Characterizing Selected South Western Agricultural Residuals for Metallurgical Purpose

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Abstract*:- An experimental study was conducted to characterize Akala (*Rubus Hawaiensis*), Mahogany (*Khaya Senegalensis*), Teak (*Tectona Grindis*) and Iroko (*Milicea Excelsa*)Masonia (*Mansoniaaltissima*), Ahun (*Alstonia boonei*), Gmelina (*Gmelinaarborea*) charcoals. Thecharcoals were sourced from Ado Ekiti (South Western Nigeria).The proximateand ultimate analyses involving the determination of moisture content, ash, volatile matter, fixed carbon and calorific value were carried for the selected charcoals. The charcoals samples were produced using slow pyrolysis method.Thecalorific values of Mahogany (26.266 MJ/kg), Akala (26.074 MJ/kg), Iroko (25.951 MJ/kg), while the teakh as the highest value of (27.878 MJ/kg).Ash contents of the selected charcoals are within the limit required for Ajaokuta coke (≤ 13.45 %) and this may result in decreased consumption rate of the selected charcoals and higher efficiency of the metallurgical process. Teak has the least moisture content followed by Akala, Mahogany and Iroko. The sulphur content is low for all the selected charcoals and this may prevent the metal from splitting when forged. Analysis of variance was carried and results showed that there are significant differences in calorific values and moisture contents of the test samples both between and within the seven selected wood species (p<0.05). From the analysis, charcoal from Teak is the most preferred for metallurgical purpose followed by Mahogany, Akala and Iroko. Alternative fuel for cupola furnace in iron melting industries has been a major challenge in Nigeria. From this study, it is evident that Teak with the highest calorific value and with other comparatively good properties is mostpreferred to other available selected charcoaland hence the need for sustainable plantation of this specie of tree in the study area.

***Keywords:* Agricultural residuals, South Western, Proximate analysis, Ultimate analysis, Coke**

I. INTRODUCTION

On the list of highly profitable and easy to find exportable products is charcoal. Apart from heating purposes, charcoal is being used for water purification[1]. Charcoal is one of the main sources of domestic energy in Cote d'Ivoire. The overall share of charcoal use in the total national fuel consumption stood at 20% in 2002 and as at 2012 it was a choice fuel for 52% of the urban population [2]. Nigeria has lost over N1 billion (U$6M) to illegal export of charcoal and logs from states in the South West and North Central to the Middle East and Europe in the last four years [3]).

The use of charcoal as a smelting fuel has been experiencing a resurgence in South America following Brazilian law changes in 2010 to reduce carbon emissions as part of President Lula da Silva's commitment to make a "green steel" [4].

Brazil uses charcoal from second and third growth mixed tropical forest and from plantations of eucalyptus species. At present the plantations supply only 10 % of the requirements but the percentage increases every year and is planned to have reached 100 by 1983, for an iron output of 500,000 tons. The total plantation area required for this production volume is 136,000 hectares (340,000 acres) yielding 2.5 million m^3 solid per year. Replanting is done after 22 years with intermediate clear fellings after 8 and 15 years. The average yield is about 20 m^3 per hectare (280 ft^3 per acre) per year which is higher than the yield from the natural forest. The species planted yield relatively dense wood. The charcoal from the mixed forest is understood to be quite satisfactory but the density and texture are variable and the plantations yield a more consistently high quality product.

The forestry operations are less mechanized than in the previously described operation and charcoal production has so far been in batch kilns built of brick. A continuous kiln is under construction with a capacity of about 60 tons per day. The cost of plantation wood at the charcoal kiln is estimated at U.S. $ 2.5 per ton of dry wood. The corresponding cost of the charcoal is about U.S. $ 8 per ton whereas charcoal from the native forest, partly purchased, is less expensive [5].

Charcoal burns at intense temperatures, up to 2700 ^oC. By comparison the melting point of iron is approximately 1200 to 1550 ^oC. Due to its porosity, it is sensitive to the flow of air and the heat generated can be moderated by controlling the air flow to the fire. For this reason, charcoal is an ideal fuel for a forge and is still widely used by blacksmiths. Charcoal is also an excellent reducing fuel for the production of iron and has been used that way since Roman times. In the 16th century England had to pass laws to prevent the country from becoming completely denuded of trees due to production of iron. In the 19th century charcoal was largely replaced by coke, baked coal, in steel making due to cost. Charcoal is far superior fuel to coke, however, because it burns hotter and has no sulfur. Until World War II charcoal was still being used in Sweden to make high-quality steel. In steel-making, charcoal is not only a fuel, but a source for the carbon in the steel as in [5].

It is in light of the foregoing, the fast depleting crude oil reserve in Nigeria, the growing insecurity in the oil producing Niger-Delta region, and the evident public concerns over toxicity and pollution; absence of local resources of coke, necessitated the need to explore other sources of energy for iron melting if Nigeria must become a manufacturing rather than consuming nation.

II. MATERIALS AND METHODS

Akala *(Rubus Hawaiensis*), Mahogany (*Khaya Senegalensis*), Mansonia (*Mansonia Altissina*), Teak (*Tectona Grindis*), Ahun (*Altsmia Congensis*), Gmelina (*Gmelina Arborea*) and Iroko (*Milicea Excelsa*)trees samples were sourced from Ado Ekiti (South Western Nigeria) and sun dried for 21 days after which they were subjected to slow pyrolysis. The test was conducted on the charcoals samples produced for proximate analysis (involving the determination of moisture content, ash, volatile matter and fixed carbon) and ultimate analysis (involving the determination of calorific value) of the selected charcoals.

