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Characterization of some Nigerian coal for effective power generation and industrial utility

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Abstract

Large numbers of trace elements occur in coals used for coal power plants combustion. In order to assess the environmental impact of the coal fuel cycle, coal and coal ash samples need to be analyzed for a number of toxic and radioactive elements. Six coal samples from Ridi-Awe and Lafia (Nasarawa State), Garin Maiganga (Gombe state) Nigeria coal deposit were collected. The samples were subjected to gross calorific value determination, X-ray diffraction spectrometry, X-ray fluorescence spectroscopy to determine it suitability for power generation and industrial utility. Base on the laboratory analysis and results, it is observed that the gross calorific values of Awe are 29.18MJ/kg, 30.79MJ/kg. Lafia are 26.10MJ/kg, 25.10MJ/kg and Maiganga are 25.50MJ/kg, 24.21MJ/kg respectively. The XRF results indicates the presence of transition metals and some trace element but void of elements such as Arsenic, tin and tungsten which makes it environmental and health hazard friendly. The proximate analysis revealed that the % ash content of Awe, Lafia, and Maiganga is 87, 62, 79. % moisture content of Awe, Lafia, and Maiganga is 8.7, 16.3, 8.3 and % volatile matter content of Awe, Lafia, and Maiganga coals is 4.3, 21.7 and 12.7 whereas % fixed carbon of Awe, Lafia, and Maiganga 78.3,55.8 and 71.1 respectively. However, in terms of coal rank, the Awe is bituminous high volatile C, whereas Lafia and Maiganga coal are Subbituminous A, hence the reactivity and maturity of the coal decrease in the order of Awe (A) < Lafia (L) < Maiganga (M). The result shows that the coal samples are void of nitrogen and dangerous radioactive elements.

Keyword: Coal, Calorific Value, Ash, Volatile, Bituminous, Moisture, Power, XRF, XRD, Awe, Lafia, Maiganga

INTRODUCTION

Coal is one of the natural resources whose existence is quite abundant in the world (Rahman *et al, 2019*). Its deposits exist in nearly every region of the world; commercially significant coal resource occurs in Europe, Asia, Australia, North America, and Africa (Adebiyi, 2016). Both developed and developing countries uses coal to provide a reliable source of electricity generation and feedstock for chemicals, fuels and steel production. It is also the cheapest source of electricity generation in the world. These underlying dynamics have fueled the global consumption of coal; energy self-sufficiency predominantly in the emerging economies of sub-Saharan Africa remains a serious problem (Bengba, 2018).

Nigeria is the largest economy and exporter of crude oil in Africa with estimated crude oil reserves of 35 billion barrels, 187 trillion cubic feet of natural gas, and over 4 billion metric

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tons of coal. Furthermore, the efficacious exploration for coal has led to the discovery of vast coal deposits in 14 of the 36 states of the country (Bengba, 2018). In spite of Nigeria's vast energy potential, the country remains perennially plagued by an energy crises because most of these energy potential has not been properly harnessed (Ibitoye and Adenikinju, 2007). This has resulted in low electric power generation, poor distribution and transmission losses and perpetual blackouts. This unfortunate situation has greatly undermined Nigeria's potential for sustained socioeconomic growth, infrastructural development and energy security. Therefore, there is a critical need for low-cost, sustained electricity production and power supply, generated from cheap sources of energy such as coal. With cheap coal based electric power, the real sector of Nigerian economy will be greatly enhanced, spurring socioeconomic growth, infrastructural development, jobs creation and improved living standards.

The Nigerian coal are sub-bituminous (black coals) of capanian – maastrichtian age, and lignite (brown coals) of tertiary age. Consequently by discovery, the Lafia-Obi coal deposit in the Middle Benue trough is geologically the oldest deposits in Nigeria. (Chukwu, *et al,* 2016; Felix and Yomi, 2013).

