Quality Assessments and Industrial Usages of Cretaceous Okaba Coal, Anambra Basin, Nigeria

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Abstract

Quality assessments have been carried out on coal samples from Okaba in the Anambra Basin of Nigeria principally to determine its mineralogical composition, chemical characteristics and its cokability or otherwise. The Okaba coal, on the average, contains 4.53% clay minerals, 6.18% pyrite, 2.94% carbonate and 1.66% quartz, and (by difference from 100) contains 84.70% macerals. Chemical analysis indicates that the coal, on the average, contains 12.51% moisture, 11.48% ash, 47.49% volatile matter and 28.53% fixed carbon. It contains 0.71% sulphur, 76.36% organic carbon, 5.95% hydrogen, 0.81% nitrogen, 10.46% oxygen, and 0.05% phosphorus, and has a low free swelling index (FSI) of 0.5. These characteristics indicate that Okaba coal is non-cokable and not suitable for use in the generation of heat for the working of blast furnace for iron smelting. However, it is suitable for electric power generation and as a domestic fuel. Okaba coal is also rich in resinous and waxy materials, and is therefore, a suitable raw material for the chemical industry and in the manufacture of plastics, when fractionally distilled.

Introduction

Geological exploration for oil and coal led to the discovery of coal in the Mamu Formation (formerly called the 'Lower Coal Measures') of the Anambra sedimentary Basin of south-eastern Nigeria (Simpson, 1954). With test drillings and, later, mining operations in Enugu, the Formation became the subject of many reports. Simpson (1954) noted a distinctive sequence of sandstones, shales and mudstones with coal at many levels. The shales and mudstones often alternate with thin bands and lenses of siltstones to form a characteristic “striped” rock. De Swardt et al. (1963) reported the occurrence of rhythms in the Mamu Formation around Enugu where the Formation is more sandy; it becomes more shaly and thicker at Okaba and Odókpono. They also reported the occurrence of coals in the Nsukka Formation (formerly called the 'Upper Coal Measures'), located 4 miles north of Okaba town.

Coal beds are widely deposited within the sedimentary succession of the Benue Trough of Nigeria (Obaje, 1994). Significant amongst these coal deposits are those within the Mamu Formation in the Okaba area of the Lower Benue Trough.

An open cast mining of the Okaba coal was embarked upon in 1997, by the Nigerian Coal Corporation. The stripping of the overburden to the coal seam exposed some 20 metres of beds which this study is based. Little published work on quality assessment exists for the Okaba coal. The purpose of this work is to assess the quality of the Okaba coal its relevance to possible industrial usages.

Stratigraphy

The Campanian Maastrichtian stratigraphic succession in the Anambra Basin begins with Nkpоро Formation, which is predominantly marine shales of Campanian age overlain by the Mamu Formation (Early to Late Maastrichtian), paralic sandstones, mudstones and coals. The Ajali Formation (Middle to Late Maastrichtian) a sandy tidal deposit lies above and the Late Maastrichtian to Danian Nsukka Formation, also a paralic coaly sequence completes the succession (Obianuju, 2005).

Uméji (2002), subdivided the Mamu Formation into three lithologic units which are: i). black carbonaceous marine shales which are overlain by more sandy units (shore face deposits), showing typical heterolithic wave rippled, flaser bedded, fine, white sandstones interlaminated with dark or grey mudstones; ii). the coal-bearing facies; iii). an upper unit composed of fine to medium-grained sandstone, with climbing ripple-lamination. The studied section lies within the upper part of the coal-bearing facies.
Sampling and Sample Preparation

Eight sample sites were selected from the opencast mines of Okaba coal deposit for this study. A bulk sample of approximately 300g of coal was collected from each of the eight locations and sealed in polythene bags for transport to the laboratory for analysis. From each bulk sample, approximately 100g of coal was hand picked for petrographic studies and another 100g for proximate and ultimate analyses. The remaining bulk sample was used for Free Swelling Index test.

