

*Full Length Research Paper*

## The Implications of the Rank of Coal Deposit at Maiganga, Gombe, Nigeria

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### **Abstract**

The coal deposit at Maiganga is recently being exploited for power generation. In order to assess its quality and ascertain its rank, a proximate analysis was conducted by this study. The result of the analysis shows that the coal deposit has low calorific value, high percentage of ash, inherent moisture, and volatile matter. Relatively, there is decrease in absolute density, more organic matter, and rich in water, oxygen, and hydrogen. It was therefore established that the coal falls within the lignite rank. Inherently, the Maiganga lignite comes with various implications which include; limited use, generation of huge waste (ash), low thermal value, easy accessibility and availability, and susceptibility to weathering.

**Keywords:** Coal deposit, proximate analysis, Maiganga, Lignite, Rank, Implications.

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### **INTRODUCTION**

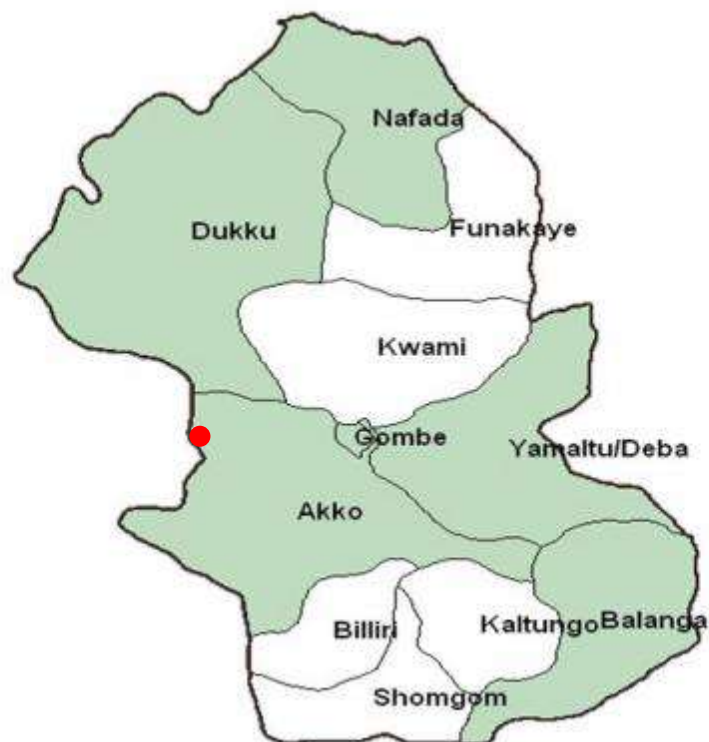
Coal is a readily combustible rock, which contains more than 50% by weight of carbonaceous material (Kuznetsov *et al.*, 2014) formed from a coalification process of altered plant remains. Coal is made up of organic (carbon-containing) compounds. In addition to the carbon content, these organic compounds contain elements such as hydrogen, oxygen, nitrogen, and sulphur. Hydrogen, oxygen, and other elements, which are in smaller amounts gradually dissociates from the plant matter after the plant dies begins to decay, thereby relatively increasing the carbon content of the material. Besides its organic component, coal contains inorganic (Finkelman, 1993) components. These are made up of mineral and non-mineral matter. The material classed as 'mineral matter' (Nowicki, 2016; Iskhakov *et al.*, 2008; Saikia, 2009) embraces all the minerals and other inorganic elements (Zherebtsov *et al.*, 2008; Purevsuren *et al.*, 2016) occurring in coal, namely; inorganic elements incorporated

within the organic compounds of the coal macerals (Vuković *et al.*, 2016; Guerrero *et al.*, 2013), dissolved salts and other inorganic substances in the pore water of the coal and discrete inorganic particles (crystalline or non-crystalline) representing the actual mineral components (Ward, 2002; Gupta *et al.* 2006; Nayak, 2013; Popov *et al.* 2011).

As the organic and inorganic materials are deeply buried in the earth chemical and physical changes occur under continuing process which involves increase in temperature and pressure. The extent of this process determines the rank of coal. Each coal rank has some peculiar characteristics and implication. Having established that the Maiganga coal falls within the lignite rank, this paper discusses some associated implications of the Maiganga coal.