Three Nigerian coals (Onyeama, Lafia-Obi and Garin Maiganga) were investigated to estimate their suitability in developing formed coke for use as blast furnace coke. It shows that the highest cumulative percentage stability and lowest cumulative percentage friability were observed in Lafia-Obi coal samples with values 67.54% and 32.46% followed by Onyema with 66.92% and 33.08% and that of Garin Maiganga with 55.04% and 44.96% (Chukwu, *et al* 2016). Low and medium temperature carbonaceous of Onyeama and Lafia-Obi shows improved and satisfactory percentage stability and friability for semicokes.

Calorific value is the complex function of the elemental composition of the coal and can be determine experimentally using bomb calorimeter (Mahapatra, 2016). It's the most important parameter that determines the economics of the power plant operation. Studies have shown that the calorific value of coal may vary considerably with a deposit (Mahapatra, 2016).

Studies have shown that there's abundance of coal deposit in Nasarawa and Gombe States (Felix and Yomi, 2013), but the natural coal resource is not fully harnessed and maximized, this was the prompt for investigation and estimation of the calorific value and characterization of the coal for power generation and industrial usability. In view of the review done, there is limited literature on the physical, chemical and calorific value of the coal samples of these areas. Hence, no study is yet reported where the gross calorific value of coal of this area is systematically investigated to characterize and optimize the calorific value of coal using X-ray diffraction, X-ray fluorescence, proximate analysis and oxygen bomb calorimeter techniques which this paper is meant to achieve. Harnessing the coal in commercial quantity will definitely boost the country and especially the state economy; this research could lead to that. It also will give a good knowledge of the exploration of coal for power generation and industrial utility. Consequently, impurities and dangerous radioactive nuclides which may be part of the elemental components of the coal of these locations need to be known in order to estimate the environmental pollutants for appropriate exploration (Chukwu, *et al,* 2016; Felix and Yomi, 2013).

MATERIALS AND METHODS

Study Area.

The study area include Awe and Lafia in Nasarawa state and Maiganga in Gombe state. Lafia-coal mine with longitude 08^{0}28′11.7′′and latitude 08^{0}35′17.2′′ and Awe coal deposits with longitude 08^{0}39′20.5′′ and latitude 08^{0}14′5.09′′ of Nasarawa state. Garin Maiganga longitude 09^{0}59′16.02′′ and latitude 11^{0}09′934′′ coal mine of Gombe state which is located northeast of Nigeria. Two coal samples each of Awe, Lafia and Maiganga were collected. They are the primary materials used in this study. The samples were stored in appropriately labeled air tight containers to retain their as received conditions.

Sample collection

Before collecting the samples, the spot were cleared and at least 25 cm of Coal surface were scrapped from the top and the place is leveled. 5kg each of fresh samples of coal out-crops were collected from three different coal beds in Awe and Lafia areas of Nasarawa state North Centre Nigeria and Maiganga area of Gombe state North east Nigeria. Ashing of the raw coals was carried out by weighing 1.0 g of each sample into a covered crucible and put in a Gallenhamp muffle furnace which was maintained at 550°C for 6 h, and the % ash calculated.

Sample Preparation

The coal sample collected was reduced to laboratory samples size of 12.5mm for total moisture and 212 microns sieve (Top Size) for Testing and Analysis. The Preparation of Lab samples is done at coal laboratory preparation room Centre for Dry Land Agriculture (CDA) Bayero University Kano. The preparation consists of following steps: 1) Primary Crushing: The gross sample collected is fed to primary crusher and the coal size is reduced to 12.5mm size with help of mechanical crushing. 2) After Primary crushing of coal sample, one portion (one fourth of the gross sample) called Part-1 will be used for determination of total moisture and the other portion (three fourth of the gross sample) called Part-2 will be used for Testing and analysis. 3) Secondary Crushing: After primary crushing of coal, Part-2 of the coal sample is sent to secondary crusher, coning and quartering of coal sample is carried out at secondary crusher and the sample is further reduced to 3.35 mm of size. 4) Pulveriser: Coning and quartering of coal sample is done and pulveriser will reduce the coal sample to powdered form and the top size of 212 Micron is attained. Precaution were be taken so that further sieving and pulverising is not needed at the time of testing in case the pulveriser is not in working condition, the testing is done at sample of 3.35-micron

X-Ray Fluorescence.

