OPEN ACCESS

Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) | ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Characterization of Selected Coal Mining Sites in Kogi State Nigeria for Power Plant Generation

AFU Damilola Johnson[1*], Omoseebi A.O[2], Ekun Adekunle[3], Obaiyi Yusuf[4], Ige Ibukun[5]

[1,2,4]Department of Mining Engineering, Federal University of Technology Akure, Nigeria
[3]Zhong Sing Mining Investment, Auchi, Edo State, Nigeria

DOI: https://doi.org/10.36348/sjet.2025.v10i08.002 | **Received:** 03.06.2025 | **Accepted:** 08.08.2025 | **Published:** 16.08.2025

***Corresponding author:** AFU Damilola Johnson
Department of Mining Engineering, Federal University of Technology Akure, Nigeria

Abstract

Fifteen coal samples were collected from Dangote, Zouma. and Omelewu coal sites, Kogi, State. Five samples from each site were subjected to laboratory tests which include proximate analysis, ultimate analysis, calorific value and total Sulphur content determination to determine their suitability for power generation. ASTM D3173, ASTM D5142, ASTM D3175, and ASTM D5865 standards were used respectively. Tests were carried out at FUTA laboratories and Sheda Science and Technology laboratory, Abuja, Nigeria. Dangote coal is a sub-bituminous B, low Sulphur and medium ash coal; Zouma sub-bituminous C, low Sulphur, medium ash coal, while Omelewu coal is a sub-bituminous C, low Sulphur, low ash coal. The coal samples analyzed are suitable for power generation (Heating value: 8,300 - 9,500 Btu/lb; Moisture content: 16.52% - 17.49%; Low Sulphur content <1.0); low to medium Ash contents 8.0-15.0%) and is in agreement with requirements published by coal-fired power plant operators. Gross calorific values, inherent moisture and contents of Zouma sub-bituminous coal make it more largely suitable for pulverized coal combustion when compared with the coal fuel used for the Genessee Phase 3 power station in Canada.

Keywords: coals, characterization, proximate, ultimate analysis and power generation.

I. INTRODUCTION

Coal is a solid, brittle, combustible, carbonaceous rock formed by the decomposition and alteration of vegetation by compaction, temperature and pressure. It varies in color from brown to black and is usually stratified [1]. Coal accounts for 41% of the world's energy source for electricity generation [2]. This is distantly followed by gas (21%), hydro (16%), nuclear (13%), oil (5%) and other renewables (3%) [3]. Coal is the key fuel for generating electricity on almost all continents, with almost all developed and developing countries relying on coal for the stable and secure supply of electricity [4]. Export of coal to other parts of the world between the period 1916 and 1959 served as viable source of revenue generation in Nigeria [5]. Available data shows that coal of sub-bituminous grade occurs in about 22 coal fields spread in over 13 States of the Nigerian Federation [6]. Throughout history, coal has been used as an energy source, primarily burned for the production of electricity and or heat and is also used for industrial purposes, such as refining metals [7].

Coal is the largest source of energy for the generation of electricity worldwide, as well as one of the largest worldwide anthropogenic sources of carbon-dioxide releases [8]. The rank of coal is based on the degree to which the original plant material has been transformed into carbon and can be seen as a rough indication of how the coal is: the older the coal, the higher the carbon content and the coal with the highest carbon content is the best and cleanest type of coal to use [9]. As one moves down the coal rank the heat given out decreases and dirtiness of the fuel and moisture content increases [9]. Over the past few decades, the world has become increasingly wary of coal combustion emissions because of concern about trace, minor and major metal releases into the environment [10]. Several Studies on trace and major elemental composition of coal have been reported in literature. The modes of occurrence and concentration of elements in coal have been reported in previous works [11]. According to the reports issued by environmental groups in 2004 and world Health organization in 2008, coal particulates pollution is estimated to shorten approximately 1,000,000 lives annually worldwide [12].

With the world crusade about global emission rate to the atmosphere, the developing country like Nigeria is clamouring for how to generate electricity by several means such as solar, gas plant to mention a few in order to meet the citizen daily electricity consumption. While the industries generate electricity by themselves for productions. This inadequate supply of electricity necessitates the use of coal at the biggest cement factory in Nigeria (Dangote Cement) for powering its power plant in order to meet the daily production of cement (999 trucks – a truck carries 45 tons at Obajana Factory) [13]. Nigeria produced a conservative peak load forecast of 8,900MW and an average generation of less than 4,000MW, the resultant massive load shedding has made Nigeria an unattractive environment for existing and prospective manufacturers. Manufacturers operating in Nigeria spend a weekly average of N1.8 billion on diesel to run their electric power generating sets [14]. In addition, it is claimed by the Manufacturers Association of Nigeria (MAN) that an estimated 60 million Nigerians now own power generating sets for their electricity, while the same number of people spend a staggering N1.56 trillion ($13.35m) to fuel them annually. This is besides private power generation by industrial consumers, which is almost at the same level [15].

Several researches have been conducted on coal samples in Nigeria until recently when major attention is given to coal due to its demand by Dangote Cement Factories (Obajana and Ibese Plants). Olaleye Investigated some Nigerian coals and showed that they have relatively low ash and moisture contents, low sulphur content and medium to high calorific value, make Nigerian coals favorable compared with other sub-bituminous coals in coal-producing countries of the world, thereby making them a good export commodity [16]. They are superior as regards ease of ignition, combustion characteristics and freedom from clinker [16,17]. The coals burn with a long flame and require large combustion space.

