Quality Assessment of Igaliwo and Olokwu Coals in the Northern Anambra Basin of Nigeria

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Chemical and geochemical studies have been carried out on coal samples from Igaliwo and Olokwu coal deposits in northern Anambra Basin of Nigeria. The studies were carried out principally to determine the chemical and geochemical characteristics of the coals in order to ascertain their potential relevance to possible industrial usages. Proximate analysis indicated that the moisture content of the coal samples, on average, varied from 19.27% in Olokwu coal to 20.37% in Igaliwo coal, ash content from 4.88% in Olokwu coal to 6.48% in Igaliwo coal, volatile matter content from 36.39% in Igaliwo coal to 37.97% in Olokwu coal, and fixed carbon content from 36.76% in Igaliwo coal to 37.88% in Olokwu coal. Ultimate analysis revealed that the percentage of carbon in the coals, on average, ranged from 52.01% in Igaliwo coal to 54.74% in Olokwu coal, hydrogen from 4.34% in Igaliwo coal to 4.49% in Olokwu coal, nitrogen from 1.41% in Igaliwo coal to 1.42% in Olokwu coal, oxygen from 14.42% in Igaliwo coal to 14.43% in Olokwu coal, sulphur from 0.78% in Olokwu coal to 0.98% in Igaliwo coal, and phosphorus from 0.001% in Olokwu coal to 0.003% in Igaliwo coal. The heating (calorific) values of the coals, on average, varied from 9275 Btu/lb in Igaliwo coal to 9740 Btu/lb in Olokwu coal. Generally, both coals have low free swelling index (FSI) of zero (0). These characteristics put together suggest that both coals cannot be used by the steel industry, mostly for the manufacture of coke for metallurgical processes such as iron and steel production. However, they are suitable for electricity generation, heating boilers and ovens in industrial process heating, manufacturing organic chemicals and production of gas and automotive fuel.

**Keywords:** Igaliwo Olokwu coals, low quality, non-coking and sub-bituminous.

**INTRODUCTION**

Coal was first discovered in Nigeria in 1909 at the Udi near Enugu within the Anambra Basin in 1909 by the Mineral Survey of Southern Nigeria (Orajaka et al., 1990; Famuboni, 1996). Between 1909 and 1913, more coal seams were discovered within the Basin at Enugu and Ezimo in Enugu State; Orukpa in Benue State; Odokpono, Okaba and Ogboyaga in Kogi State. These seams belong to the Mamu Formation (Lower Coal Measures) of Middle Campanian – Late Maastrichtian age (Simpson, 1954).

Coal seams of the Nsukka Formation (Upper Coal Measures) of Late Maastrichtian – Paleocene age outcropped at Inyi west of the Enugu Escarpment (De-Swardt and Casey, 1963).

Intensive exploration and exploitation activities commenced in 1916 at Ogbete drift mine near Enugu. Over time, other mines sprang up in the region within the Anambra Basin. In 1950, the Ogbete mine’s operations and others in the country were merged into a new Corporation called the Nigerian Coal Corporation (NCC) with responsibility to manage the resources produced at these mines.

Production started from a modest beginning (24,903 tonnes in 1916) and gradually rose to an annual output of about 742,922 tonnes in 1966 just before the outbreak of the Nigerian civil war (NCC, 1974; NCC, 1982). During this period of growth, coal played a significant role in Nigeria’s economic development. Coal was mainly utilised by the Nigerian Railway Corporation (NRC) to operate its locomotives, by the Electricity Corporation of Nigeria **Corresponding Author:** Dr. Fatoye Felix Bamidele; Department of Mineral and Petroleum Resources Engineering, Kogi State Polytechnic, Lokoja, Nigeria. Email: feliztoye@yahoo.com
(ECN) later National Electric Power Authority (NEPA) again changed to Power Holding Company of Nigeria (PHCN) and now Electricity Distribution Company (EDC) for the generation of electricity; and by the Nigerian Cement Company (NIGERCEM) at Nkalagu for firing its kilns.