Standard method EDXRF with software version 10.3.0.159 and maximum energy of 40KeV from Umaru Musa Yar'adua University Katsina State Nigeria was used with average voltage supply of 25.2Kv for the analysis of the elemental composition of coal samples and was carried out base on ASTM D5291 standard techniques. Elemental analysis is an accurate method used for determining the carbon -hydrogen - nitrogen content of coal by combustion using various techniques. However, it could be used for determining the origin and the evolution of coal and with limited accuracy.

Proximate Analysis

1 g of each coal sample passing a 212 μm test sieve was used for proximate analysis.
Moisture content was analysed using the air oven method at 550^{0}C. The moisture, volatile matter and ash content were determined by proximate analysis base on the America Society for Testing Material (ASTM D3173 and D3174) at the chemistry laboratory 1 of Federal University Dutse, Jigawa State. The determination of total moisture was done when one fourth of gross sample of size 12.5 micron is used for total moisture test.
Percentage Fixed carbon is thus calculated:

% fixed carbon = 100 – (% Moisture + % Ash + % Volatile matter) 1

Gross Calorific Value

1g of coal sample was used in CAL3K oxygen bomb calorimeter which uses both isothermal and adiabatic methods in one system (Isobaric) at the center for Dry Land Agriculture (CDA) Bayero University Kano to carry out this experiment. The precision accuracy is 0.000001 c; which is the temperature resolution of the calorimeter and has specific heat capacity of 0.897J/g ^{0}C.The firing wire is used to place the crucible containing 1g of coal in the balance and torrid, half gram of benzoic acid was placed into the crucible and the balance stabilized. The mess is typed into the calorimeter (the character does have the option of transferring the mess automatically from the balance). The crucible is loaded into the little assembly, the lid assembly is easily placed into the bomb vessel into the filling station and the beds lab filled with oxygen for about 15secs. to 20secs. The bomb is placed into the calorimeter and closed for about 2.5min. The calorimeter determines the gross calorific value of the coal sample in it. The little opened automatically which shows that it is done. The first coal sample A1 result is 29.18MJ/Kg which appeared on the screen. The experiment is repeated for the rest of the samples and the following results were obtained.

RESULTS AND DISCUSSION

Proximate Analysis.

The result of proximate analysis shown in table 1 of the three samples of coals from the three locations on air-dried basis and the fixed carbon were obtained by method of difference using equation 1.

The range of moisture contents is from 3.30% to 16.3%. The Lafia (L) coal sample had the highest moisture content of 16.3%, followed by Awe (A), and then Garin Maiganga (M) coal samples with 8.3%, respectively. There is much difference between the volatile matter contents of Awe, Lafia and Garin Maiganga coal samples. The Awe coal sample had the lowest volatile matter content (4.3%). The highest fixed carbon content of 78.3% was recorded in Awe coal sample, followed by 71.1% and Lafia coal samples with values of 55.8%, Table 1 respectively.

It is observed that Garin Maiganga coal sample with the lowest inherent moisture content (8.3%) would be the easiest to handle and store followed by Awe (8.7%), and then Lafia (16.3%) coal samples as seen from table1.

Ash content affects coal and ash handling systems, pulverisers (abrasion), furnace, super heater, re-heater, economizer, soot-blowing intervals (slagging and fouling propensity, erosion, and corrosion), pollution control equipment, and unburnt carbon in ash (Chukwu, *et al,*2016). Lafia coal sample with the lowest ash content (6.2%) would cost less in terms of investment in ash handling equipment and pulveriser abrasion followed by Garin Maiganga (7.9%), and Awe (8.7%) coal samples. The volatile matter content of coal affects storage behavior (oxidation, danger of spontaneous combustion, and loss of heating value), pulveriser outlet temperature and required fineness for pulverization, burner settings, furnace, combustion behavior, and efficiency (ignition, flame shape and stability, and burnout and carbon content of fly ash) (Chukwu, *et al,*2016). Awe coal sample with the lowest volatile matter (4.3%) would have the least danger of spontaneous combustion. This is followed by Garin Maiganga (12.7%), and Lafia (21.7%) samples as shown from table 1.

