VOL. 07 NO. 9,
FEBRUARY, 2025
E-ISSN 3026-958X
P-ISSN 3027-1169

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Science Innovation & Technology Research (JSITR)

Geochemical and Quality Assessment of Ikpabacha Coal in the Northern Anambra Basin of Nigeria

Felix Bamidele Fatoye[1]; Shaib Abdulazeez Shehu[2]; & Mardiyat Oniya Ibrahim[2]

[1]Department of Geosciences, Confluence University of Science and Technology, Osara, Kogi State, Nigeria. [2]Department of Civil and Mining Engineering, Confluence University of Science and Technology, Osara, Kogi State, Nigeria.
Corresponding Author: fatoyefb@custech.edu.ng
DOI: https://doi.org/10.70382/ajsitr.v7i9.030

Abstract

Coal is a combustible material consisting mainly of organic components (macerals) and minor inorganic components (minerals). The potential relevance of coal in metallurgical, power generation, and other industries depends on these components. Coal is considered one of the cheapest and most reliable energy sources responsible for electricity production worldwide. Hence, in sourcing coking coals for metallurgical industries and thermal coals for power generation in the country, coal samples from the Ikpabacha coal deposit in the northern Anambra Basin of Nigeria have been subjected to proximate analysis, ultimate analysis, calorific value determination, and free swelling index test primarily to determine the suitability of the coal for metallurgical processes and power generation. Results from the proximate analysis indicated that the average composition of the coal includes 18.70% moisture, 3.36% ash, 34.67% volatile matter, and 43.27% fixed carbon. The ultimate analysis also revealed that coal, on average, consists of 47.62% carbon, 3.47% hydrogen, 1.30% nitrogen, 13.43% oxygen, 1.06% sulphur, and 0.002% phosphorus. The coal has, on average, H/C ratio of 0.07 and O/C ratio of 0.28. The average heating (calorific) value of the coal samples is 8185 Btu/lb (4547.59 kcal/kg), and it has a free swelling index (FSI) of zero (0). These characteristics suggest that coal is non-coking and cannot

be used in the metallurgical industry to manufacture iron and steel. However, coal is appropriate for electricity generation, boilers, and ovens in industrial heating.

Keywords: Ikpabacha Coal, Coal Geochemistry, Low Quality, Non-coking, Sub-bituminous

Introduction

Coal is a combustible organic sedimentary rock composed mainly of consolidated carbonaceous material derived from vegetation. In other words, it is a carbon-rich, combustible, stratified organic sedimentary rock composed of altered and/or decomposed plant remains of non-marine origin combined with varying minor amounts of inorganic material (MacDonald *et al.,* 2011). What is now coal was originally formed as peat millions of years ago by the prolonged accumulation of plant material in a swampy environment. The peat was subsequently altered to coal through chemical and physical processes. Coal varies in colour from brown to black and in lustre from dull to bright or shiny. It is non-crystalline, brittle, and generally strongly layered or banded.

Nigeria is endowed with large deposits of coal. The majority of the coal deposits in the country occur in the Benue Trough (Lower, Middle, and Upper) and the Anambra Basin. However, the coal deposits of the Anambra Basin contain Nigeria's largest and most economically workable coal resources (Fatoye *et al*., 2020). The Nigerian coals are lignites (brown coals) of Tertiary age and sub-bituminous (black coals) of Cretaceous age. However, the coal deposit at Obi/Lafia in the Middle Benue Trough is the only bituminous coal (coking coal) discovered in this country so far, and it has an estimated reserves of 22 million tonnes (Obaje, 1997). In general, coal quality depends largely on its geological age; hence, the Nigerian coals are of poorer quality than the older Carboniferous coals of Europe and America (Nehikhare, 1987).

Coal is used in the metallurgical industry to produce iron and steel. It is used for electricity generation. Coal is also used in heating in the manufacturing processes. For instance, it can be used to heat kilns to produce cement, paper, ceramic, glass, and bricks. In addition to the manufacturing of coke, generating electricity, and heating, the carbonization (or dry distillation) of coal can produce a large number of volatile matters as by-products such as coal tar, light oils, chemicals, sulphur, ammonia, and hydrocarbon gases. For example, coal tar is a source of dyes, drugs, flavourings, perfumes, plastic, synthetic rubbers, paint

products, varnishes, and adhesives. Light oils are used to make solvents, detergents, synthetic fibres (such as rayon and nylon), and antiseptics. Ammonia, as ammonium sulphate, is used as a fertilizer, and sulphur is an ingredient in plant insecticides. The gas from coke ovens, called coal gas, is primarily used as fuel. The gas can also be processed to produce automotive fuel. Some coal by-products can also be used to manufacture soaps, shampoo, matches, etc.

Coal is one of the cheapest and most reliable sources of energy and is responsible for electricity production worldwide. In many countries like India, China, Germany, and the USA, coal is their primary source of electricity and energy. Countries that depend on coal for electricity generation include Poland, Australia, South Africa, etc.