2.1 Proximate analysis

Proximate Analysis involved the determination of moisture, ash, volatile matter and fixed carbon. The methods used in this work were adopted from [6]. The reported proximate analysis of Ajaokuta coke was adopted from [7] in [6] and values are as presented in Table 2.

2.2 Moisture content

The silica crucible for the test was preheated at 105 ^oC for 1 hour. One gramme of charcoal sample was then placed in the crucible and heated at 105 ^oC for 1 hour. The loss in weight accounts for the moisture content. The results are as presented in Table 1.

2.3 Volatile matter

The standard crucible was preheated in the muffle furnace at 970 ^oC for 7 minutes. The crucible was cooled in the desiccators and 1 g of charcoal sample was placed in it with three drops of benzene. The crucible (with the lid on) was now placed in the muffle furnace at 970 ^oC for 7 minutes. The loss in weight accounts for the volatile content of the charcoal. The results are as presented in Table 1.

2.4 Ash

The standard silica crucible was preheated at 825 ^oC for 1 hour. It was then cooled in the desiccators. 1 g of charcoal sample was placed in the crucible (with the lid on) and it was heated at 825 ^oC for1 hour. The incombustible residue gives the ash content of the charcoal. The results are as presented in Table 1.

2.5 Fixed carbon

The fixed carbon is obtained from the relation and the results presented in Table 1 as well:

Fixed carbon % = 100 – Moisture % - Ash % - Volatile matter % …1

2.6 Ultimate analysis

The calorific value test of the selected charcoals was conducted using bomb calorimeter and the results are as presented in Table2. The higher heating value determines the quantitative energy of the fuels [8].

The elemental chemical constituents such as Carbon and hydrogen were determined by using the relationship between the ultimate analysis and proximate analysis as shown in equations 2 and 3:

$$\%C = 0.97FC + 0.7(VM - 0.1A) - MC(0.6 - 0.01MC) \quad \ldots 2$$

$$\%H = 0.036FC + 0.086(VM - 0.1A) - 0.0035MC^2(1 - 0.02MC) \quad \ldots 3$$

where;

FC is % of fixed carbon

A is % of ash

VM is % of volatile matter

MC is % of moisture content

III. RESULTS AND DISCUSSION

Table 1: Proximate analysis of selected charcoals

Type of charcoal	% MC	% ASH	% VM	% FC
Akala(*Rubus Hawaiensis*)	2.92	0.5	37.14	59.44
Gmelina(*Gmelina Arborea*)	4.10	0.44	40.49	54.98
Mansonia(*Mansonia Altissima*)	3.17	2.20	44.61	50.03
Iroko(*Milicea Excelsa*)	3.68	4.66	55.39	36.27
Ahun(*Alstoniaboonei*)	2.77	2.88	67.52	26.84
Mahogany(*Khaya Senegalensis*)	3.28	2.88	55.84	38.01
Teak(*Tectona Grindis*)	2.19	1.89	60.76	35.17

Table 2: Ultimate analysis of selected charcoals

Parameter	Akala	Gmelina	Mansonia	Iroko	Ahun	Mahogany	Teak
Moisture	2.92	4.10	3.17	3.68	2.77	3.28	2.19
Mineral matter (%)	0.5	0.44	2.20	4.66	2.88	2.89	1.89
Carbon (%)	81.95	79.35	77.80	71.56	71.51	73.89	75.26
Hydrogen (%)	5.30	5.40	5.29	5.99	6.72	6.11	6.46
Nitrogen (%)	0.82	0.86	0.93	0.84	1.52	1.06	0.89
Sulphur (%)	0.81	0.48	0.49	0.62	0.65	0.59	0.64
Oxygen (%)	7.7	9.37	10.12	12.65	13.95	12.18	12.67
Calorific Value (MJ/kg)	26.074	24.673	24.597	25.951	24.887	26.266	27.878

3.1 Discussion of Characterization Results

Moisture content: The moisture contents of 2.92 %, 4.10 %, 3.17 %, 3.68 %, 2.77 %, 3.28 % and 2.19 % as shown in Table 1 and Fig. 1 were obtained for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. From Fig. 1 it could be seen that Melina has the highest moisture content followed by Iroko, Mahogany, Mansonia, Akala, Ahun and Teak with the least moisture content. The moisture contents of the selected charcoals are higher than 0.94 % and 0.38 % obtained for *erythrophleum* suaveolens charcoal and Ajaokuta coke respectively and exceed the range required for the operation of the Ajaokuta Steel Plant blast furnace as in [6].