All samples were initially crushed and pulverized, and a representative split was taken for petrographic analysis. Samples for proximate and ultimate analyses were crushed in a rotary mortar and sieved through a 0.425mm size sieve, while samples for petrographic studies were crushed and prepared in a cylindrical mould of dimension 2cm x 4cm. This was done by filling the moulds containing the crushed samples with epoxy, followed by curing and polishing with automatic grinders. Proximate and ultimate analyses and free swelling index were done based on ASTM standard (1992).
**Mineralogy**

Coal, is organic in origin; however, it contains some inorganic matters called macerals. Most of the macerals contained in coal occur in the form of mineral inclusions, and they constitute the bulk of the non-combustible portion of coal which, on burning are left behind as ash (Diesel, 1992). Petrographic analysis of Okaba coal (Table 1) however, indicates all of the samples contain, on the average 15.31% minerals and, by difference from 100, 84.70% macerals. The mineral composition on the average is made up of 4.53% clay minerals (particularly illite and kaolinite), 6.18% pyrite, 2.94% carbonate and 1.66% quartz. According to Diesel (1992), most of the clay and quartz minerals in coal were added to the coal deposit by wind or ground water during the coal forming process. Many of these minerals occur in close association with the coal matrix either as infillings of cleats and cell lumens or as partial metasomatic replacement of organic matter (Beeston, 1981), while others are concentrated in concretions, lenses or dirt bands (Davis, 1992).

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Clay Minerals (%)</th>
<th>Pyrite (%)</th>
<th>Carbonate (%)</th>
<th>Quartz (%)</th>
<th>Minerals (%)</th>
<th>Macerals (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>3.40</td>
<td>7.10</td>
<td>3.80</td>
<td>0.80</td>
<td>15.10</td>
<td>84.90</td>
<td>100</td>
</tr>
<tr>
<td>C2</td>
<td>2.30</td>
<td>3.30</td>
<td>3.10</td>
<td>1.40</td>
<td>10.10</td>
<td>89.90</td>
<td>100</td>
</tr>
<tr>
<td>E1</td>
<td>7.00</td>
<td>5.70</td>
<td>1.30</td>
<td>3.40</td>
<td>17.40</td>
<td>82.60</td>
<td>100</td>
</tr>
<tr>
<td>E2</td>
<td>2.20</td>
<td>4.00</td>
<td>2.50</td>
<td>0.80</td>
<td>9.50</td>
<td>90.50</td>
<td>100</td>
</tr>
<tr>
<td>N1</td>
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<td>82.30</td>
<td>100</td>
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<td>W1</td>
<td>5.00</td>
<td>7.20</td>
<td>3.00</td>
<td>1.40</td>
<td>16.60</td>
<td>83.40</td>
<td>100</td>
</tr>
<tr>
<td>W2</td>
<td>4.10</td>
<td>6.30</td>
<td>2.10</td>
<td>2.70</td>
<td>15.20</td>
<td>84.80</td>
<td>100</td>
</tr>
<tr>
<td>Average %</td>
<td>4.53</td>
<td>6.18</td>
<td>2.94</td>
<td>1.66</td>
<td>15.31</td>
<td>84.70</td>
<td>100</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.40</td>
<td>88.60</td>
<td>100</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.60</td>
<td>95.40</td>
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<td>Z</td>
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<td></td>
<td></td>
<td></td>
<td>1.30</td>
<td>98.70</td>
<td>100</td>
</tr>
</tbody>
</table>

X: Bokaro (India) sub-bituminous coal (after Laxminarayana et al; 2002)
Y: Newcastle (England) bituminous coal (after Jensen et al; 1982)
Z: South Wales (Britain) anthracite (after Jensen et al; 1982)
C1 C2: This study.

**Geochemistry**

**Organic Chemistry**

Proximate analysis of Okaba coal (Table 2) shows that the coal, on the average, contains 12.51% moisture, 11.48% ash, 47.49% volatile matter and 28.53% fixed carbon.

**Inorganic Chemistry**

Ultimate analysis (Table 3) shows that Okaba coal, on the average, contains 76.36% carbon, 5.95% hydrogen, 10.46% oxygen, 0.81% nitrogen, 0.71% sulphur, and 0.05% phosphorus.

Free swelling index (FSI) is a traditional and quick measurement of a coal's overall coking characteristics. According to Blackmore (1985), coals are generally considered to have coking properties if their FSI is over four (4). However, coals that are classified as metallurgical coals generally have a FSI of seven (7) or more (the top of the scale is nine). Based on this rating, Okaba coal, with FSI of 0.5 on the average, does not possess metallurgical quality.
Table 2: Summary Table of Proximate Analysis Results.

