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Chemical analysis of coal deposit for power generation: A case study of Bukan-Kwato in Lafia L.G.A of Nasarawa state, Nigeria

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ABSTRACT

Nigeria, the most populated country of Africa is reactivating her coal industry as a supplementary energy source. Bukan—Kwato coalfield is one of the recently discovered coal deposits in Lafia that is receiving great attention from investors and entrepreneurs of coal energy. The coal serves as the prime target for power generation by the Nigerian Government, yet little is known about the basic properties of the deposit. The research seeks to achieve the objectives of collection of fresh coal samples from the mining site, so as to carry out the chemical analysis, determine the calorific value, and suggest the best methods for processing coal. The coal samples were collected from the study area and were subjected to proximate, ultimate, and calorific value determination in order to determine the intrinsic properties of the coal. Proximate analysis was carried out on pulverized samples using the Muffle furnace, carbon and hydrogen were determined using the method described in the Liebig method while nitrogen was obtained using the Kjeldahl method. The sulfur content was obtained using the ESCHKA method and the oxygen content was calculated by difference on an air-dried basis. Calorific value was determined using the isoperibol calorimeter. The results obtained compared with the standard pulverized coal fire plants show that the coal has a medium-to-high carbon content of 54.68%, high moisture content of (9.72%), nitrogen (3.5%), sulfur (24.24%), and ash (31.74%) with a corresponding low volatile matter of 20.28%. The high ash content in the coal can be used as thermal coal for power generation.

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1. Introduction

Energy plays an important role in ensuring industrial progress which depends on the creation of wealth and the establishment of a high standard of living for the people. Among the fossil fuels, coals play a vital role in the industry and our day today's activities of which coal can be used for thermal power generation which further helps to generate electricity, it can also be used in the steel and cement industries as fuel for extraction of iron from iron ore and cement.

Coal is an organic rock generally formed from the accumulation and preservation of dead plant materials. The plant remains that are usually buried and settled in a swampy environment undergo physical and chemical alterations under anoxic conditions as a result of heat and pressure which after a long period of the coalification process is transformed into coal. This organic-rich rock can consist of a significant amount of inorganic components (Riepe, 1993). The inorganic constituent of coal is usually expressed by its ash yield

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mineral matter, sulfur contents, and trace element contents. The organic components are the several biologically formed materials called macerals with a range of distinct chemical and physical characteristics that are fundamental to many coal properties.

Coal is generally classified into three major types based on its heating value and fixed carbon content. These are the lignite coal, the bituminous, and the anthracite. These two parameters of coal classification have an inverse relationship with other coal parameters such as coal moisture and volatile matter content. In between this major classification is the sub-bituminous coal with less moisture content and high heating value than the lignite and semi anthracite whose carbon content and volatile matter composition are higher than that of the bituminous coal but lower than that of anthracite.

1.1. Location, extent & geology

The study area is located at Bukan-Kwato in Lafia L.G.A of Nassarawa state. It falls between latitude 8° 29′ 20.00″ N and 8° 29′ 00″ N, longitude 8° 32′ 10.00″ E and 8° 32′ 50.00″ E. It is situated in the central part of Nigeria (Fig. 1). It covers about four square kilometers and can be accessed through the Lafia—Benue highway with a good road network linking the area. The area is characterized by warm and humid with dry and rainy seasons and it falls within the Guinea Savannah vegetation.

The area comprises the Awgu Formation, underlain by basal sandstones of Lafia Formation within the Southern Benue Trough. This area consists of grey-bedded shales with occasional sandstone beds (Fig. 2). At the contact with the Lafia Formation, it tends to be very sandy and difficult to differentiate from the Lafia Sandstone (Benkheli, 1989; Obaje and Ligouis, 1996). The sandstones are usually fine-to-coarse grain. Where the sandstones are coarse, they are very permeable and water-bearing (Offodile, 2002).