Nigerian coals are suitable for boiler fuel, domestic heating, briquette, and production of high calorific gas and a wide range of chemicals such as waxes, resins, adhesives, and dyes. Their low sulphur and ash content characteristics and low thermoplastic properties (MSMD, 2008) make the sub-bituminous coals appropriate for electricity generation. Obi/Lafia coal in Nasarawa State can be used to produce coke of metallurgical quality.

Unfortunately, the country has low coal utilization despite its importance in industrial development. The coal sector is one major area that can change this great country's economic and energy destiny. Its potential for growth and development is on the upswing.

It has been confirmed that there is a large deposit of coal beds within the sedimentary succession of the Anambra Basin of Nigeria (Obaje *et al*., 1999), especially the Mamu Formation in the Ikpabacha area of the Basin. However, there is lack of prior detailed geochemical studies on Ikpabacha coal. Geochemical analysis of coal can reveal a huge volume of information about the quality of coal and its possible utilization (Zhao *et al*., 2019). Coal with high carbon content is required in metallurgical processes and power generation. Furthermore, the lower the moisture, ash, and sulphur content of coal, the better the quality of the coal.

Therefore, this study aims to assess the geochemical characteristics and quality of Ikpabacha coal to determine its prospective relevance to metallurgical processes and power generation.

Location of the Study Area

Ikpabacha coal deposit is situated on Latitude 07^0 06' 27.3" N and Longitude 07^0 11' 44.7" E. It is located in Igalamela/Odolu Local Government Area of Kogi State (Fig. 1).

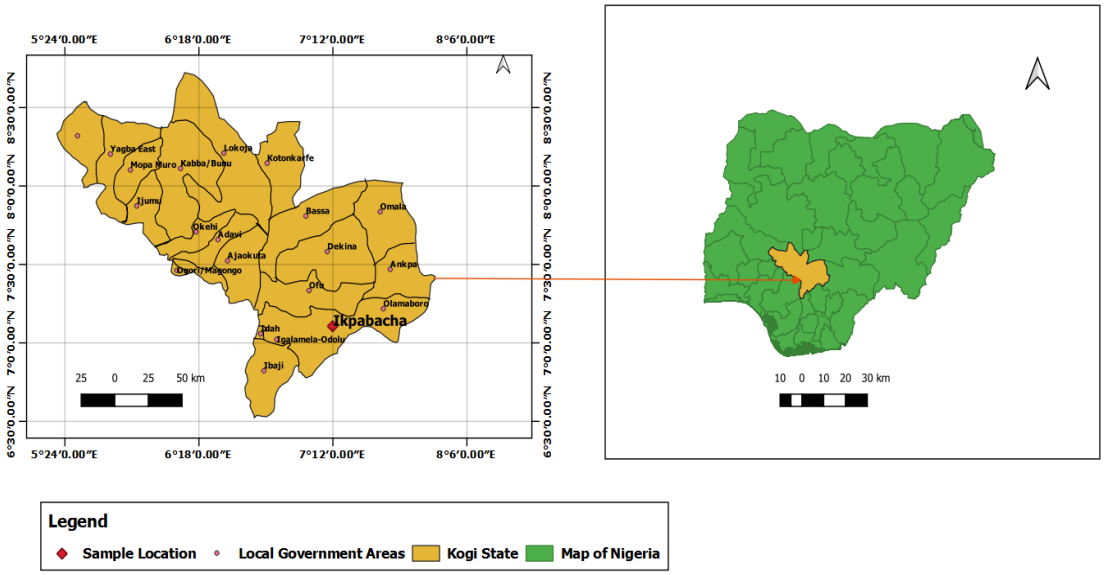


Figure 1: Location map of the study area (modified from map of Nigeria).

Regional Geological Setting

The study area is situated within the Anambra Basin of Nigeria. Sedimentation in the Anambra Basin began with the Nkporo Formation, which contains marine and paralic shales (Fig. 2), overlain by the Mamu Formation, containing paralic sandstones, mudstones, and coals. TheAjali Formation, a deposit of fluviodeltaic sandstones, lies on the Mamu Formation and constitutes its lateral equivalents in most places (Obaje *et al*., 1999). The Nsukka Formation, a sequence of marine shales and paralic coal, is deposited to end the succession in the Anambra Basin (Umeji, 2005).

