Energy Potential Study of Some Tropical Wood Species from Nigeria

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ABSTRACT

Aims: To carry out experimental study of the energy potential of some tropical wood species.
Study design: It involved sample collection, experimental analysis and numerical validation of the obtained calorific values.
Place and Duration of Study: National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka, Enugu State, Nigeria between November 2016 and September 2018.
Methodology: Wood waste (saw dust) from ten (10) selected tropical wood species sourced from sawmills in Benin City, Nigeria were subjected to proximate analysis, ultimate analysis as well as energy content study.
Results: Thermal conversion characteristics of low ash content (0.2 – 2.76 %), very high volatile matter (87.51 – 90.94%), low moisture content (8.62 – 10.53%.), relatively high carbon, hydrogen and oxygen contents as well as low nitrogen and sulphur contents were observed. Obtained calorific values were validated using three already existing correlations.
Conclusion: Among the 10 species studied, *Afzelia africana* (Apa) was found to be best suited for energy generation while *Triplocyton scleroxylon* (Obeche) was found to be least suited.

Keywords: Energy; wood waste; ultimate analysis; proximate analysis; calorific value.

1. INTRODUCTION

One of the key factors that drive the development of a country is the availability of electricity [1-2]. With Nigeria currently experiencing inadequate supply of electricity, there is a great need for the application of renewable sources of energy to complement the current fossil fuel-based power systems which account for about 65% of the electricity produced in the country [3]. Though renewable sources such as the hydro and solar are already being applied, there's need to increase the energy mix to include other renewable sources which are readily available. One of such sources is biomass, specifically wood or wood residues.
Wood wastes (sawdust, off-cuts, wood barks, plain shavings as well as rejects) are available in Nigeria in large amounts [4]. The trees which are obtained from forest reserves approved and developed by the government for logging purpose find use in various end value applications such as furniture works, paper production and as a source of fuel for cooking. The quantity of this energy resource that is generated in Nigeria is estimated to be in the range of 1.8 to 5.2 million tonnes per annum [5-8]. These wood wastes which greatly contribute to the pollution of the ecosystem owing to their current disposal methods [9-10] would readily aid in attaining adequate power supply if optimally applied. One of the major reasons for the poor exploitation of this great resource lies in the lack of adequate data with

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regards to the energy potential of the available local wood species unlike the coniferous wood species such as the spruce and willows which are specially grown and developed for the sole purpose of energy generation in most parts of Europe due to their energy content and thermophysical properties. A knowledge of the energy potential of local wood species is therefore very important in planning effective ways of exploiting and utilizing our forest resources (wood) for energy production, hence the need for this work.

A number of efforts have been made in the study of wood waste as a potential national source of energy. Aina et al. [11] reported the energy potential of wood wastes with regards to charcoal production for domestic use as an alternative cooking fuel. Akintunde and Seriki [12] investigated the effect of mixing paper waste with sawdust briquette as a means of improving its calorific value (CV). Akinola and Fapetu [13] evaluated energy availability in seven (7) tropical wood species obtained from Akure, Nigeria which include; Obeche (*Triplochiton scleroxylon*); Iroko (*Melicia excelsa*); Danta (*Nesogordonia papaverifera*); Mahogany (*Khaya ivorensis*); Omo (*Cordia platythyrsa*); Mansonia (*Mansonia altissima*) and Afara (*Terminalia superba*). They reported an average energy content of 21.754 MJ/kg and electricity equivalent of 6.06kWh per kg of wood biomass pyrolyzed. More recently, Akhator et al. [14] experimentally investigated the physico-chemical properties and energy potential of wood wastes from five (5) tropical species obtained from sawmills in Benin Metropolis which include Ekki (*Lophira alata*), Ohia (*Celtis sp*), Danta (*Nesogordonia papaverifera*), Omah (*Cordia millenii*), Black Afara (*Terminalia superba*). They reported suitability of the woods as feedstock for renewable energy generation on account of their high thermal energy potential values. Considering the numerous wood species that abound in the tropics, this study is therefore aimed at investigating the energy potential of other wood species in Nigeria not previously studied with a view to boosting the data base for biomass application and energy policy formulation.