### **MATERIALS AND METHOD**

Having pulverized each of the coal samples collected from



**Figure 1.** Map of Gombe State indicating the study area

from various locations in the coal mine, they were packaged and well-labeled Maiganga A1, A2, B1 and B2; then analyzed. The Maiganga A1 and A2 are from different locations on seam A and Maiganga B1 and B2 are from seam B.

### MOISTURE CONTENT

This is determined by heating an air-dried coal sample at  $105^{\circ}\text{C} - 110^{\circ}\text{C}$  ( $221^{\circ} - 230^{\circ}\text{F}$ ) under specified conditions until a constant weight is obtained.

#### Materials

Crucible, oven, balance, tong, desiccators and 5 prepared coal samples.

#### Method

- 1). Weigh empty clean crucible as  $Wt_1$ .
- 2). Weigh 1g of coal sample,  $Wt_2$  into the crucible. Weight of crucible + sample is recorded as  $Wt_3$ .
- 3). Introduce the crucible + sample into the oven at  $110^{\circ}\text{C}$  and leave for one hour.
- 4). Remove from oven, cool in the desiccators and re-weigh. This is recorded as  $Wt_4$ .

$$\text{Weight of moisture content} = Wt_3 - Wt_4$$

$$\text{Percentage of moisture} = \frac{Wt_3 - Wt_4}{Wt_2} \times 100$$

### VOLATILE MATTER

The volatile matter of coal is determined rigidly by controlled by standards. In Australian and British laboratories, this involves heating the coal sample to  $900 \pm 5^{\circ}\text{C}$  ( $1650 \pm 10^{\circ}\text{F}$ ) for 7 minutes in a cylindrical silica crucible in a muffle furnace. American Standard Procedures involves heating to  $950 \pm 25^{\circ}\text{C}$  ( $1740 \pm 45^{\circ}\text{F}$ ) in a vertical platinum crucible. These two methods give different results and thus the method used must be stated. Here, the former is used.

#### Materials

Crucible, furnace, tong, balance, desiccators, and 5 prepared coal samples.

#### Method

- 1). Weigh empty clean crucible as  $Wt_1$
- 2). Weigh 1g of coal sample,  $Wt_2$  into the crucible. Weight of crucible + sample is recorded as  $Wt_3$ .

- 3). Introduce the crucible + sample into the furnace at a temperature of 900°C and leave for 7 minutes
- 4). Remove from furnace, cool in the desiccators and re-weigh, record as  $Wt_4$

$$\text{Weight of volatile matter} = Wt_3 - Wt_4$$

$$\text{Percentage of volatile matter} = \frac{Wt_3 - Wt_4}{Wt_2} \times 100$$

## ASH CONTENT

This analysis is fairly straight-forward, with the coal thoroughly burnt and the ash material expressed as a percentage of the original weight.

### Materials

Crucible, furnace, tong, balance, desiccators, and 5 prepared coal samples.

### Method

- 1). Weigh empty clean crucible as  $Wt_1$ .
- 2). Weigh 1g of coal, sample,  $Wt_2$  into the crucible. Weight of crucible + sample is recorded as  $Wt_3$ .
- 3). Introduce the crucible + sample into the furnace at temperature of 825°C and leave for one hour.
- 4). Remove from furnace, cool in the desiccators and re-weigh, record as  $Wt_4$ .

$$\text{Weight of ash content} = Wt_4 - Wt_1$$

$$\text{Percentage of ash} = \frac{Wt_4 - Wt_1}{Wt_2} \times 100$$

## Fixed Carbon

This is only arithmetic. It is simply determined by subtracting the percentages of moisture, volatile matter, and ash from the samples, i.e. 100% - %moisture + %volatile matter + %ash.

