. In fact, genuine combustion processes often produce other chemicals. A typical representation of an actual combustion process is shown in Fig. 1. Fuel and air react to produce the items on the right.

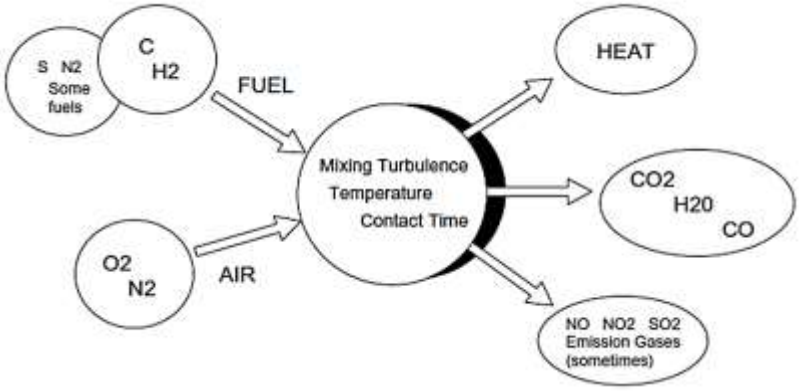

Fig. 1-Actual combustion process

Also, reducing the environmental impact of burning fossil fuels to generate energy can be achieved in large part by using wood waste for energy utilization in steam generators [36–41]. By progressively replacing the usage of fossil fuels, waste wood could help mitigate global warming [42]. Despite previous study on the many benefits and potential of using wood waste as fuel in Nigeria, the potential for energy generation has not yet been completely realized. The lack of sufficient information on the energy properties and chemical makeup of the wood species that are available in the nation may be the reason why fuel wood cannot be completely utilized as an energy source. Thus, the moisture content, calorific values, and combustion analysis of a few chosen wood samples will be examined in this study.

2. Materials and Methods

2.1 Materials

In this study, the following materials and equipment were used for the experimental analysis:

i. Alstonia (Altonia Spp)
ii. Afara (Terminalia Superba)
iii. Danta (Nesogordonia Paraverifera)
iv. Okwen (Brachystegia spp)
v. Yukumo (Kiranico)

An electronic precision balance and a bomb calorimeter are among the tools utilized for the laboratory analysis. The calorific value of the wood waste samples was ascertained using this apparatus, which was also utilized for moisture content, and combustion analysis.



Fig. 2-Electronic precision balance



Fig. 3-Oxygen bomb calorimeter

2.2 Methods

In this investigation, the following methodologies were used.

2.2.1 Moisture Content Analysis

The formula used for determining the moisture content is given in Equation 1.

$$\% \text{ MC} = \frac{(\text{g} - \text{x})}{\text{g}} \times 100 \qquad (1)$$

where

g = Samples of wood weight

x = The weight of dry matter

(g - x) = The loss in weight

2.2.2 Calorific Value of Biomass (Wood) Samples

A 1g amount of each fuel sample was carefully weighed into the crucible, and once the moisture content was determined, a fuse wire (nickel, whose weight is known) was stretched between the electrodes. To absorb the nitrogen and sulphur combustion products, two milliliters of water were added to the bomb. The bomb was then pumped with pure oxygen through the valve until the pressure reached 25 atm. After that, the bomb was placed inside the weighted water volume of the calorimeter. The stirring was initiated after the required electrical connections were completed, and the fuel was ignited when the thermometer displayed a steady temperature. Until the maximum temperature was attained, thermometer readings were obtained every 30 seconds. After removing the bomb, the exhaust valve was gradually opened, and the device's contents were meticulously weighed in preparation for further examination. Using the bomb calorimeter and Equation (2), the gross heat of combustion of every wood sample was determined in the laboratory.

$$CV = \frac{E\Delta\text{T} - \Phi - \text{V}}{g} \qquad (2)$$

where

CV= Calorific value

EΔT= Change in temperature

V= Volume of alkaline

g= Weight of sample

Φ= Constant

2.2.3 Ultimate Analysis

The carbon, oxygen, hydrogen, nitrogen, and sulphur content were determined as shown in Equations (3) to (6).

i. Carbon Content

$$\% \text{ Carbon} = \frac{(B-T)\times M\times 0.003\times 100\times 1.33)}{g} \quad (3)$$

where

B = Blank Titre

T = Sample Titre

g = Weight of sample

ii. Nitogen Content

$$\% \text{ Nitrogen} = \frac{(\text{T} * \text{M} * 0.014 * \text{DF})}{\text{g}} \times 100 \quad (4)$$

where

M = Molarity of the acid used

g = Weight of sample

T = Titre value

DF = Dillusion factor diluted

iii. Sulphur Content

$$\% \text{ Sulphur} = \frac{\text{x}*0.1373}{\text{g}} \times 100 \quad (4)$$

Where,

g = Weight of sample

x = Weight of $BaSO_4$

iv. Hydrogen content

$$\% \text{ Hydrogen} = \frac{\text{wt of H2O} \times 0.1119 \times 100}{\text{wt of pellet}} \quad (5)$$

