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Proceedings of the 3rd Conference of the Arabian Journal of Geosciences (CAJG-3)

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Evaluation of Coal Quality: A Case Study of Ankpa Coal, Mamu Formation Anambra Basin, South-Eastern Nigeria

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Abstract

Coal, being an economic deposit, can be used for various purposes depending on their properties and composition. Hence, the need to carry out a detailed investigation on Ankpa coals. Ankpa coals fall within the Mamu Formation of Anambra Basin in south-eastern Nigeria. The coals were investigated to deduce the rank and the coal quality with respect to power generation, cokability, handling, fueling, combustion, agglomeration, and slagging potential. Nine coal samples were collected from two boreholes (BH-2) and (BH-4) having depths of 16.5 and 27.4 m, respectively, and were subjected to proximate, ultimate, and elemental analyses. Moisture content ranges from 2.10 to 8.75 wt%, ash content, 4.45–26.8 wt%, volatile matter, 40.10–56.9 wt%, and the fixed carbon 20.45–39.24 wt%. The moderate moisture, low to high ash content, and high volatiles matter in the coals suggest high volatile sub-bituminous, non-coking coal. The carbon content range from 23.3 to 52.4%, hydrogen 1.73–6.88%, oxygen 9.57–18.9%, nitrogen 1.42–2.93%, and sulphur 0.73–4.15%. The sulphur content (>0.8%) and nitrogen content (>1.5%) indicate non-coking coal and it would pollute the atmosphere during combustion by releasing flue gases. The agglomeration and slagging were deduced by the ratio of C/H, FC/V, SiO_2/Al_2O_3, Fe_2O_3/CaO, silica ratio (G), and base/acid ratio (B/A). The agglomeration level and tendency of the coals to slag varies from weak to strong. The coals are not suitable for coking, but can be used for power generation, combustion applications, and fuelling due to its high combustibility.

Keywords

Agglomeration · Coal · Cokability · Formation · Proximate

1 Introduction

Coals exist in many parts of the world such as China, Australia, USA, Russia, and Germany. In Nigeria, coal deposits are found mainly in Benue Trough and Anambra Basin. Minor occurrences have been reported in Bida and Sokoto Basins. The Cretaceous Anambra basin (Fig. 1) is one of the inland sedimentary basins in Nigeria formed during the break up and separation of the African and South American plates (Burke et al., 1971). The current energy crisis facing the country has made Nigeria embrace power generation from coal as a major source of energy, in addition to conventional hydro and thermal sources. Within the Anambra Basin, the Campanian–Maastrichtian Mamu Formation has coal deposits in localities such as Owukpa, Okaba, and Ogboyaga. The Awo Akpali coal mine in Ankpa is recently discovered and little or no information on the coal has been provided with respect to its quality and possible utilization. The studies were principally carried out to determine the rank, cokability, power generation potential, combustion, agglomeration, and slagging potential of the coal in order to ascertain their potential relevance to possible utilization and resource potential.

2 Materials and Methods

Nine coal samples from two boreholes were collected from Awo Akpali coal mine in Ankpa. The coordinates of the sample area fall in Anambra basin within latitudes N 7° 23′ and N 7° 26″ and longitudes E 7° 36′ and E 7° 39″. The studied boreholes are BH-2 and BH-4 having depths of 16.5 m and 27.4 m, respectively. Four coal samples were

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F. Lucci et al. (eds.), *Selected Studies in Geomorphology, Sedimentology, and Geochemistry*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-43744-1_6

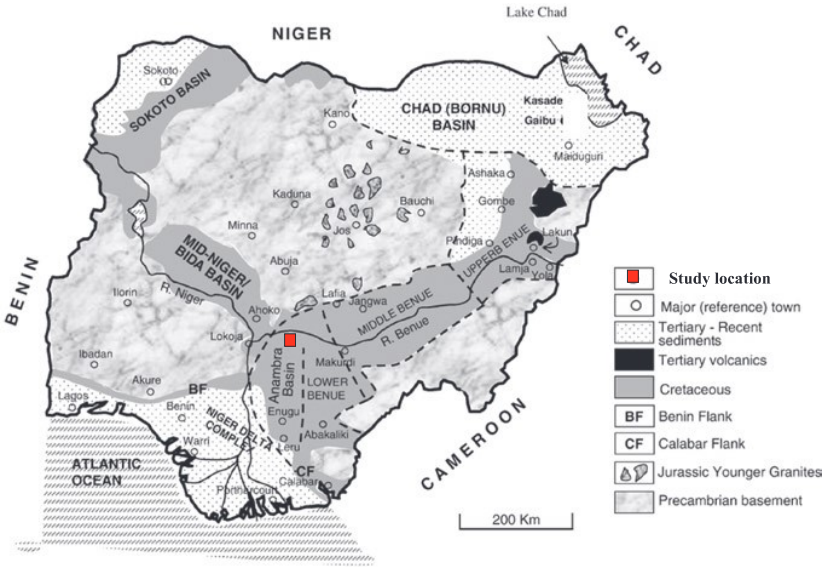


Fig. 1 Geological map of Nigeria showing the location of study (Anambra basin) modified after (Obaje, 2009)