Five (5) coal samples were collected from Lafia-Obi (Nasarawa State), Okaba (Kogi State), Lamja (Adamawa State), Okpara and Onyeama (Enugu State) to determine their properties and classify them by rank using proximate analysis [6]. Auto-ignition temperatures, reactivity and activation energies of the various coal samples were also determined. Results obtained showed that Lafia-Obi coal could be ranked the highest as bituminous (low volatile) coal, Okpara and Onyeama coals both were both bituminous A coals, while Okaba coal was found to be sub-bituminous B coal. Lamja coal was found to be a lignite A coal. The study concluded that Lafia-Obi, Okpara and Onyeama coals may be used for power generation. Lamja and Okaba coals were not recommended for power generation because of their low calorific values [6]. Coal samples from Enugu State (Okpara West Area, Okpara West Bank and Onyeama) and Gombe State (Doho and Gamawa) were analyzed to determine their physical properties and to classify them by rank using proximate analysis [18]. His findings revealed that the reactivity and activation energies of the various coal samples depend on the coal type, source and particle size, while for some coals, the reactivity and activation energies increase with decrease in particle size (Okpara West Bank coal), in others, reactivity and activation energies decrease with decrease in particle size (Onyeama, Okpara West Area and Doho coals). However, in all cases, reactivity increases with increase in temperature [19].

Investigation were made on three Nigerian coals (Onyeama, Lafia-Obi and Gairin Maiganga) to determine their suitability in developing formed coke for use as blast furnace coke. Parameters that were used included the shatter index (proportion of weight of standard specimens retained by sieve), expressed as percentage stability and friability. The highest cumulative percentage stability and the lowest cumulative percentage friability was observed in Lafia-Obi with values of 67.54% and 32.46%, followed by Onyeama with 66.92% and 33.08% and then Garin Maiganga with 55.04% and 44.96% respectively. Medium and low temperature carbonization of Onyeama and Lafia-Obi coal samples gave an improved and satisfactory percentage stability and friability for semi-cokes [19].

In this research all the samples collected and tested were from Kogi state, Nigeria. The results from this research were compared with outcome from Olaleye [16].

The aim of this research article is to characterize coal samples from three selected locations in Kogi state, Nigeria for power generation. The objectives of the research are namely; to carry out proximate and ultimate analysis, determine the calorific values, and compare the results with Characteristics of Sub-Bituminous Coal used by the Genesee Phase 3 Power Station in Canada.

2.0 The Significance of this Research Article

This research will help determine the suitability of some Nigerian coals (from Kogi State) for use in different fields, not only in Nigeria, but as an export commodity to other coal-consuming countries around the world. This will assist the potential investor in Nigeria's power sector to make a decision on areas of the coal's performance that may be suspected, requiring further investigation by a larger-scale form of testing (pilot-scale simulation or full-scale testing) and also serve as a justification for investment.

2.1 Limitation of the Research

This research presents findings from proximate, Ultimate Analyses and Calorific Values determination from the selected three locations. Further analysis such as petrographic, thermogravimetric analyses and other suitable methods of coal analysis should be performed to confirm the ranks and grade of the coal deposits.

3.0 Characterization of Coal

Various methods are used for this purpose such as, proximate analysis, determining petrographic constituents and reflectance and thermal analysis. These analyses are also used for solving operational problems. Proximate and ultimate analyses are generally not adequate since they cannot be used to explain high amounts of unburned particles and petrographic effects [20]. However, standard laboratory analyses of coal are often unreliable predictors of power plant performance [21]. Nevertheless, laboratory data may be valuable as an indicator of areas of the coal performance that may be suspect, requiring investigation by a larger-scale form of testing. It also gives a measure of the variability of the coal's quality over the mine. There are over sixty analyses that are used to evaluate the physical and chemical properties of coal [22]. Results from the proximate and ultimate analysis with calorific value and Sulphur content determination were used in the classification of the coal samples.

3.1 Proximate Analysis

The proximate analysis of coal gives the relative amounts of the moisture, ash, volatile matter and fixed carbon as determined by a series of prescribed or standard test methods. Inherent moisture, volatile matter and ash content are all determined by ASTM D3173, ASTM D-3175 and ASTM D-3174 test methods, respectively [1].

3.2 Ultimate Analysis

The ultimate analysis of coal involves determination of the weight percent carbon as well as Sulphur, nitrogen and oxygen (usually estimated by difference). Trace elements such as chlorine, mercury and other elements that occur in coal are often included as part of this analysis. Carbon determination includes carbon present as organic carbon occurring in the coal substance and any carbon present as mineral carbonate. The hydrogen determination includes hydrogen present in the organic materials as well as hydrogen in all of the water associated with the coal. In the absence of evidence to the contrary, all of the nitrogen is assumed to occur within the organic matrix of the coal. On the other hand, Sulphur occurs in three forms in coal: as organic Sulphur compounds; as inorganic sulphides that are, for most part, primarily the Iron-sulphides pyrites and marcasite (FeS2); and as inorganic sulphates (Na_2SO_4, $CaSO_4$).

3.3 Calorific Value

Calorific (or heating) value is a measure of the amount of energy that a given quantity of coal will produce when burned, expressed in Joules/Kilogram (J/kg). Many methods for determining calorific value exist. However, a more recent test method is the ASTM D-5865. For practical applications in a coal-burning facility, corrections are made to the gross calorific value to account for the water vapour. The net calorific value is thus defined as the heat produced by combustion of a unit quantity of coal at constant atmospheric pressure under conditions such that all water in the products of combustion remains in the form of vapour [1]. Calorific value determines the quantity of coal per unit of output and coal mass flow, it also affects the capacity of the furnace, pulverizers, burners, feeding systems, fans, pollution control equipment, and coal and ash handling systems [23].