Where 0.1119 is a constant derived from empirical equation in Leibig-Pregle method.

v. Oxygen Content

$$\% \text{ Oxygen} = 100 - (\text{C} + \text{H} + \text{N} + \text{S} + \% \text{ Ash}) \quad (6)$$

2.2.3 Combustion Analysis

Since each wood sample contains carbon, hydrogen, oxygen, nitrogen, and sulphur, the chemical formula is expected to contain the aforementioned elements as suggested by [16] and represented by Equation (7):

$$CaHbOdNeSf \quad (7)$$

Knowing the final analysis of the wood fuel allows one to determine a, b, c, d, and f using this generic chemical formula. Equation (8) was used to assess the combustion analysis of the five wood samples (i.e., Alstonia, Afara, Danta, Yukumo, and Okwen). The corresponding N_2 will now show up in the equation as follows since the oxygen is provided as air:

$$C_aH_bO_dN_eS_f + x\ O_2 + x\ (79/21)\ N_2 \longrightarrow pCO_2 + qH_2O + rSO_2 + sN_2 \quad (8)$$

3. Results and Discussion

The results of the moisture content of the wood samples are displayed in Table 1 and Fig. 3. This was obtained using equation (1).

Table 1- Percentage moisture content of different samples of wood waste

Moisture content	**Alstonia**	**Afara**	**Danta**	**Okwen**	**Yukumo**
Weight of sample (g)	1.004	1.001	1.000	1.006	1.002
Weight of dry matter (x)	0.930	0.928	0.923	0.933	0.928
Loss in weight (g-x)	0.074	0.073	0.077	0.073	0.074
% moisture	7.37	7.29	7.70	7.26	7.39

Okwen has the lowest moisture content and Danta has the highest, based on the percentage moisture level of the various wood samples. However, the results range from 7.70% to 7.26%. Energy is needed to drive out any water content in the fuel before the initial stage of combustion can take place in combustion systems. This lowers system efficiency and may cause the combustion temperature to drop below the ideal level. Lowering the combustion temperature below the ideal level can cause the fuel to burn incompletely, releasing tars and creosote that could accumulate in the flue, particularly if it is lengthy or involves direction changes, as well as particles. Additionally, the water may re-condense in the flue, which could cause corrosion and the slow buildup of material, which could eventually cause blockages or fire. Furthermore, because of the weight of the water and the energy needed to evaporate it, biomass with a high moisture content has a substantially lower net energy density by mass and volume. In addition to being less efficient and having less net energy available, storing biomass with a high moisture content increases the risk of composting, which can lead to biomass loss and perhaps increase the danger of fire due to mold growth and high temperatures. Moreover, while high moisture content lowers conversion system efficiency [44, 46] and decreases the energy available from wood wastes during combustion because heat is needed to evaporate it [44], this comparatively low moisture concentration favors thermo-chemical conversion.

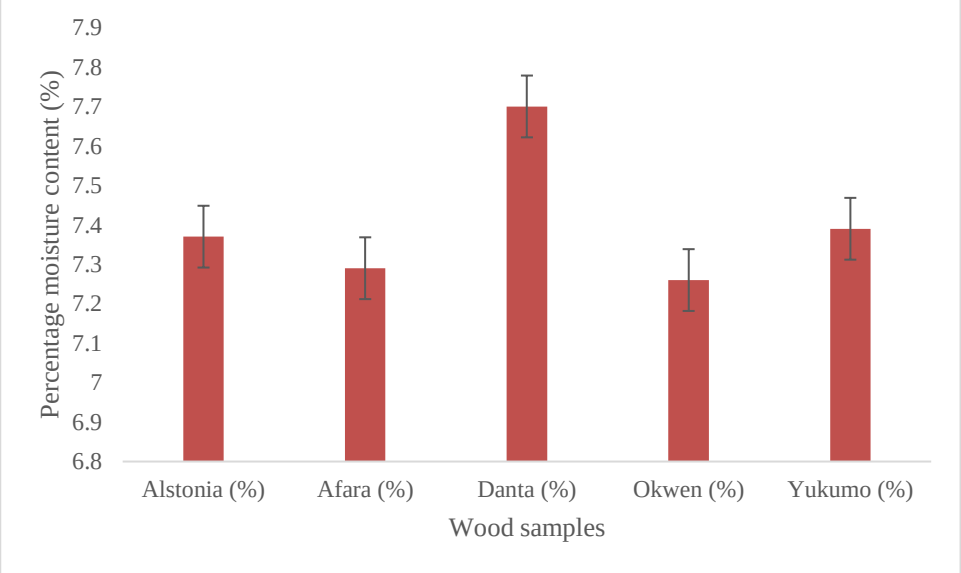

Fig. 3-Evaluation of percentage moisture content

The samples' calorific value is shown in Table 2. Equation (2) was utilized to obtain this. The results demonstrated the high calorific value of the different samples of wood.