2. MATERIAL AND METHODS

In this experimental study, wood waste from ten (10) tropical wood species of class size 45-60cm diameter and mean age of 110 years were analysed to determine their potential for energy conversion application. They include *Acacia sp* (Acacia), *Afzelia africana* (Apa), *Celtis sp* (Ohian), *Brachystegia eurycoma* (Okwen), *Bombax bounopozense* (Bombax), *Blighia sapida* (Ukpe), *Piptadeniastrum africanum* (Ekhimi), *Cleistopholis partens* (Otu), *Triplocyton scleroxylon* (Obeche) and *Albizia sp* (Albizia) [15]. These wood waste samples were obtained from 14 sawmills located within Benin City, Edo State, Nigeria. These wood species are also grown in Ogun, Ekiti and Ondo States of Nigeria . The obtained waste samples were dried to reduce the moisture content and equal mass for each specie was then subjected to experimental procedures as briefly discussed in the following sections.

Some of the materials used in this study include: bomb calorimeter, moisture analyser, oven, muffle furnace, fume cupboard, micro-Kjedahl digestion flask (500ml capacity), Ohaus weighing balance, micro-Kjedahl distillation unit, 100 ml conical flask and reagents. Proximate analysis and ultimate analysis were carried out while the calorific values of the selected species were also determined.

2.1 Proximate Analysis

The proximate analysis indicates the behaviour of the wood waste when it is heated. It consists of the Moisture Content (%MC), Ash Content (%A), Volatile Matter (%VM) as well the Fixed Carbon (%FC) [16].

2.1.1 Moisture Content (MC)

The moisture content which is an indicator of the amount of water in a wood sample was determined using the Association of Analytical Chemists method (AOAC) [17]. Porcelain crucibles were washed and dried in an oven at 100°C for 30 minutes and allowed to cool in a desiccator. 1 gram of the sample was placed into weighed crucibles and then put inside the oven set at 105°C for 4 hours. The samples were removed from the oven after this period and then cooled and weighed. This process was repeated for all the samples with the crucibles weighed until a constant weight was obtained. The formula used for determining the percentage moisture content [17] is given as:

$$\%\,\mathrm{MC} = \frac{(\mathrm{g}-\mathrm{x})}{\mathrm{g}} \times 100 \tag{1}$$

Where, g is the mass of sample, x is the mass of dry matter and (g - x) represents the loss in mass.

2.1.2 Ash Content (A)

The AOAC experimental procedure [17] was applied. The residue remaining after all the moisture have been removed and the fats, proteins, carbohydrates, vitamins and organic acids burnt away by ignition at about 600°C is called ash. It is usually taken as a measure of the mineral content of the raw waste. Using AOAC method [17], 1gram of the finely ground samples was weighed into porcelain crucibles which have been washed, dried in an oven at 100°C, cooled in a desiccator and weighed. They were then placed inside a muffle furnace and heated at 600°C for 4 hours. After this, they were removed and cooled in a desiccator and then weighed. The percentage ash content was obtained thus:

$$\%\,\mathrm{Ash} = \left(\frac{\mathrm{y}}{g}\right) \times 100 \tag{2}$$

Where, g is the mass of sample and y is the mass of ash.

2.1.3 Volatile Matter (VM)

The method described by Meynell [18] was used. The dried residue was heated in a muffle furnace at 600°C for two hours. The heated residue was cooled in a dessicator and weighed.

$$\%\,\mathrm{VM} = \left(\frac{\mathrm{w}-\mathrm{z}}{\mathrm{g}}\right) \times 100 \tag{3}$$

Where, g is the mass of sample, w is the mass of dry matter and z is the mass of residue.

2.1.4 Fixed Carbon

This was done according to Berkowitz method [19] as shown below:

$$\%\,\mathrm{FC} = 100 - (VM + Ash + MC) \tag{4}$$

2.2 Ultimate Analysis (Dry)

The Ultimate Analysis gives the chemical elements (Carbon, Oxygen, Hydrogen, Nitrogen, Sulphur) that comprises the wood waste substances together with the ash content [16].

2.2.1 Carbon Content

In this analysis, the method prescribed by Walkley and Black [20] was used.

$$\%\,\mathrm{Carbon} = \frac{0.399 \times (B-T) \times m}{g} \tag{5}$$

Where, B is the blank titre, T is the sample titre, g is the mass of sample and m is the molarity of ferrous ammonium sulphate solution.