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Moisture Content (%)</th>
<th>Ash Content (%)</th>
<th>Volatile Matter (%)</th>
<th>Fixed Carbon (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>12.90</td>
<td>11.20</td>
<td>48.25</td>
<td>27.65</td>
<td>100.00</td>
</tr>
<tr>
<td>C2</td>
<td>13.20</td>
<td>10.60</td>
<td>47.35</td>
<td>28.85</td>
<td>100.00</td>
</tr>
<tr>
<td>E1</td>
<td>12.70</td>
<td>11.40</td>
<td>47.10</td>
<td>28.80</td>
<td>100.00</td>
</tr>
<tr>
<td>E2</td>
<td>13.00</td>
<td>10.80</td>
<td>48.40</td>
<td>27.80</td>
<td>100.00</td>
</tr>
<tr>
<td>N1</td>
<td>11.80</td>
<td>12.10</td>
<td>46.65</td>
<td>29.45</td>
<td>100.00</td>
</tr>
<tr>
<td>N2</td>
<td>12.60</td>
<td>11.50</td>
<td>47.55</td>
<td>28.35</td>
<td>100.00</td>
</tr>
<tr>
<td>W1</td>
<td>11.50</td>
<td>12.30</td>
<td>46.85</td>
<td>29.35</td>
<td>100.00</td>
</tr>
<tr>
<td>W2</td>
<td>12.40</td>
<td>11.90</td>
<td>47.75</td>
<td>27.95</td>
<td>100.00</td>
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<tr>
<td>Average %</td>
<td>12.51</td>
<td>11.48</td>
<td>47.49</td>
<td>28.53</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 3: Summary Table of Ultimate Analysis Results

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Carbon (%)</th>
<th>Hydrogen (%)</th>
<th>Oxygen (%)</th>
<th>Nitrogen (%)</th>
<th>Sulphur (%)</th>
<th>Phosphorus (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>75.05</td>
<td>6.45</td>
<td>11.00</td>
<td>0.91</td>
<td>0.76</td>
<td>0.06</td>
<td>94.23</td>
</tr>
<tr>
<td>C2</td>
<td>76.87</td>
<td>5.75</td>
<td>10.25</td>
<td>0.78</td>
<td>0.70</td>
<td>0.05</td>
<td>94.40</td>
</tr>
<tr>
<td>E1</td>
<td>76.42</td>
<td>5.98</td>
<td>10.28</td>
<td>0.80</td>
<td>0.71</td>
<td>0.05</td>
<td>94.23</td>
</tr>
<tr>
<td>E2</td>
<td>75.51</td>
<td>6.45</td>
<td>10.92</td>
<td>0.85</td>
<td>0.74</td>
<td>0.06</td>
<td>94.53</td>
</tr>
<tr>
<td>N1</td>
<td>77.76</td>
<td>5.23</td>
<td>10.08</td>
<td>0.73</td>
<td>0.64</td>
<td>0.04</td>
<td>94.48</td>
</tr>
<tr>
<td>N2</td>
<td>76.37</td>
<td>6.09</td>
<td>10.34</td>
<td>0.81</td>
<td>0.73</td>
<td>0.05</td>
<td>94.39</td>
</tr>
<tr>
<td>W1</td>
<td>77.26</td>
<td>5.55</td>
<td>10.22</td>
<td>0.75</td>
<td>0.66</td>
<td>0.05</td>
<td>94.49</td>
</tr>
<tr>
<td>W2</td>
<td>78.62</td>
<td>6.10</td>
<td>10.55</td>
<td>0.83</td>
<td>0.74</td>
<td>0.06</td>
<td>93.90</td>
</tr>
<tr>
<td>Average %</td>
<td>76.36</td>
<td>5.95</td>
<td>10.46</td>
<td>0.81</td>
<td>0.71</td>
<td>0.05</td>
<td>94.33</td>
</tr>
</tbody>
</table>

x: Wyoming (USA) sub-bituminous coal (after Spath and Amos, 1995)
y: Newcastle (England) bituminous coal (Jensen et al, 1982)
z: South Wales (Britain) anthracite (after Jensen et al, 1982)
C1 C2: This study
Discussion

Comparing the mineral composition of 15.31% in Okaba coal with 4.60% in Newcastle (England) bituminous coal and 1.30% in South Wales (Britain) anthracite (Table 1), Okaba coal contains much inorganic matter. When compared with the Wyoming (USA) sub-bituminous coal that contains 16.6% moisture, 7.9% ash, 47.2% volatile matter and 28.3% fixed carbon (Spaeth et al., 1995), Okaba coal is sub-bituminous. Jensen et al. (1982) also gave values for Saar (Germany) sub-bituminous coal of 15.10% moisture, 12.35% ash, 46.10% volatile matter and 26.45% fixed carbon which is similar to those of Okaba coal samples (Table 2) thereby indicating sub-bituminous rank for Okaba coal. These characteristics contrast with Newcastle (England) bituminous coal that contains 4.31% moisture, 0.20% ash, 31.26% volatile matter and 64.23% fixed carbon and South Wales (Britain) anthracite which, according to Jensen et al. (1982), contains 3.51% moisture, 1.32% ash, 21.63% volatile matter and 73.90% fixed carbon. These values clearly indicate that Okaba coal is neither a bituminous coal nor an anthracite but a sub-bituminous coal.