Table 2-Calorific value of wood samples

Calorific value	**Alstonia**	**Afara**	**Danta**	**Okwen**	**Yukumo**
Weight of sample (g)	1.000	1.001	1.000	1.006	1.002
Change in temperature (ΔT)	2.354	2.333	2.353	2.359	2.342
Burnt wire (B)	6.5	6.5	6.5	6.5	6.5
Φ = B x 2.3	14.95	14.95	14.95	14.95	14.95
Volume of alkali (V)	6.4	6.3	6.4	6.4	6.3
Calorific Value (kJ/kg)	30,673.18	30,673.21	30,738.38	30,738.38	30,516.81

Among the wood wastes assessed, Okwen wood waste has the highest calorific value, followed by Afara and Alstonia wood waste, while Danta wood waste has the lowest calorific value (Fig. 4). However, as other researchers have previously reported comparable results, all of the acquired values were high [41, 43]. According to [44], the calorific values of wood species range between 18.5 and 21.0MJ/kg, and there is little variation in the calorific value of wood among species. The results also showed a good energy content.

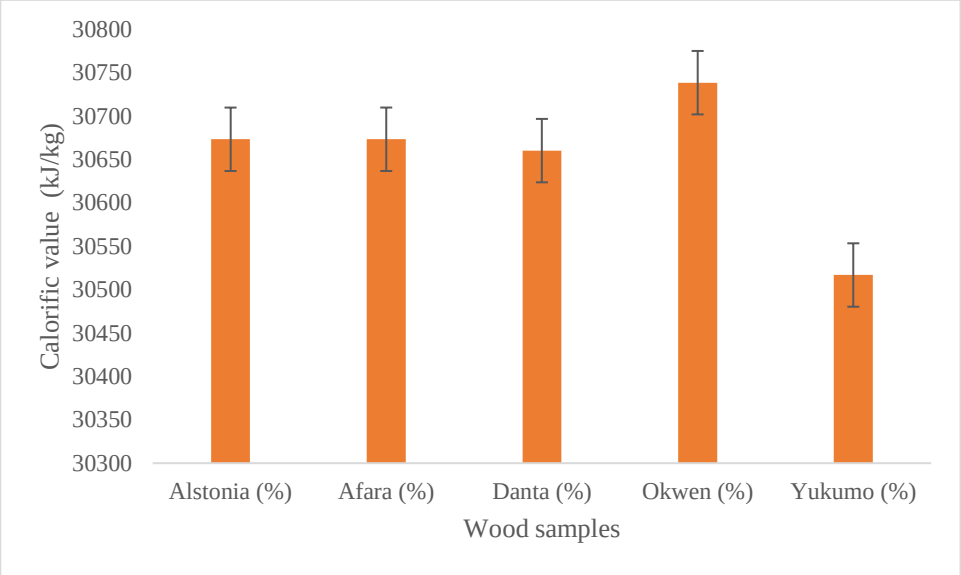

Fig. 4-Evaluation of calorific value of wood waste

The different wood wastes were chemically analysed using Equations (3) and (4). Table 3 displays a summary of the chemical formulas for the different wood waste samples.

Table 3-Chemical Formula of Wood Samples

Calorific value	Chemical formula
Alstonia	$C_{3.9233}H_{4.76}O_{2.50875}N_{0.03923}S_{0.003125}$
Afara	$C_{3.791}H_{4.59}O_{2.63063}N_{0.0329}S_{0.0025}$
Danta	$C_{3.8467}H_{4.62}O_{2.56625}N_{0.0271}S_{0.0025}$
Okwen	$C_{3.9117}H_{4.73}O_{2.5318}N_{0.0329}S_{0.003125}$
Yukumo	$C_{2.6425}H_{4.18}O_{2.8513}N_{0.0321}S_{0.0025}$

Nitrogen gas (N_2) has the highest percentage composition of wet gases present, whereas sulphur (IV) oxide (SO_2) has the lowest percentage composition, as shown in Fig. 5. The amount of water vapor and SO_2 that are present during the burning of the wood are the exhaust gases. The water vapor is 11.402% at 0.015% exhaust SO_2. According to the Bureau of Energy Efficiency, boiler corrosion is accelerated when fuel contains 0.5% or more sulphur. The findings therefore demonstrated that the SO_2 content of Alstonia wood is extremely low and suitable for boiler combustion. But for the dry analysis, as illustrated in Fig. 6, the amount of SO_2 in the exhaust gases without water vapor is the only exhaust gas that is being examined. Accordingly, the findings demonstrated that, when the Alstonia wood was burned on a dry basis, the proportion of SO_2 would rise to 0.017%, which is likewise extremely low and suitable for boiler combustion.