3.4 Coal Classification

Coals are classified according to RANK, TYPE and GRADE.

The degree of 'metamorphism' or coalification undergone by a coal, as it matures from peat to anthracite, has an important bearing on its physical and chemical properties, and is referred to as the 'rank' of the coal [24].

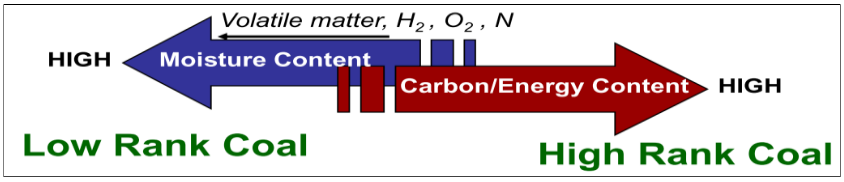

Plate 1: Coal ranking [24]

The rank of coal is its degree of maturation and is an indication of the extent of metamorphism the coal has undergone (see plate 1). Rank is also a measure of carbon content as the percentage of fixed carbon increases with the extent of metamorphism. Lignites and sub-bituminous coals are referred to as being low in rank, while bituminous coals and anthracites are classified as high-rank coals. The heating value of coals increases with increasing rank but begins to decrease in higher rank coals due to significant increase in volatile matter [25].

The American Standard for Testing and Materials (ASTM) classification system (ASTM D388) is popular in the industry. The ASTM D388 distinguishes among four coal classes, each of which is subdivided into several groups shown in Table 1 [25].

Table no 1: ASTM Coal Classification by Rank

Class/ Group	Fixed Carbon (%)	Volatile Matter (%)	Heating Value (Btu/Ib)
Anthracite			
Meta- anthracite	> 98	< 2	-
Semi- anthracite	92- 98	2- 8	-
Bituminous			
Low- volatile	78-86	14- 22	-
Medium –volatile	69-78	22 – 31	-
High- volatile A	<69	>31	>14,000
High- volatile B	-	-	13,000- 14,000
High- volatile C	-	-	10,500- 13,500
Class/ Group			
Anthracite	-	-	
Meta- anthracite	-	-	
Sub-bituminous			
Sub-bituminous A	-	-	10,500- 13,500
Sub-bituminous B	-	-	9,500- 10,500
Sub-bituminous C	-	-	8,300- 9,500
Lignite			
Lignite A	-		6300- 8300
Lignite B	-		<6300

**Calculated on dry, mineral-matter-free coal. Correction from ash to mineral matter is made by means of the Parr formula: mineral matter=1.08[percent ash + 0.55(percent sulfur). Ash and sulfur are on a dry basis. *Calculated on mineral-matter-free coal with bed moisture content. *Coals with heating values between 10,500 and 11,500 Bru/lb are classified as high volatile C bituminous if they possess caking properties or as subbituminous A if they do not*[25].

4.0 MATERIALS AND METHOD

Materials used for samples collection include; diggers, polythene nylon, paper tape, metre tape, Chiesel, harmer and permanent marker. Active working mine were divided into 5 portions while 1 sample were collected from each portion for the three selected locations (Omelewu, Zouma and Dangote) and were stored in appropriately labelled air-tight containers to retain their properties as it is in its natural form.

4.1 Location of the study Area

The study location is in Kogi State, Nigeria. Omelewu coal site lies between latitude 007° 43’ 46.8’’ and 007° 43’ 47.9’’ north, and longitude 007° 14’ 25.6’’ and 007° 14’ 27.6’’ east; Zouma lies between latitude 007° 46’ 14.2’’ and 007° 46’ 26.1’’ north, and longitude 007° 27’ 40.7’’ and 007° 30’ 42’’ east; and Dangote lies between latitude 007° 42’ 31.7’’ and 007° 42’ 29.5’’ north, and longitude 007° 30’ 4.3’’ and 007° 30’ 43.7’’ east. The coal sites lies Olamaboro Local Government Area and Ankpa Local Government Area of Kogi state, Nigeria.

Equipment used for samples collection include, sledge hammer, Chisel, digger, polythene bags, masking tape, marker and sack.

4.1 Samples Preparation

The coal sample was prepared using both the mechanical and manual methods so as to meet the desired analytical specifications using an array of sample preparation equipment. Crushing of the samples from a top-size of about 500 - 600mm, and to a suitable size distribution range of 30.5 – 100mm was carried out manually through the use of hammer. A pulveriser shown in Plate 2 was then used to prepare samples from a top size of 6mm down to a suitable size distribution range of 150 – 250µm as shown in plate 3.4. An automatic sieve shaker, shown in Plate 3, was used for sieving the samples to the desired size distribution required for each test. 600g of 250-microns size of representative sample of coal was used to carry out analysis for proximate analyses, and calorific values. This research was carried out at Professor Julius Okojie Central Research Laboratory of the Federal University of Technology, Akure, Ondo State, Nigeria. The tests conducted on the coal samples includes; coal density determination, Proximate analysis (Volatile matter, Moisture content, Mineral matter, Fixed carbon, Ash content) and Calorific value determination.