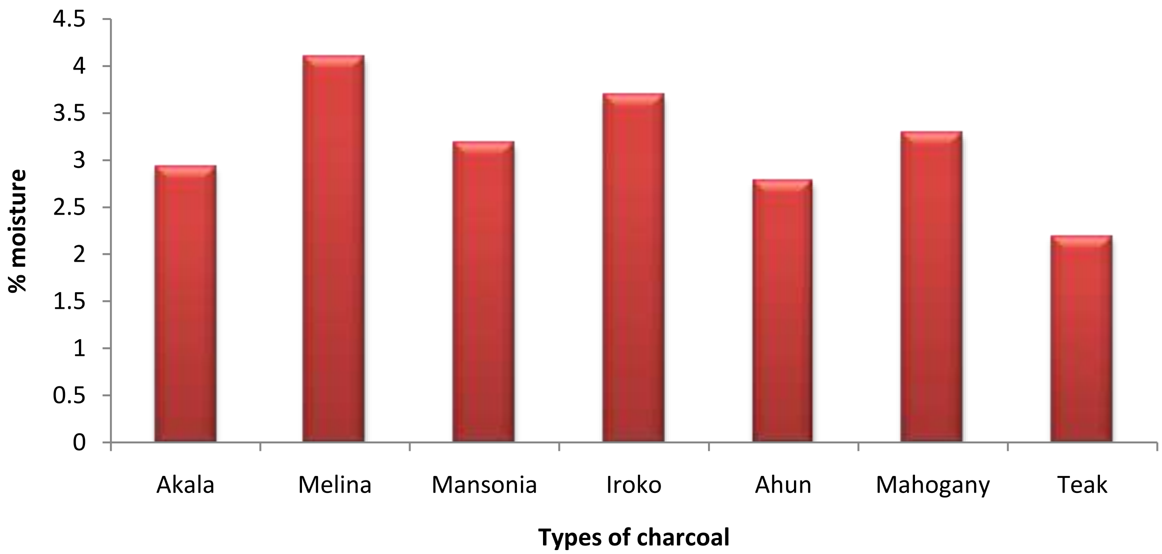

Figure 1: Moisture contents of the selected charcoals

Ash content: The percentage ash content of 0.5, 0.44, 2.20, 4.66, 2.88, 2.89 and 1.89as shown in Table 1 and Fig. 2 were determined for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. From Fig. 2 it could be seen that Gmelina has the least ash content followed by Akala, Teak, Mansonia, Ahun, Mahogany and Iroko is left with the highest ash content. All the ash contents of the selected charcoal are lower than 6.13 % obtained for *erythrophleum* suaveolens charcoal and far lower than 13.45% reported for Ajaokuta coke within the limit required for Ajaokuta (Olorunnishola and Akintunde, 2013). Furthermore, the ash contents of the selected charcoals are far lower than 24%, for typical Indian coke as reported by[9] in [6]. The ash in coke is of great significance in the blast/cupola furnace operation. High ash lowers the carbon content and requires the use of more limestone as fluxes and thus the use of more energy for slagging. This results in increased fuel rate and lower efficiency of the metallurgical process. It has been reported that 1% increase in ash causes an increase of 1.5-2% in coke rate, 1.5% in flux rate and lower blast furnace efficiency by 3-5% as in [6].