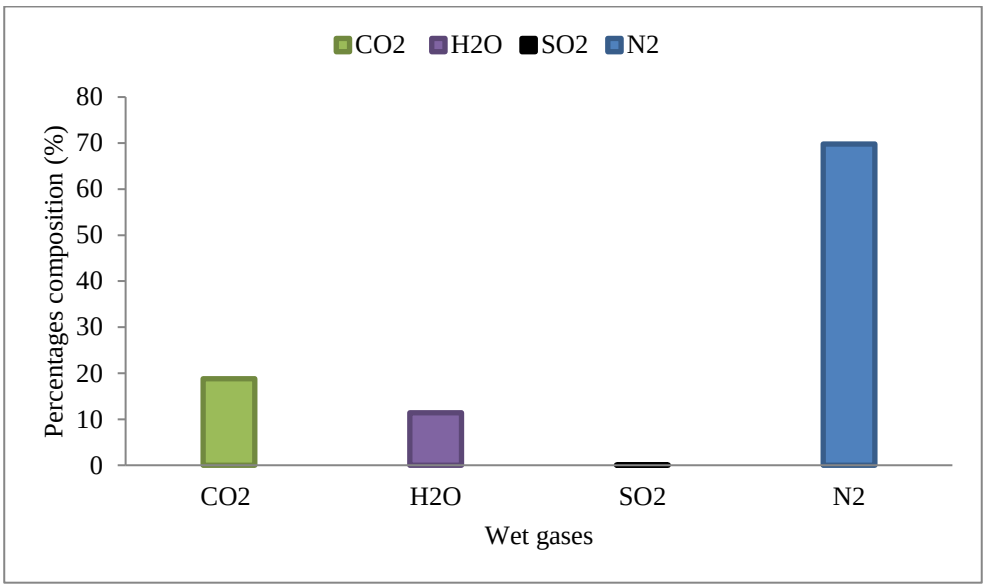

Fig. 5-Percentage composition of wet gases for Alstonia Wood

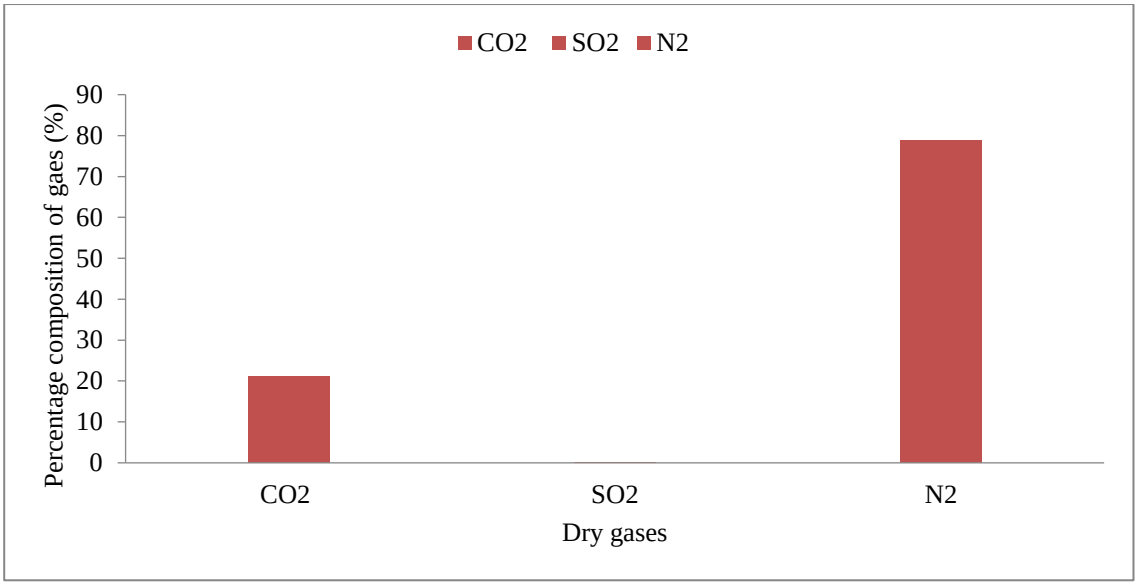

Fig. 6-Evaluation of percentage composition of dry gases for Alstonia wood

Figs. 7 and 8 show the results of the percentage composition of the dry and wet gases for Afara wood. The amount of the exhausted water vapor and SO_2 that are present during the combustion of the Afara wood are being examined in this wet study (Fig. 7). Accordingly, the results indicated that the Afara wood had a 0.0126% SO_2 content and an 11.6% water vapor content. The results also showed that the percentage composition of SO_2 in the Afara wood after combustion was 0.0142% when water vapor was absent. The percentage composition of other gases increases as a result.

