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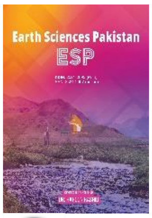

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RESEARCH ARTICLE

GEOLOGY AND GEOCHEMICAL STUDIES OF THE CRETACEOUS OKOBO COAL DEPOSIT, ANAMBRA BASIN, NIGERIA

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ABSTRACT

Coal consists of mainly organic materials and minor inorganic constituents. These components determine coal's possible value in the metallurgical, power generation, and other sectors. Coal is one of the most affordable and dependable energy sources used to produce electricity globally. Geological mapping of Okobo coal in the Anambra Basin of Nigeria was carried out and coal samples taken and subjected to proximate analysis, ultimate analysis, calorific value determination, and free swelling index test in order to source coking coals for metallurgical industries and thermal coals for power generation in the nation. The average composition of the coal, according to the results of the proximate analysis, is 11.94% moisture, 5.66% ash, 36.73% volatile matter, and 45.67% fixed carbon. The ultimate analysis also showed that the average composition of coal is as follows: 60.20% carbon, 4.46% hydrogen, 1.59% nitrogen, 15.52% oxygen, 0.65% sulphur, and 0.027% phosphorus. The coal samples have an average heating (calorific) value of 10452 Btu/1b (24311 kj/kg) and a free swelling index (FSI) of zero (0). These traits imply that coal is non-coking and unsuitable for use in the production of iron and steel in the metallurgical sector. The coal, however, is suitable for boilers, industrial heating ovens, and the production of power.

KEYWORDS

Okobo Coal, Geochemistry, Low Quality, Non-coking, Sub-bituminous.

1. INTRODUCTION

Coal is a combustible organic sedimentary rock that is rich in carbon. It is made up of decayed and/or altered non marine plant remains, together with small amounts of inorganic material (MacDonald et al., 2011). The long-term buildup of plant matter in a marshy environment created what is now coal millions of years ago as peat. After then, the peat underwent physical and chemical transformations to become coal. Coal can be dull, bright, or lustrous, and its colour can range from brown to black. It is typically heavily layered or banded, brittle, and non-crystalline.

Nigeria possesses huge coal reserves. The Anambra Basin and the Benue Trough (Lower, Middle, and Upper) contain the majority of the nation's coal resources. Nigeria's greatest and most economically viable coal resources, however, are found in the coal deposits in the Anambra Basin (Fatoye et al., 2020). The coals found in Nigeria are sub-bituminous (black coals) of Cretaceous age and lignites (brown coals) of Tertiary age. The only coking coal found in the country to date, however, is the Obi/Lafia coal deposit in the Middle Benue Trough, which contains 22 million tonnes of reserves (Obaje, 1997). The geological age of coal generally determines its quality; hence, Nigerian coals are of lower grade than the older Carboniferous coals found in Europe and America (Nehikhare, 1987).

In addition to being used to generate power, coal can be used to make coke for metallurgical processes and as a chemical feedstock to create a variety of synthetic compounds, including colours, oils, and waxes. Boilers and ovens are heated using it in industrial process heating. Gas and vehicle fuel are produced using coal.

Briquettes, boiler fuel, high calorific gas, residential heating, and a range of chemicals such as waxes, resins, adhesives, and dyes can all be made from Nigerian coals. Because of their low levels of ash and sulphur, as well as their poor thermoplastic properties, Nigerian sub-bituminous coals are useful for energy production (MSMD, 2008). Obi/Lafia coal in Nasarawa State can be used to make metallurgical-pure coke.

Sadly, despite coal's significance for industrial progress, the nation uses it sparingly. One significant sector that has the power to alter the economic and energy fortunes of the country is the coal industry. Its capacity for expansion and advancement is increasing.

Various studies on the chemical composition of the coal deposits in the Mamu Formation in the Anambra Basin have been published by a number of authors. The geochemical properties of the Okobo coal deposit, however, are poorly understood. Geochemical analysis can provide valuable information about a coal's quality and possible applications (Zhao et al., 2019).

In order to ascertain the coal's potential for use, particularly in metallurgical processes and the production of electricity, this study aims to examine the geological and geochemical characteristics of Okobo coal in Anambra Basin of Nigeria.

1.1 Study Area Location

Okobo coal deposit is located south of Okaba coal mine about 12km east of Ankpa town in Ankpa Local Government Area of Kogi State (Figure 1). The coal deposit is situated on Latitude 70 30' 24.1'' N and Longitude 70 42' 38.8'' E.