Plate 2: Pulverizer

Plate 3: Automatic sieve shaker

4.2 Ultimate Analysis

Ultimate Analysis was performed at Sheda Science and Technology Complex Abuja, Nigeria. Coal passing through a sieve having an aperture of 212µm was used for this analysis. Ultimate analysis was carried out making use of the TRUSPEC CHN Elemental Determinator manufactured by LECO Corporation shown in Plate III and IV. The equipment is supplied with a reference material with known elemental composition. This reference material (Prox-Plus) was used to determine the accuracy of the CHN Elemental Determinator (Plate III) before commencing the tests.

Procedures: 1.0g of sample was loaded into porous crucibles and subjected to combustion in an oxygen-rich environment. Typical run duration is about 7 – 10 minutes. The system converts the coal catalytically to Nitrogen, CO2 and water, which are separated with a gas chromatographic column and detected through a sensor. The results were displayed on the computer monitor in terms of percentage carbon, hydrogen and nitrogen on an air dried basis. This was based on ISO 12902 – CHN instrumental method.

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

$$Oxygen\,(\%) = 100 - (Carbon + Hydrogen + Nitrogen + Ash + Moisture) \quad (1)$$

Plate 4: CHN Elemental Determinator (Main Unit)

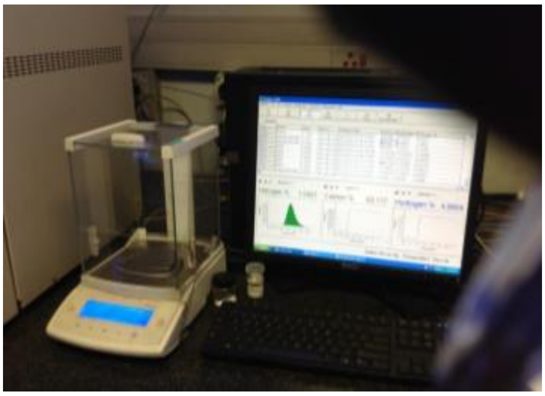

Plate 5: CHN Elemental Determinator (Display Monitor)

4.3 Determination of Density of the Coal Samples

The density was determined by weighing the mass (mg) of each coal samples on the weighing balance to know the weight of each coal sample. A 250ml measuring cylinder was filled to with distilled water (initial volume, Vi). Grain Coal sample was gently and carefully put into the measuring cylinder containing distilled water and change in volume was recorded (Final volume, Vf). Then the density is being determined using the equation below.

$$Density = \frac{mass}{Change in volume} = \frac{mass}{Vf - Vi}\ x\ 100 \quad (2)$$

4.4 Proximate Analysis

Moisture Measurement: (ASTM D3173) standards was used for the moisture content determination.

$$moisture\ content = \frac{Weight of\ sample - weight of\ dried sample}{Weight of\ sample} x100 \quad (3)$$

Measurement of Ash Contents: (ASTM D5142) standard was used to determine ash content.

$$ash\ content = \frac{Weight of\ sample - weight of\ dried sample}{Weight of\ sample} x100 \quad (4)$$

Measurement of Volatile Matter: ASTM D3175, specification was used to determine the volatile matter.

$$Volatile\ matter = \frac{Weight of\ sample - weight of\ dried sample}{Weight of\ sample} x100 \quad (5)$$

Measurement of Fixed Carbon: Determination of fixed carbon is carried out using the equation below:

$$Fixed Carbon = 100 - (volatilematter + ashcontent)\% \quad (6)$$

Determination of Mineral Matter: INDIAN STANDARD, ISO/R/679, specification was used to determine Mineral Matter.

$$\text{Mineral Matter} = \frac{M_1 + M_2 + P + HCL + 1.1A +}{M_1} \; x\ 100\% \qquad (7)$$

$$F = \frac{MM}{A_1} \qquad (8)$$

Where, Where M_1 = mass in grams of sample taken; M_2= mass in grams of sample after extraction; P= mass in grams of pyrites in the extracted coal; H C l= mass in grams of hydrochloric acid in the extracted coal; A= mass in grams of ash, less iron oxide from the pyrites in the extracted coal; F= mineral matter factor; A1= percentage of ash in the original coal and MM= Mineral Matter

4.5 Determination of Calorific Values of Coal samples

ASTM D5865 standard was used to determine gross calorific value. In determining the calorific value, coal samples of aperture size of 250µm were used for this analysis. The calorific value of the samples is determined using the e2k combustion bomb calorimeter.

4.6 Determination of Total Sulphur Content

Total Sulphur was determined using infra-red (IR) spectroscopy method as specified by ISO 19579. Coal samples passing through a test sieve with an aperture of 212µm were used for determination of total Sulphur content. Samples were then conditioned in a dry oven at a temperature of 105±5^{0}C for 60 minutes, transferred into a desiccator cabinet and allowed to cool for approximately 30 minutes. A LECO S-144 Dual Range Sulphur detector (shown in Plate 6) was used for the test. 0.35g of coal sample was placed in a combustion system to burn in a stream of pure oxygen at a maximum operating temperature of 1350 ^{0}C. This oxidizes the Sulphur content and breaks down Sulphur-bearing compounds to form SO2. Anhydrous magnesium perchlorate removes all moisture, and the SO2 flows to the infra-red detection cells where Sulphur is measured by infra-red absorption detectors. SO2 absorbs infra-red energy at a precise wavelength within the infra-red spectrum. Average run time was 3 – 5 minutes. Results were displayed automatically on the computer monitor in percentage Sulphur on an air-dried basis.