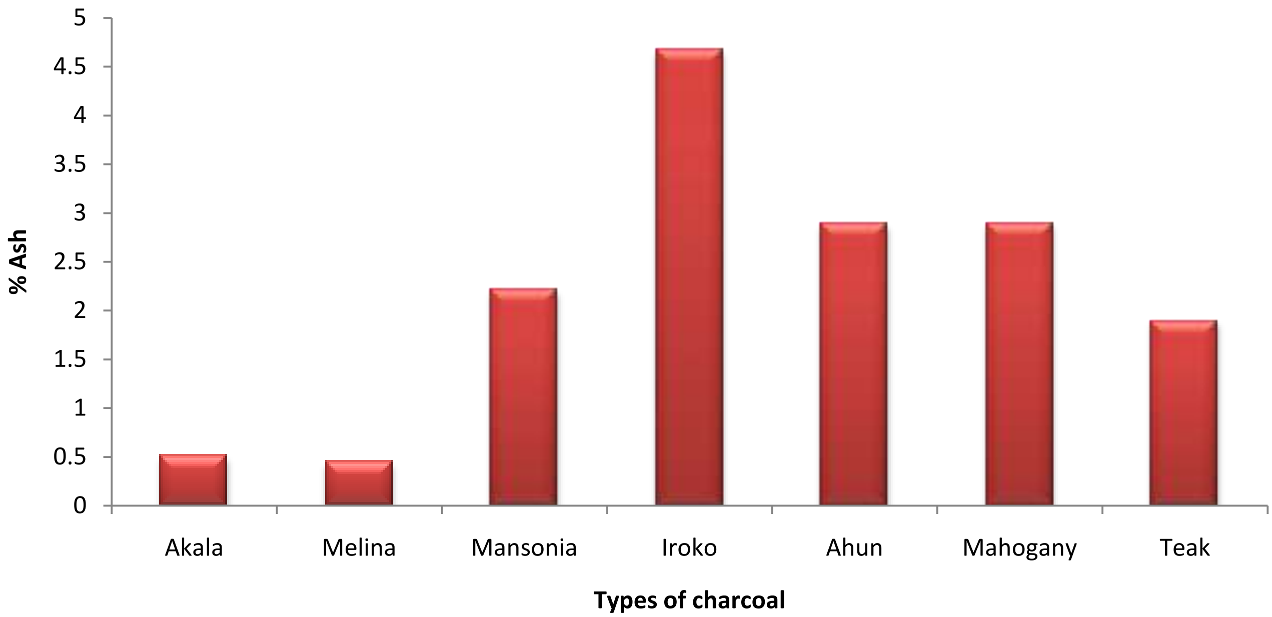

Figure 2: Ash contents of the selected charcoals

Volatile matter: The average percentage volatile matter of 37.14, 40.49, 44.61, 55.39, 67.52, 55.84 and 60.77 were determined for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. From Fig. 3, it is shown that Ahun has the highest volatile matter followed by Teak, Mahogany, Iroko, Mansonia, and Gmelina while Akala has the least value of volatile matter. The volatile matter of the selected charcoals as shown in Table 1 is higher than 6.77% determined for the *erythrophleumsuaveolens* charcoal and 2.72% reported for Ajaokuta cokeas in [6]. The volatile matter other than water in charcoal comprises all those liquid and tarry residues not fully driven off in the process of carbonization. If the carbonization is prolonged and at a high temperature, then the content of volatile is low. When the carbonization temperature is low and time in the kiln is short, then the volatile matter content increases. High volatile charcoal is easy to ignite but may burn with a smoke flame. Low volatile charcoal is difficult to light and burns very cleanly. The volatile matter of a coal should not be allowed to drop below 35.00 and the ash held below 7.00 if possible as in [9].

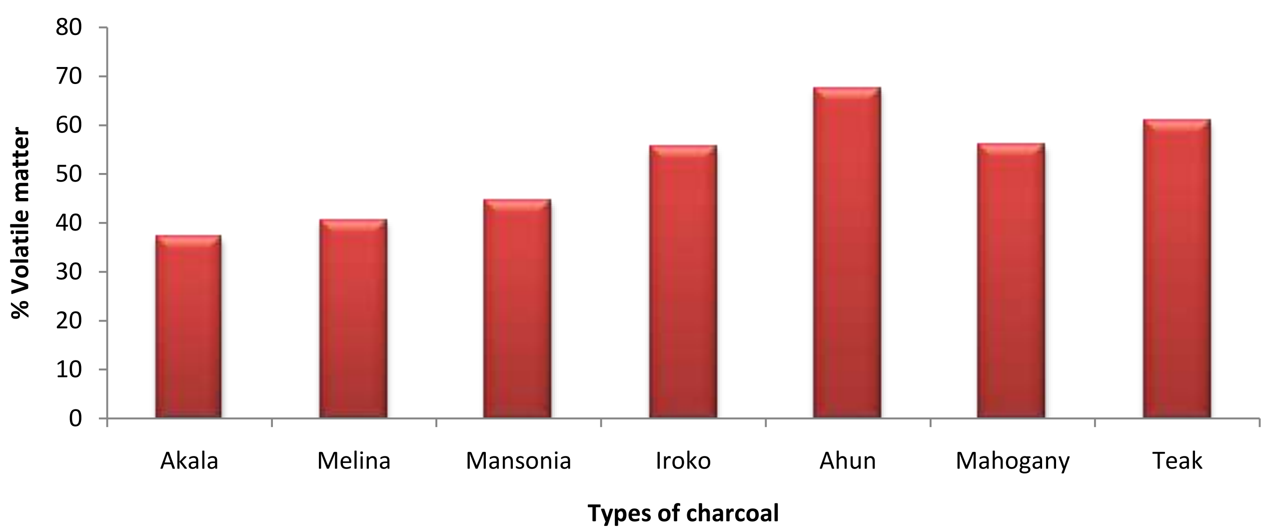

Figure 3: Volatile matter contents of the selected charcoals

Sulphur: The sulphur contents of 0.81 %, 0.48 %, 0.49 %, 0.62 %, 0.65 %, 0.59 % and 0.64 % were determined Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. From Fig. 4, it is shown that Akala has the highest sulphur content followed by Ahun, Teak, Iroko, Mahogany and Mansonia while Gmelina has the least sulphur content. The sulphur content of all the selected charcoals are higher than 0.003% and 0.14% for *erythrophleumsuaveolens* charcoal and coke respectively, and they all meet the requirement for Ajaokuta (0.9%) as in [6]. Also the sulphur contents of the selected charcoals are in the range of 0.61 % determined for Indian coke and lower than therange of 0.83 – 0.91% determined for German coke as reported by[6]. These sulphur contents are also within the range of 0.55 – 0.60% for coke used for efficient, high productivity blast furnace in United Kingdom as reported by[10]in[6].The lower the sulphur the better and sulphur in iron can exist either as iron sulphide (FeS) or manganese sulphide (MnS). The ferrous sulphide forms brittle, low melting point, yellowish brown films round the solid cast iron or steel crystals and causes the metal to split when forged. It also tends to promote the formation of cementite and thus a harder iron [6].