Ultimate analysis (Table 3) shows that Okaba coal on the average, contains 76.36% carbon, 5.95% hydrogen, 10.46% oxygen, 0.81% nitrogen, 0.71% sulphur, and 0.05% phosphorous. These values are also similar to those of Wyoming (USA) sub-bituminous coal (Table 3), indicating that Okaba coal is sub-bituminous. Gross et al. (2003) also stated that Dietz (USA) coal that is rank sub-bituminous contains 73.66% carbon, 5.19% hydrogen, 18.80% oxygen and 0.98% nitrogen. This composition is also similar to that of Okaba coal thereby placing Okaba coal in the same sub-bituminous rank. Sulphur is commonly present in most Nigerian coal in the form of pyrite and marcasite (Orajakwa et al., 1990).

Sulphur in the form of pyrite has a serious effect on the quality of iron but the sulphur (pyrite) can, however, be removed by an additional appropriate amount of limestone, desulphurisation of the pig iron and washing (Obaje, 1994). The higher the sulphur content the more limestone is required for washing. The effectiveness of washing coal depends on the sophistication of the preparation plant and the nature of the sulphur. With conventional cleaning, most of the pyritic sulphur can be removed, but the organic sulphur is bound to the coals and is not removed (Blackmore, 1985). Zimmerman (1979) gave 0.05 0.06% of sulphur as a safe limit while Gray et al. (1978) gave an even lower limit of 0.03%. Though the sulphur content of Okaba coal (0.8%) falls within the ratings for coke-making, its pyritic nature makes it unsuitable for coke production.

Phosphorus is another element with adverse effect on iron quality. Unlike sulphur, its final placement in the iron product is not easily controlled by adjustment of slag volume. Care must therefore be taken that the coals used in coke making have a low initial phosphorus content. Gray et al. (1978) gave 0.03% as a safe limit while Bustin et al. (1985) gave a lower limit of < 0.12%. Based on these ratings, Okaba coal with 0.05% phosphorus on the average does not possess the suitable phosphorous content for coking.

Coal moisture, volatile matter, and ash content as well as free swelling index are rank- dependent parameters and they determine coal coking qualities (Jauro et al., 2008). Okaba coals are poor in those qualities and are therefore not suitable for coke making. Peng (2002) also stated that the volatile matter (apart from its use in coal ranking) is one of the most important parameters used in determining their suitable applications. Metallurgical coals according to Blackmore (1985) are commonly divided into three categories according to their content of volatile matter: low-, medium-, or high-volatile content. Lower-volatile coals (31–33%) are strongly expanding and create strong pressure during cooking. If used alone, many low-volatile coals make a strong coke, due to high fixed carbon and other coking characteristics, but could break the walls of a coke oven if used alone. Okaba coals are good examples of low-volatile coals (> 36%) and tend to have the opposite tendencies. They contract, exert less wall pressure and make a weak coke if used alone. Mid-volatile coals (33–36%), as might be expected, have properties between these two extremes. Low volatile coals can expand to the point of sticking in the ovens or breaking the oven walls. It is invariably necessary to blend with either medium or high-volatile coals to prevent excessive expansion of coke in the ovens (Loison et al., 1989 in Jauro et al. 2008). In the rating of coking coals for blending by Gray et al. (1978), volatile matter content of between 31.0 33.0% is graded as good, 33.0 36.0% as medium, and greater than 36.0% as poor. Based on this rating, and with values of 46.65% to 48.40%, none of the Okaba coal samples possess suitable volatile matter content for coking. Volatile matter yield of coal, when determined, is used to:

i. Establish the rank of coals,

ii. Indicate coke yield on carbonization,
iii. Provide the basis for purchasing and selling, or
iv. Establish burning characteristics.
Blackmore (1985), also recommended an ash content of 6-8% and moisture content of 6% for a good coking coal thereby making Okaba coal with 11.48% ash and 12.51% moisture content (Table 2) unsuitable for coke production.