2.2.2 Nitrogen Content

The micro-Kjedahl method as described by Pearson [21] was used.

$$\%\,\mathrm{Nitrogen} = \frac{(\mathrm{T} \times \mathrm{M} \times 0.014 \times \mathrm{DF})}{\mathrm{g}} \times 100 \tag{6}$$

Where, M is the molarity of the acid used, g is the mass of sample, T is the Titre value and DF represents the Dillusion factor.

2.2.3 Sulphur Content

1g of the pulverized wood sample was mixed with 3g of a mixture of magnesium oxide and anhydrous sodium carbonate (2:1). The mixture was heated to 400^0C for two hours in a muffle furnace. It was cooled and digested in water, after which barium chloride was added to precipitate the sulphate as barium sulphate ($BaSO_4$). The precipitate was then filtered and the amount of sulphur determined.

$$\%\ \text{Sulphur} = \frac{s \times b}{g} \times 100 \quad (7)$$

Where, s is the mass of $BaSO_4$, b represents the atomic mass of barium (0.1373) and g is the mass of sample.

2.2.4 Hydrogen Content

$$\%\ \text{Hydrogen} = \text{Mass of } H_2O \times \frac{0.1119 \times 100}{\text{mass of pellet}} \quad (8)$$

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

2.2.5 Oxygen content

The oxygen content was obtained using equation (9).

$$\%\ \text{Oxygen} = 100 - (\text{C} + \text{H} + \text{N} + \text{S} + \text{Ash}) \quad (9)$$

2.3 Calorific Value, Energy Content and Electrical Power

Calorific value (CV) is defined as the amount of energy per unit mass or volume released on complete combustion of a fuel. The calorific value is the maximum usable heating value released in complete burning of a specific volume of fuel. In this analysis, AOAC procedure [22] was applied using the bomb calorimeter. 1g of the sample pellets was burned in the oxygen model bomb calorimeter. The heat of combustion was calculated as the gross energy.

The formula used for determining the calorific value as stated in AOAC [22] is given as:

$$\text{Calorific value} = \frac{E\,\Delta T - \phi - V}{g} \times 100 \quad (10)$$

Where, E is the energy equivalent of the calorimeter = 13,039.308 kJ/kg, Φ = 2.3 x burnt wire, V is the volume of calorimeter, ΔT is the change in temperature and g is the sample mass.

In order to validate the obtained experimental CV, three correlations: Channiwala and Parikh [23], Yin [24] and Garcias *et al*. [25] from literature developed for the prediction of the calorific values of various biomass were applied. The choice of these equations was mainly based on their applicability to wood wastes as they were developed variously as functions of the ultimate analysis [23-24] as well as a combination of ultimate and proximate analyses [25]. The applied equations are as follow;

$$CV = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211A \text{ [23]} \quad (11)$$

$$CV = 0.2949C + 0.8250H \text{ [24]} \quad (12)$$

$$CV = 10.8 - 0.0984A + 0.1133FC - 0.1653M + 0.1277C + 0.0196O \text{ [25]} \quad (13)$$

Where, A, C, H, S, O, N, FC and M represents Ash, Carbon, Hydrogen, Sulphur, Oxygen, Nitrogen, Fixed Carbon and Moisture Contents of the material, respectively, expressed on the basis of percentage dry weight.

Having obtained the CV of each wood specie, the energy content or thermal energy potential (MJ) was then determined using equation (14) below as given by Olisa and Kotingo [26];

$$EC = \rho \times v \times CV \quad (14)$$

Where, ρ is the wood sample density (kg/m^3), v is the volume of wood processed (m^3) and CV is the calorific value (MJ/kg).

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis

Table 1 presents the proximate analysis of the selected wood species.