2. Materials & Method of Study

The materials used on the field and for the laboratory analysis include the following: global position system, marker/masking tape, topographical map, notebook, digital camera, muffle furnace, Parr 6400 Isoperibol calorimeter to determine the calorific value, weighing balance, crucible, lid, desiccator cabinet, hand rifler, centrifugal mill, double roller, crusher, Osborn 10 × 6 inch jaw crusher. Field photograph of the study area showing the mining area and the over burden in Bukan Kwato is shown in Plate 1. Samples were collected using the grab method from Bukan Kwato, Lafia L.G.A of Nasarawa state for laboratory analysis (Fig. 3 and Plate 2).

2.1. Sample preparations

The principle of mixing and then dividing, using the mechanical and manual methods was used to generate

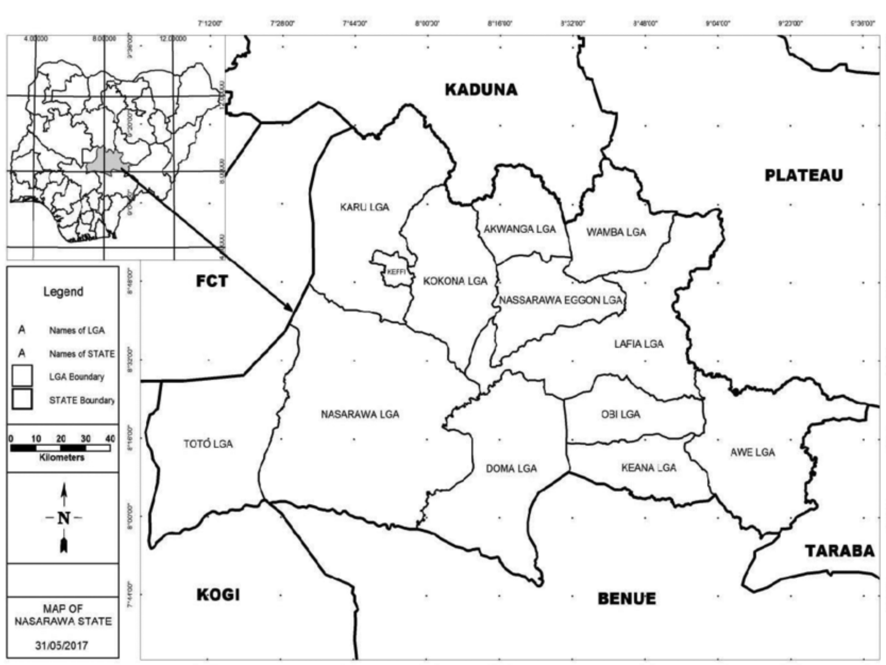

Figure 1. Map of Nasarawa state showing Lafia L.G.A. Source: Agidi et al. (2018).