However, coal production has steadily declined in the last few decades due to the loss of two of its traditional customers, who switched from coal to diesel, natural gas and hydro resources for the generation of electricity and for transportation services. Coal has been relegated to the background especially after oil was discovered in commercial quantity in Nigeria, and the country became over-dependent on it as its primary source of energy.

The Nigerian civil war was another major factor in the decline of coal production in the country. A number of coal mines became inaccessible during the period and were abandoned. Most of the abandoned mechanizing production ended badly, as both the implementation and maintenance of imported mining equipment proved troublesome, and hurt production (NCC, 2011). Nevertheless, the Federal Government is currently planning to revitalize the coal mining industry and expand power generation by attracting foreign companies to develop these large coal resources and construct coal-fired generating plants that will connect to the country’s electrical distribution grid.

The Nigerian coal industry must be seen as a long neglected economic frontier that needs urgent resuscitation. It is one major area that can change the economic fortune of this great country. Its potential for growth is on the upward swing.

Therefore, this research work is aimed at investigating the chemical and geochemical characteristics of Igaliwo and Olokru coal deposits in order to ascertain their potential relevance to possible industrial usages.

**Location of the Study Area**

Igaliwo coal deposit is situated on Latitude 7° 38’ 23.3” N and Longitude 7° 35’48.7” E while Olokru coal deposit is situated on Latitude 7° 37’ 50.2” N and Longitude 7° 37’ 29.3” E. Both deposits are located off Abejukolo road in Omala Local Government Area of Kogi State (Figure 1).

![Location map of the study area](modified from map of Nigeria).

**Regional Geological Setting**

The study area lies within the Anambra Basin of Nigeria. The structural setting and general geology of the Anambra Basin have been documented by various workers (Reyment, 1965; Kogbe, 1989; Nwajide, 1990; Nwajide and Reijers, 1996; Obaje et al., 1999). Sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine and paralic shales of the Nkporo Formation (Figure 2), overlain by the Early – Late
Maastrichtian coal measures of the Mamu Formation, comprising paralic sandstones, mudstones and coals. The Middle – Late Maastrichtian fluviodeltaic sandstones of the Ajali Formation lie on the Mamu Formation and constitute its lateral equivalents in most places. In the Paleocene, the marine shales and paralic coaly sequence of the Nsukka Formation were deposited to complete the succession in the Anambra Basin (Umeji, 2005).

MATERIALS AND METHODS

Ten coal samples of approximately 300g each were collected from each of the two coal deposits (Igaliwo and Olokwu coal deposits). The samples were taken from the coal’s outcrops. Samples collected were kept in an airtight polyethylene bags prior to analyses. The coal samples were pulverized and sieved to pass 60 mm sieve size. All analytical determinations were done according to the American Standard for Testing Materials (ASTM) 1992 standards methods. All sample analyses were carried out at Mineral Laboratory, Kentucky, USA.

Proximate Analysis

Chemical composition of the coals was defined in terms of their proximate analysis. The parameters of proximate analysis are moisture, volatile matter, ash, and fixed carbon.

**Determination of Moisture Content:** Exactly 1.00g of the pulverized sample of each coal was placed in separate pre-weighted silica crucibles and subjected to a temperature of 105°C for 1 hour in the absence of air, until a constant weight was attained.

**Determination of Ash Content:** Exactly 1.00g each of pulverized samples were weighted into three separate platinum crucibles and subjected to a temperature of 750°C in a muffle furnace for about 2 hours until a constant weight was attained.

**Determination of Volatile Matter:** 1.00g of pulverized sample of each coal was weighted and covered in a 10ml platinum crucible. The same was subjected to a temperature of 950°C in a muffle furnace for 7 minutes.