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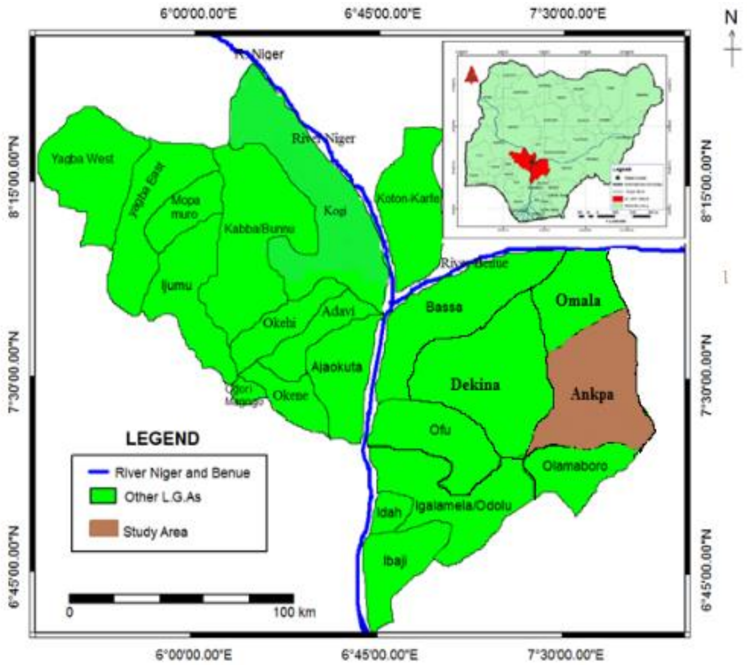

Figure 1: Map showing location of the study area

1.2 Regional Geological Setting

Stratigraphic sequence in the Anambra Basin began with the primarily marine shales of the Nkporo Formation (Campanian), which was followed by the Mamu Formation (Maastrichtian), composing of coals, mudstones, and sandstones. Located on the Mamu Formation, the fluviodeltaic sandstones of the Ajali Formation (Upper Maastrichtian) make up the majority of its lateral counterparts. The succession in the Anambra Basin is then completed by a paralic coaly series of the Nsukka Formation (Paleocene) (Nwajide and Reijers, 1996; Obaje et al., 1999; Umeji, 2005).

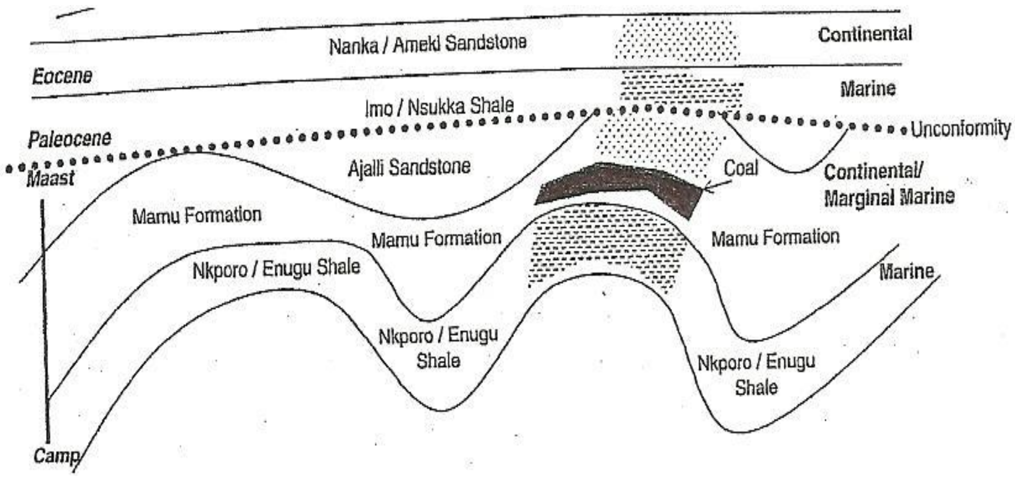

Figure 2: Stratigraphic sequence in the Anambra Basin (Obaje, 2009).

2. Materials and Methods

2.1 Field Work, Sample Collection and Preparation

In order to create a geological map and collect coal samples for analytical research on the study area, geological mapping was done around Okobo village and the surrounding area. Traverses were made throughout the whole area. Rock types, seam thickness, the sample locations and geographical coordinates were noted at each outcrop that was visited. Ten coal samples were collected from coal outcrops in the Okobo coal deposit and stored in airtight bags in order to preserve their original state. The American Standard for Testing Materials, ASTM D2013 was followed for preparing the samples. All sample analyses were performed at Mineral Laboratory, Kentucky, USA.