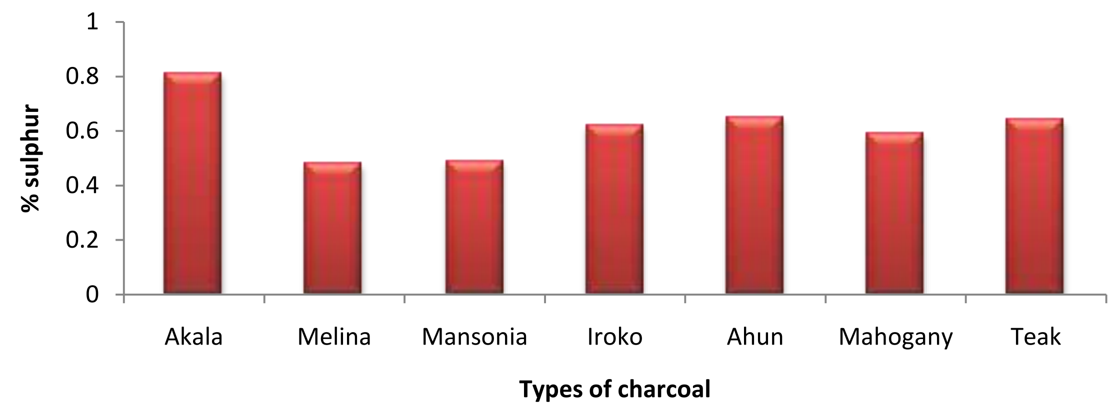

Figure 4: Sulphur contents of the selected charcoals

Fixed carbon content: The percentage fixed carbon contents of 59.44, 54.98. 50.03, 36.27, 26.84, 38.00 and 35.17 as shown in Table 1 and Fig. 5 were obtained for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. Fig. 5 showed that Akala has the highest fixed carbon followed by Gmelina, Mansonia, Mahogany, Iroko and Teak while Ahun has the least value of fixed carbon. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce a metal. But the industrial user must strike a balance between the friable nature of high fixed carbon charcoal and the greater strength of charcoal with a lower fixed carbon and higher volatile matter content to obtain optimum blast furnace operation. The essential characteristics of a good charcoal for foundry melting are low moisture, ash and sulphur, with high volatile matter and fixed carbon [9].

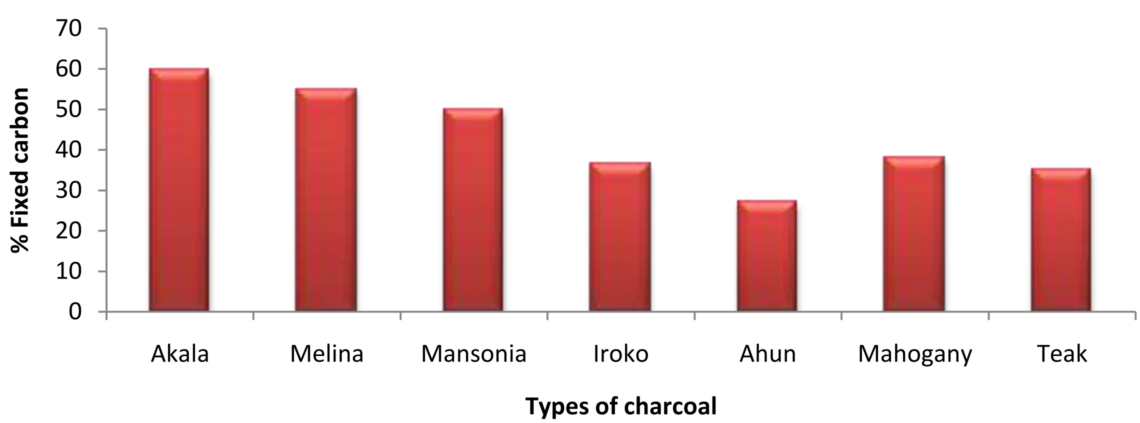

Figure 5: Fixed carbon contents of the selected charcoals

Calorific value: The calorific values of 26,074 kJ/kg, 24,673 kJ/kg, 24,597 kJ/kg, 25,951 kJ/kg, 24,887 kJ/kg, 26,266 kJ/kg and 27,978 kJ/kgas shown in Table 2 and Fig. 6 were determined for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. Fig. 6 showed that Teak has the highest calorific value followed by Mahogany, Akala, Iroko, Ahun, and Gmelina, while Mansonia has the least calorific value. The calorific values of all the selected charcoals are lower than 30,066.54 kJ/kg obtained for *Erythrophleumsuaveolens* charcoal and that of the reported value of 30,500kJ/kg for coke [6].Any fuel that is to be used in any combustion is checked by its calorific values. Cost of fuel is also affected by calorific value of fuel. The higher the calorific value of fuel the better is the heating capacity.