Table 1. Proximate analysis of wood samples

S/N	Wood species	Fixed Carbon (%)	Volatile Matter (%)	Moisture Content (%)	Ash (%)
1.	*Acacia sp* (Acacia)	0.35	89.37	9.68	0.6
2.	*Afzelia africana* (Apa)	0.46	88.23	10.00	1.31
3.	*Celtis sp* (Ohian)	0.12	88.92	9.84	1.12
4.	*Brachystegia eurycoma* (Okwen)	0.21	87.51	9.52	2.76
5.	*Bombax bounopozense* (Bombax)	0.08	87.69	10.17	2.06
6.	*Blighia sapida* (Ukpe)	0.34	88.71	9.84	1.11
7.	*Piptadeniastrum africanum* (Ekhimi)	0.18	89.38	10.17	0.27
8.	*Cleistopholis partens* (Otu)	0.05	88.16	10.53	1.26
9.	*Triplocyton scleroxylon* (Obeche)	0.17	90.21	9.09	0.53
10.	*Albizia sp* (Albizia)	0.24	90.94	8.62	0.2
Mean		**0.22**	**88.91**	**9.75**	**1.12**
Standard Deviation		**±0.129**	**±1.093**	**±0.559**	**±0.804**

The fixed carbon content which is a major factor in the determination of the heating value ranged from 0.05 – 0.46% with the lowest and highest values obtained for *Cleistopholis partens* (Otu) and *Afzelia africana* (Apa) respectively. With regards to the volatile matter composition, a range of 87.51 – 90.94% was obtained with a mean of 88.91% and a standard deviation of ±1.093. This result is in total agreement with the submission of Akinola and Fapetu [13] as well as Huhtinen [27] who analysed woods from European forests such as pines, spruce, birch and alder. These studies reported that the volatile matter composition of wood is typically high and above 80%. The ash content was typically low ranging from 0.2 – 2.76 % and this was desirable on account of its enhancing effect on the heating value [28]. This low ash content and very high volatile matter are highly desirable qualities as they show good suitability of the wood specie for thermal energy conversion application brought about by the high hydrocarbon quantity they indicate [13,14]. The moisture content ranged from 8.62 – 10.53%. These low moisture content values are very desirable as it enhances the thermochemical conversion process [27] and also increases the thermal energy to be obtained from the process since less energy will be required to vaporize it [13].

3.2 Ultimate Analysis

Table 2 presents the ultimate analysis of the selected wood species samples on the basis of percentage dry weight

Table 2. Ultimate analysis of wood samples

Wood specie	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Acacia sp (Acacia)	59.05	5.46	35.13	0.32	0.03
Afzelia africana (Apa)	58.26	5.27	36.15	0.29	0.03
Celtis sp (Ohian)	55.06	5.04	39.62	0.25	0.03
Brachystegia eurycoma (Okwen)	47.72	5.74	46.35	0.18	0.02
Bombax bounopozense (Bombax)	45.38	5.53	48.94	0.14	0.01
Blighia sapida (Ukpe)	56.66	5.16	37.88	0.28	0.03
Piptadeniastrum africanum (Ekhimi)	52.67	5.60	41.48	0.24	0.02

Cleistopholis partens (Otu)	49.11	5.33	45.34	0.20	0.02
Triplocyton scleroxylon (Obeche)	46.28	5.46	48.07	0.17	0.02
Albizia sp (Albizia)	50.07	5.53	44.16	0.22	0.02
Mean	**52.03**	**5.41**	**42.31**	**0.23**	**0.023**
Standard Deviation	**±5.03**	**±0.21**	**±4.98**	**±0.06**	**±0.007**

The carbon composition was highest for eight (8) out of the ten (10) species with the exceptions being *Bombax bounopozense* (Bombax) and *Triplocyton scleroxylon* (Obeche) in which the oxygen composition was higher by about 2%. The carbon content ranged from 46.28 – 59.05%. This result of relatively high carbon content which is desirable on account of its influence in increasing the heating value is in close agreement with the results obtained by Akinola and Fapetu [13] who reported a range of 50 -60% and Akhator et al. [14], 55.35 - 58.92% using other tropical wood species. The relatively high hydogen and oxygen contents typically indicate high energy potential since they in conjunction with the carbon form the active reactants in the combustion process. The nitrogen and sulphur contents are low as expected and desired since this will ensure very low emission of NOx and SOx as products of combustion. These results agree with the report of Hutihen [27] on the expected chemical content of wood fuels.

3.3 Density, Calorific Value and Energy Content

Table 3 presents the densities of the species as obtained from Carsan *et al.* [29], the experimentally obtained calorific values as well as the calculated energy contents.

Table 3. Density, Calorific Value, Energy Content of wood samples.