**Determination of Fixed Carbon:** The fixed carbon is said to be the difference of the sum total of moisture, ash and volatile from 100%, that is;

\[
\text{Fixed Carbon} \% = 100 - (\% \text{ moisture content} + \% \text{ ash content} + \% \text{ volatile matter content}).
\]

Ultimate Analysis

Geochemical composition of the coals was defined in terms of their ultimate analysis. Ultimate (Elemental) analysis is dependent on quantitative analysis of various elements present in the coal samples, such as carbon, hydrogen and oxygen (the major components) as well as nitrogen, sulphur and phosphorus.

**Determination of Carbon and Hydrogen:** 1.00g of coal is burnt in a current of oxygen thereby converting C and H of coal into CO₂ and H₂O respectively. The products of combustion (CO₂ and H₂O) were passed over weighted
tubes of anhydrous CaCl₂ and KOH which absorbed H₂O and CO₂ respectively. The increase in the weight of CaCl₂ tube represents the weight of water (H₂O) formed while increase in the weight of KOH tube represents the weight of CO₂ formed. The percentage of carbon and hydrogen was then calculated.

**Determination of Nitrogen:** Nitrogen was determined by Kjeldahal's method. 1.00g of pulverized coal was heated with concentrated H₂SO₄ in the presence of potassium sulphate and copper sulphate in a long-necked flask thereby converting nitrogen of coal to ammonium sulphate. When 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 H₂SO₄ was then determined by titrating against standard NaOH solution. Thus, the amount of acid neutralized by liberated ammonia was determined.

**Determination of Oxygen:** Oxygen is traditionally determined by subtracting the amount of the other elements, carbon, hydrogen, nitrogen, sulphur, moisture and ash from 100%.

\[
\% \text{ of oxygen in coal} = 100 - (\% C + \% H + \% N + \% S + \% M + \% A)
\]

**Determination of Sulphur:** A 1.00g sample of coal of 0.2mm particle size was heated with Eschka mixture (which consists of 2 parts of MgO and 1 part of anhydrous Na₂CO₃) at 800°C. After burning amount of sulphur present in the mix was retained as oxides and it was precipitated as sulphate. The sulphate formed was precipitated as BaSO₄ (by treating with BaCl₂). The percentage of sulphur in coal was calculated from the weight of coal sample taken and weight of BaSO₄ precipitate formed.

**Determination of Phosphorus:** Phosphorus was determined by treating 1.00g of the coal ash with a hot mixture of HNO₃, H₂SO₄ and HF acids. This volatilized the silica and dissolved the phosphorus to precipitate a complex phospho-molybdate from which the phosphorus content was estimated.

**Calorific Value Analysis**

A bomb calorimeter was used to measure the calorific value of the coal. A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy was used to ignite the coal; as the coal was burning, it heated up the surrounding air, which expanded and escaped through a tube that leads the air out of the calorimeter. When the air was escaping through the copper tube it also heated up the water outside the tube. The change in temperature of the water was then accurately measured with a thermometer. This reading, allowed for calculating calorie content of the coal.

**Determination of Free Swelling Index**

10.00g of finely grounded coal sample was weighed into a dry platinum crucible. The crucible was placed in a muffle furnace and the temperature raised to 800°C for 2 hours or until all volatiles were driven off. The crucible was removed from the furnace and allowed to cool naturally. The cross section of the coke ‘button’ was then compared to a series of standard profiles (chart) to determine the free swelling index.

**RESULTS AND DISCUSSION**

Proximate analysis revealed that the studied coals are characterized by high moisture, medium to high ash, medium to high volatile matter and low fixed carbon contents. Comparing these characteristics with other coals (X, Y and Z in Tables 1 and 2), the studied coals are similar to Saar (Germany) sub-bituminous coal but contrast with Newcastle (England) bituminous coal and South Wales (Britain) anthracite thereby placing Igaliwo and Olokwu coals in sub-bituminous rank.