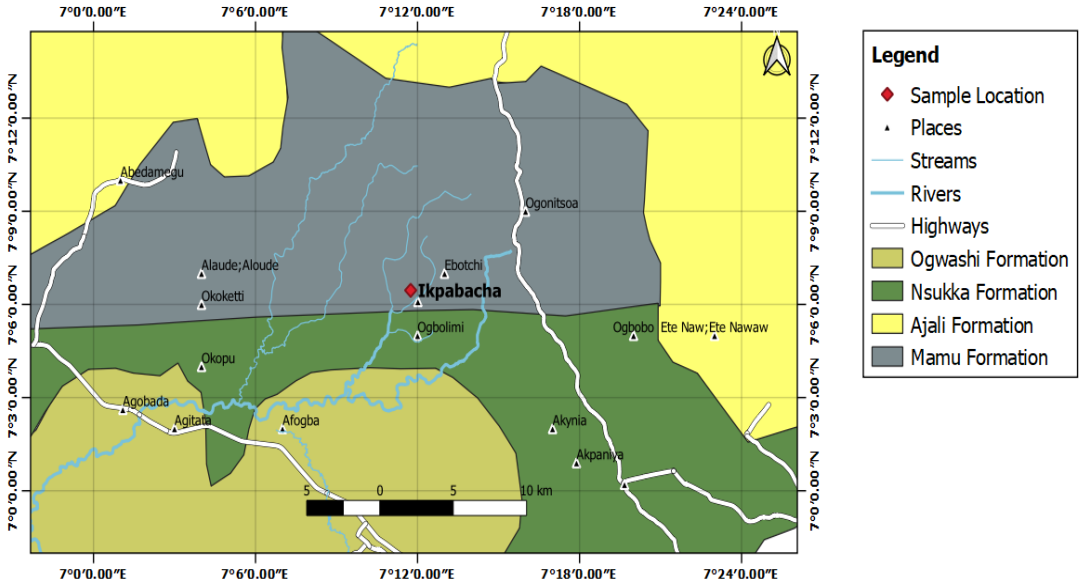


Figure 2 Geological map of the study area.

MATERIALS AND METHODS

Seven coal samples were taken from coal outcrops in the Ikpabacha coal deposit and kept in airtight polyethylene bags to retain their as-received condition. Sample preparations were done according to the American Standard for Testing Materials, ASTM D2013 method.

Proximate Analysis

Proximate analysis was used to measure the coal's percentage moisture, ash, volatile matter, and fixed carbon content. The proximate analysis was done using ASTM D3172 – 73 (2013).

Determination of Moisture Content

1.00g of pulverized coal sample was thinly spread on a previously dried crucible placed in an oven whose temperature was maintained at 105°C for 3 hours. The difference in weight before and after the period was measured as the moisture content.

Determination of Ash Content

1.00g of pulverized coal sample was weighed into a platinum crucible and kept in a muffle furnace at a regulated temperature of 750°C for 2 hours until a constant weight

was attained. The ash content was evaluated by comparing the weight before and after combustion.

Determination of Volatile Matter Content

A 1.00g pulverized coal sample was weighed and covered in a 10ml platinum crucible. The same combusted to a temperature of 950^{o}C in a muffle furnace for 7 minutes, after which the sample was removed, allowed to cool in a desiccator, and re-weighed to obtain weight loss, which was estimated as the percentage of volatile matter.

Determination of Fixed Carbon Content

The difference between 100 and the total sum of moisture, ash, and volatile substances was calculated as the fixed carbon content.

Ultimate Analysis

Ultimate analysis was used to measure the percentage of carbon, hydrogen, and oxygen (the major components) as well as nitrogen, sulphur, and phosphorus present in the coal. Carbon and hydrogen were determined using ASTM D5373 – 08.

Determination of Carbon and Hydrogen

1.00g of coal was burnt in a current of oxygen to convert the C and H to CO_2 and H_2O, respectively. The combustion products (CO_2 and H_2O) were passed over weighted tubes of anhydrous $CaCl_2$ and KOH, which absorbed both carbon dioxide and water. The weight difference of the $CaCl_2$ tube was used to estimate the weight of water formed, while the weight difference of the KOH tube represented the weight of carbon dioxide formed. The percentage of carbon and hydrogen was then calculated.

Determination of Nitrogen

Nitrogen was determined by Kjeldahal's method, where 1.00g of pulverized coal was heated with concentrated H_2SO_4 with the addition of potassium sulphate and copper sulphate in a long-necked flask, thereby converting nitrogen of coal to ammonium sulphate. When a clear solution was obtained, it was treated with 50% NaOH solution. The ammonia thus formed was distilled over and absorbed in a known quantity of standard sulphuric acid solution. The volume of unused H_2SO_4 was then determined by titrating against standard NaOH solution. Thus, the amount of acid neutralized by liberated ammonia was determined.

Determination of Oxygen

The concentration of oxygen was estimated by subtracting the amount of the other elements, carbon, hydrogen, nitrogen, sulphur, moisture, and ash, from 100%.

Determination of Sulphur

Sulphur was determined by high-temperature combustion test method where a 1.00g sample of coal of 0.2mm particle size was heated with a mixture of MgO and anhydrous Na_2CO_3 at 800ºC. After burning, the amount of sulphur in the mix was retained as oxides and precipitated as sulphate. The sulphate formed was precipitated as $BaSO_4$ (by treating with $BaCl_2$). The percentage of sulphur in coal was calculated from the weight of the coal sample taken and the weight of $BaSO_4$ precipitate formed.