## CALORIFIC VALUE

Strictly speaking, the calorific value is neither part of the proximate analysis nor part of the ultimate analysis. It is in fact, one of the many physical properties of coal and is therefore discussed under it in several instances. For the analysis of coal, the calorific value is determined in a bomb calorimeter by either a static (isothermal) or an adiabatic method. In the isothermal method (ASTM D 3286; ISO 1928), a weighed sample of coal is burned in oxygen under controlled conditions and the calorific value is computed from temperature observation made before, during and after combustion, with appropriate allowances

made for the heat contributed by other processes. The adiabatic method (ASTM D2015; ISO 1928) consists of burning the coal sample in an adiabatic bomb calorimeter under conditions. The calorific value is calculated from observations made before and after the combustion. The computed value for the calorific value of coal is usually expressed in British thermal units per pound, kilocalories per kilogram, or kilojoules per kilogram (1.8Btu/lb = 1.0Kcal/kg = 4.187Kj/kg).

### Materials

Crucible, bomb calorimeter (Leco AC-350), balance, 200ml water, and 5 prepared coal samples.

### Method

- 1). Weigh 1g of sample into the crucible.
- 2). Introduce into the combustion chamber, the crucible does not touch the bottom of the combustion chamber.
- 3). Put the combustion chamber + crucible + sample into the bomb and place into the container that has the 200ml of water inside the calorimeter. The stirrer under the cover of the bomb calorimeter ensures even distribution of the heat as it automatically stirs.
- 4). After 8 minutes, the reading is taken from the computerized readings by a side of the bomb calorimeter.

## TOTAL SULPHUR

The samples were analyzed for total sulphur with the computerized XRF equipment. And the press method was employed.

### Materials

Computerized XRF, sample cups, sample tray, printer, pistil, and 5 prepared coal samples.

### Method

- 1). Put on the computer and the printer after which you turn the key of the XRF clockwise. The machine will take about 2 hours to butt. Then click "minipal" (the model of the machine) on the monitor to open.
- 2). Measure about  $\frac{3}{4}$  of the sample into the sample cup. Use the pistil to press it in order to remove any air, cover and put on one of the sample positions in the tray (the tray has 12 sample positions). Select the sample position and label name on the screen.
- 3). Click "measure", as the tray appears, click the sample position, the 1% position on the system is selected for it to start the analysis. The result is displayed as it gets to the 100% mark.
- 4). Then the result recorded.



Figure 2. Coal deposit at Seam A, Maiganga Mine

Table 1. Proximate Analysis Maiganga Coals

S/N	Coal source	Moisture content (wt. %)	Ash content (wt. %)	Volatile matter (wt. %)	Fixed carbon (wt.%)	Calorific value (j/g)
1.	Maiganga A1	5.51	19.30	42.53	32.66	4981.5
2.	Maiganga A2	4.41	31.34	35.53	28.71	4237.5
3.	Maiganga B1	3.77	44.00	31.92	20.31	3200.3
4.	Maiganga B2	3.12	48.48	25.61	22.79	2248.8

Table 2: Total Sulphur Determination of Maiganga Coal

	Coal Source			
	Maiganga A1	Maiganga A2	Maiganga B1	Maiganga B2
Total Sulphur (wt. %)	0.35	0.96	0.79	0.77

**Note:** Before you open the x-ray tube, it must be on the reference, R mark if not it will leak and kill the person instantly. And make sure the machine is not analyzing another sample at the moment.

**RESULT AND DISCUSSIONS**

The results obtained in proximate and sulphur analysis from coal samples are presented in Tables 1 above. With a calorific value of 4981.5j/g, 4237.5j/g for Maiganga A1 and A2, and 3200.3 Cal/j, 2248.8 j/g for Maiganga B1 and B2 respectively, and fixed carbon of 32.66 wt. %, 28.71

wt.% for Maiganga A1 and A2 and 20.31 wt.%, 22.79 wt.% for Maiganga B1 and B2 respectively, the result establishes the Maiganga coal as lignite. This is owing to the fact that the calorific value and fixed carbon, which are low falls within the lignite range. Lignite coal has peculiar implications unlike the others, higher rank of coals.