The average moisture content of Igaliwo coal is 20.37% (Table 1) while that of Olokwu coal is 19.27% (Table 2). The moisture content of the two coals is very high compared with high rank coals (Tables 1 and 2). This high moisture content would result in a decreased plant capacity and an increase in operating costs (Jauro et al., 2008) with consequent decrease in the calorific value and the concentration of other constituents (IEA/OECD, 2002). Moisture is an undesirable constituent of coals because it reduces the heating value (water does not burn!) and its weight adds to the transportation costs of coal. The moisture content required for good coking coal is 1.5% (Obaje, 1997). However, the Central Fuel Research Institute (CFRI), India in Chukwu et al. (2012) stipulated a range of 1 – 4% moisture for semi-coke used in low shaft furnace. Therefore, the values recorded in Igaliwo and Olokwu coals are above the stipulated rating for coking coal. However, based on Gunn et al. (2012) recommendation of maximum 18 – 30% moisture content for thermal coals, the coals are suitable for generation of electricity and heating for manufacturing of cement, ceramics, glass, paper, bricks, etc.

The average ash content of Igaliwo coal is 6.48% (Table 1) and that of Olokwu coal is 4.88% (Table 2). Lower ash content is an essential requirement for coke making coals, because some of the ash would end up in the coke on carbonization and in the blast furnace (Akpabio, 1998). The lower the ash content of a coal, the better its application as a source of fossil fuel especially in the steel industry (Wessiepe, 1992). Ash reduces plasticity and determines the behaviour of slag and fouling in
The high ash content is also an indication of low degree of coalification and hence immaturity of the coal. An ash content of less than 10% is recommended by Akpabio et al. (2008; Bustin et al., 1985; Averitt, 1974). Industrial experience indicates that a 1% weight increase of ash in the coke reduces metal production by 2 or 3% weight (Diez et al., 2002). Maximum of 10 – 20% is recommended by Thomas (2002) in coking coals, as higher ash contents reduce the efficiency in the blast furnace. However, coking coal with ash content up to 20% are being used for smelting iron in some parts of the world (Afonja, 1974). In such cases, coke and flux consumption per tonne of pig iron produced is relatively high. In a steam coal, high ash content will effectively reduce its calorific value.

Recommended maximum ash contents for steam coals for use as pulverized fuel are around 20% (Thomas, 2002).

Table 1: Proximate Analysis Results of Igaliwo Coal Samples

<table>
<thead>
<tr>
<th>Sample Number</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>Igaliwo 1</td>
<td>20.05</td>
<td>4.58</td>
<td>37.83</td>
<td>37.54</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 2</td>
<td>20.68</td>
<td>8.38</td>
<td>34.96</td>
<td>35.98</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 3</td>
<td>20.11</td>
<td>4.35</td>
<td>38.37</td>
<td>37.17</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 4</td>
<td>20.27</td>
<td>7.54</td>
<td>36.15</td>
<td>36.04</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 5</td>
<td>20.67</td>
<td>8.25</td>
<td>35.46</td>
<td>35.62</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 6</td>
<td>20.56</td>
<td>5.17</td>
<td>37.21</td>
<td>37.06</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 7</td>
<td>20.34</td>
<td>6.50</td>
<td>36.31</td>
<td>36.85</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 8</td>
<td>20.19</td>
<td>7.73</td>
<td>35.53</td>
<td>36.55</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 9</td>
<td>20.43</td>
<td>4.78</td>
<td>36.50</td>
<td>38.29</td>
<td>100.00</td>
</tr>
<tr>
<td>Igaliwo 10</td>
<td>20.40</td>
<td>7.52</td>
<td>35.58</td>
<td>36.50</td>
<td>100.00</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>20.37</strong></td>
<td><strong>6.48</strong></td>
<td><strong>36.39</strong></td>
<td><strong>36.76</strong></td>
<td><strong>100.00</strong></td>
</tr>
<tr>
<td>X</td>
<td>15.10</td>
<td>12.35</td>
<td>46.10</td>
<td>26.45</td>
<td>100.00</td>
</tr>
<tr>
<td>Y</td>
<td>4.31</td>
<td>0.20</td>
<td>31.26</td>
<td>64.23</td>
<td>100.00</td>
</tr>
<tr>
<td>Z</td>
<td>3.15</td>
<td>1.32</td>
<td>21.63</td>
<td>73.90</td>
<td>100.00</td>
</tr>
</tbody>
</table>