Determination of Phosphorus

Phosphorus was determined by treating 1.00g of the coal ash with a hot mixture of HNO_3, H_2SO_4, and HF acids. This volatilized the phosphate and dissolved the phosphorus to precipitate a complex phospho-molybdate from which the phosphorus content was estimated.

Calorific Value Analysis

The calorific value of the coal was measured using a bomb calorimeter. Electrical energy was used to ignite the coal; the surrounding air expanded when the coal was burning and escaped through a tube out of the calorimeter. The water outside the tube was also heated up during the escape of air through the tube. The change in temperature of the water was then accurately measured with a thermometer as the calorific content of the coal.

Free Swelling Index Test

10.00g of finely grounded coal sample was weighed into a dry platinum crucible, which was then placed in a muffle furnace at 800ºC for 2 hours until all volatiles were driven off. After cooling, the coke "button" cross-section was compared to a series of standard profiles (chart) to determine the free swelling index.

RESULTS AND DISCUSSION

Table 1: Proximate analysis results of Ikpabacha coal samples

Sample Number	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)
Ikpa 1	19.39	3.76	34.17	42.68
Ikpa 2	18.66	2.87	34.38	44.09
Ikpa 3	19.17	3.50	33.82	43.51
Ikpa 4	17.80	2.96	35.64	43.60
Ikpa 5	17.93	4.21	35.21	42.65
Ikpa 6	18.58	2.86	34.63	43.93
Ikpa 7	19.34	3.37	34.87	42.42
Average	**18.70**	**3.36**	**34.67**	**43.27**

The average moisture content of Ikpabacha coal is 18.70% (Table 1). Moisture is an unwanted component of coals because it reduces the heating value. The moisture content required for good coking coal is 1.5% (Obaje, 1997). Conversely, the Central Fuel Research Institute (CFRI), India, stipulated a 1 – 4% moisture range for semi-coke in low shaft furnaces (Chukwu *et al*., 2012). Therefore, the value recorded in Ikpabacha coal is above the stipulated rating for coking coal. However, Gunn *et al*. (2012) recommended a maximum of 18 – 30% moisture content for thermal coals, thereby making the studied coal suitable for generating electricity and heating for manufacturing processes.

The average ash content of Ikpabacha coal is 3.36% (Table 1). Ash is the inorganic component of coal or the inorganic residue from burning coal. The lower the ash content of coal, the better its application as a fossil fuel source, especially in the steel industry. The Ash content of coal determines the behaviour of slag and fouling in the combustion chamber (ASTM, 1987). The high ash content indicates a low degree of coalification and, consequently, immaturity of the coal. Less than 10% ash content is recommended for good coking coals (Averitt, 1974; Bustin *et al.,* 1985; and Akpabio *et al*., 2008), as higher ash contents reduce the efficiency in the blast furnace. In steam coal, high ash content will effectively reduce its heating value. Though the ash content of the studied coal is within the less than 10% recommended for good coking coals, its high moisture content makes it unsuitable for coke making. However, coal is appropriate for electricity generation and heating for manufacturing processes based on less than 20% ash content, as proposed for steam coals by Thomas (2002).

The average volatile matter content of Ikpabacha coal is 34.67% (Table 1). Volatile matter represents the flammable gases and vapour that are released when coal is heated. Volatile matter includes light hydrocarbon compounds such as carbon dioxide (CO_2), methane (CH_4), etc. that were yielded by the decomposition of each layer of dead plant material by aerobic or oxygen-requiring bacteria during coalification. Volatile matter also includes hydrogen, oxygen, nitrogen, sulphur, phosphorus, and carbon, which are lost in the form of gases and vapour on carbonization. Volatile matter is used in coal ranking, an important parameter used to determine the appropriateness and applications of coal (Chen and Ma, 2002). In coke production, a volatile matter range of 20 – 35 % is proposed by Thomas (2002).The recommended volatile matter limits in stoker firing for electricity generation are 25 – 40% (Thomas, 2002). These proposed ratings make Ikpabacha coal unsuitable for coke making. However, coal is appropriate for electricity generation and heating for manufacturing processes.

The average fixed carbon content of Ikpabacha coal is 43.27% (Table 1). The fixed carbon content of coal is the carbon found in the material left after volatile materials are driven off. The fixed carbon content of coal is directly related to its moisture and volatile matter; the higher the moisture and volatile matter contents of coal, the lower the fixed carbon content. The studied coal contains low fixed carbon content compared with high-rank coals due to its high moisture and volatile matter contents. High carbon content is crucial for coke-making (Diez *et al*., 2002). A maximum of 46 – 86% is recommended for coking coals (Fatoye and Ibitomi, 2021). Ikpabacha coal contains very low fixed carbon and is below the recommended rating for coking coals. However, it can be used for electricity generation and for heating purposes.

There is a relationship between moisture, ash, volatile matter, and fixed carbon contents of the coal. The plot of these components versus the coal samples revealed this relationship (Fig. 3). The moisture content of the coal samples is directly proportional to the ash content and inversely proportional to the fixed carbon content. This implies that samples with high moisture have high ash and low fixed carbon, and vice versa.