2.2 Proximate Analysis

Proximate analysis is essential in order to assess the quality of coal and its applicability for a range of uses, including metallurgical processes and power production. The calorific value and overall performance of the coal are directly impacted by the information proximate analysis provides regarding the moisture, ash content, volatile matter, and fixed carbon content. The ASTM D3172–73 (2013) was used to do the proximate analysis.

2.2.1 Determination of Moisture Content

A previously dried crucible was placed in an oven set at 105^{o}C for 3 hours, and 1.00g of pulverized coal was sprinkled lightly on it. The moisture content was determined by comparing the weight before and after the interval.

2.2.2 Determination of Ash Content

A sample of pulverized coal weighing 1.00g was placed in a platinum crucible and heated to 750^{o}C for 2 hours in a muffle furnace until the weight remained constant. By comparing the weight before and after burning, the amount of ash was determined.

2.2.3 Determination of Volatile Matter Content

A 1.00g sample of crushed coal was placed within a 10ml platinum crucible. After it had burned for 7 minutes at 950^{o}C in a muffle furnace, the sample was taken out, allowed to cool, and then reweighed to determine the weight loss, which was calculated as the percentage of volatile matter.

2.2.4 Determination of Fixed Carbon Content

The fixed carbon content was determined as the difference between 100 and the entire sum of the volatile compounds, ash, and moisture.

2.3 Ultimate Analysis

Ultimate analysis is used in determining the elemental composition of coal, which includes carbon, hydrogen, nitrogen, oxygen, and sulphur. These elements are crucial for comprehending the characteristics, combustion behaviour, and uses of coal.

2.3.1 Determination of Carbon and Hydrogen Content

1.00g of coal was burned in oxygen current to convert the C and H into CO_2 and H_2O, respectively. After the combustion products (CO_2 and H_2O) were passed over weighted tubes of anhydrous $CaCl_2$ and KOH, carbon dioxide and water were absorbed. While the weight difference of the $CaCl_2$ tube was used to determine the weight of water formed, the weight difference of the KOH tube showed the weight of carbon dioxide produced. The proportions of carbon and hydrogen were then calculated. ASTM D5373-08 was used to determine carbon and hydrogen.

2.3.2 Determination of Nitrogen Content

Kjeldahal's method, 1.00g of pulverized coal was heated with concentrated H_2SO_4. With the addition of potassium and copper sulphates in a long-necked flask, the nitrogen in the coal was transformed into ammonium sulphate. When a clear solution was obtained, a 50% NaOH solution was added. A known volume of a standard sulphuric acid solution was used to absorb and distill the resultant ammonia. The amount of unused H_2SO_4 was then determined by titrating against a standard NaOH solution. Thus, it was determined how much acid the released ammonia neutralized.

2.3.3 Determination of Oxygen Content

The oxygen content was calculated by subtracting the amounts of carbon, hydrogen, nitrogen, sulfur, moisture, and ash from 100%.

2.3.4 Determination of Sulphur Content

The high-temperature combustion test method was used to determine the quantity of sulphur in a 1.00g sample of coal with a particle size of 0.2 mm by heating it to 800°C with a mixture of MgO and anhydrous Na_2CO_3. The amount of sulphur in the mixture precipitated as sulphate after burning and was kept as oxides. The resultant sulphate precipitated as $BaSO_4$ upon treatment with $BaCl_2$. The amount of sulphur in coal was calculated using the weight of the coal sample and the weight of the $BaSO_4$ precipitate that was produced.

2.3.5 Determination of Phosphorus Content

1.00g of coal ash was treated with a hot solution of HNO_3, H_2SO_4, and HF acids in order to determine the amount of phosphorus in the coal sample. The complex phospho-molybdate that was produced when the phosphate volatilized and the phosphorus dissolved was used to determine the phosphorus concentration.

2.4 Calorific Value Analysis

The calorific value of the coal was determined using a bomb calorimeter. Electrical energy ignited the coal, and as it burned, the surrounding air expanded and escaped through a tube from the calorimeter. The water outside the tube also heated when the air escaped through it. The calorific content of the coal was then ascertained by carefully measuring the temperature change of the water using a thermometer.

2.5 Free Swelling Index Test

A dry platinum crucible filled with 10.00g of finely ground coal was placed in a muffle furnace that was adjusted to 800°C for 2 hours until all volatiles were eliminated. The cooled coke "button" cross-section was compared to a set of reference profiles (chart) in order to determine the free swelling index.