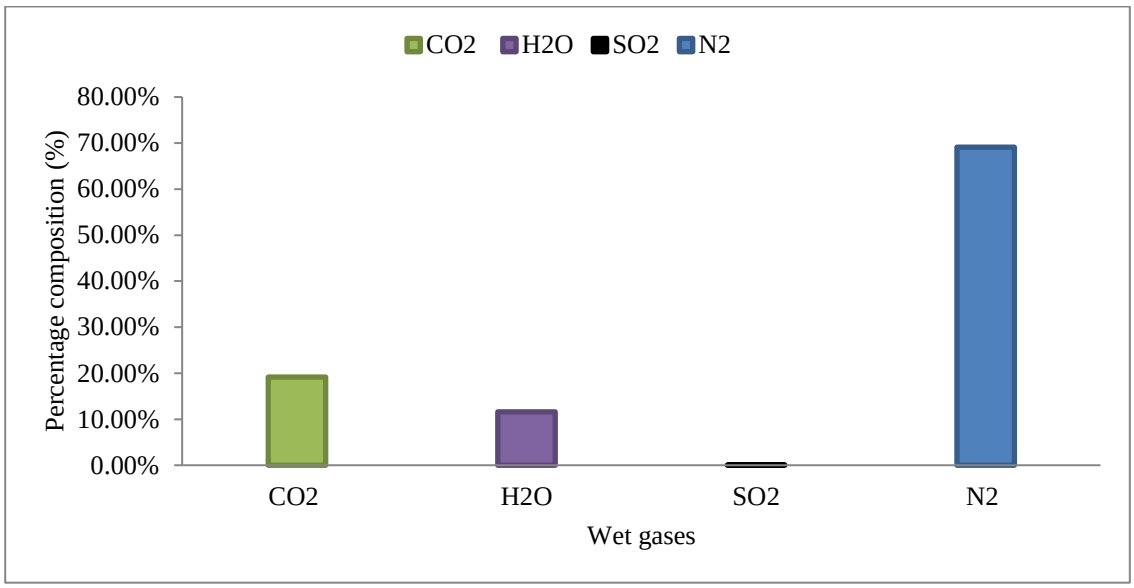

Fig. 7-Percentage composition of wet gases for Afara wood

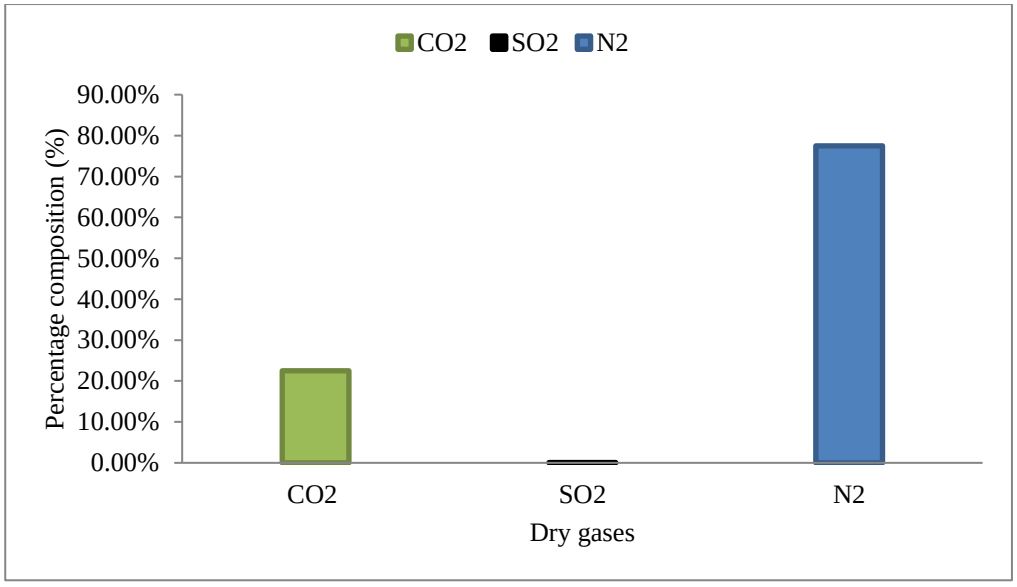

Fig. 8-Percentage composition of dry gases for Afara wood

The percentage composition of Danta wood's moist gases is displayed in Figs. 9 and 10. The amount of water vapor and SO_2 that are present during the combustion of the Danta wood are the subject of this wet analysis. Fig. 9 provides an illustration of this. As a consequence, the results indicated that the Danta wood's SO_2 content was 0.0124%, while its water vapor percentage was 11.444%. Additionally, this is quite low and suitable for boiler combustion. The amount of SO_2 in the exhaust gases without water vapor is the only exhaust gas that is being examined in this dry study. The findings also revealed that the proportion of SO_2 in the Danta wood during combustion is 0.014% on a dry basis. This raises the other gases' percentage composition once more. Fig. 10 also provides an illustration of this.