Plate 6: LECO S-144 Dual Range Sulphur Detector

5. RESULTS AND DISCUSSION

5.1 Proximate Analysis Result

The mean values obtained from proximate analysis results of the five representative samples from each coal deposit are graphically depicted in Figure 1.

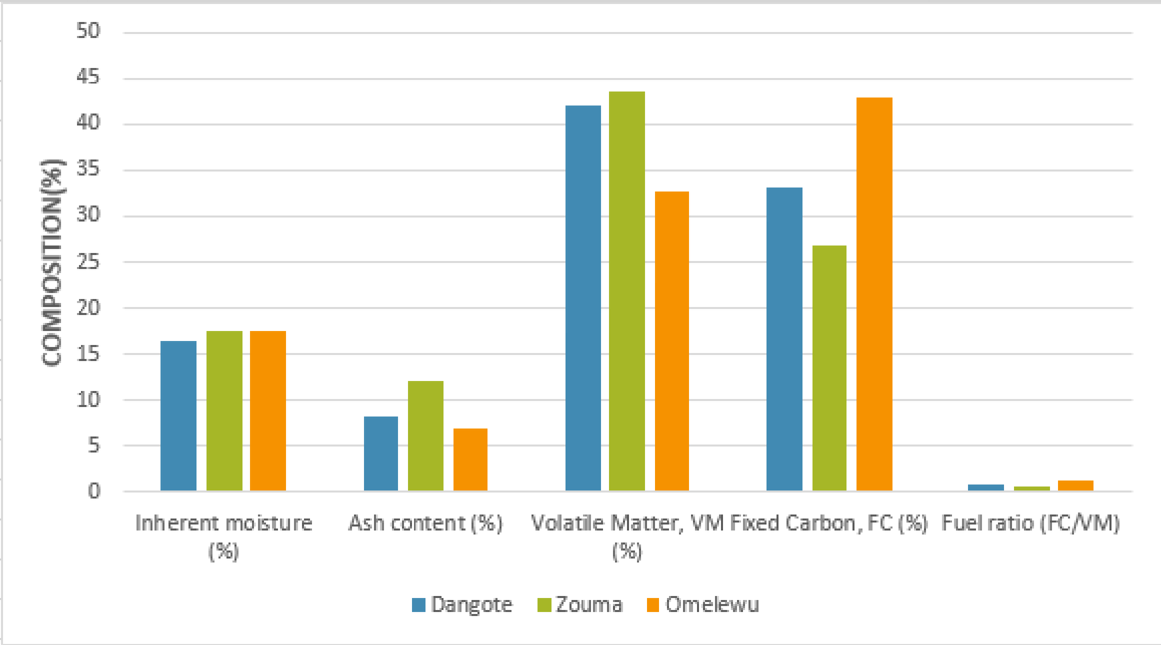

Figure no 1: Mean of the Proximate Analyses Result of the three Coal deposits

Average moisture Content: The average inherent moisture contents range from 16.52% to 17.49%. The Zouma coal deposit (17.49%) had the highest moisture content, followed by Omelewu (17.43%) and Dangote coal deposit (16.52%) respectively as shown in Figure 2. Moisture content affects coal (and ash) handling and storage (coal flow properties, behavior in frost, dust emissions), and pulverizer capacity. An increase in moisture increases the flue gas volume flow rate and influences the excess air requirements with consequent effect on fans, air preheater and pollution control equipment. Increased moisture lowers thermal efficiency of boiler and can influence burner design [23]. Dangote coal deposit with the lowest inherent moisture content (16.52%) would be the easiest to handle and store followed by Omelewu (17.43%), and then Zouma (17.49%) coal samples

Volatile Matter: Zouma had the highest (43.45%), followed by Dangote (42.00%) while Omelewu (32.67%) coal deposit had the lowest volatile matter content.

Fixed Carbon content: The highest fixed carbon content of 42.88% was recorded in Omelewu coal sample, followed by Dangote and Zouma coal samples with values of 33.23% and 26.84%, respectively.

Ash content affects coal and ash handling systems, pulverizers (abrasion), furnace, super heater, reheater, economizer, soot blowing intervals (slagging and fouling propensity, erosion, corrosion), pollution control equipment and unburnt carbon in ash [23]. Omelewu coal sample with the lowest ash content (7.01%) would cost less in terms of investment in ash handling equipment and pulverizer abrasion followed by Dangote (8.24%) and Zouma (12.19%) coal samples.

The volatile matter content of coal affects storage behavior (oxidation, danger of spontaneous combustion, loss of heating value), pulverizer outlet temperature and required fineness for pulverization, burner settings, furnace, combustion behavior and efficiency (ignition, flame shape and stability, burnout and carbon content of fly ash) [23]. Omelewu coal sample with the lowest volatile matter (32.67%) would have the least danger of spontaneous combustion when compared with Dangote (42.00%) and Zouma (43.45%) coal samples respectively.

5.2 Ultimate Analysis Result

The mean values obtained from proximate analysis results of the five representative samples from each coal deposit are graphically depicted in Figure 2.

