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Quality Assessment of Coal Deposits around Molko Area, Gombe, NE Nigeria.

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Abstract: *This study present detailed chemical compositional characteristic of coal deposits for quality assessment. The study area falls within the Gongola basin, North-eastern Nigeria. Seven core coal samples were collected from three boreholes of approximately 25 meters depth each in Molko area around Mallam Sidi in Gombe state, North-eastern Nigeria. Assessment of coal quality based on proximate (volatile matter, fixed carbon, ash, moisture), ultimate (H, N, O, S) analyses of the Molko coals was carried out. International Standard Organisation (ISO) standards were followed for proximate and ultimate analyses. X-Ray fluorescence were used for the major and minor elements analysis.The results of proximate analysis of coal average value of Air Moisture 0.04%, Inherent Moisture 4.18%, Total Moisture 4.23%, Ash content 31.37%, Volatile matter 40.69%, Fixed carbon 23.71% and Gross calorific value 19005j/g. The study revealed that the Molko coal show an appreciable property of coking quality and thus can be employed in the generation of substantial heat for the working of blast furnace.*

I. Introduction

The study area is located in the North-Eastern part of Nigeria on latitude $10^0 26^l 18^{ll}$N and longitude $11^0 15^l\ 25^{ll}$E (Figure 1). The Cretaceous geology of the Upper Benue Trough to which the study area falls, includes a lower continental unit formed by the Bima Sandstones series deposited in a lacustrine-deltaic environment. Above, the marine sequence of shales with interbedded carbonates represents the Turonian and the Senonian stages. The Cretaceous sequence is capped by the regressive formation of the Gombe Sandstone of Maastrichtian age. The Tertiary is represented by the continental deposits of the Kerri-Kerri Formation is restricted to the western part of the Upper Benue Trough (Cater, 1963). The Trough was formed by several subbasins whose evolution and distribution were closely controlled by a fracture system where the N55^{0}E trend dominates. The E-W grabens filled with deposits of Upper Aptian age (Allix et al, 1981 and Brunet et al., 1988) is related to tensional movements (Popoff et al., 1983). From the Upper Aptian to Lower Albian times, the Kaltungo Fault, an inherited Pan-African mylonite, has played as a sinistral wrenching responsible with other faults of the formation of pull-apart basins (Benkhelil, 1982, Benkhelil & Robineau, 1983).

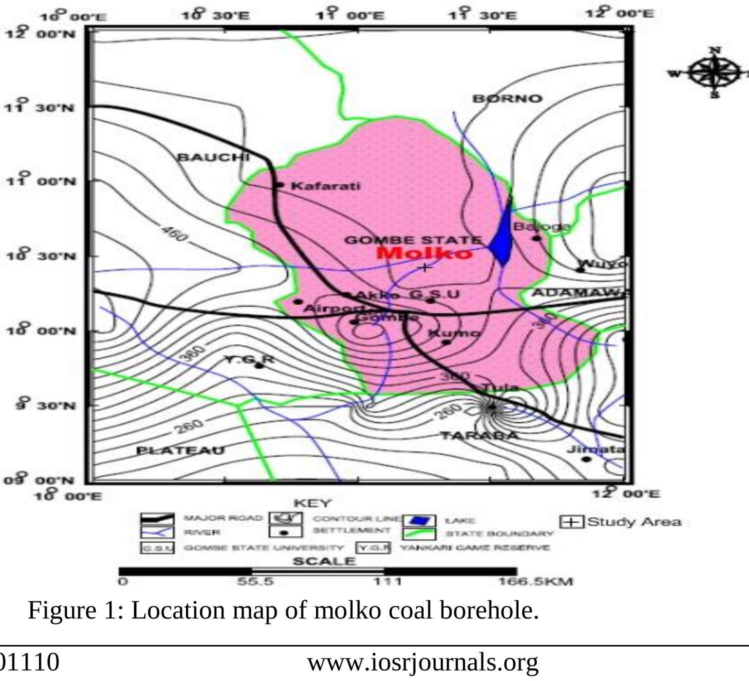


Figure 1: Location map of molko coal borehole.