obtained from BH-2, while five coal samples were collected from BH-4. Seam 1 and seam 2 of BH-2 are 1.4 and 0.5 m thick, respectively, while Seam 1 and 2 of BH-4 have thicknesses of 0.6 m and 1 m, respectively. The proximate analysis of the coals was carried out by Proximate Analyser (VG0STBR model), ultimate by Ultimate Analyser (Advant'X model), and elemental analysis was performed with XRF machine (Thermo scientific advant'X 1200 model). All the analyses were carried out according to American Society for Testing and Materials (ASTM) D388 (1992) at National Steel Raw Material Exploration Agency (NSRMEA) Kaduna Nigeria. Nine coal samples were subjected to proximate analysis to determine the moisture content, volatile matter, ash, fixed carbon, and calorific value, while five samples were analysed for ultimate analyses to determine the carbon, hydrogen, oxygen, nitrogen, and sulphur content. The inorganic geochemical analyses were carried out mainly for the major oxide elements.

3 Results

The results of the proximate, ultimate, and major oxide geochemistry are presented in Tables 1, 2, and 3.

4 Discussion

4.1 Coal Quality, Rank, and Agglomeration

Based on the proximate data (Table 1), the moisture content ranges from 2.10 to 8.75 wt%, ash content varies between 4.45 and 26.8 wt%, volatile matter ranges from 40.10 to 56.9 wt%, while the fixed carbon is between 20.45 and 39.24 wt%. The coal has moderate moisture, low to high ash content, and high volatile matter; thus classified as high volatile sub-bituminous coal (Guo et al., 2018). The volatile

Table 1 Proximate data and Calorific values of Ankpa coal samples (air dried)

S/N	Samples code	Sample type	Lithology	M (%)	Ash (%)	VM (%)	FC (%)	CV (MJ/Kg)	FC/VM
1	AK1A	Borehole	Coal	4.11	20.04	51.90	23.95	26.24	0.46
2	AK1B	Borehole	Coal	6.69	21.30	43.70	28.31	23.94	0.65
3	AK1C	Borehole	Coal	5.41	10.05	45.82	38.72	25.01	0.85
4	AK1D	Borehole	Coal	7.61	4.45	48.70	39.24	26.70	0.81
5	AK3A	Borehole	Coal	8.75	13.90	56.90	20.45	28.85	0.36
6	AK3B	Borehole	Coal	8.52	7.70	52.30	31.48	27.71	0.60
7	AK3C	Borehole	Coal	2.70	19.60	40.10	37.60	21.21	0.94
8	AK3D	Borehole	Coal	2.10	26.80	52.90	28.20	26.99	0.53
9	AK3E	Borehole	Coal	3.95	23.90	43.70	28.45	22.51	0.65

Note M: moisture content; VM: volatile matter; FC: fixed carbon; CV: calorific value

Table 2 Ultimate data of Ankpa coal samples

S/N	Sample code	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)	C/H
1	AK3A	72.42	6.14	9.57	1.83	1.82	11.79
2	AK3B	73.61	6.88	11.94	2.90	1.59	10.69
3	AK3C	23.28	1.73	18.96	1.42	4.15	13.46
4	AK3D	58.78	4.68	14.43	2.41	0.73	12.56
5	AK3E	70.22	5.97	12.35	2.51	1.51	11.76

Note C/H: carbon/hydrogen

Table 3 Major elemental composition of Ankpa coal samples analysed

S/N	Sample code	Lithology	Sample Type	SiO_2	Al_2O_3	Fe_20_3	TiO_2	MgO	P_2O_5	K_2O	CaO	Na_2O
1	AK1A	Coal	Borehole	24.24	7.99	2.37	2.65	0.91	1.26	0.61	0.48	0.38
2	AK1B	Coal	Borehole	16.26	6.59	4.55	2.07	0.45	0.89	0.46	0.71	0.40
3	AK1C	Coal	Borehole	11.02	3.25	2.53	1.38	0.81	1.44	0.24	0.56	0.42
4	AK1D	Coal	Borehole	25.56	6.12	3.39	-	0.61	0.87	-	0.36	0.20
5	AK3A	Coal	Borehole	11.51	3.80	4.62	0.93	0.51	1.47	0.60	1.34	0.51
6	AK3B	Coal	Borehole	6.52	3.93	2.69	1.05	0.23	1.58	-	0.46	0.63
7	AK3C	Coal	Borehole	58.04	19.29	8.69	2.02	1.13	1.86	2.96	1.22	0.57
8	AK3D	Coal	Borehole	36.82	5.80	1.04	-	0.70	1.21	1.01	0.31	0.44
9	AK3E	Coal	Borehole	11.92	4.59	3.89	1.08	0.56	0.71	0.31	0.70	0.59

matter contents and ultimate analysis data (Table 2) are in accordance with rank. The results of ultimate analyses (Table 2) and rank determinations classify these coals as sub-bituminous B/C (Guo et al., 2018). These types of coals are characterized by low nitrogen but high oxygen and relatively moderate sulphur contents. In the evaluation of coal quality, the most important relationship is that between volatile matter and ash content (Dıez et al., 2002), and in the studied samples, this relationship was found to be negative.