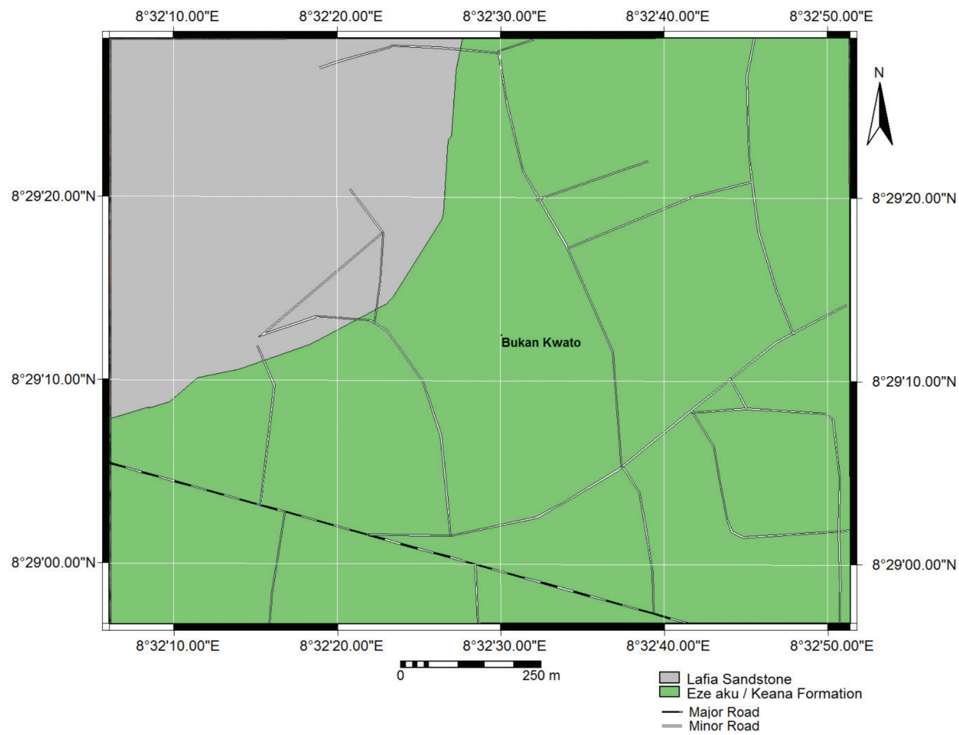

Figure 2. Geological map of the study area. Source: Mallo (2011).

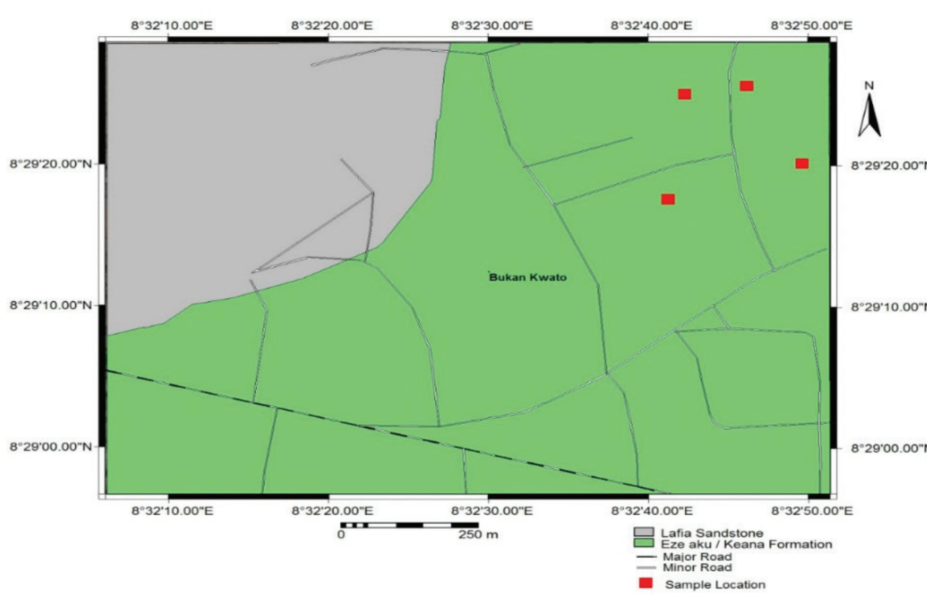

Figure 3. Map of the study area showing sampling points.

a representative sample of the coal, to the desired analytical specifications using an array of sample preparation equipment. Crushing of the sample from a top size of 150 mm to a suitable size distribution range of 12.5–50.0 mm was carried out using an Osborn 10 × 6 inch jaw crusher. A double roller crusher was used to crush the sample from a maximum top size of 25 mm to size distribution of a range of 1–6 mm. A Retsch ZM200 ultra centrifugal mill was then used to prepare the sample from a top size of 6 mm down to a suitable size distribution range of 212–4,750 µm. An automatic sieve shaker was used for sieving the sample to the

Plate 1. Field Photograph of Bukan Kwato Coal mine (overburden).

Plate 2. Sample collection on the field using Grasp Method.

desired size distribution required for the test while a hand rifler, was used to split the sample into representative sub-samples for analysis.

3. Proximate Analysis

3.1. Moisture content

The coal sample passing a 212 μm test sieve is stored in the proximate analysis room for at least 30 minutes before the test was carried out. The crucible with lid was heated. The crucible and lids are cooled for 10 minutes and then put in a desiccator cabinet for a minimum period of 10 minutes. An electronic balance is then used to weigh the crucible before uniformly spreading 1.00 g of the conditioned sample after recording the mass of the crucible and content. The crucible and content are then loaded into the air oven at a temperature of 600°C–800°C for at least 30 minutes. The crucible with dried sample was removed from the oven, the lid is replaced and allowed to cool for 10 minutes, then placed in the desiccator cabinet for another period of 10 minutes before being weighed finally, the moisture content of the coal is calculated from the loss in mass.