S/N	Wood specie	Density (kg/m^3)	Calorific Value (MJ/kg)	Energy Content (MJ)
1.	*Acacia sp* (Acacia)	520	19.255	10015.2
2.	*Afzelia africana* (Apa)	790	19.066	15065.3
3.	*Celtis sp* (Ohian)	650	17.208	11186.5
4.	*Brachystegia eurycoma* (Okwen)	730	16.324	11913.6
5.	*Bombax bounopozense* (Bombax)	370	15.792	5842.3
6.	*Blighia sapida* (Ukpe)	580	18.056	10474.8
7.	*Piptadeniastrum africanum* (Ekhimi)	480	16.901	8112
8.	*Cleistopholis partens* (Otu)	410	16.621	6814.2
9.	*Triplocyton scleroxylon* (Obeche)	320	15.944	5100.8
10.	*Albizia sp* (Albizia)	520	16.883	8777.6
Mean			**17.205**	**9330.23**
Standard Deviation			**±1.218**	**±3036.14**

As shown in Table 3, the calorific value ranged from 15.792 – 19.255 MJ/kg. This is in close agreement with the findings of Huhtinen [27] who reported 18.5 – 21 MJ/kg and Akhator et al. [14] who reported 19.45 – 20.15MJ/kg. Consideration of the obtained standard deviation of ±1.218 indicates less variation in the calorific values of wood species which justifies the use of wood wastes from a mix of different wood species as commonly found in sawmills.

Fig. 1-3 show the plots obtained on comparing the experimentally obtained calorific values and the correlation-based result obtained on substituting the appropriate ultimate and/or proximate analyses parameters into the chosen correlations (equations 11-13). Fig. 1 is a plot of the experimental CV against the theoretical CV obtained using the Channiwala and Parikh Correlation (equation 11). As shown in the figure, a root mean square (rms) value of

0.9285 was obtained which clearly indicates a very close correlation between the experimentally obtained result and the theoretical result. For Fig. 2 which shows the relationship between the Yin correlation and the experimental result, a close relationship is also established represented by the rms of 0.929. A consideration of this obtained high rms value reveals the influence of the carbon and hydrogen contents in the energy characteristics of the wood waste as these are the only two parameters considered in the Yin correlation (equation 12). A rms of 0.8666 was obtained as shown in Fig. 3 using the CV correlation given by Garcia *et al*. (equation 13). This correlation which is a hybrid of ultimate and proximate analyses parameters gives a relatively low rms value compared to the other two former cases. This could be as a result of the inclusion of the moisture content parameter in the equation which is expected to be minimal for enhanced energy application. However, the range of high rms values obtained in the three correlation cases are indicative of a close relationship between the experimental and theoretical CV and thus, validates the obtained experimental CV results.