3. Results and Discussion

3.1 Geology of the Study Area

The geographical co-ordinates of sample locations taken were used to produce a geological map of the study area (Figure 3).

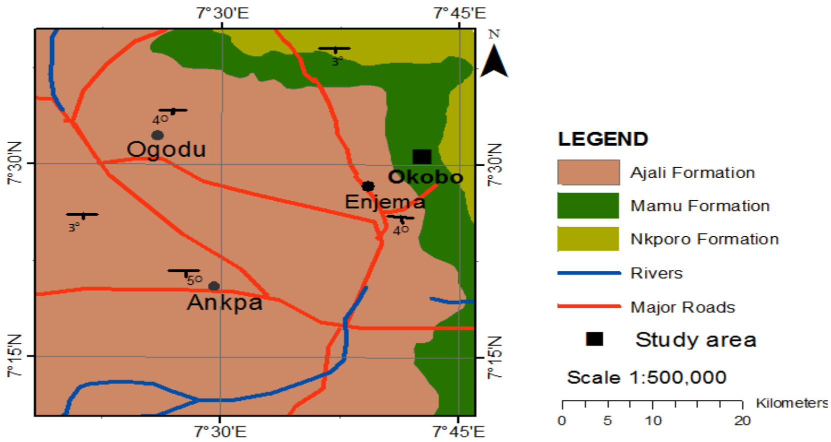

Figure 3: Geological map of the study area

Stratigraphical analysis of the coal formation's sedimentary sequence revealed that the coal is part of the Mamu Formation, a sequence of paralic sandstones, shale, and coals (Figure 4). The coal seam is black, shiny, hard, and banded, and it is between 1.0 and 1.5 m thick. Below it is a layer of clay that is about 0.3 m thick, and above it is a layer of shale that is about 2.0 m thick and intercalated with clay (Figure 5). The overburden associated rocks have been excavated (Figure 4).

Figure 4: Part of Okobo coal mine

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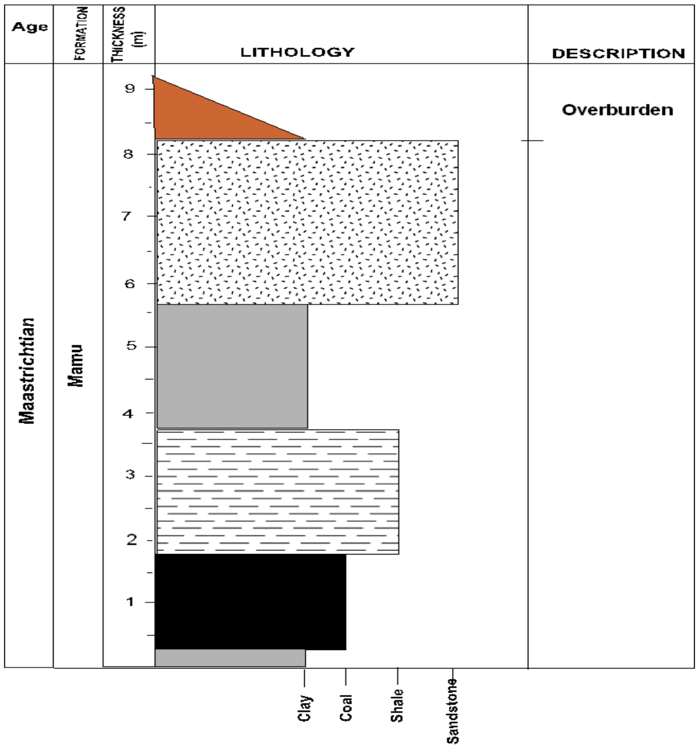

Figure 5: Lithologic segment of the Mamu Formation at Okobo coal mine

Table 1: Results of proximate analysis of Okobo coal samples

Sample Number	Moisture Content (%)	Ash Content (%)	Volatile Matter Content (%)	Fixed Carbon Content (%)
Okobo 1	11.94	5.06	36.47	46.53
Okobo 2	11.94	6.26	36.99	44.80
Okobo 3	12.46	4.85	36.29	46.40
Okobo 4	11.87	5.32	36.97	45.84
Okobo 5	11.77	6.35	37.02	44.86
Okobo 6	12.35	4.98	36.33	46.43
Okobo 7	11.97	5.61	36.59	45.83
Okobo 8	10.88	6.76	37.64	44.72
Okobo 9	12.42	5.50	36.17	45.91
Okobo 10	11.80	5.91	36.82	45.47
Average	**11.94**	**5.66**	**36.73**	**45.67**
X	**11.50**	**3.60**	**41.60**	**54.80**
Y	**2.80**	**5.70**	**8.40**	**85.90**
Z	**4.50**	**31.10**	**20.00**	**44.40**