The percentage of the moisture content of the result is high (Table 1), and would have been higher if analyzed as mined. In general, the moisture content increases with decreasing rank. The presence of moisture is an important factor in both the storage and the utilization of coals, as it adds unnecessary weight during



**Figure 3.** Coal pile in the Maiganga Coal mine store

transportation, reduces the calorific value (Jo et al. 2014; Sakurovs et al. 2016; Moon et al. 2014), and poses some handling problems. It must be noted that the mineral compounds introduced from the plant precursors and water on burial and introduced in the lignite during extraction are not only ballast in coal transportation, but also are harmful impurities that impair its processing (Gagarin, 2008). On drying in the air, this water content may be reduced considerably, but in lignite there is shrinkage, cracking and breaking into small pieces, and this means so much wastage that transmission in this form is practically precluded.

A great deal of heat is consumed in evaporating this high water content and this lowers the calorific value considerably. The latent heat of vaporization is high. This reduces the flame temperature. A great deal of heat is needed to evaporate the high water content of the Maiganga lignite. Coal with high moisture content has a higher reactivity than the coal with high ash content; the un-combustion fraction of coal with high moisture content is lower. It is believed that coal with high moisture content is easier to use for power purposes. Hence lignite is used for power generation. The calorific value of the maiganga coal is low due to the high moisture and oxygen, but less fixed carbon. For coal-fired power plants such as the Ashaka Cement PLC power plant, which is using the Maiganga lignite, information of the moisture content (and ash content) in the coal is important to determine and

control the dynamical behavior of the power plants. E.g., high moisture content in the coal results in a decreased maximum load gradient of the plant.

The percentage ash on the other hand, which is high from the result of the analysis (Table 3), is from the inorganic component of the coal. They include minerals such as pyrite and marcasite from metals that accumulated in the living tissues of the ancient plant. Quartz, clay and other minerals are also added to coal deposits by wind and groundwater. Sometimes coal ash also contains significant amount of lead, barium, arsenic, or other elements that poses environmental hazard. Ash either escapes into the atmosphere or is left in the combustion vessel and must be discarded. The amount and nature of the ash and its behaviour at high temperatures affect the design and type of ash-handling system employed in coal-utilization plants. At high temperatures, coal ash becomes sticky (i.e., sinters) and eventually forms molten slag (Lee et al. 2016). The slag then becomes a hard, crystalline material upon cooling and re-solidification. Ash lowers the fixed carbon of coal, decreasing its heating value. The greater the ash content, the higher the un-combustion fraction. The higher the ash content the slower the oxygen consumption near the burner. The implication of the high proportion of the volatile constituents to fixed carbon of the Maiganga lignite (Table 1) means that the fuel would burn quickly with a long smoky flame that is difficult to control (Wilson,

1924). Also, this implies a marked tendency to disintegrate, as it is of low specific gravity. Much of the lignite therefore, is liable to pass out without burning.

For the total sulphur content of the analyzed samples (Table 2), it is apparent that they are not high (Patrakov and Fedorova, 2011, He *et al.*, 2005; Saika *et al.*, 2015). This is typical of Nigerian lignite, a factor that gives them an advantage over those elsewhere. The implication therefore, is that the Maiganga lignite does not constitute considerable risk to both human and the environment (Jin and Bian, 2013), or impair the quality (Ulanovskii and Miroshnichenko, 2008) of the coal, which ordinarily would have been the case if the sulfur content is high.

### Weathering

Weathering starts as coal is unearthed and/ or removed from the coal seam unless precautionary measures are taken to preventing its reaction with oxygen (air) and changes in temperature and humidity. At ambient temperature, the reaction of the coal with oxygen occurs readily, resulting in, primarily oxidation (Novikova *et al.*, 2010) of the coal's organic constituents, which aids the increase in the oxygen content. Consequently, the coal's atomic hydrogen-to-carbon ratio decreases. Cox and Nelson (1984) posit that low rank coals will lose about 190 Btu-per-pound for each 1% increase in oxygen content. High rank coals, on the other hand lose about 240 Btu-per-pound for each 1% increase in oxygen content. For a matter of weeks, the oxygen content of freshly mined and crushed lignite can increase in percentage when stored in air at ambient temperature. Spontaneous combustion of the coal under certain conditions can be the resultant effect of such rapid oxidation (Seoane and Leiros, 2000).