X: Saar (Germany) sub-bituminous coal (after Jensen and Bateman, 1979)
Y: Newcastle (England) bituminous coal (after Jensen and Bateman, 1979)
Z: South Wales (Britain) anthracite (after Jensen and Bateman, 1979)

Table 2: Proximate Analysis Results of Olokwu Coal Samples

<table>
<thead>
<tr>
<th>Sample Number</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>Olokwu 1</td>
<td>19.01</td>
<td>5.91</td>
<td>37.52</td>
<td>37.52</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 2</td>
<td>19.48</td>
<td>3.85</td>
<td>38.43</td>
<td>38.24</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 3</td>
<td>18.89</td>
<td>5.84</td>
<td>37.65</td>
<td>37.62</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 4</td>
<td>19.43</td>
<td>3.83</td>
<td>38.11</td>
<td>38.63</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 5</td>
<td>19.37</td>
<td>4.93</td>
<td>38.02</td>
<td>37.68</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 6</td>
<td>18.96</td>
<td>5.98</td>
<td>37.59</td>
<td>37.47</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 7</td>
<td>19.39</td>
<td>4.86</td>
<td>37.98</td>
<td>37.77</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 8</td>
<td>19.28</td>
<td>5.72</td>
<td>37.81</td>
<td>37.19</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 9</td>
<td>19.44</td>
<td>3.81</td>
<td>38.32</td>
<td>38.43</td>
<td>100.00</td>
</tr>
<tr>
<td>Olokwu 10</td>
<td>19.41</td>
<td>4.07</td>
<td>38.27</td>
<td>38.25</td>
<td>100.00</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>19.27</strong></td>
<td><strong>4.88</strong></td>
<td><strong>37.97</strong></td>
<td><strong>37.88</strong></td>
<td><strong>100.00</strong></td>
</tr>
<tr>
<td>X</td>
<td>15.10</td>
<td>12.35</td>
<td>46.10</td>
<td>26.45</td>
<td>100.00</td>
</tr>
<tr>
<td>Y</td>
<td>4.31</td>
<td>0.20</td>
<td>31.26</td>
<td>64.23</td>
<td>100.00</td>
</tr>
<tr>
<td>Z</td>
<td>3.15</td>
<td>1.32</td>
<td>21.63</td>
<td>73.90</td>
<td>100.00</td>
</tr>
</tbody>
</table>

X: Saar (Germany) sub-bituminous coal (after Jensen and Bateman, 1979)
Y: Newcastle (England) bituminous coal (after Jensen and Bateman, 1979)
Z: South Wales (Britain) anthracite (after Jensen and Bateman, 1979)

The average volatile matter content of Igaliwo coal is 36.89% (Table 1) while that of Olokwu coal is 37.97% (Table 2). Volatile matter represents the components of coal, except for moisture which are liberated at high
temperature in the absence of air. Volatile matter includes light hydrocarbon compounds such as carbon dioxide (CO₂), methane (CH₄), 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 that are lost in the form of gases and vapour on carbonization. The high volatile matter content in most of the coals is a reflection of the exceptionally large proportion of hydrogen in the coals (Orajaka et al., 1990). In pulverized fuel firing for electricity generation, most boilers are designed for a minimum volatile matter of 20 – 25%. In stoker firing for electricity generation, the volatile matter limits recommended are 25 – 40% (Thomas, 2002). There is virtually no limit for the volatile matter for coals used in the production of cement. In coke production, high volatile matter content will give a lower coke yield so that the best quality coking coals have a volatile range of 20 – 35% but values of 16 – 36% can be used (Thomas, 2002). Bustin et al. (1985) recommended a much lower value of less than 1.5% volatile matter for good metallurgical coal. The volatile matter apart from its use in coal ranking is one of the most important parameters used in determining their suitability and applications (U.S. Energy Information Administration, 2008; Chen and Ma, 2002). The volatile matter of Igaliwo and Olokwu coals is in consonance with the reports of (Okolo, 1988) who observed that Nigerian coals have high volatile matter and as such are potential sources of energy and feedstock for the chemical and allied industries. Based on volatile matter content proposed for coking coals by Thomas (2002), both Igaliwo and Olokwu coals are unsuitable for coke making. However, the coals are appropriate for electricity generation and heating for manufacturing processes.