3.2. Volatile matter

In obtaining the volatile matter, the crucible and the content were loaded into the furnace at a temperature of 600°C−800°C for at least 7 minutes, The crucible with the dried sample was removed from the furnace, the lid is replaced and allowed to cool for 10 minutes, and then placed in the desiccator cabinet for another minimum period of 10 minutes before being weighed. After which the difference was calculated to determine the volatile matter.

3.3. Ash content

Coal samples passing a test sieve with an aperture of 212 μm were stored in the proximate analysis room for at least 30 minutes before the test commenced. After which the crucibles and lids were conditioned in the furnace and allowed to cool at room temperature, 1.00 g of coal sample was put into each crucible. The crucibles were loaded into the furnace equipped with a preprogrammed temperature controller. The furnace temperature was ramped to 500°C ± 10°C over a period of 60 minutes; held at 500°C ± 10°C for 30 minutes; ramped to 815°C ± 10°C over a period of 60 minutes; and held at 815°C ± 10°C for 60 minutes. The crucibles were removed and placed on an asbestos slab to cool down for 10 minutes. After which the crucibles were transferred to a desiccator cabinet and allowed to further cool down for 10 minutes. The crucibles were removed and weighed, with differences calculated to determine ash content.

3.4. Fixed carbon

Fixed carbon consists mostly of carbon but also contains hydrogen, oxygen, sulfur, and nitrogen not driven off with the gases. Fixed carbon was calculated through the formula:

% fixed carbon = 100 – (% moisture + % ash + % volatile matter)

4. Ultimate Analysis

Ultimate analysis determines the percentage mass fraction of the major constituents of coal such as carbon, hydrogen, sulfur, nitrogen, and, usually by difference, oxygen. Therefore, a lump of coal passing through a sieve having an aperture of 212 μm was used for this analysis.

4.1. Carbon and hydrogen

The carbon and hydrogen content are determined simultaneously by the combustion tube method as described in the Liebig method. In the Liebig method, 2 g of the coal sample was burnt in a current of oxygen to 850–9,000c after which all the hydrogen was converted into water and all the carbon to carbon dioxide. The product was now absorbed by suitable reagents and determined gravimetrically. The oxides of sulfur are retained by lead chromate, chlorine by silver gauze, and oxides of nitrogen by red lead.

4.2. Nitrogen

The method used to obtain the nitrogen content was the Kjeldahl method. In the Kjeldahl method, 1 g of the sample was heated with concentrated sulfuric acid containing 8 g of potassium sulfate, in the presence of a catalyst, to convert the nitrogen into ammonium sulfate. The ammonia is then released, and recovered by distillation, and determined by titration.

4.3. Sulfur content

The Eschka method was used to obtain the sulfur content therefore 10 g of the sample and Eschka mixture (two parts by mass of 5 g magnesium oxide and one part of 5 g anhydrous sodium carbonate) are thoroughly mixed and heated together in an oxidizing atmosphere gradually to a temperature of 800°C ± 25°C, and held at this temperature until oxidation of the sample is complete. The sulfur compounds evolved during combustion react with the magnesium oxide (MgO) and sodium carbonate (Na_2CO_3) and under oxidizing conditions are converted to magnesium sulfates ($MgSO_4$) and sodium sulfates (Na_2SO_4). The sulfates are extracted with hydrochloride acid solution, and then, by adding barium chloride ($BaCl_2$) solution, precipitated from the resulting solution as barium sulfates ($BaSO_4$). The precipitate is filtered, ashes, and weighed.

4.4. Oxygen content

Oxygen content was calculated by the difference on an air-dried basis as follows:

Oxygen (%) =100 – (carbon + hydrogen + nitrogen + ash + moisture)

5. Determination of Calorific Value

Coal samples passing a sieve with an aperture of were 4,750 μm were used for this analysis. The calorific value of the samples was determined by combustion.