X: Ohai coal, (New Zealand), Sub-bituminous coal (after Beamish, 1994)

Y: Yarrabee coal, (Indonesia), Bituminous coal (after Beamish, 1994)

Z: Singrauli coal, (India), Bituminous coal (after Dwiredi and Kumar, 2022)

Moisture is an undesirable component since it lowers the calorific value of coals. The moisture content of 11.94% in the investigated coal (Table 1) is higher than the 1.5% threshold needed for coking coals (Obaje, 1997; Jauro, 2011; Ryemshak and Jauro, 2013). However, it falls within the range of 30% moisture content recommended for thermal coals used to produce electricity (Gun et al., 2012). Coal needs to have low moisture content since high moisture content lowers its heating value.

Since ash lowers coal's fixed carbon content, which in turn lowers its calorific value, coal must also contain a small amount of ash. Boiler slagging and fouling are caused by coal's high ash concentration (ASTM, 1987). For industrial uses, coal with less ash is preferable. The coal under examination has an ash concentration of 5.66%, which is within the 10% range needed for high-quality metallurgical coals (Averitt, 1974; Bustin et al., 1985; Akpabio et al., 2008; Ryemshak and Jauro, 2013). Additionally, the indicated value is within the safe range of 40% required for steam coals suitable for power generation, according to (Thomas, 2002).

Compared to the suggested ratings of 27.70 to 30.30% volatile matter content needed for a suitable coking coal, the value of 36.73% volatile matter content found in the investigated coal (Table 1) is higher (Adeleke et al., 2011). Additionally, the value exceeds the 20–25% ratings that are advised for steam coals used to generate electricity (Thomas, 2002; Onyemali et al., 2017).

The moisture content of coal determines its fixed carbon content. A coal's fixed carbon content increases with decreasing moisture content and vice versa. The coal under study has a high moisture content (11.94%), which contributes to its low fixed carbon content of 45.67% (Table 1). During carbonization, a high carbon concentration is necessary to produce coke (Diez et al., 2002). The quality of a coal is positively correlated with its fixed carbon concentration.

When comparing the proximate properties of the examined coal to those of other coals (X, Y, Z in Table 1), the results show a discrepancy with the values known for high rank coals. Nonetheless, the results are comparable to low rank sub-bituminous coals' known values (Table 1).

Table 2: Results of ultimate analysis of Okobo coal samples					
Sample Number	**Carbon Content (%)**	**Hydrogen Content (%)**	**Nitrogen Content (%)**	**Oxygen Content (%)**	**Sulphur Content (%)**
Okobo 1	60.96	4.40	1.58	15.41	0.65
Okobo 2	59.43	4.52	1.59	15.62	0.64
Okobo 3	59.80	6.60	1.53	15.91	0.66
Okobo 4	60.15	4.44	1.58	15.81	0.67
Okobo 5	60.91	4,42	1.62	15.42	0.64
Okobo 6	60.68	4.51	1.67	14.87	0.64
Okobo 7	59.97	4.57	1.55	15.97	0.66
Okobo 8	60.23	4.53	1.61	15.86	0.65
Okobo 9	60.54	4.34	1.57	15.40	0.64
Okobo 10	59.33	4.27	1.60	14.94	0.65
Average	**60.20**	**4.46**	**1.59**	**15.52**	**0.65**
X	**76.36**	**5.95**	**0.81**	**10.46**	**0.71**
Y	**76.44**	**4.90**	**1.53**	**13.78**	**0.83**
X	**87.73**	**4.78**	**1.09**	**7.52**	**1.28**

X: Okaba coal, (Nigeria), Sub-bituminous coal (after Fatoye *et al*., 2012)

Y: Leicester-Shire coal (Britain), Sub-bituminous coal (after Drakeley, 2014)

Z: Durham coal (Britain), Bituminous coal (after Drakeley, 2014)

Along with hydrogen and oxygen, carbon is one of the main elements that make up coal. The kind of coal and its geological history determine the element's concentration. For industrial applications, coal with high carbon content must have a high heating value and be of superior quality. The examined coal's carbon content of 60.20% (Table 2) is less than the 75–90% carbon ratings for coking coals suggested by (Stach et al., 1982).