The average fixed carbon content of Igaliwo coal is 36.76% (Table 1) and that of Olokwu coal is 37.88% (Table 2). The coals are characterized by low fixed carbon content compared with high rank coals (Tables 1 and 2). The fixed carbon content of a coal has a direct relation with its moisture and volatile matter, therefore, the low fixed carbon content in the coals is as a result of their high moisture and volatile matter contents. Fixed carbon content determines the coke yield of coal samples (Diez et al., 2002; Schober, 1987). High carbon content is essential for coke making coal because it is the mass that forms the actual coke on carbonization (Diez et al., 2002). Maximum of 46 – 86% is recommended by Lowry (1945) in coking coals. Both coals contain very low fixed carbon below the recommended rating for coking coals given by Lowry (1945). However, they could be utilized in thermal power plants and other small industries for combustion processes.

Table 3 Ultimate Analysis and Calorific Value Results of Igaliwo Coal Samples

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Carbon (%)</th>
<th>Hydrogen (%)</th>
<th>Nitrogen (%)</th>
<th>Oxygen (%)</th>
<th>Sulphur (%)</th>
<th>Phosphorus (%)</th>
<th>Total (%)</th>
<th>Calorific Value (Btu/Ib)</th>
<th>Calorific Value (KJ/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igaliwo 1</td>
<td>54.14</td>
<td>4.53</td>
<td>1.49</td>
<td>14.27</td>
<td>0.94</td>
<td>0.001</td>
<td>75.37</td>
<td>9661</td>
<td>22471.486</td>
</tr>
<tr>
<td>Igaliwo 2</td>
<td>49.88</td>
<td>4.15</td>
<td>1.33</td>
<td>14.56</td>
<td>1.01</td>
<td>0.004</td>
<td>70.93</td>
<td>8889</td>
<td>20675.814</td>
</tr>
<tr>
<td>Igaliwo 3</td>
<td>53.24</td>
<td>4.20</td>
<td>1.35</td>
<td>14.37</td>
<td>0.97</td>
<td>0.003</td>
<td>74.13</td>
<td>9763</td>
<td>22708.738</td>
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<td>Igaliwo 4</td>
<td>52.86</td>
<td>4.33</td>
<td>1.41</td>
<td>14.46</td>
<td>0.97</td>
<td>0.004</td>
<td>74.03</td>
<td>9020</td>
<td>20980.520</td>
</tr>
<tr>
<td>Igaliwo 5</td>
<td>50.98</td>
<td>4.50</td>
<td>1.45</td>
<td>14.23</td>
<td>1.01</td>
<td>0.004</td>
<td>72.17</td>
<td>9445</td>
<td>21969.070</td>
</tr>
<tr>
<td>Igaliwo 6</td>
<td>53.62</td>
<td>4.24</td>
<td>1.27</td>
<td>14.31</td>
<td>0.96</td>
<td>0.003</td>
<td>74.40</td>
<td>8937</td>
<td>20787.462</td>
</tr>
<tr>
<td>Igaliwo 7</td>
<td>51.33</td>
<td>4.47</td>
<td>1.46</td>
<td>14.44</td>
<td>1.01</td>
<td>0.002</td>
<td>72.71</td>
<td>9568</td>
<td>22255.168</td>
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<td>Igaliwo 8</td>
<td>52.71</td>
<td>4.31</td>
<td>1.44</td>
<td>14.51</td>
<td>0.95</td>