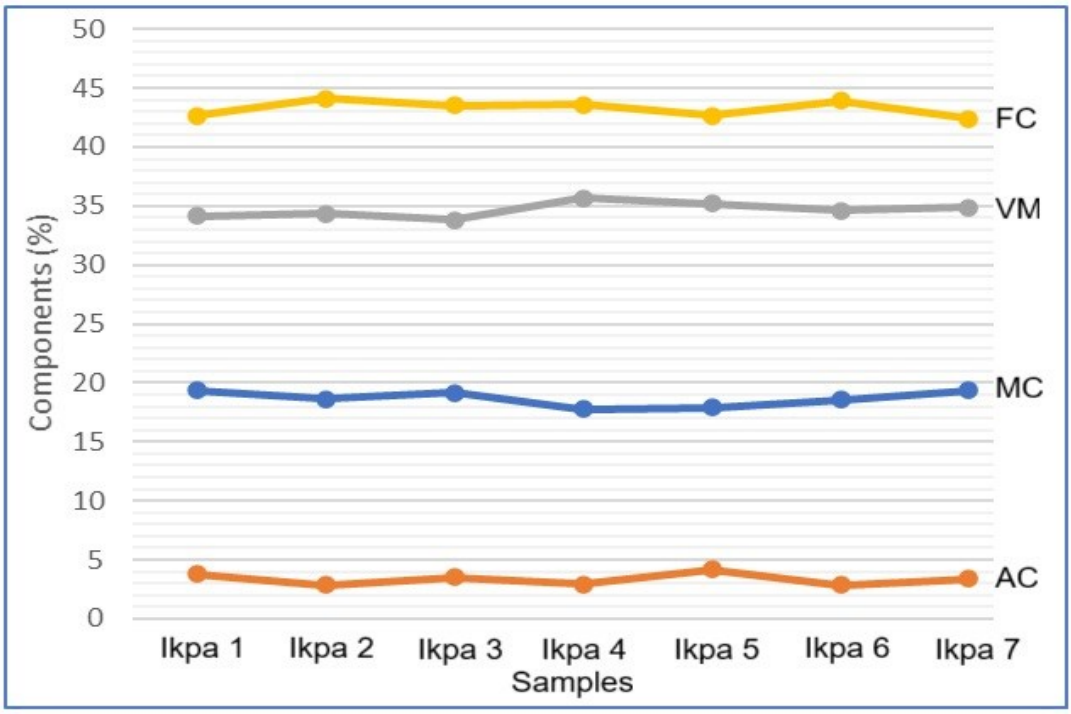


Figure 3: Components/samples graph

Proximate analysis revealed that Ikpabacha coal has high moisture, medium to high ash, high volatile matter, and low fixed carbon contents. High moisture and low carbon content cause the coal to have low energy efficiency. Comparing these characteristics with other coals, the Ikpabacha coal is similar to Huntly sub-bituminous coal in New Zealand, which contains 13.40% moisture, 4.20% ash, 44.90% volatile matter and 50.90% fixed carbon (Beamish, 1994). It is comparable to Tadkeshwar sub-bituminous coals in Gujarat in India (Rasheed *et al*., 2015) and Wyodak-Anderson sub-bituminous coal in the USA (Stricker and Ellis, 1999). However, there is a disparity between the studied coal and Singrauli coal in India, which is considered bituminous with 4.50% moisture and 31.10% volatile matter (Dwiredi and Kumar, 2022). These comparisons thereby placed Ikpabacha coal in sub-bituminous rank.

Table 2: Ultimate analysis of Ikpabacha coal samples

Sample Number	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulphur (%)	Phosphorus (%)	H/C	O/C
Ikpa 1	46.61	2.95	1.21	13.46	0.85	0.003	0.06	0.29
Ikpa 2	47.37	3.41	0.93	14.21	0.97	0.003	0.07	0.30
Ikpa 3	46.93	3.70	1.42	13.30	1.38	0.001	0.08	0.29
Ikpa 4	49.20	2.91	1.70	12.87	0.79	0.002	0.06	0.26
Ikpa 5	48.85	4.10	1.37	12.43	1.26	0.003	0.08	0.25
Ikpa 6	47.56	3.86	0.97	14.11	1.30	0.002	0.08	0.30
Ikpa 7	46.80	3.37	1.51	13.62	0.89	0.001	0.07	0.29
Average	**47.62**	**3.47**	**1.30**	**13.43**	**1.06**	**0.002**	**0.07**	**0.28**

The average carbon content of Ikpabacha coal is 47.62%, while the average hydrogen content is 3.47% (Table 2). Carbon and hydrogen are the main combustible constituents of coal. The higher the carbon content of coal, the higher its calorific value and the better the quality for coke making and power generation. A maximum of 75 – 90% carbon and 4.5 – 5.5% hydrogen is recommended in coking coals (Fatoye and Ibitomi, 2021). Based on these recommendations, Ikpabacha coal has no coking ability; hence, it is unsuitable for coke production in metallurgical processes. However, it is appropriate for electricity generation and heating for manufacturing processes.