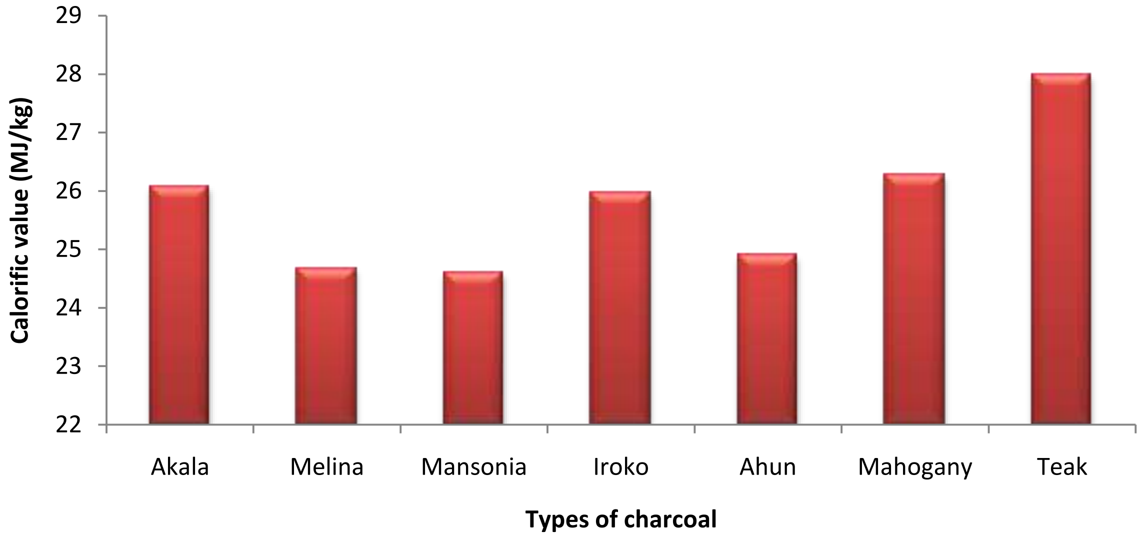

Figure 6: Calorific values of the selected charcoals

Carbon content: The carbon contents obtained for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak are 81.95 %, 79.35 %, 77.8 %, 71.56 %, 71.51 %, 73.89 %, and 75.26 % as shown in Table 2 and Fig. 7 respectively. From Fig. 7, it is shown that Akala has the highest carbon content followed by Gmelina, Mansonia, Teak, Mahogany, Iroko and Ahun respectively.

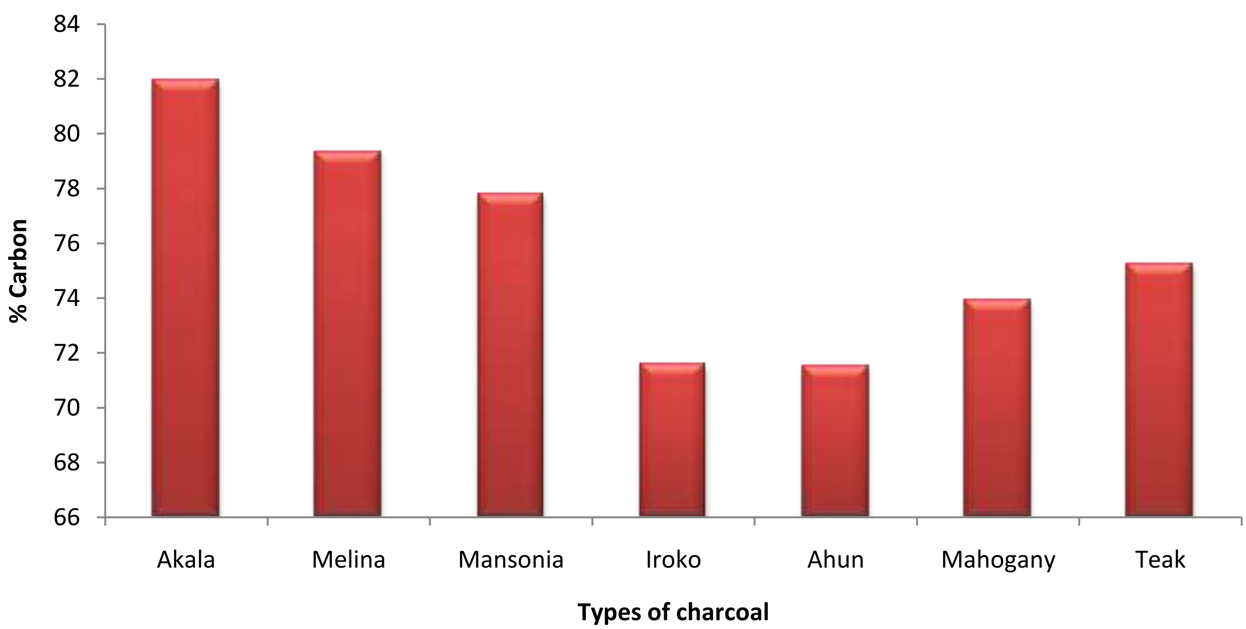

Figure 7: Carbon contents of the selected charcoals

Hydrogen: The percentage hydrogen contents of Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak were determined as 5.3, 5.4, 5.29, 5.99, 6.72, 6.11 and 6.46 respectively as shown in Table 2. Fig. 8 showed that Ahun has the highest hydrogen content followed by Teak, Mahogany, Iroko, Gmelina and Akala, while Mansonia has the least hydrogen content.