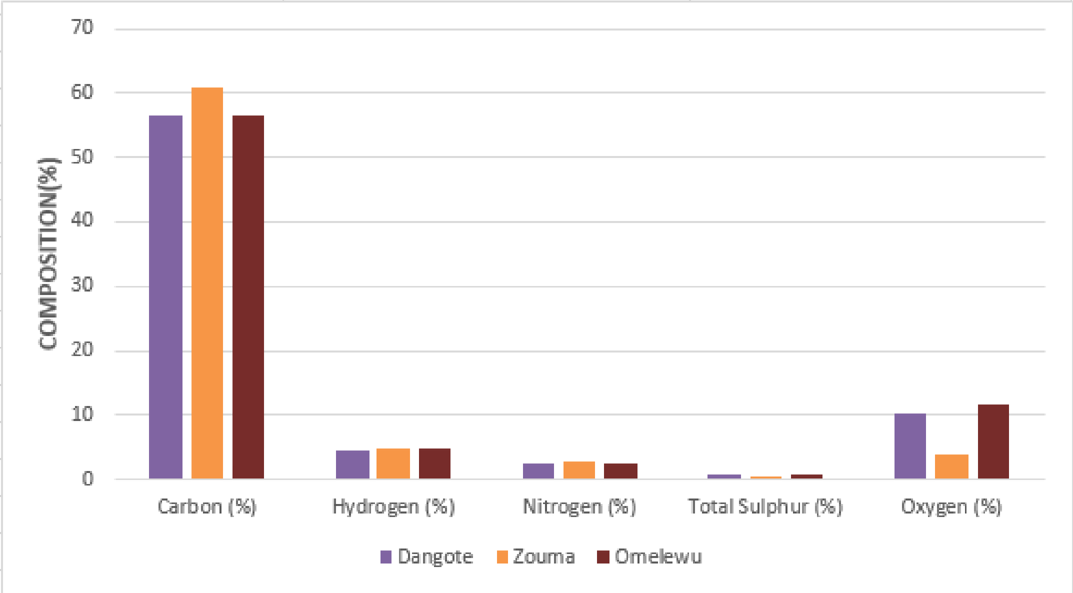

Figure no 2: Mean of the Ultimate Analyses Result of the three Coal deposits

The elemental composition of carbon, hydrogen, nitrogen, total Sulphur and oxygen in the coal samples are shown in Figure 2. The percentages of the elemental carbon of Dangote, Zouma and Omelewu Coal samples were as follows: 56.43%, 60.92%; and 56.40%, and hydrogen 4.45%, 4.67% and 4.85%. Zouma coal sample had the lowest total Sulphur content of 0.51%, while Omelewu sample had the highest value of 0.74%. The oxygen contents of the coal samples fall between 3.00% and 12.00%. The Zouma coal sample had the lowest oxygen content of 3.77%, followed by Dangote and Omelewu coal samples with 10.37 and 11.72%, respectively. The Zouma coal sample had the highest nitrogen content of 2.68%, followed by the Omelewu coal sample with 2.68% while the Dangote had the lowest value of 2.47%. Carbon and hydrogen are the major combustible constituents of coal, and both of them are high in the coal samples. The higher the carbon content, the higher the calorific value and the better the quality of the coal for power generation.

5.3 Result of the Calorific Values Determination

The mean calorific values obtained for the three coal are graphically depicted in Figure 3.

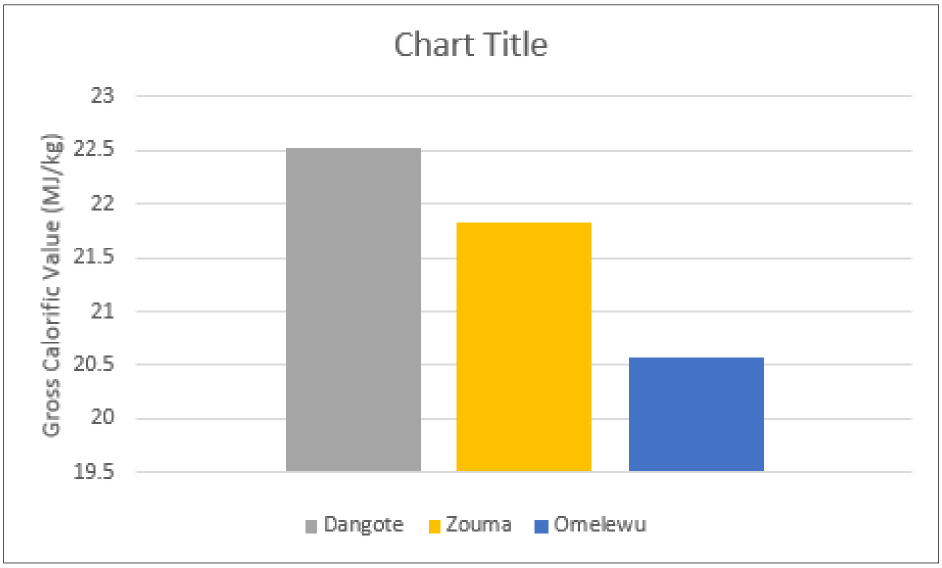

Figure no 3: Mean Calorific Values of the Coal deposits

From Figure no 3 above, the Dangote coal sample had the Mean highest gross calorific value of 22.52MJ/kg, followed by the Zouma coal sample with 21.83MJ/kg and Omelewu coal sample with 20.58MJ/kg. 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 coal is in the range of 9.5 MJ/kg to 27 MJ/kg [27].

Thus, all the coal samples would be suitable for power generation. The Dangote coal sample, with the highest heating value of 22.53MJ/kg, would be the best for heating and power generation.