The degree of metamorphism or transformation coal has undergone determines the manner of weathering it experiences. Owing to its low level of transformation and the high percent moisture content of the Maiganga lignite, it is susceptible to weathering (Kharytonov and Kroik, 2011; Xie, 2015) and could deteriorate within a few weeks of storage (Figure 3) or transportation. The weathering reduces the quality of the lignite considerably, dropping its calorific value by as much as 30% (Kogbe, 1976). It implies that the Maiganga lignite needs to be adequately stored or used within a short time.

### Accessibility and Availability

The lignite at the study area is very readily accessible because its veins are located relatively near the surface, in a comparatively shallow depth, and with frequently thick seam. This eliminates the need for underground excavation and hugely reduces the cost of production, which is not the case with other types of coal. The surface mining, open-cast (Ristović, 2011; Chen *et al.*, 2014) employed at the mine eliminates the build-up of

methane (CH<sub>4</sub>) or carbon monoxide risk.

Easy accessibility ensures continuous availability and production of lignite. Hence, power plants using lignite for electricity generation always have it whenever needed. Therefore, the Ashaka Cement PLC power plant, which is the sole user of the lignite from the study area would enjoy availability of the material for continuous power generation.

### Waste Generation

Surface mining method is employed in winning the coal at Maiganga. This is based on the fact of the rank of the coal, which makes it easily accessible and not competent enough to sustain the underground method. Consequently, this method generates huge waste due to the overburden excavation. Overburden dumps are littered all over the place as result.

Power plants using the lignite would generate huge fly ash (Ram *et al.* 2015; Argyopoulos *et al.*, 2013; Polic *et al.*, 2005, Michitake *et al.*, 1998; Gwenzi and Mupatsi, 2016; Siddique, 2008). This is due to the mixture mineral (Kuznetsov and Kuznetsova, 2008; Ivanov, 2010) that was deposited with the plant matter during coal formation, which is still very much available in lignite, having experienced low degree of coalification. Particulate matter (PM), especially submicron ash rich in toxic heavy metals, which are high in low rank coals such as lignite are emitted from the coal-fired power plants from coal-fired plants. This would not only foul and corrode the boiler, consequently affecting the safe operation of boiler and the efficiency of heat exchanger, but is harmful to human health and environment (Zhou *et al.*, 2010).

Coal ash is usually made up of fly ash (Mehra *et al.*, 1998) and bottom ash. Fly ash, which is normally finer, is more than 85% of the ash produced during combustion. Less than 15% of the coal ash produced during coal combustion is the bottom ash, which is the coarse fraction that falls to the bottom of a furnace (Bhattacharya and Kim, 2016).