Conclusions
Quality assessments based on sulphur content and proximate analysis indicate that the Okaba coals are of medium quality, non-coking and sub-bituminous. These put together suggest that none of the eight Okaba coal samples possesses some coking qualities suitable for coke making blends. However, Okaba coal is suitable for electric power generation and as a domestic fuel. Okaba coal also is rich in resinous and waxy materials and is therefore a suitable raw material for the chemical industry and also for use in the manufacture of plastics, when fractionally distilled. Okaba coal is also a good producer of gas fuel, and is suitable for complete gasification using the oxygen enriched steam blast process. It can also be processed to produce automotive fuel.

Okaba coal has high volatile matter, ash and moisture which make it unsuitable for coke-making. Though the sulphur content is low, its pyritic nature makes the coal un-cokable. Sulphur and phosphorus are undesirable constituents of coal, even in small quantities. However, when coal is burned most of the sulphur is emitted into the atmosphere as sulphur dioxide (SO₂) and sulphur trioxide (SO₃). These are serious pollutants. Sulphur also lowers the quality of coke and steel products made with coke. Coke is made out of coal and the quality of the coal determines to a large extent the quality of the resulting coke. More than 90% of the coke consumed in the steel industry is used in the blast furnace while a small quantity is used in the foundry processing of metals. In the blast furnace, coke is used in the reduction of iron ore and as a source of process heat. It provides the energy to produce iron by burning to form carbon dioxide at “tuyeres” of the blast furnace. Coke further reacts with carbon dioxide and moisture injected into the blast furnace to produce carbon monoxide and hydrogen reductants that converts iron oxide ores into iron.

REFERENCES


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Note to Contributors

Introduction
The Journal is the scientific publication of the Nigerian Mining and Geosciences Society. Its scope covers the fields of the geosciences, mining, metallurgy, materials science and geoenvironmental studies.

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Edited by
Uka Nwajide, K. Mosto Onuoha, Usman M. Turaki and C.S. Nwajide
1991, 149p, Paperback
978-31208-0-8

This compendium aptly highlights the historical perspectives of the first thirty years of the Society which was named at birth on 15th January, 1961, the Nigerian Mining, Geological and Metallurgical Society (NMGS) by the 10 founding “parents”, and subsequently became the Nigerian Mining and Geoscience Society (NMGS) in 1977. High points on a wide range of issues, are succinctly presented in the publication. The NMGS experience in which recognizable but interrelated specialists have success-fully continued to exist under the same umbrella body, is obviously unique and symbolic. Consequently, persons interested in the evolution, development and growth of multi-disciplinary learned organizations, would find this book highly valuable.

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Proceedings of the International Workshop on Natural and Man-Made Hazards in Nigeria
Records of the international meeting, Awka, Anambra State, Nigeria, 31 January – 3 February, 1993
Edited by
K. Mosto Onuoha and Matthew E. Offodile
1995, 56p, Paperback
978-30956-1-7

The book constitutes the NMGS input to the Nigerian Programme on the United Nations Decade for Natural Disaster Reduction, 1990-1999. It contains illuminating contributions on the tragic explosions of Lakes Nyos and Monoun in the Cameroon; the devastating erosion and land degradation in the eastern part; the emerging desertification of the northern region; and the earthquake episodes in the western sector of Nigeria. Other subjects are on waste management, flooding and pollution; the legal implications of environmental degradation, and the Workshop communicate outlining the conclusions and recommendations. On the whole, the book is a useful reference to all, since everyone is invariably affected or concerned with the monitoring, control, protection and management of the ecosystem.

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NMGS Annual Lecture Series Volume One
Edited by
A. Azubuike Elueze and Chukwuemeka J. Ikelionwu
1999, 77p, Paperback
978-020-822-8

This publication contains the first six presentations of the Nigerian Mining and Geosciences Society (NMGS) Annual Lecture Programme being organized under the aegis of Mobil Producing Nigeria Unltd. The topics are highly captivating, and the contributors are among the best intellectual resources in Nigeria. These correspondingly cover developmental planning, projects financing, energy and mineral resources development and technological adaption/transfer, and include P.C. Asiodu, A.O. Bamgbola, E.A. Hanvoti, B.R.H. Anderson, F. Okiobio and J. Aminu. Altogether, everyone would find the materials readily comprehensible and educative.

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