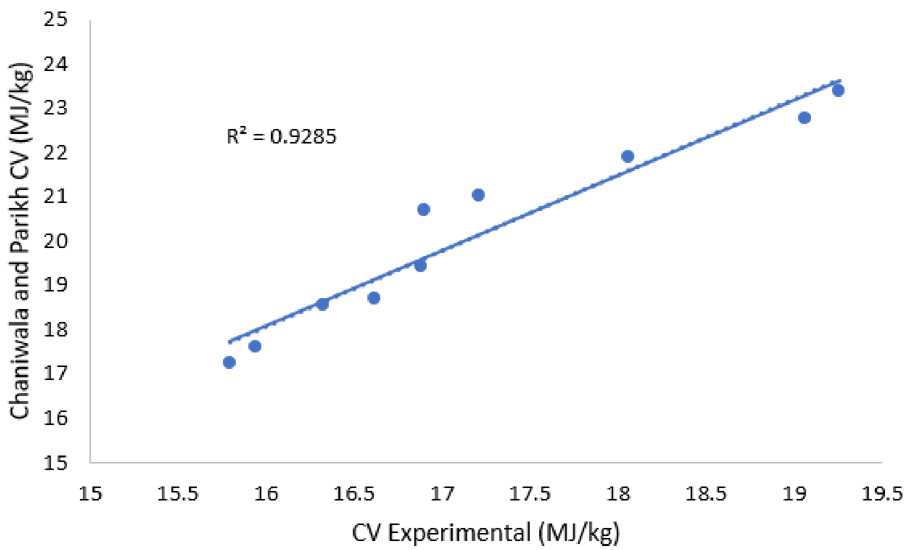

Fig. 1. Plot of experimental CV against Channiwala and Parikh CV correlation

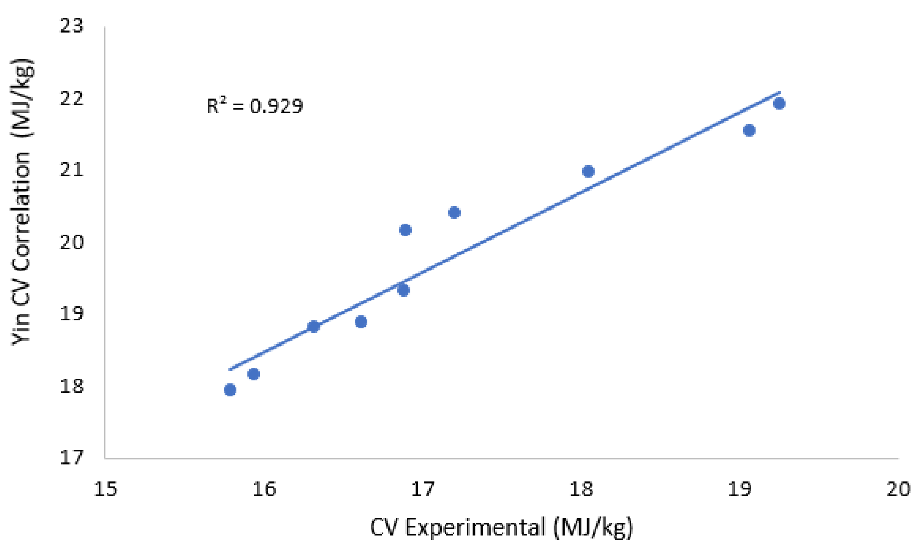

Fig. 2. Plot of experimental CV against Yin CV correlation

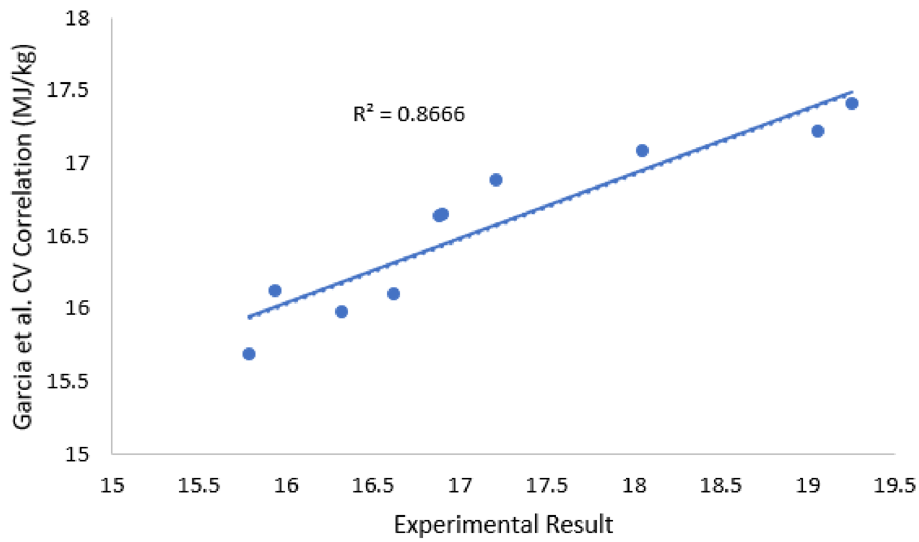

Fig. 3. Plot of experimental CV against Garcia et al. CV correlation

A consideration of the energy content as presented in Table 3 reveals a significant variance from one wood specie to another. This variation which is directly linked to the density of the particular wood specie for the same volume of wood waste considered shows that some wood species are better suited for energy conversion than others. This comparison is more properly captured in Fig. 4 which shows a comparison of the energy content obtainable from a unit volume of waste from the ten (10) studied wood species.