The average nitrogen content of Ikpabacha coal is 1.30%, while the oxygen content is 13.43% (Table 2). The less the oxygen content of coal, the better the coal. The greater the oxygen content, the lower the carbon and hydrogen content available for combustion and, hence, the lower the heating value. Based on nitrogen and oxygen contents, coal is more appropriate for the generation of electricity and heating for manufacturing processes.

The average sulphur content of Ikpabacha coal is 1.06%, while the phosphorus content is 0.002% (Table 2). The sulphur content of the coal is high and above the rating of less than 1.0% recommended for coke-making (Bustin *et al*., 1985). Sulphur and phosphorus are unwanted elements in coal as they contribute to producing brittle steel. They also cause slagging and fouling in the boilers, thereby reducing their efficiency and causing corrosion. The coal is better used in electricity generation and heating for manufacturing processes because of its high sulphur content.

The H/C ratio of the coal is 0.07, which is low compared with high-ranked coal. This implies that carbon maturation is lower in the coal. The O/C ratio is 0.28, which is also low compared to high-ranked coals. The low O/C ratio indicates the oxygenic condition of the coal during formation (Cheng, 2019).

There is also a relationship between the coal samples' carbon content and other major elements such as hydrogen, nitrogen, oxygen, and sulphur. The carbon content is indirectly compared to the hydrogen, nitrogen, oxygen, and sulphur contents (Fig. 4). This implies that samples with high carbon content have low hydrogen, nitrogen, oxygen, and sulphur, and vice versa. This suggests that the concentration of carbon from organic materials during coalification resulted in the loss of oxygen, hydrogen, nitrogen, and other elements.

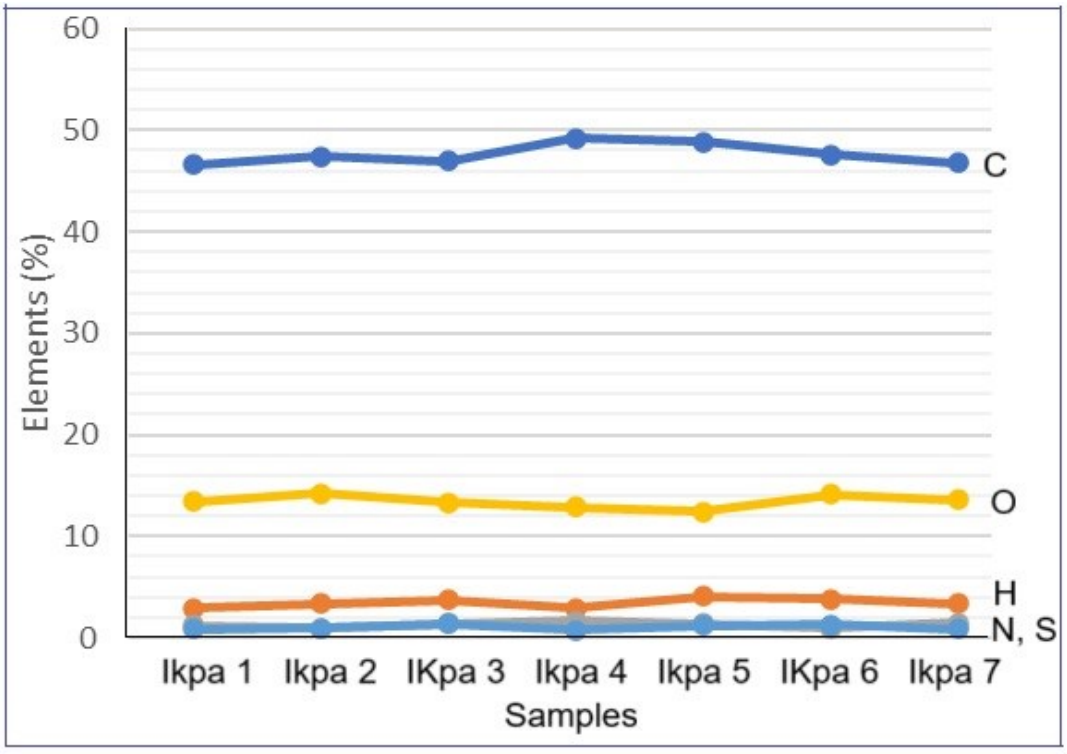


Figure 4: Elements/samples graph

Ultimate analysis indicated that the studied coal is characterized by low carbon, medium hydrogen, high nitrogen, high oxygen, and high sulphur contents. Comparing these characteristics with other coals, Ikpabachacoal is similar to Leicester-Shire sub-bituminous coalin Britain, which contains76.44% carbon, 4.90% hydrogen, 1.53% nitrogen, 13.78% oxygen, and 0.83% sulphur (Drakeley, 2014). However, there is a dissimilarity between the studied coal and Durham bituminous coal in Britain, consisting of 87.73% carbon, 4.78% hydrogen, 1.09% nitrogen, 7.52% oxygen, and 1.28% sulphur (Drakeley, 2014). This, therefore, placed the coal studied in sub-bituminous rank.