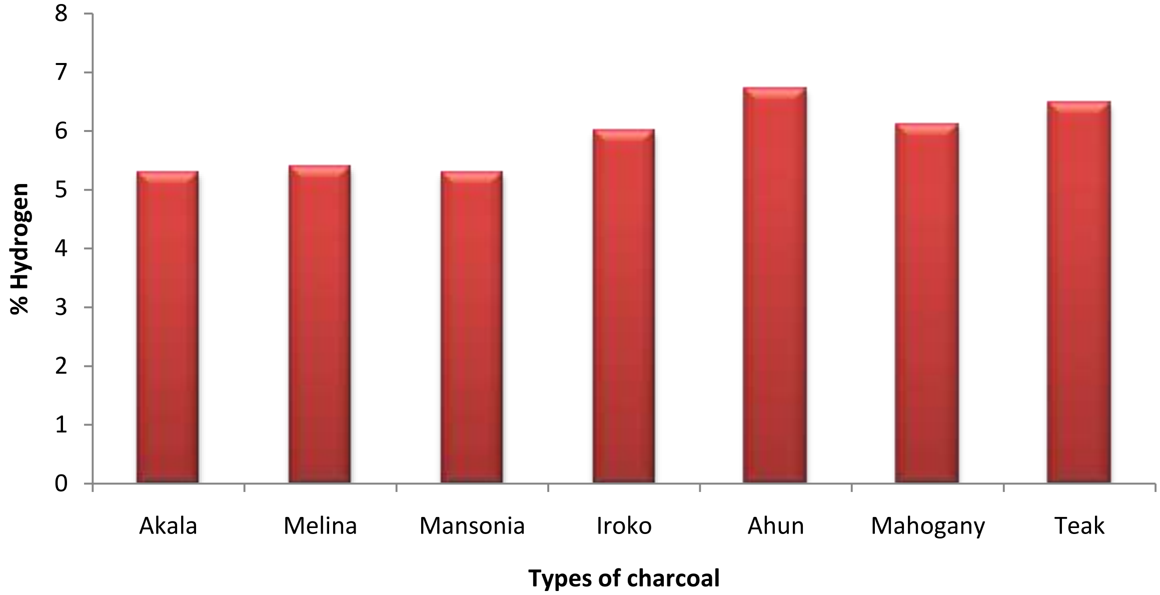

Figure 8: Hydrogen contents of the selected charcoals

Nitrogen: The percentage nitrogen contents of 0.82, 0.86, 0.93, 0.84, 1.52, 1.06 and 0.89 as shown in Table 2 were determined for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. Fig.9 shows that Ahun has the highest nitrogen content followed by Mahogany, Mansonia, Teak, Gmelina and Iroko, while Akala has the least nitrogen content.

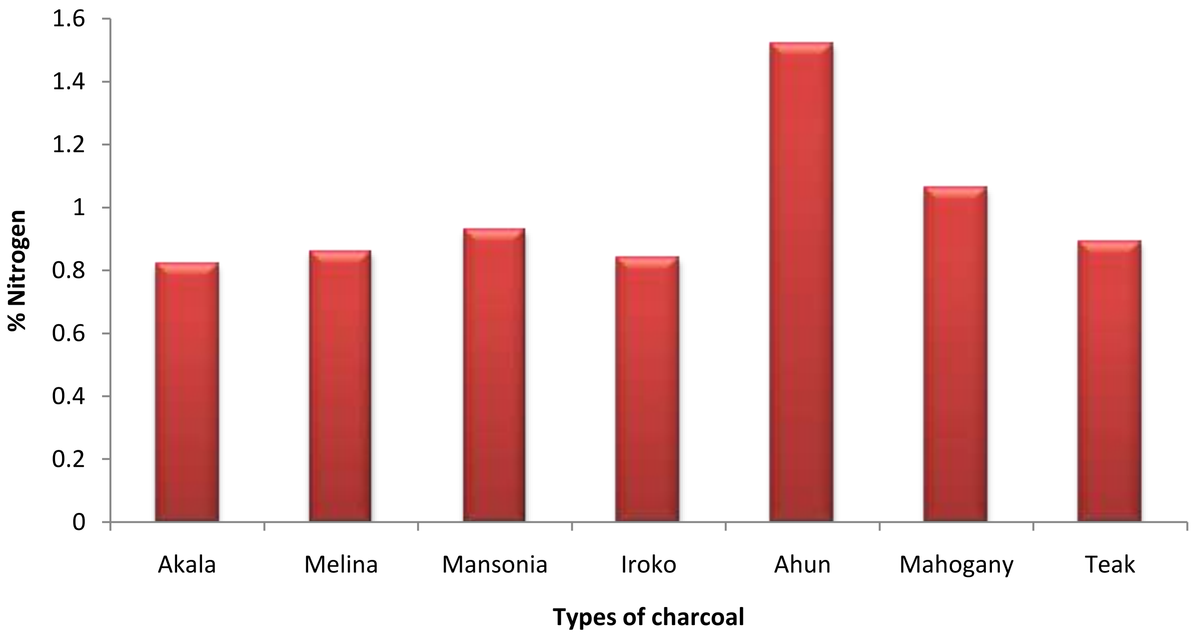

Figure 9: Nitrogen contents of the selected charcoals

Oxygen: Percentage oxygen contents of 7.7, 9.37, 10.12, 12.65, 13.95, 12.18 and 12.67 as shown in Table 2 were determined for Akala, Gmelina, Mansonia, Iroko, Ahun, Mahogany and Teak respectively. Fig. 10 also shows that Ahun has the highest oxygen content followed by Teak, Iroko, Mahogany, Mansonia and Gmelina, while Akala has the least oxygen content.