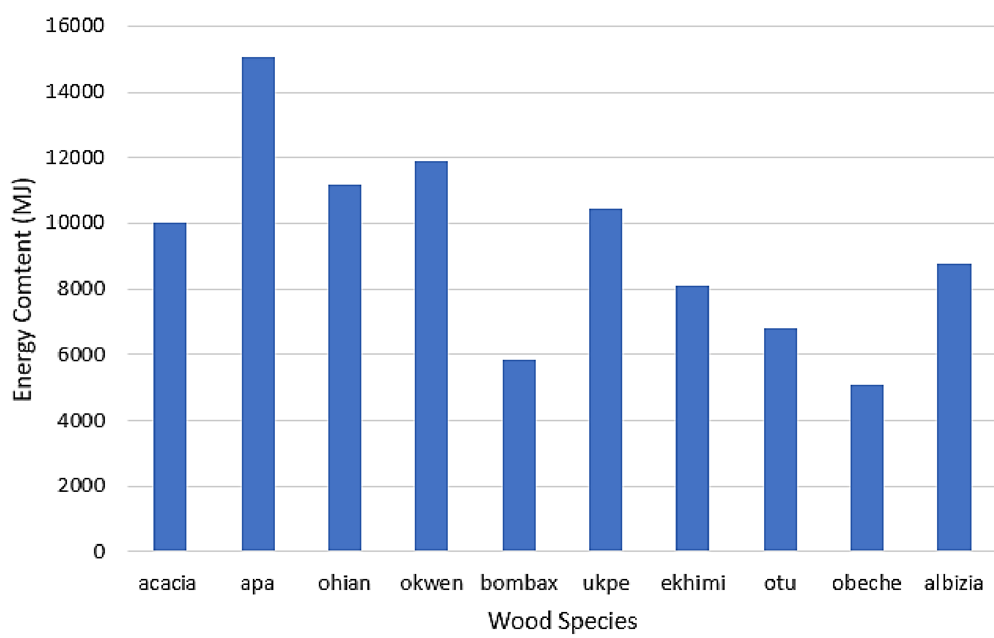

Fig. 4. Energy content obtainable per volume of wood waste

As shown Fig. 4, wood waste from *Afzelia africana* (Apa) gave the highest energy content value while that of *Triplocyton scleroxylon* (Obeche) gave the lowest value. A consideration of their characteristics such as the fixed carbon, ultimate analysis as well as the calorific values shows a similar trend that clearly indicates that *Afzelia africana* (Apa) is better suited for energy generation than the other species considered. In order to ensure optimum exploitation of wood in energy production, such woods with higher energy potential (in this case, *Afzelia africana* (Apa)) should therefore be specially cultivated and applied either singly or mixed with other high energy potential wood species (in this case, *Celtis sp* (Ohian) and *Brachystegia eurycoma* (Okwen).

4. CONCLUSION

The energy potential of wood waste (saw dust) from 10 selected tropical wood species have been investigated using proximate analysis, ultimate analysis as well as energy content study. The results obtained have shown desirable thermal conversion characteristics of low ash content, very high volatile matter, low moisture content, relatively high carbon, hydogen and oxygen contents as well as low nitrogen and sulphur contents. The calorific value of these species have been obtained experimentally and validated using three different CV correlations with the rms value ranging between 0.8666 and 0.929. Among the 10 species studied, *Afzelia africana* (Apa) has been found to be best suited for energy generation on the basis of obtained energy content while *Triplocyton scleroxylon* (Obeche) was found to be least suited.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author EPA initiated the study and jointly supervised it alongside Author AIO. Author JOA managed the literature searches, carried out the field and laboratory work of the study, and wrote the first draft of the manuscript. The results and discussions were jointly done by Author JOA and Author EPA. All authors read and approved the final manuscript.

REFERENCES

1. Obanor AI. An Integrated and Pragmatic Approach to the Power Challenges in Nigeria. A Lecture Delivered at the 1st Public Lecture/Award Ceremony Organized by Nigeria Institute of Mechanical Engineers (NIMechE) in Benin City, Edo State Nigeria; 2015.
2. Akinola AO. Design of a thermochemical reactor for conversion of selected wood biomass to fuel a stationary diesel engine. Unpublished PhD Thesis at the Federal University of Technology, Akure, Nigeria; 2012.
3. Ikeme J, Ebohon, OJ. Nigeria's electric power sector reform; what should form the key objectives? Energy Policy. 2005;33:1213-1221.