Table 3: Calorific value results of Ikpabacha coal samples

Sample Number	Calorific Value (Btu/1b)	(kcal/kg)
Ikpa 1	7447	4137.56
Ikpa 2	8135	4519.81
Ikpa 3	7842	4357.02
Ikpa 4	9206	5114.85
Ikpa 5	8651	4806.50
Ikpa 6	8320	4622.59
Ikpa 7	7694	4274.79
Average	**8185**	**4547.59**

The average calorific value of Ikpabacha coal is 8185 Btu/Ib (Table 3). The calorific value (CV) of coal is the amount of heat released by coal combustion. Mineral matter, moisture, and ash contents of coal help determine its heating or calorific value. The less these contents, the better the calorific value. The low heating values recorded in the studied coal result from its high moisture and low carbon content. Bustin *et al*. (1985) recommended 14499Btu/Ib for good metallurgical coal. Based on this recommendation, the coal is not good for metallurgical processes. However, it is suitable for combustibility.

Comparing the calorific values of the studied coal with other coal deposits, Ikpabacha coal contrasts with San Pedro bituminous coal in the USA that contains 12000 Btu/1b (Warwick and Hook, 1995) and Barakar anthracite in India that has 15700Btu/1b (Sethi, 2014). However, the coal is similar to Wyodak-Anderson sub-bituminous coal in the USA, which consists of 8220 Btu/1b (Stricker and Ellis, 1999). These comparisons, therefore, also placed Ikpabacha coal in sub-bituminous rank.

Free swelling index (FSI) is a traditional and quick measurement of a coal's overall coking characteristics. The coal samples have zero (0) swelling index. Coals are generally considered to have coking properties if their FSI is over four. The top of the scale is nine. This implies that Ikpabacha coal is unsuitable for coke manufacturing for metallurgical processes. The lower the free swelling index of steam coal, the higher the combustion efficiency. This also means that Ikpabacha coal with zero (0) free swelling index is suitable for heating and generation of electricity.

CONCLUSION

Proximate, ultimate, and calorific value analyses, as well as free swelling index test, revealed that Ikpabacha coal has high moisture, medium ash, high volatile matter, low carbon, high sulphur, low calorific values, and zero (0) free swelling index.

By comparing with high-ranking coals, these characteristics suggest that the studied coal is of low quality, non-coking, and sub-bituminous. Therefore, the coal cannot be used in the metallurgical industry to manufacture iron and steel. However, it is appropriate for electricity generation. The Federal Government should try and rejuvenate the coal mining industry and expand power generation by attracting foreign companies to develop large coal resources in the country including Ikpabacha coal and construct coal-fired generating plants that will connect to the country's electrical distribution grid.

The coal is good in heating boilers and ovens in industrial process heating. Cement, glass, ceramic, paper, brick, and other industries can use it for this purpose. However, in addition, combustion efficiency tests can as well be carried out on the coal for further determination of its suitability for heating.

RECOMMENDATIONS

The following recommendations are proposed for effective utilization of the coal:

- Geophysical investigations and drilling exercises should be undertaken to determine the thickness and continuity of the coal seams because it does appear that the Northern Anambra basin is underlain by large coal seams.
- Coal prospecting and mining operations are capital intensive. Therefore, the Federal government should endeavour to heavily fund coal exploration programmes in order to ensure its maximum exploration and utilization.
- The coal industry is recovering world-wide and many developed countries are reverting to the use of coal for power generation, the Federal government should strive to pay more attention to Ikpabacha coal and other deposits by building coal–based power stations of thousands of megawatts thereby replacing oil–fired and gas–fired power stations with coal–fired ones. Apart from longer life span, coal–fired stations have advantages of simple operation and cheap maintenance costs.

These will enhance the development of this coal deposit and other ones thereby leading to additional income per capital earnings and improved balance-of-payments position for Nigeria.

ACKNOWLEDGEMENT

We sincerely appreciate the Tertiary Education Trust Fund (TETFUND) for giving us an Institutional-Based Research (IBR) grant (CUSTECH/DRID/ADMIN/IBR/TETF/2024/VOL.2.9). The Management of Confluence University of Science and Technology, Osara is also gratefully acknowledged for the approval given for the release of the grant.

COMPETING INTERESTS

The authors declare no conflict of interest.

REFERENCES

Akpabio, I. O., Chagga, M. M. & Jauro, A. (2008). Assessment of some Nigerian coals for metallurgical applications. *Journal of Minerals and Materials Characterization Engineering,* 7:301 – 306.

ASTM (1987). Gaseous fuel; coal and coke. Petroleum products, lubricants and fossil fuels. Easton, MD, USA., Vol 05.05, pp. 278 – 282.

ASTM (2013). Standard practice for preparing coal samples for analysis. 6p.