Table 1: Result Proximate Analysis

Properties	Sample's ID		
	Awe (A)	Lafia (L)	Garin Maiganga (M)
Moisture content (%)	8.7	16.3	8.3
Ash content (%)	8.7	6.2	7.9
Volatile Matter (%)	4.3	21.7	12.7
Fixed carbon (%)	78.3	55.8	71.1

From the results Table 1 it indicates that the coal of Awe has 8.7%, Lafia has 6.2%, and Maiganga has 7.9% ash content. Because coal ash has significant effect on the efficiency of the boiler, it shows that medium ash content of Awe and Maiganga will reduce the boiler's efficiency. Therefore the comparably medium value of the ash total elemental constant should be a cause of concern due to the fact that some of the elements could impact adverse effects on Flora and Sauna health's including human health.

Table 2 shows the ASTM classification of ash. According to ASTM ash classification which is very important in coal grading. Coal which has ash <8% for superior coal, ash ≥8% to <12% for good coal and ash ≥12% to <16% for fair coal whereas ash >16% for poor coal. By this, the coal of Awe and Maiganga are classified as good coal and that of Lafia is said to be superior by the virtue of this investigation. Ash is well known as a secondary determinant of coal price while heat and sulfur content are considered as the primary determinants internationally (Mahamudul *et al,* 2013). In fact, ash concentration of coal is inversely proportional to coal price. Hence, the coal sample Awe and Maiganga could have fewer prices in the market compare to the coal of Lafia which could have a higher price because of the ash contents as seen in table 2.

High ash content of coal has impact on the boiler such as Slugging, fouling, and reduction of boiler's efficiency. Therefore it is observed that all the three (3) coals samples have low ash contents and as such may not have much effect in the boiler.

Table 2: ASTM Ash Classification and grading of three coal locations.

Classification	Composition type	Awe(A)	Lafia(L)	Maiganga(M)
High ash	>15.0			
Medium ash	8.0-15.0	✓		✓
Low ash	< 8.0		✓	

The volatile matter is an important parameter for coal end users because it impacts the coke strength, gas balance and thermal coal ignitability. If the VM is high, it lowers the coke yield. Hence the coal of Awe with VM of 4 .3 have a high coke yield followed by Maiganga with VM of 12.7 and then Lafia with 21.7 volatile content as shown in table 2. The ease of combustion of the coal samples is in order of, Awe > Maiganga > Lafia.

In a combustion process, the fixed carbon is the combustible residue left after the volatile matter distills off. It represents the portion of coal that must burn in solid state. The fixed carbon form and hardness are indication of the caking properties of a fuel. Therefore, increase in the fixed carbon increases the caking ability of the coal to produce fuel for fire-power plant. This implies that the coal of Awe have more caking properties to produce fuel followed by coal of Maiganga and Lafia coal sample as shown in table 1.

From table 1, the moisture content of the three coal samples are seen. Lafia has the highest moisture content of 16.3 which reduces the relative efficiency of heating when a coal is combusted. This implies that Awe and Maiganga whose moisture contents are 8.7 amd 8.3 will have a relatively high efficiency of heating when the coal is combusted. This is why low-rank, high moisture coals have lower calorific values.

3.2 Calorific Value.

The laboratory results of the calorific values of coals samples as carried out using the digital oxygen bomb calorimeter (CAL3K) is as shown in the table 3.

From Table 2, it is observed that Awe A1and A2 coal samples had the highest gross calorific value of 29.18MJ/kg and 30.79MJ/kg, followed by the Lafia L1and L2 coal samples with 26.10MJ/kg and 25.10MJ/kg, and the Garin Maiganga M1and M2 coal samples with 25.10MJ/kg and 24.21MJ/kg.