4. Ogunwusi AA. Wood waste generation in the forest industry in Nigeria and prospects for its industrial utilization. Civil and Environmental Research, 2014;6(9). ISSN 2224-5790.
5. Aina OM. Wood waste utilization for energy generation. Proceedings of the International Conference on Renewable Energy for Developing Countries. 2006. Accessed 14 August 2018. Available: http://cere.udc.edu/Aina.pdf.
6. Dosunmu OO, Ajayi AB. Problems and management of sawmills waste in Lagos. Proceedings of International Symposium on Environmental Pollution Control and Waste Management. 2002;271-278.
7. Francesco VE, Antonini BLZ. Wood fuel handbook. Italy: AIEL;2008.
8. Sambo AS. The place of renewable energy in the Nigerian energy sector. World Future Council Workshop on Renewable Energy Policies, Addis Ababa; 2009.
9. Arimoro FO, Ikomi RB, Osalor EC. The impact of sawmills wood wastes on the water quality and fish communities of Benin River, Niger Delta area, Nigeria. International Journal of Science and Technology. 2007;2(1):1-12.
10. Kehinde AL, Awoyemi TT, Omonona BT, Akande JA. Technical efficiency of saw-dust production in Ondo and Osun State. Nigeria Journal of Forest Economics. 2009;16:11-18.
11. Aina OM, Adetogun AC, Adedokun MO, Onilude MA. Alternative cooking fuels from sawmill wastes. Proceedings at the Farm Management Association of Nigeria Conference, Asaba, Nigeria; 2005.
12. Akintunde MA, Seriki ME. Effect of paper paste on the calorific value of sawdust briquette. International Journal of Advancements in Research & Technology. 2013;2(1). ISSN 2278-7763.
13. Akinola OA, Fapetu OP. Characteristics study of wood wastes from sawmills. British Journal of Applied Science & Technology. 2015;6(6):606-612.
14. Akhator EP, Obanor AI, Ugege AO. Physico-chemical properties and energy potential of wood wastes from sawmills in Benin Metropolis, Nigeria. Nigerian Journal of Technology. 2017;36(2):452 – 456.
15. Kalu C, Atagan S, Ani PI. Marketing of round wood in Benin City, Edo State, Nigeria. Journal of Applied Sciences Research. 2009;5(7):785-789.
16. Nag PK. Power Plant Engineering. 4th ed. New Delhi: McGraw Hill; 2008.
17. Association of Analytical Chemists. Official methods of analysis. 14th ed. Arlington: AOAC; 1990.
18. Meynell PJ. Planning a digester. Dorset: Prison Press; 1982.
19. Berkowitz N. An introduction to coal technology. 2nd ed. Canada: Academic Press; 1994.
20. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 1934;37:29-38.
21. Pearson D. The chemical analysis of foods. New York: Churchill Livingston; 1979.
22. Onwuka GI. Food analysis and instrumentation: theory and practice. 1st ed. Nigeria: Naphathali prints; 2005.
23. Channiwala SA, Parikh PP. A unified correlation for estimating HHV of solid, liquid and gaseous fuels. Fuel. 2002;81:1051-1063.
24. Yin C. Prediction of higher heating values of biomass from proximate and ultimate analyses. Fuel. 2011;90(3):1128-1132.
25. Garcia R, Pizarro C, Lavin AG, Bueno JL. Spanish biofuels heating value estimation. Part II: Proximate analysis data. Fuel, 2014;117:1139-1147.
26. Olisa YP, Kotingo KW. Utilisation of palm empty fruit bunch as solid fuel for steam boiler. European Journal of Engineering and Technology. 2014;2(2). ISSN 2056-5869.
27. Huhtinen M. Wood energy: wood as a fuel. Materials for 5EURES Training Sessions, NCP, Finland; 2009.
28. Loo SV, Koppejan J. The handbook of biomass combustion and co-firing. Earthscan. 2008.

29. Carsan S, Orwa C, Harwood C, Kindt R, Stroebel, A, Neufeldt, H, et al. African wood density database. World Agroforestry Center, Nairobi. 2002. Accessed 9 August 2018. Available www.worldagroforestry.org/treesnmarkets/wood/data.php?id=8#.