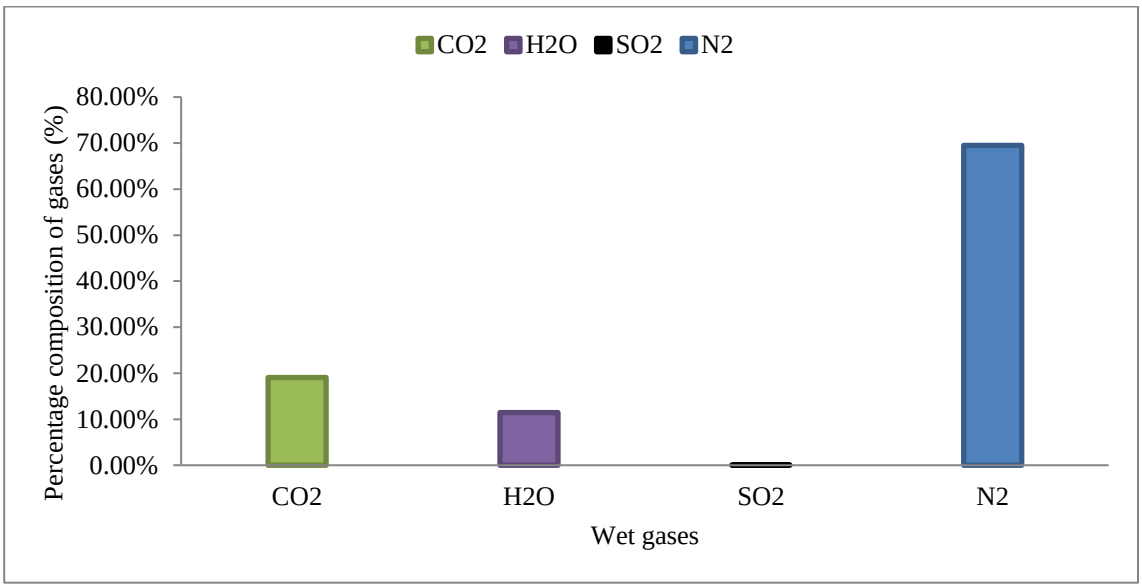

Fig. 9-Percentage composition of wet gases of Danta wood

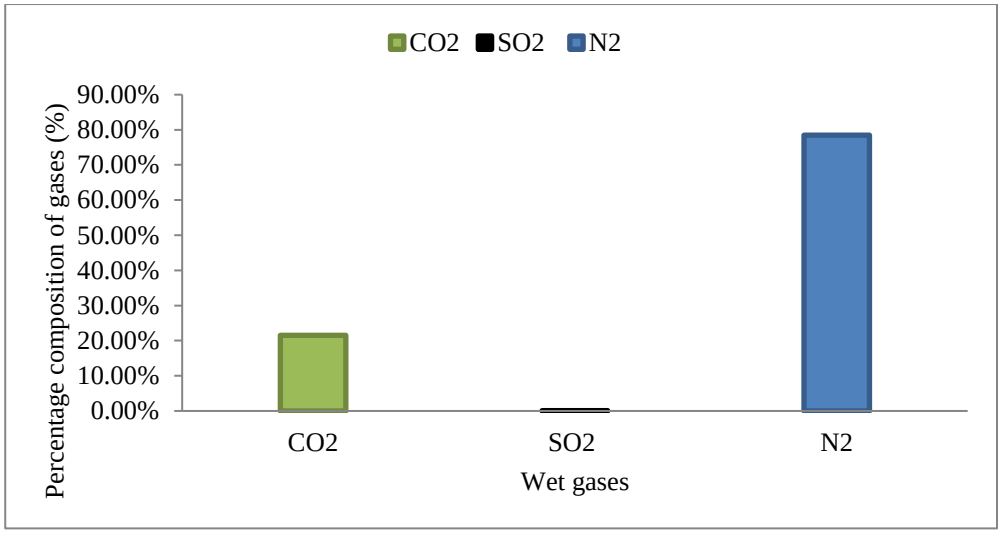

Fig. 10-Percentage composition of dry gases of Danta wood

The percentage composition of Okwen wood's moist gases was displayed in Figs. 11 and 12. The amount of exhausted water vapor and SO_2 that are present during the burning of Okwen wood are the subject of this wet analysis. Fig. 11 provides an illustration of this. As a consequence, the Okwen wood's SO_2 content was 0.0151%, while its water vapor percentage was 11.411%. Additionally, this is quite low and suitable for boiler combustion. The amount of SO_2 in the exhaust gases without water vapor is the only exhaust gas that is being examined in this dry study. The findings also revealed that the percentage of SO_2 in the Danta wood during combustion is 0.017% on a dry basis. This raises the other gases' percentage composition once more. Fig. 12 also provides an illustration of this.