<td>0.004</td>
<td>73.92</td>
<td>8890</td>
<td>20678.140</td>
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<tr>
<td>Igaliwo 9</td>
<td>49.90</td>
<td>4.51</td>
<td>1.47</td>
<td>14.50</td>
<td>0.98</td>
<td>0.003</td>
<td>71.36</td>
<td>9304</td>
<td>21641.104</td>
</tr>
<tr>
<td>Igaliwo 10</td>
<td>51.44</td>
<td>4.16</td>
<td>1.43</td>
<td>14.55</td>
<td>1.00</td>
<td>0.002</td>
<td>72.58</td>
<td>9273</td>
<td>21568.998</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>52.01</strong></td>
<td><strong>4.34</strong></td>
<td><strong>1.41</strong></td>
<td><strong>14.42</strong></td>
<td><strong>0.98</strong></td>
<td><strong>0.003</strong></td>
<td><strong>73.16</strong></td>
<td><strong>9275</strong></td>
<td><strong>21573.650</strong></td>
</tr>
<tr>
<td>X:</td>
<td>67.60</td>
<td>4.80</td>
<td>1.20</td>
<td>17.70</td>
<td>0.80</td>
<td>0.06</td>
<td>92.16</td>
<td>8683</td>
<td>20196.658</td>
</tr>
<tr>
<td>Y:</td>
<td>83.47</td>
<td>6.68</td>
<td>0.59</td>
<td>8.00</td>
<td>0.20</td>
<td>0.04</td>
<td>98.98</td>
<td>12000</td>
<td>27912.000</td>
</tr>
<tr>
<td>Z:</td>
<td>91.44</td>
<td>3.36</td>
<td>0.09</td>
<td>2.70</td>
<td>0.09</td>
<td>0.03</td>
<td>97.71</td>
<td>15700</td>
<td>36518.200</td>
</tr>
</tbody>
</table>

X: Wyoming (USA) sub-bituminous coal (after Spath and Amos, 1995)
Y: Newcastle (England) bituminous coal (after Jensen and Bateman, 1979) and San Pedro (USA) bituminous coal (after Warwick and Hook, 1995)
Z: South Wales (Britain) anthracite (after Jensen and Bateman, 1979) and Barakar (India) Anthracite (after Sethi, 2014)
Ultimate analysis indicated that the studied coals are also characterized by low carbon, medium to high hydrogen, high nitrogen and high oxygen contents. Comparing these characteristics with other coals (X, Y and Z in Tables 3 and 4), the studied coals are similar to Wyoming (USA) sub-bituminous coal but contrast with Newcastle (England) bituminous coal and South Wales (Britain) anthracite thereby placing Igaliwo and Olokwu coals in sub-bituminous rank.

The average carbon content of Igaliwo coal is 52.01% (Table 3) while that of Olokwu coal is 54.74% (Table 4), and the average hydrogen content of Igaliwo coal is 4.34% (Table 3) while that of Olokwu coal is 4.49% (Table 4). Carbon and hydrogen are the principal combustible elements in coal. Maximum of 75 – 90% carbon and 4.5 – 5.5% hydrogen is recommended by Lowry (1945) in coking coals. Based on carbon content, Igaliwo and Olokwu coals have no coking ability, hence unsuitable for coke production for metallurgical processes. However, they are appropriate for electricity generation and heating for manufacturing processes.