Averitt, P. (1974). Coal resources of the United States, U.S Geological Survey. Nigerian coals; A resources for energy and investments, Raw Materials Research and Development Council, Abuja, 89 – 105.

Beamish, B. B. (1994). Proximate analysis of New Zealand and Australia coals by thermogravimetry. *New Zealand Journal of Geology and Geophysics*. 37:4, 387 – 392.

Bustin, R. M., Cameron, A. R., Greve, D. A. & Kalkreuth, W. D. (1985). Coal petrology. Its principles, methods and applications. Geological Association Canada. Short Course Notes. 230p.

Chen, P. & Ma, J. (2002). Petrographic characteristics of Chinese coals and their applications in coal utilization processes. Fuel, 81:1389 – 1395.

Cheng, Q. (2019). The contribution of bacteria to organic matter in coal-measure source rocks. Acta Geochimica. 38(3):364 – 375.

Chukwu, C. J., Obasi, N. A., Jauro, A., Ezeribe, A. I., Nwachuckwu, C. B. & Putshak, J. D. (2012). Physical and plastic properties of three Nigerian coals. *Asian Journal of Materials Science,* 4: 45 – 51.

Diez, M. A., Alvarez, R. & Barriocanal, C. (2002). Coal for metallurgical coke production: Production of coke quality and future requirements for coke making. *International Journal of Coal Geology,* 50: 389 – 412.

Drakeley, T. J. (2014). The ultimate composition of British coals. University of Chicago.238 p.

Dwiredi, A. & Kumar, A. (2022). Investigation of the ultimate and proximate analysis of coal samples from the Singrauli coalfield, India. *International Journal of Current Science Research and Review.* 5(1):198 – 202.

Fatoye, F. B., Gideon, Y. B. & Omada, J. I. (2020). Maceral characterization of the Cretaceous Effin–Okai coal deposit in Northern Anambra Basin, Nigeria. *Communication in Physical Sciences,* 5(3): 223–232.

Fatoye, F. B. & Ibitomi, M. A. (2021). Quality evaluation of Udane–Biomi coal in the Northern Anambra Basin of Nigeria. *Communication in Physical Sciences*, 7(4):444–453.

Gunn, P., Gunn, A. & Mackenzie, H. (2012). Advanced coal science. Coal arketing International Ltd.

MacDonald, J. G., Burton, C. J., Winstanley, I. & Lapidus, D. F.(2011). Collins Internet-Linked Dictionary of Geology. Leaning Solutions Specialty Publications Ltd., an Imprint of Rombic Concepts Ltd., 480p.

Ministry of Solid Minerals Development, (2008). Coal – exploration opportunities in Nigeria. Ministry of Solid Minerals Development in Conjunction with Nigerian Geological Survey Agency, 4 – 7.

Nehikhare, J. I. (1987). Minerals and industry in Nigeria. Geological Survey Department. 2nd Edition, 18 – 23.

Obaje, N. G. (1997). Petrographic evaluation of the coking potential of the Cretaceous Lafia-Obi coal deposits in the Benue Trough of Nigeria. *Journal of Mining and Geology*, 43:4 – 7.

Obaje, N. G., Ulu, O. K. & Petters, S. W. (1999). Biostratigraphic and geochemical controls of hydrocarbon prospects in the Benue Trough and Anambra Basin, Nigeria. *NAPE Bulletin*, 14:18–54.

Rasheed, M. A., Srinivasa Rao, P. L., Boruah, A., Hasan, S. Z., Patel, A., Velani, V. & Patel, K. (2015). Geochemical characterization of coals using proximate and ultimate analysis of Tadkeshwar coals, Gujarat. *Journal of Geosciences. Scientific and Academic Publishing.* 5(4):113 – 119.

Sethi, A. (2014). Information on raniganj coalfield. Important India. www.importantindia.com

Stricker, G. D. & Ellis, M. S. (1999). Coal quality and geochemistry, powder River Basin, Wyoming and Montana. 1999 resource assessment of selected Tertiary coal beds and zones in the Northern Rocky Mountains and Great Plains Region: In U. S. Geological Survey Professional Paper 1625 – A.

Thomas, L. (2002). Coal Geology. John Wiley and Sons Ltd; 384 p.

Umeji, O. P. (2005). Palynological study of the Okaba coal mine section in the Anambra Basin, Southern Nigeria. *Journal of Mining and Geology*. 41(2) pp. 194.

Warwick, P. D. & Hook, R. W. (1995). Petrography, geochemistry, and depositional setting of the San Pedro and Santo Tomes Coal Zones: Anomalous algae-rich coals in the middle part of the Claiborne Group (Eocene) of Webb County Texas. *International Journal of Coal Geology*, 28(2):303 – 342.

Zhao, Q., Niu, Y., Xie, Z., Zhang, K., Zhou, J. & Arbuzov, S. (2019). Geochemical characteristics of elements in coal seams 4_1 and 4_2 of Heshan coalfield, South China. Energy Exploration and Exploitation, 38, 1, pp. 137 – 157.