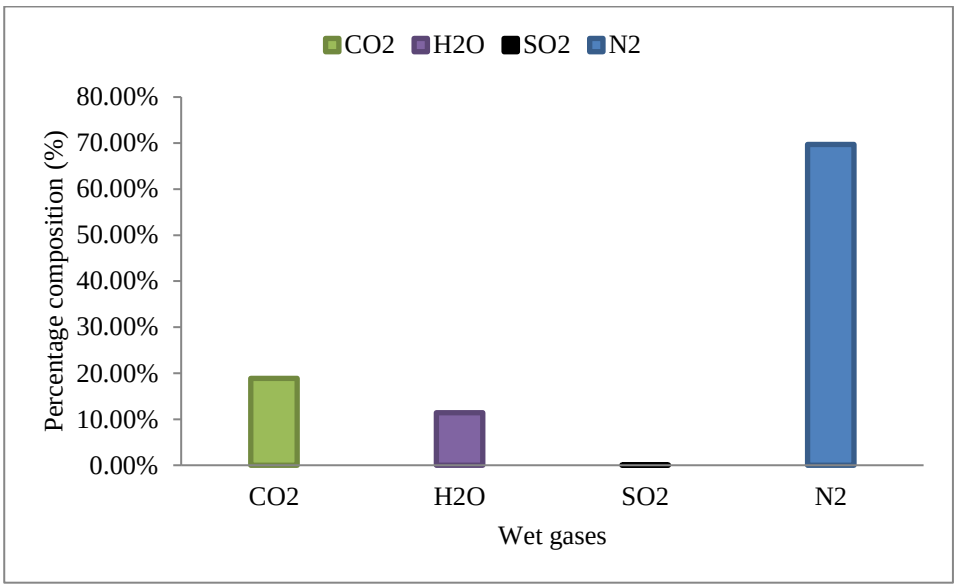

Fig. 11-Percentage composition of wet gases of Okwen wood

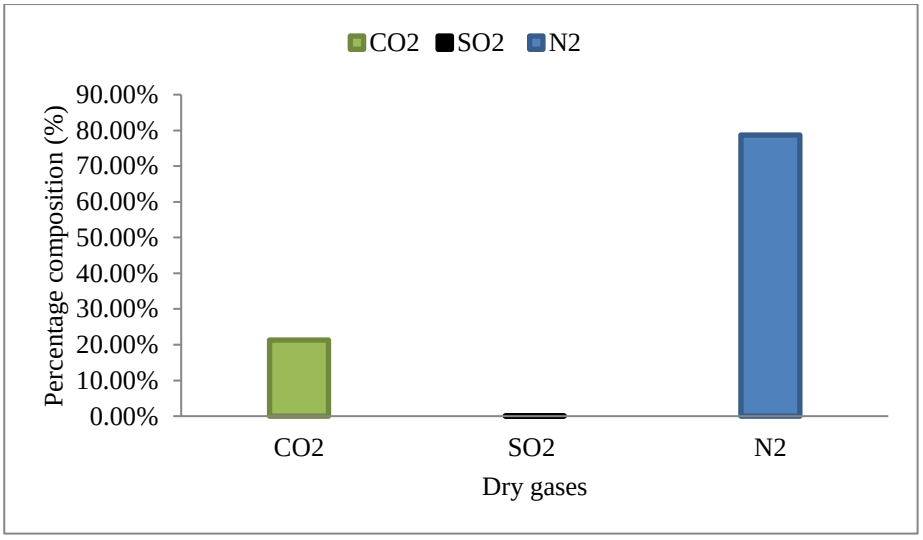

Fig. 12-Percentage composition of dry gases of Okwen wood

Figs. 13 and 14 show the percentage composition of moist gases in Yukumo wood. The amount of water vapor and SO_2 that are present during the Yukumo wood's combustion are the exhaust gases that are the subject of this wet analysis. Fig. 13 provides an illustration of this. As a consequence, the Yukumo wood's SO_2 content was 0.019%, while its water vapor percentage was 15.732%. Additionally, this is quite low and suitable for boiler combustion. The amount of SO_2 in the exhaust gases without water vapor is the only exhaust gas that is being examined in this dry study. The findings also demonstrated that the Yukumo wood's dry basis SO_2 composition during burning is 0.022%. This raises the other gases' percentage composition once more. This is further illustrated in Fig. 14. Based on the wet and dry basis for the exhaust products from the combustion analysis of several wood samples, SO_2 is incredibly low, ranging between 0.01 and 0.02%. As previously said, low SO_2 means that these fuel woods would not be dangerous for boilers because low SO_2 denotes a slow rate of corrosion and high SO_2 suggests a severe rate of corrosion.

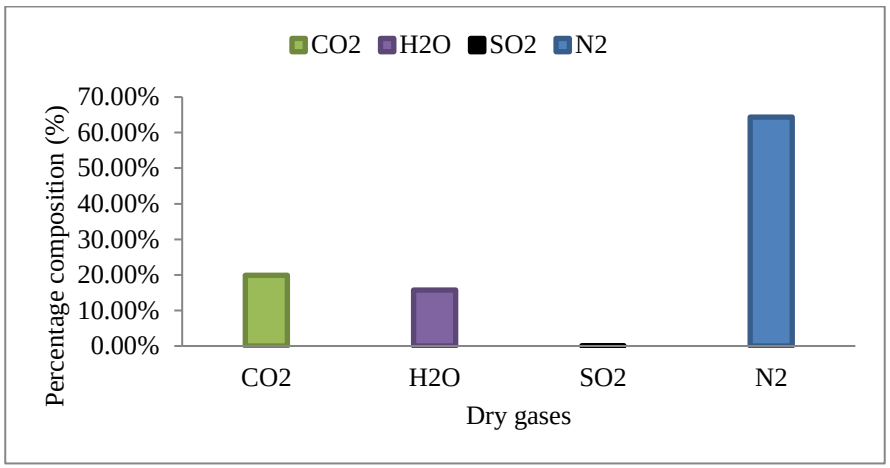

Fig. 13-Percentage composition of wet gases of Yukumo wood