One of the major perimeters for determining the suitability of power plant for electricity generation is the gross calorific value. It is the amount of heat content in a given sample of coal. Therefore, from table 3, we have the chart below on figure1. Results obtained from the gross calorific value determination carried out on the six coal samples are shown in Figure 1. The calorific value gives the heating value or the heat of combustion of a substance. It has been suggested that the calorific value of power plant coals is in the range of 9.5 MJ/kg to 27MJ/kg (Chukwu, *et al* 2016; Adebiyi, 2016).Thus; all the coal samples would be suitable for power generation. Generally, the greater the oxygen percentage, the lower the percentage of Carbon and Hydrogen available for combustion, hence the lower the heating value (Chukwu, *et al* 2016).

From table 3, the calorific values for the coals were consistent with carbon value and oxygen content of the coals. Additionally, the comparatively lower value of M1and M2 (Maiganga) and L1 and L2 (Lafia) coal can be attributed to high value of oxygen present.

But the sample A1 and A2 (Awe) coal with the highest energy values signify the highest value of carbon content and lowest value of oxygen content which is translated as the highest calorific value of coal investigated. Hence, the results indicate that reactivity and maturity of the coal decreases in the order of

Awe (A) ⟶ Lafia (L) ⟶ Maiganga (M)

Likewise the heating value of the coal increases in the order of

Maiganga (M) ⟶ Lafia (L) ⟶ Awe (A)

For the coal samples analyzed, the correlation between carbon content and calorific value of coal is the strongest. This means that the carbon content of the coal samples contributes the strongest to the calorific value of the coals (Bemgba, 2018).

Consequently, M1 and M2 coal sample of Mainganga which has the lowest calorific value showed the lowest content of nitrogen and sulphur and may be considered the coal with the lowest potential environmental pollutants. Hence, the Maiganga coal will be for cement and steel manufacturing. Whereas, the A1 and A2 coal samples of Awe is most preferred for power generation as well as industrial and domestic heating as seen in figure1.

The Awe coal sample, with the highest heating value of 30.79 and 29.18 MJ/kg, would be the best for heating and power generation. The heat of combustion of any organic compound is associated with the bond energies between the atoms forming the chemical structure of the compound and therefore with the character of the bonds.

Table 3: Samples and their Calorific values

Sample's Id	Calorific value in MJ/kg
A1	29.18
A2	30.79
L1	26.10
L2	25.10
M1	25.50
M2	24.21

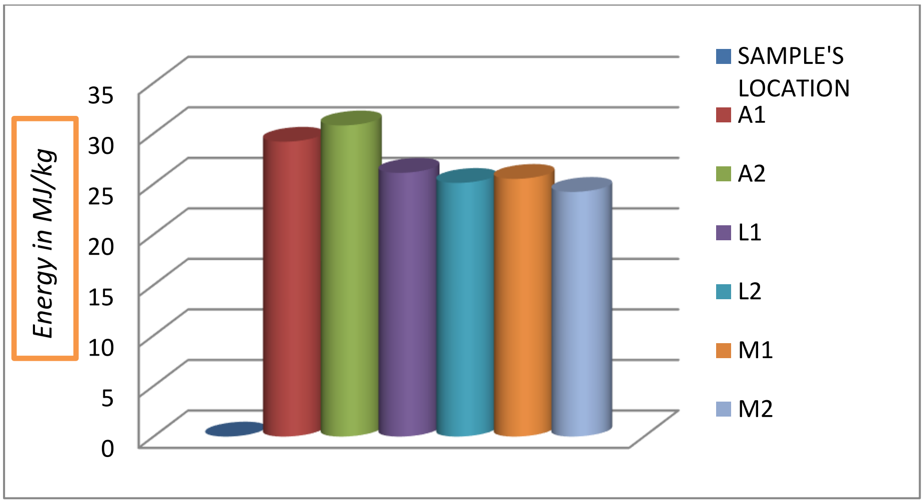

Figure 1: Energy verses location

Ranking of (6) coal sample using the ASTM classification as shown in table 4 indicates that the coal from Awe location is Bituminous high volatile (B and C) whereas Lafia coal is subbituminous A and Maiganga (M1) coal is subbituminous A and M2 is subbituminous B. Comparison between Nigeria, China and America's coal indicates that both China and America coal has high value for Ti and Mn, whereas Nigeria coal has low, which makes Nigeria coal environmentally friendly than China and America coal (Adebiyi 2016).