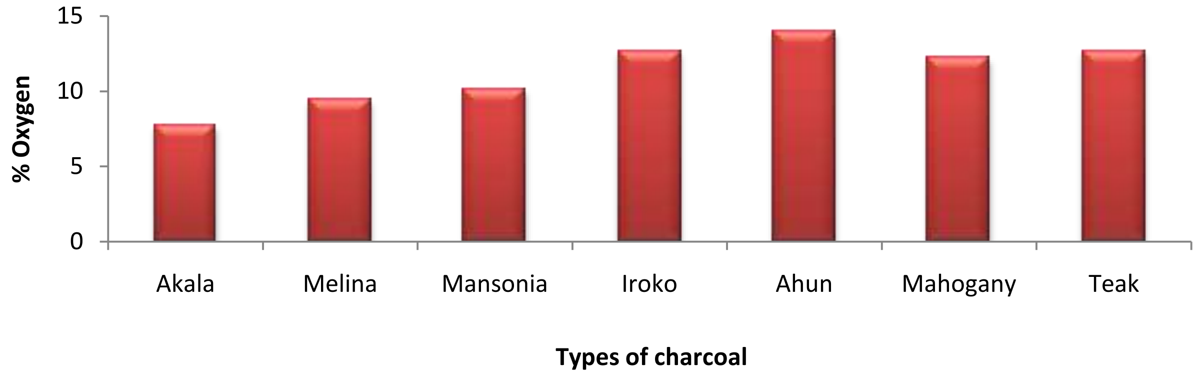

Figure 10: Oxygen contents of the selected charcoals

Finally the elemental constituents such as Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur are useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design.

IV. STATISTICAL ANALYSIS OF RESULTS

The sources of variations considered in carrying out the analysis of this work are: Wood species, Calorific value, Moisture content. SPSS version 16.0 was used to obtain the results shown in Tables 3 to 5.

Table 3: Analysis showing the mean calorific value of the test sample

Parameter	Species	Replicate	Mean	Std. deviation
Calorific value (MJ/kg)	Akala	3	20.074	0.00058
	Gmelina	3	24.673	0.00058
	Mansonia	3	24.597	0.00058
	Iroko	3	25.591	0.00058
	Ahun	3	24.887	0.00058
	Mahogany	3	26.266	0.00058
	Teak	3	27.878	0.00058
Grand	Mean	21	24.852	

Table 4: Analysis showing the moisture content of the test sample

Parameter	Species	Replicate	Mean	Std. deviation
Moisture content	Akala	3	2.913	0.1528
	Gmelina	3	4.093	0.1528
	Mansonia	3	3.160	0.1000
	Iroko	3	3.680	0.1000
	Ahun	3	2.760	0.1000
	Mahogany	3	3.270	0.1000
	Teak	3	2.190	0.1000
Grand	Mean	21	3.152	

Table 5: Summary of ANOVA for the tested parameters

Parameter	Sum of square	Df	Mean square	F	Sig.
Calorific value (MJ/kg)					
Between items	103.889	6	17.315	8.496E15	0.000
Within items	0.000	12	0.000		
Total	103.889	18			
Moisture content (%)					
Between items	6.945	6	1.157	9.470E3	0.000
Within items	0.001	12	0.000		
Total	6.946	18			

4.1 Discussion of statistical analysis results

Result in Table 3 showed that the grand mean for the calorific value of the seven tested charcoal samples from the seven selected wood species is 24.852 MJ/kg. Teak was found to have the highest calorific value of (27.878 MJ/kg), Mahogany (26.266 MJ/kg), Iroko (25.591), Ahun (24.887 MJ/kg), Gmelina (24.673 MJ/kg), Mansonia (24.597 MJ/kg) and the least was Akala (20.074 MJ/kg). Table 4 also showed that the grand mean of moisture content for all the test samples was 3.152 %. Gmelina had the highest moisture content of 4.093 %, followed by Iroko (3.68 %), Mahogany (3.27 %), Mansonia (3.16 %), Akala (2.913 %), Ahun (2.76 %) and lastly Teak (2.190 %).

The result of analysis of variance as shown in Table 5 showed that there are significant differences in calorific values of the test samples both between and within the seven selected wood species ($p<0.05$). There are also significant differences in moisture content of the samples both between and within the selected wood species ($p<0.05$).

V. CONCLUSION

Teak had the least moisture content followed by Akala, Mahogany, Iroko. Teak also had highest calorific value of (27.878 MJ/kg) followed by Mahogany (26.266 MJ/kg), Akala (26.074 MJ/kg) and Iroko (25.951 MJ/kg). All the ash contents of the selected charcoals are lower than 6.13 % obtained for *erythrophleum* suaveolens charcoal and far lower than 13.45% reported for Ajaokuta coke and within the limit required for Ajaokuta. The ash contents of the selected charcoals are far lower than 24%, for typical Indian coke. This may result in decreased consumption rate of the selected charcoals and higher efficiency of the metallurgical process [6].

The sulphur content of all the selected charcoals are higher than 0.003% and 0.14% for *erythrophleumsuaveolens* charcoal and coke respectively, and they all meet the requirement for Ajaokuta (0.9%). Also the sulphur contents of the selected charcoals are in the range of 0.61 % determined for Indian coke and lower than the range of 0.83 – 0.91% determined for German coke. Sulphur content of Teak is (0.64), Mahogany (0.59), Akala (0.81) and Iroko (0.62). This lower sulphur content will prevent the metal from splitting when forged and it will also reduce the formation of cementite and thus a softer iron [6].

Finally, from the above analysis Teak is the most preferred wood specie for charcoal production for metallurgical purpose followed by Mahogany, Akala and Iroko. The high calorific value of Teak may be the probable reason why it is mostly preferred to other available selected species and why it is now relatively scarce in the study area.

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