The grade of iron is negatively impacted by coal's high oxygen concentration. Consequently, a coal's quality improves with decreasing oxygen content. The oxygen content of 15.52% found in the coal under study (Table 2) falls below the 20% oxygen limit set for coking and thermal coals (Stach et al., 1982; Gunn et al., 2012).

Sulphur and phosphorus are two components that have a detrimental effect on the quality of steel and other coal-based goods. For example, they lead to the production of brittle steel and reduce the efficiency of boilers by creating slagging and fouling. They also lead to boiler corrosion. The investigated coal's 0.65% sulphur content (Table 2) is below the 1.5–1.6% sulfur content levels needed to make coke (Ryemshak and Jauro, 2013). They even advocate a lower maximum sulphur level of 1.0% while manufacturing coke (Stach et al., 1982; Bustin et al., 1985).

The coal under study is comparable to sub-bituminous coals with known values (X and Y in Table 2) and different from higher rank coals with known values (Z in Table 2) when compared to other coals based on its final characteristics (Table 2).

Table 3: Results of calorific value analysis of Okobo coal samples		
Sample Number	**Calorific Value**	
	Btu/1b	**kj/kg**
Okobo 1	10547	24532
Okobo 2	10356	24088
Okobo 3	9997	23253
Okobo 4	9997	23253
Okobo 5	10846	25228
Okobo 6	10802	25125
Okobo 7	10334	24036
Okobo 8	10551	24542
Okobo 9	10718	24930
Okobo 10	9876	22972
Average	**10452**	**24311**
X	**8044**	**18709**
Y	**12000**	**27912**
X	**15700**	**36518**

X: Kideco Jaya Agung coal (Indonesia), Sub-bituminous coal (after Rahman et al., 2020)

Y: San Pedro coal (USA), Bituminous coal (after Warwick and Hook, 1995)

Z: Barakar coal (India), Anthracite (after Sethi, 2014)

The quantity of heat emitted during coal combustion is known as the calorific value (CV) of coal. Coal's ash, moisture, and mineral matter contents all affect how much heat or calorific value it has. The higher the calorific value, the lower these contents are. The coal under investigation has a low heating value of 10452 Btu/1b (Table 3), which is lower than the minimum value of 14499 Btu/1b required for good metallurgical coals but above the 8500 Btu/1b required for heating coals (Wendy, 2017; Bustin et al., 1985).

In contrast to bituminous coal and anthracite of known values, the examined coal is comparable to sub-bituminous coal of known value when its calorific values are compared to those of other coal deposits (Table 3).

A conventional and rapid way to gauge the general coking properties of a coal is to use the free swelling index (FSI). The swelling index of the coal samples is zero (0). If a coal's FSI is more than four (4), it is generally regarded as having coking qualities. Nine (9) is the highest number on the scale. This suggests that the coal is not appropriate for metallurgical procedures that require the production of coke. The combustion efficiency of steam coal increases as its free swelling index decreases. Additionally, Okobo coal with a free swelling index of zero (0) is appropriate for both heating and electricity production.

4. Conclusion

Okobo coal, located in the Anambra Basin of Nigeria has been subjected to geological and geochemical investigations. According to geological field research, the coal is found in the Mamu Formation, which is a series of coals, sandstones, and shales. The coal seam is dark, hard, shiny and layered. It is between 1.0 and 1.5 meters thick.

According to the results of the proximate, ultimate, calorific value and free swelling index studies, the coal has high moisture content, low carbon content, low calorific value, and zero (0) free swelling index. The high moisture content of 11.94% recorded in the studied coal suggests that the coal is immature because of its low degree of coalification. High moisture coals are unsuitable for coke production and electricity generation (Ryemshak and Jauro, 2013). The low calorific value of 10452 Btu/1b obtained in the coal is as a result of its low carbon (60.20%) and high moisture (11.94%) levels. In addition to producing brittle steel, the high moisture content of the coal will cause furnace slagging and fouling, which will reduce furnace efficiency. As a result, the furnaces will corrode. When compared to high rank coals, these characteristics suggest that the coal is sub-bituminous, low grade, and non-coking. Consequently, Okobo coal is therefore not appropriate for making coke for use in metallurgical processes. However, it can be used to produce electricity. Coal can be used in industries to heat ovens and boilers used in production processes. Additional testing on the coal's metallurgical and combustion efficiency can be carried out to ascertain its suitability for these and other operations.

Conflicts of Interest

No conflicts of interest are disclosed by the writers.

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