The average nitrogen content of Igaliwo coal is 1.41% (Table 3) while that of Olokwu coal is 1.42% (Table 4), and the oxygen content of Igaliwo coal is 14.42% (Table 3) while that of Olokwu coal is 14.43% (Table 4). The nitrogen content of both coals is high compared with high rank coals (Tables 3 and 4). The less the oxygen content of a coal the better the coal. As oxygen content increases, moisture holding capacity increases and caking power decreases. Based on nitrogen and oxygen contents, the coals are more appropriate for generation of electricity and heating for manufacturing processes.

The average sulphur content of Igaliwo coal is 0.98% (Table 3) and that of Olokwu coal is 0.78% (Table 4) while the phosphorus content of Igaliwo coal is 0.003 (Table 3) and that of Olokwu coal is 0.001 (Table 4). The sulphur content of the coals is low and within the rating of < 1.0% recommended by Bustin et al. (1985) for coke-making, but their pyritic nature makes them unsuitable for coke making. Pyritic coal contributes to producing brittle steel, causes slagging and fouling in the furnace thereby reducing its efficiency and causes corrosion of the furnace. Phosphorus is another element with adverse effect on iron quality. Based on sulphur and phosphorus contents, the coals are better used in electricity generation and heating for manufacturing processes.

Comparing the calorific values of the studied coals with other coals (X, Y and Z in Tables 3 and 4), the studied coals contrast with San Pedro (USA) bituminous coal and Barakar (India) anthracite but similar to Wyoming (USA) sub-bituminous coal thereby also placing Igaliwo and Olokwu coals in sub-bituminous rank.

The average calorific value of Igaliwo coal is 9275 Btu/lb (Table 3) while that of Olokwu coal is 9740 Btu/lb (Table 4). These average calorific values are low compared with high rank coals (Tables 3 and 4). The low heating values recorded in the two coals are as a result of high moisture content (IEA/OECD, 2002). The calorific value (CV) of a coal is the amount of heat per unit mass of coal when combusted. Mineral matter, moisture and ash contents of a coal help in determining its heating value. The less these contents the better the calorific value. Bustin et al. (1985) recommended 14499 Btu/lb for good metallurgical coal. Based on this recommendation, none of the coals is good for metallurgical processes. However, they are suitable for combustibility.
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. 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 FSI of seven (7) or more (the top of the scale is nine). This implies that Igaliwo and Olokwu coals are unsuitable for manufacturing of coke for metallurgical processes. The lower the free swelling index of a steam coal, the higher the efficiency of combustion (Blackmore, 1985). This also means that Igaliwo and Olokwu coals with zero (0) free swelling index are good for heating and generation of electricity.

CONCLUSION

Proximate, ultimate and calorific value analyses as well as free swelling index test revealed that Igaliwo and Olokwu coals both have high moisture, low ash, high volatile matter, low carbon, low sulphur, low calorific values and zero (0) free swelling index. All these characteristics suggest that the coals are non-cooking. Though the sulphur content is low, but the pyritic nature of the sulphur makes the coals non-cooking and therefore not suitable to be employed in the generation of substantial heat for the working of blast furnace for iron smelting. However, they can be used as a source of energy in the production of electrical power using steam generation. The coals are suitable in heating boilers and ovens in industrial process heating. The cement, glass, ceramic, paper and brick industries can use them for this purpose. The coals are also good source of raw material for manufacturing products such as drugs, dyes, oils, waxes, plastics, synthetic rubbers, pesticides, insecticides, antiseptics, paint products, solvents, synthetic fibres, flavourings, perfumes, varnishes, adhesives, soaps, detergents, fertilizers, shampoo and numerous other organic chemicals. In addition, gasification and liquefaction of the coals will produce gaseous and liquid fuels that can be easily transported (e.g. by pipeline) and conveniently stored in tanks.

ACKNOWLEDGEMENT

We sincerely appreciate Tertiary Education Trust Fund (TETFUND) for giving us grant for this research work. The Management of Kogi State Polytechnic, Lokoja is gratefully acknowledged also for the approval given for the release of the grant.

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Accepted 31 December 2019


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