The heat released is proportional to the calorific value of the substance. 1.0 g of coal sample in a nickel-chromium crucible was placed in a combustion vessel, which is surrounded by water. The sample was then ignited. The calorimeter jacket was held at a constant temperature by modulating the fan speed while the heat generated by the burning sample caused the bomb and bucket temperature to rise. The temperature of the water was measured by an electronic thermometer. Any minute heat flow between the jacket and the surrounding during the test was continuously monitored by a microprocessor and necessary corrections of any heat leak were applied automatically. The heat released is proportional to the gross calorific value (air-dried basis) of the sample and displayed automatically by the instrument.

6. Results and Discussion

The result of all the parameters analyzed is shown in Table 1, the inherent moisture content of the coal sample is 9.72% which indicates that the coal sample has a high moisture content compared to standard. Moisture content usually affects coal handling, storage, and pulverized capacity. An increase in moisture content increase flue gas, volume flow rate, and influence the excess air requirement with a consequent effect on fans, air preheater, and pollution control equipment. An increase in moisture content lowers the thermal efficiency of the boiler and can influence burner design. Therefore, the Nasarawa coal sample will lower the thermal efficiency of the boiler and can influence burner design because of its high moisture content. The sample from Bukan-Kwato coalfield

Table 1. Comparison of properties of Bukan-Kwato coal with standard bituminous coal quality requirement for pulverized coal-fired plants.

Coal	Chemical properties	Max	Min	Mean	Coal sample
1	Moisture %	15.94	6.03	10.32	9.72
2	Volatile matter %	45.10	25.49	36.87	20.28
3	Fixed carbon %	60.39	30.70	50.58	38.26
4	Ash %	43.81	4.41	12.56	31.74
5	Total sulfur %	9.07	0.62	3.0	24.24
6	Hydrogen %	5.36	3.39	4.78	9.72
8	Nitrogen %	3.03	0.35	1.40	3.56
9	Oxygen %	12.57	2.16	7.53	7.50

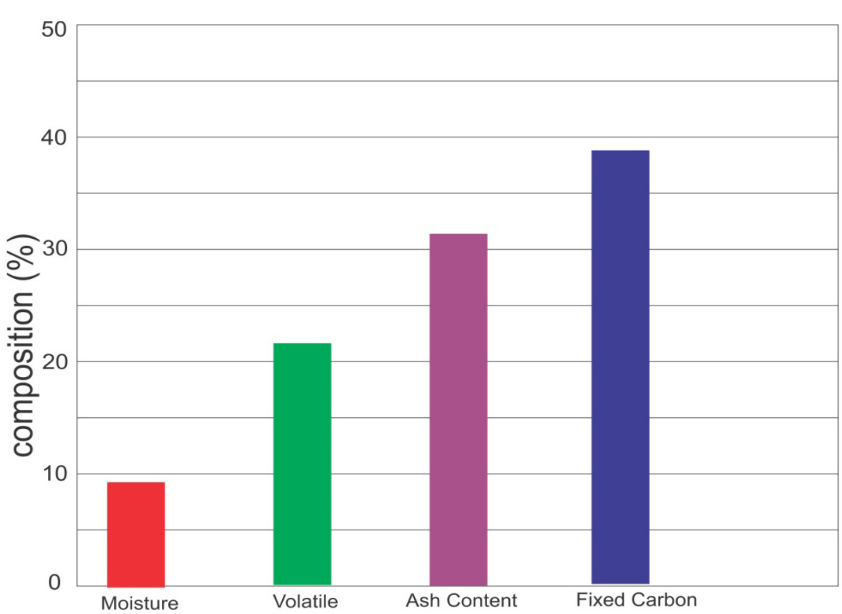

Figure 4. Proximate analysis result (histogram) of the coal sample.