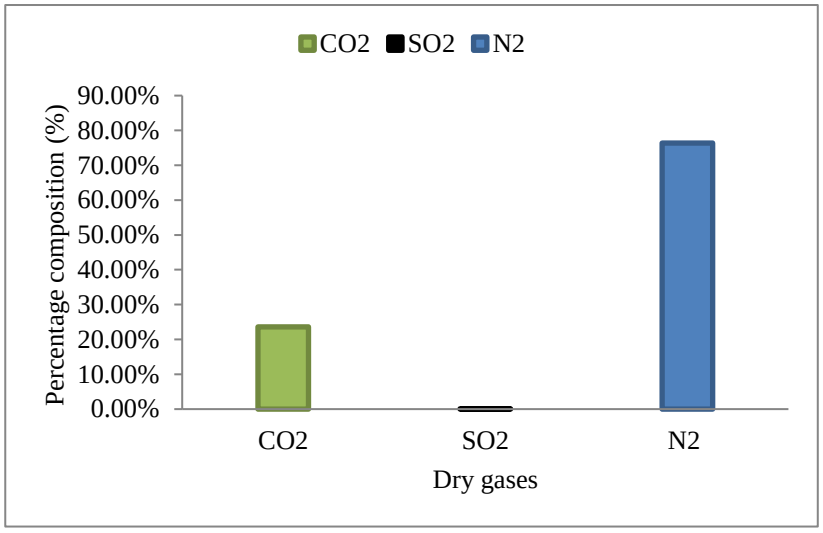

Fig. 14-Percentage composition of dry gases of Yukumo wood

4. Conclusions

A green economy, energy access, and appropriate waste management—particularly for developing nations like Nigeria—will all be aided by the focus on energy transition and renewable energy, or bioenergy. The use of renewable energy is growing worldwide as a result of the shift away from fossil fuels. The combustion characteristics of tropical wood waste for energy production in Nigeria were experimentally analysed in this research work. Five distinct wood waste samples were collected from the wood site and subjected to laboratory analysis. The calorific value, moisture content, and combustion assessments were performed. The results indicated that wood wastes from Benin metropolis are suitable as feedstock to generate electricity through thermo-chemical conversion processes. Analyses of the combustion performance of the different wood samples also revealed that, in comparison to CO_2 emitted during combustion of traditional fossil fuels, the amount of CO_2 released to the atmosphere during combustion is extremely low. In other words, instead of being burned carelessly at the dumpsite, which would pollute the environment and cause environmental dangers and climate damage, wood waste from dumpsites should be used for energy.

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