5.4 Suitability of Selected Coal Samples for Pulverized Coal-Fired Power Generation

Pulverized Coal Combustion is the most commonly used method in coal-fired power plants [28]. This technology is well developed, and there are thousands of units around the world, accounting for well over 90% of coal-fired capacity, and can be used to fire a wide variety of coals, although it is not always appropriate for those with a high ash content [26]. Results of the analysis of the coal samples were benchmarked with requirements of existing pulverized coal combustion plants from around the world.

Table no 2: Comparison of Three Coal Deposits with Characteristics of Sub-Bituminous Coal used by the Genesee Phase 3 Power Station in Canada

Parameters	Genesee Phase 3, Canada		Coal samples	
		Dangote	Zouma	Omelewu
Coal type	Sub-bituminous	Sub-bituminous	Sub-bituminous	Sub-bituminous
Gross Calorific Value (MJ/kg)	17.9	22.53	21.92	20.58
Ash (%)	19.4	8.24	12.19	7.01
Moisture content (%)	20	16.52	17.49	17.43
Total Sulphur (%)	0.2	0.63	0.51	0.74

Source [28]

Table no 2 compares the characteristics of the sub-bituminous coal used by the Genesee 3 Phase power station in Canada with the three coal samples which have been confirmed to be sub-bituminous coals.

The table shows that only the sulphur contents of Dangote, Zouma and Omelewu coals exceed the benchmark while the ash contents, Lower Moisture contents were observed in the selected coal sites with higher Calorific values than the coal used at Genesee 3 phase power station of Dangote, making it suitable for pulverized-coal combustion power station which results in low cost in driven off the moisture and higher heating value. However, irrespective of the deficiencies noted, corrections may be affected through beneficiation or blending with other appropriate coals.

5.5 Ranking of Analyzed selected Coal Samples Using ASTM Classification Standard

Using Table 2. results of proximate analyses in Figure 3 and calorific values in Figure 3, Table 2 was obtained, showing the classification of the three (3) coal samples based on ASTM D388 specifications. Based on the results above, the Fixed Carbon (<69%) and Volatile Matter (>31%) values obtained imply that the coals may only be ranked using the Heating Value (Btu/lb) parameter.

Table 2: Ranking of Omelewu, Zouma and Dangote Coal Samples using the ASTM Classification

Coal Rank	Heating Value Criteria (Btu/lb) (Miller, 2005)	Coal Samples (Heating Value, Btu/lb)		
		Dangote (9,688.01)	Zouma (9,380.84)	Omelewu (8,271.70)
Bituminous High-volatile B	13,000 - 14,000			
Bituminous High-volatile C	10,500 – 13,000			
Subbituminous A	10,500 – 11,500			
Subbituminous B	9,500 – 10,500	*		
Subbituminous C	8,300 – 9,500		*	*
Lignite A	6,300 – 8,300			
Lignite B	<6,300			

Source [25]

Table 2 shows that Dangote coal is a Sub-Bituminous B coal. Zouma and Omelewu coal are Sub-Bituminous C coal. All the three coals were ranked low coal (8,300-9,500Btu/lb) This classification agree with published data shown in Table 1. (Note: Btu/lb:1 MJ/kg=429.9Btu/lb)

5.6 Ash and Sulphur Classification of Omelewu, Dangote and Zouma coals

From results of proximate and ultimate analyses shown in Figures 2 and 3 respectively, table 3 was obtained, showing the ash and Sulphur classifications of the coal samples.

Table 3: Ash and Sulphur Classification of Omelewu, Dangote and Zouma coals

*Classification	*Compression Range a.r (%)	Coal Samples (Heating Value, Btu/lb)		
		Dangote	Zouma	Omelewu
Ash Content				
High Ash	> 15.0			
Medium Ash	8.0 – 15.0	*	*	
Low Ash	< 8.0			*
Sulphur Content				
High Sulphur	> 3.0			
Medium Sulphur	1.0 – 3.0			
Low Sulphur	< 1.0	*	*	*

Source[28]

Table 3 showed that both Dangote and Zouma were medium- ash coals, while Omelewu is a low-ash coal. All the coal samples were classified as Low-Sulphur coals < 1.0. This result confirmed result from Olaleye work[16].

6.0 CONCLUSION AND RECOMMENDATIONS

Fifteen selected coal samples from Omelewu, Dangote and Zouma deposits were used for the classification and characterization of the three coal deposits for firing power plant at Dangote Cement Factory located at Obajana (Kogi State) and Ibese (Ogun state). The selected deposits had met the specifications required for the coals to be used in powering power plant.

I hereby recommend the following;

i. Further research should be conducted on the selected coal samples due to coal variability and uncertainty within the same deposit with depth.
ii. More samples data should be collected for laboratory tests due to uncertainty in coal property.
iii. Thermogravimetric and petrogravic analysis should be carried out on the selected coal samples.
iv. Electricity generation from coal is the most feasible solution to the power supply problem facing Nigeria.
v. In keeping with its published Roadmap for Power Sector Reform, it is needful for the government to aggressively exploit Nigeria's abundant coal reserves for this purpose.
vi. Both pulverized coal combustion and fluidized bed combustion technologies may be deployed to ensure that Nigerian coals are used for generation of much-needed electricity.
vii. The ash content present in coal is important in the design of the furnace grate, combustion volume, pollution control equipment and ash handling systems of a furnace while volatile matter indicates easy ignition of fuel, so it can be used in domestic stoves and furnaces all in small appliances.

Availability of Data and Materials: All data and materials used are from laboratory tests carried out in FUTA.