Table 4: Ranking of coal six coal samples using the ASTM classification.

Coal Rank	Health value criteria (Btu/lb)	A1	A2	L1	L2	M1	M2
		12547	13240	11223	10793	10965	10410
Bituminous high volatile B	13,000-14,000		✓				
Bituminous high volatile C	10,500-13,000	✓					
Subbituminous A	10,500-11,500			✓	✓	✓	
Subbituminous B	9,500-10,500						✓
Subbituminous C	8,300-9,500						
Lignite A	6,300-8,300						
Lignite B	< 6300						

The high volatile Bituminous coals A1 and A2 table 3, in the middle Benue trough on the part could constitute the bulk of the raw material for coke making consumable in the blast furnace of the Ajaokuta steel company whereas the subbituminous coals of Lafia and Maiganga locations will be good for power generation.

The comparison of the elemental peak of the coal samples as obtained from the EDXRF various peaks of the elements are represented on table 4. It shows that all the coal samples contain about 22 elements: Al, Si, Fe, Ca, K, Ti, Cr, Mn, Mg, Ni, Cu, Zn, Zr, Pb, S, Ba, V, Sr with various peaks.

The coal samples do not contain elements such as Na, Sn, Cl, As and some have negligible amount of Th, and Pb example, A2 and L2. This variation in peaks is as a result of geological age, formation and locations of coal samples. The coal samples also contain some minute proportion of sulfur as seen from table 5.

Table 5: Peaks distribution of some element in Ridi- Awe, Lafia and Maiganga coal samples.
The peak distribution of elements shows the mode of occurrence of the coal samples of each location. The elemental composition shows that the coal samples of these locations Awe, Lafia and Maiganga contain negligible amount of radioactive elements which makes it environmental friendly for coal power plant citation. The emission of radionuclides should be considered when evaluating environmental impact of coal burning power plants.

CONCLUSION

The studies conducted reveals that Maiganga coal sample is bituminous high Volatile coal as a result of its gross calorific value. Lafia and Awe coal deposit is ranked as sub-bituminous which will be good for chemical production such as chloroform, benzene and coal tar. It could be very good for coking and suitable for use in low shaft furnace for pig iron production. All the coals

Element	Ridi-Awe A1	Ridi-Awe A2	Lafia L1	Lafia L2	Maiganga M1	Maiganga M2
Al	382	217	38	37	19	1
Si	2118	2750	985	440	412	196
Fe	6637	4086	6375	11331	12574	6922
Ca	132	684	3619	4939	6070	6238
K	104	1026	76	56	21	53
Ti	573	2706	1065	2464	1223	696
Cr	54	87	24	62	13	14
Mn	85	90	4760	5958	2050	1834
Mg	3	1	0	1	0	1
Ni	19	27	15	19	31	11
Cu	24	43	57	88	24	28
Zn	50	130	26	79	92	142
Na	Nil	Nil	Nil	Nil	Nil	Nil
As	0	0	0	0	0	1
Zr	7	33	16	40	19	5
Sn	0	0	1	2	0	0
Pb	2	5	5	5	5	11
S	2050	1125	3467	3984	925	1751
Ba	20	169	151	210	243	293
Th	0	4	0	1`	0	0
V	80	196	60	133	57	43
Sr	8	17	62	102	41	51

of these locations would be good for fired-power plant. The properties of Maiganga are suitable for domestic heating whereas that of Lafia and Awe could be used for cement manufacture.

Benchmarking the properties of the coal sample of these three locations against the requirement of existing coal fire power-plants from around the world shows that these coals meet most requirements. The deficiencies noted can be corrected via beneficiation or blending with coals of better properties.

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