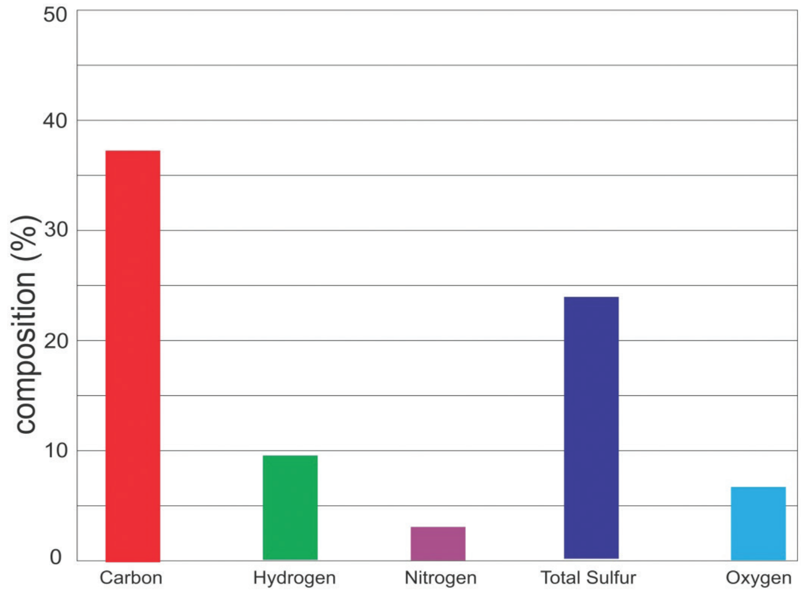

Figure 5. Ultimate analysis result (histogram) of the coal sample.

showed medium ash content of 31.74% Figure 4. The high ash content of coal from Bukan-Kwato coalfield gave an indication of potentially good quality coal for power generation. The coal samples show low volatile matter content of 20.28% which would have less danger of spontaneous combustion.

The elemental composition of carbon, hydrogen, nitrogen, sulfur, and oxygen in the coal sample is shown in Figure 5. The percentage of the elemental carbon is 38.26% and hydrogen content of 9.72% with a high total sulfur content of 24.24%. The oxygen content of the coal is 7.5% which showed medium oxygen content. The coal sample high nitrogen content of 3.56%. The nitrogen and sulfur content is an indication of the environmental unfriendliness of the fuel relative to the potential pollutant emission. Hence, the high sulfur content will definitely limit the future application of the coals particularly in the steel manufacturing industries. Coal is considered to have a high potential pollutant because of its high nitrogen and sulfur content.

Carbon and hydrogen are the major combustible constituent of coal, carbon has medium-high content, while hydrogen has high content (Fig. 5).

The calorific value gives the heating value or the heat of combustion of a substance. It has been suggested that the calorific value of power plant that uses coal are in the range of 9.5–27 MJ/kg (Burnard and Bhattacharya, 2011; Zactruba, 2009). Thus, the Bukan—Kwato coal sample has a high heating value of 26.6 MJ/kg which will be good for heating and power generation.

7. Conclusion and Recommendations

The coal samples from Bukan—Kwato in Lafia L.G.A of Nassarawa state have been analyzed to determine their suitability for power generation or iron reduction in the blast furnace. Analysis carried out on the coal samples includes proximate and ultimate analysis. The result of the proximate analysis showed that the coal has a low volatile matter of 20.28% and a high moisture content of 9.72% with a high elemental carbon content of 38.26% and that of ash content been 31.74%.

The calorific values were determine and compared with the required standard. The coal samples have a high calorific value of 26.6 MJ/kg. In conclusion, on analysis of test carried out on Bukan—Kwato coal sample, the proximate and ultimate analysis revealed that the coal sample has a medium to high carbon, and has high moisture, nitrogen, and sulfur content. However, the sample showed low volatile matter and high ash content. The calorific value showed that the coal has a higher heating value of 26.6 MJ/kg indicating its potential for efficient energy recovery during thermal conversion and good for heating and power generation.

Petrographic analysis of the Kwaton—Karfi coal, hard grove grind ability index, and drop tube furnace tests of the coal samples are recommended to complete the range of tests required for the characterization of these coals. In addition, a study of the characteristics of different ratios of a blend of these coal with a superior bituminous coal is also recommended.

For the coal to be used as coking coal, the high amount of sulfur should be trapped and used as an industrial input to minimize the effect on the environment. The coal sample analyzed should be blended with other coal deposits to reduce the amount of sulfur and increase the amount of carbon needed for heating.

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