Competing Interests: There is no conflict on interest.

Funding: Funding are self sponsored.

Authors' Contributions

Afu D.J contributed 50%, Omosebi 20%, Ekun 20%, and Ige 10%

ACKNOWLEDGEMENT

I hereby acknowledged Enachir Nigeria Enterprise for their support during the course of the project work. And also staff of the various laboratories where different tests were conducted especially the Chemists in Chemistry department, technologists in Mining and Metallurgy and Materials Engineering all from Federal University of Technology, Akure, Ondo State, Nigeria., and Sheda staff.

REFERENCES

1. Speight, G. J. (2005). Handbook of Coal Analysis. John Wiley and Sons, Inc., Hoboken, New Jersey, USA, pp. 41 – 102.
2. (Karl, 2013).http://www.eia.doe.gov/emeu/aer/txt/ptb0802a.html
3. World Coal Association. (2012). Coal matters 3/coal and electricity generation. Retrieved from < http://www.worldcoal.org/resources/wca-publications>.
4. Adewole, A. (2000**).** Investment Potentials of the Nigerian Coal Industry. Ministry of Solid Mineral Development. Nigerian Coal Corporation Journal, Vol 1 pp.5-6.
5. Kibiya, M. M. (2012). Properties of some Nigerian coals for power generation. (Unpublished master"sthesis). Ahmadu Bello University, Zaria, Nigeria.
6. Colorado Geological Survey (2005). Colorado Coal: Energy Security for the future. Vol. 8, No 2, pp. 1 – 12. http://www.psr.org/coalreport.
7. Gabbard, A. (2008). Coal combustion: Nuclear Resource or Danger. Oak Ridge National Laboratory. pp. 97 – 105.
8. Pacyna, J.M. and Pacyna E.G. (2001). Assessment of Global and regularly Emissions of Trace Metals to the Atmosphere from Anthropogenic Sources Worldwide. Environ. Rev., 9(4): pp. 269-298.

9. Zhang, S., Ren D., Zhang, C., Zeng, R., Chou, C. and Liv.J. (2002). Trace element abundances in major minerals of late Permian coals from South Western Guizhou Province, China. Int. J. Coal Greol., 53(1): pp. 55 – 64.
10. Pope C. A., III, Ezzati M., Dockery D. W. (2009). Fine-Particulate Air Pollution and Life Expectancy in the United States. The New England Journal of Medicine. 360(4): pp. 376–386.
11. Field Survey, (2016).
12. Iba, L. (2011). Beyond PHCN's privatization. Retrieved May 12, 2012, from, http://www.nigerianbestforum.com/blog/beyond-phcn%E2%80%99s-privatisation/. https://www.vanguardngr.com/2013/01/nigeria-spends-n3-5trn-annually-on-power-generators/.
13. Olaleye, B. M. (2003). Assessment of coal reserves, exploitation and utilization in Nigeria. Nigerian Journal of Engineering Management, 4(3), pp. 10 – 14.
14. Energy Commission of Nigeria, (ECN) (2009). [online] [viewed 29/08/2017] Available in www-form: <http://www.energy.gov.ng/index.php?option=com_frontpage&Itemid=1>
15. Laudan, K.J. (2008). Spontaneous ignition temperature and reactivity of some Nigerian coals. (Unpublished master's thesis). Abubakar Tafawa Balewa University, Bauchi, Nigeria.
16. Jauro A. and Chukwu C. J. (2011). Production of formed Coke from Nigerian Coals. *Petroleum and Coal*, vol. 53, no. 1, pp. 22–25.
17. Kizgut, S., Cuhadaroğlu, D., and Toroğlu, İ. (2003). Thermogravimetric characterization of Turkish bituminous coals for combustion. Turkish Journal of Chemistry 27, pp. 521-528.
18. Apriani, Y. (2009). Thermal coal use in pulverized fuel fired boilers. Retrieved September 15, 2010, from, http://bestcoaltrading.blogspot.jp/2009/12/thermal-coal-use-in-pulverised fuel.html
19. Osborne, (2013**).** Ebook ISBN:9780857097309. Hardcover ISBN: 9780857094223. Wood head publishing pp 39.
20. Carpenter et al., 2007). Fundamentals of coal combustion. Retrieved May 2, 2012 from, http://www.coalonline.info/site/coalonline/content/browser/81591/Fundamentals-of-coal combustion.
21. Brian H. B and Marty W. I. (2008). Coal Characteristics. The Energy Center at Discovery Park Purdue University. Indiana Centre for Coal Technology Research. Pp. 13 – 15.
22. Miller B. G. (2005). Coal Energy Systems. Elsevier Academic Press, Burlington, Massachusetts, USA, Vol 5, pp 6 – 9.
23. International Energy Agency. (2010). Pulverized coal combustion. Retrieved May 3, 2014, from, http://www.iea-coal.org.uk/site/2010/database-section/clean-coal-technologies.
24. Zactruba, J. (2009) Burning Coals in Power Plants—Calorific Value and Moisture.
25. International Energy Agency, (2007). Fossil fuel-fired power generation: case studies of recently Constructed coal-and gas-fired power plants. http://www.iea.org/publications/freepublications/publication/fossil-fuel-fired-power generation.html.
26. Tavoulareas, E. S., and Charpentier, J. P. (1995). Clean coal technologies for developing countries. In World Bank Technical Paper No. 286. Retrieved from http://documents.worldbank.org/curated/en/1995/07/5186832/clean-coal technologies developing-countries.