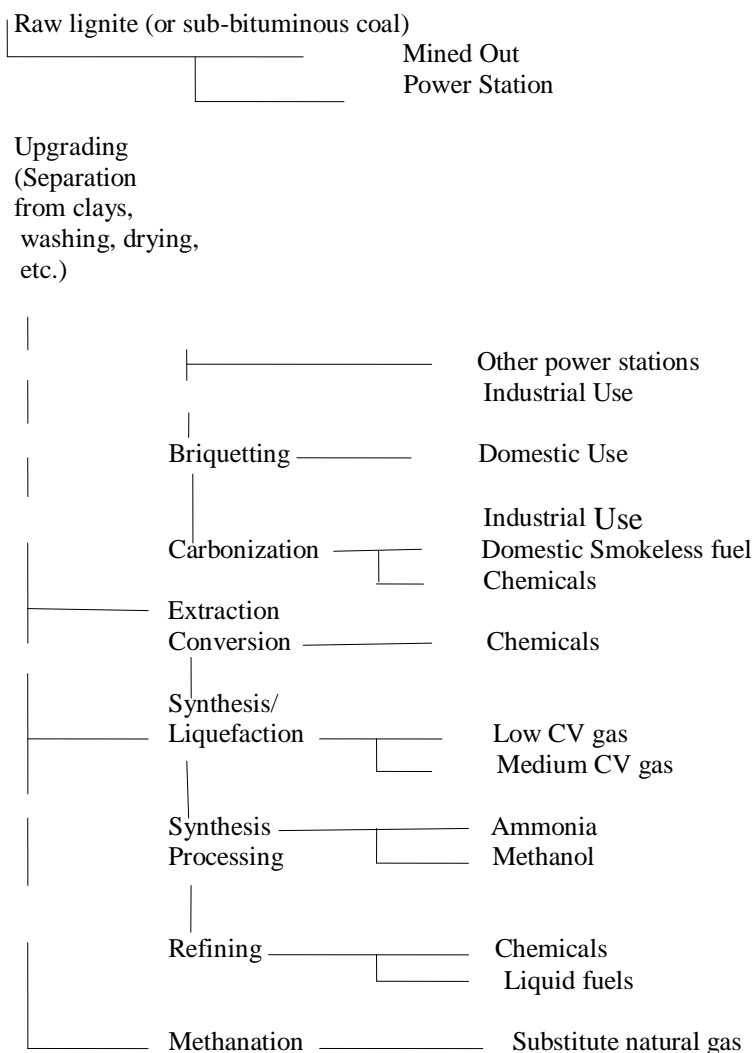
### Usage

Owing to its spontaneous combustion (Kizgut *et al.*, 2003) as it oxidizes in air (Plummer *et al.*, 2003), low heating value, high oxygen content, and moisture content (Moon *et al.*, 2014), lignite has limited use. As indicated (Table 2) lignite is mainly used for power generation (Widera *et al.*, 2016; Davis and Hower, 2012; Choi *et al.*, 2014; MMSD, 2008, Okolo and Mkpadi, 1996, Jang *et al.*, 2016) unlike the other types of coal that have diverse uses. One of the most important coal characteristics responsible for the use of and the character of resulting slag and fly ashes is the composition of the mineral matter (Vyazova *et al.*, 2008). The much ash produced by lignite is not only discharged as an air pollutant, but it is

**Table 3.** Use of coal depending on its rank

Types of Coal	Uses
<b>Low rank coals</b> Lignite Sub-bituminous	Mainly power generation Power generation Cement manufacture Industrial use
<b>Hard coal</b> Bituminous Thermal steam coal	Power generation Cement manufacture Industrial uses
<b>Metallurgical coking coal</b> Anthracite	Manufacture of iron and steel Domestic/ Industrial uses Smokeless fuel

**Source:** Modified from Ghosh and Preslas (2009)



**Figure 4.** Potential Uses of Maiganga Lignite (Modified from Okolo and Mkpadi, 1996).

ill-natured, as it decreases power efficiency (Lee and Yoo, 2014).

At present, the lignite of the study area lacking coke (Stankerevich and Zolotukhin, 2015; Lyalyuk *et al.*, 2012; Gainieva *et al.*, 2008) quality, etc is mainly used by Ashaka Cement PLC for its power generation (MMSD, 2012). However, the Maiganga lignite can be upgraded (Vostrikov *et al.*, 2016; Davies and Hower, 2012) to increase its usage, as indicated in Figure 4 (Okolo and Mkpadi, 1996). The efficient utilization (and storage) of low-rank coal amidst other techniques, includes fines briquetting (Cui *et al.*, 2015), which makes low-quality and sales-limited coal such as the Maiganga lignite the full-value, evaluable, long-term stored and combusted fuel (Nikolaeva and Burenina, 2012).

## CONCLUSION

As an organic sedimentary rock, coal is combustible and is composed of, predominantly carbon with some hydrogen, and very less amounts of some other elements. It has been established that coal is an accumulation of organic and inorganic materials, which have undergone coalification process. The extent of coalification would normally determine the rank of a coal deposit. The Maiganga coal has been established to fall within the lignite rank based on the values of its fixed carbon, moisture content, volatile matter, and ash content, determined through a proximate analysis. This apparently comes with peculiar implications. Mainly, these implications as discussed in this paper borders on mining, handling, storage, and the usage of the Maiganga lignite. Whereas it is easy to mine the lignite, it is not easy to store and/ or transport owing to the high moisture content, and even the high volatile content. The usage produces huge amount of waste in the form of ash, which are very injurious to man and the environment and even to the power plants where they are used. Also, it has been established in this paper that lignite has limited usage, mainly power generation, which is the case with the Maiganga lignite. However, it can be upgraded with the right technology to diversify its usage.

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