With respect to cokability, the moisture content (up to 8%), the high volatile matter (>36%), and high ash (>10%) indicate non-coking coals (Dıez et al., 2002; Zhang et al., 2014). The high volatiles in the coals are favourable for combustion applications and fuelling (Guo et al., 2018). The ratio of FC/V was also used to deduce the agglomeration and slagging tendency.

The percentage of carbon from the ultimate analysis of coal sample from BH-4 is not consistent with the fixed carbon obtained from proximate analysis. The carbon content ranges from 23.3 to 72.4%, hydrogen 1.73 to 6.88%, oxygen 9.57 to 18.9%, nitrogen 1.42 to 2.93%, and sulphur, 0.73 to 4.15%. Coal quality with respect to cokability, agglomeration tendency, and rank was deduced. The coal has high amount of sulphur (> 0.8%) which suggests it is not suitable for coking (Mochizuki et al., 2013). The high nitrogen content (>1.5%) in the coal would pollute the atmosphere during combustion by releasing flue gases (Carpenter et al., 2007). The agglomeration and slagging tendency were deduced by the ratio of C/H and indices generated from the major elemental composition (Tables 4 and 5). The agglomeration level of the coals varies between weak, medium, and strongly (Table 5).

Table 4 Limits of the discriminant index for slagging (Guo et al., 2018)

Tendency of slagging			
Index	Weakly	Medium	Strongly
B/A	<0.206	0.206–0.4	>0.4
G	>78.8	78.8–66.1	<66.1
SiO_2/Al_2O_3	<1.87	1.87–2.65	>2.65
Fe_2O_3/CaO	Out of 0.3–3	0.3–3	Near 1

5 Conclusion

Proximate analysis and calorific value revealed that Ankpa coal has moderate moisture content, high volatile matter and ash, suggesting it can be used in coal-fired power plant generation and fuelling due to its high combustibility. The high volatile matter and sulphur in the coal classify it as non-coking. The variation in the agglomeration level is due to combination of different agglomeration indices which ranges between weak, medium, and strong. Coal beneficiation and blending are required. It is been utilized in coal power plants to minimize environmental pollution that would arise during combustion due to high sulphur content.

Table 5 Indicators and agglomeration level of Ankpacoal samples analysed

Sample code	C/H	FC/V	B/A	G	S/A	I/C	Agglomeration degree
AK1A	–	0.46	0.14 (Weakly)	86.6 (Weakly)	3.03 (Strongly)	4.94 (Weakly)	Weakly
AK1B	–	0.65	0.26 (Medium)	74.0 (Medium)	2.47 (Medium)	6.41(Weakly)	Medium
AK1C	–	0.85	0.29 (Medium)	73.9 (Medium)	3.39 (Strongly)	4.52 (Weakly)	Medium
AK1D	–	0.81	–	85.4 (Weakly)	4.18 (Strongly)	9.42 (Weakly)	Weakly-Strongly
AK3A	11.79	0.36	0.47 (Strongly)	64.0 (Strongly)	3.03 (Strongly)	3.45 (Weakly)	Strongly
AK3B	10.69	0.60	–	65.9 (Strongly)	1.66 (Weakly)	5.85 (Weakly)	Weakly-Strongly
AK3C	13.46	0.94	0.18 (Weakly)	84.0 (Weakly)	3.01 (Strongly)	7.12(Weakly)	Weakly
AK3D	12.56	0.53	–	94.7 (Weakly)	6.35 (Strongly)	3.35(Weakly)	Weakly
AK3E	11.76	0.65	0.34 (Medium)	69.8 (Medium)	2.60 (Medium)	5.56 (Weakly)	Medium

Note C/H = carbon/hydrogen; FC/V = fixed carbon/volatile matter; B/A, base/acid ratio = $(Fe_2O_3+CaO+MgO+Na_2O+K_2O)/(SiO_2+Al_2O_3+TiO_2)$; G, silica ratio = $100•SiO_2/(SiO_2+Fe_2O_3+CaO+MgO)$; I/C = Fe_2O_3/CaO, S/A = SiO_2/Al_2O_3

The rank of the coal is high volatile sub-bituminous based on the calorific value. Desulphurization of the coals should be carried out before burning to mitigate the effect of sulphur dioxide emission.

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