A compressive phase of late Maastrichtian age is responsible for the fracturing and folding of the Cretaceous cover. The style and direction of folds are greatly influenced by the basement structures. The fracture system is mainly formed by strike slip faults resulting from a N155^{0}E trending horizontal compression.
A post-Cretaceous tectonics is marked along the western edge of the Kerri-Kerri plateau by normal faults (Adegoke et al., 1986; Benkhelil, 1982). Evidences of tensional movements also occur in the Yola branch where N-S trending normal faults are found to result from the tensional regime related to the emplacement of the Cameroon Volcanic Line (Cater el al., 1963). A second phase occurred during the Tertiary corresponding to the intense alkaline magmatic activity in relation with the Cameroon volcanic lines (Cater el al., 1963 and Bauldin, 1986). The previous studies within the region show that, coals were found at Pokitau, Doho and Kolori to the north of Gombe and at Garin Maiganga to the south of the town (Cater el al., 1963). The most important seams occur near Molko. In this area, coal was first found at Garin Maidugu, 2 miles north of Molko, where two thin seams were exposed in a native well. Chemical analysis of the Maiganga coal seams which is 70km East away from Molko area, indicated that on average, they contain 4.8% moisture, 49% ash, 31.11% volatile matter, 0.92% sulphur, 15.64% organic carbon, 0.02% phosphorus, 2283Kj/Kg calorific value and 0 Free Swelling Index (Usman, 2014).

II. Geology

The basic stratigrpahy of the study area fall within the lithostratigraphical successions for the Goongola Basin, North-eastern Nigeria were established by Carter et al. (1963) and modified by Popoff et al. (1986). The formation in the study area is Gombe formation corresponds to the name "Gombe sandstone" which was proposed by Cater et al. (1963) for the "gombe grits and clays" previously identified by Falconer (1911). A type section was designated by the former authors in the Kware stream on the southern outskirts of Gombe town.

The Gombe formation is restricted to the western part of the Gongola Basin it weathers to produces a ferruginous capping. This resistant material, along with ironstone weathered out of the sequence is responsible for the rugged and hilly topography charactering much of its outcrops. The Gombe formation is made up three major lithofacies which may ultimately prove recognizable as separate members. At the base, the Gombe Formation consist of rapidly alternating thin beds of silty shales, sometimes with plant remains, and fine to medium-grained sandstones with some intercalated thin flaggy ironstones. Individual beds vary from a few millimetres to a few centimetre in thickness.

Passing upwards, the sandstone beds become more persistent and make up the greater persistent and make up the greater part of what is here termed the "bedded facies". This lithofacies, which is well exposed at Guiwa, consist of extremely regularly bedded, fine to medium-grained white and grey quartz arenites (and occasional feldspathic sandstones) with interbedded silts, silty clays and both flaggy and vesicular ironstones. The bedded facies also contains channel-filling sandstones. These sandstones too are fine to medium -grained, frequently micaceous and show both cross-bedding and internal lamination convolute bedding occurs in one such sandstone just south of Gombe geometrically, these channel-filling bodies are thin, rerely exceeding 2 metres, but with widths often exceeding several tens of metres. They are especially common in the Mallam Sidi (study area) - Kalshingi - Gombe area. North of Gombe the bedded facies makes up the entire outcropping Gombe Formation apart from its basal transitional portion. Research indicated coal horizons in the upper part of the Gombe sandstone encountered in boreholes penetrating the subcropping part of the formation.

III. Methodology

Field work was carried out in the study area. Seven core samples were collected from Ahaka cement plc. The rotary drilling method was used in collecting the core samples in order to reveal the underlying lithology, after pitting processes have demarcated the area of concentration of coal. Samples were collected from samples bank of Ashaka Cement Plc. Detailed lithologic description of the core samples were carried out with column for; depth, rock types and colour. Samples were then collected into well labelled sample bags for storage and laboratory analysis.

Geochemical analyses of the coal samples were carried out using X-Ray fluorescence (XRF), to determine some major and trace elements. Ashing and Volatility of the coal samples were determined with Furnace Machine, while moisture contents of coal were estimated using Oven. Bomb Calorimeter was used to determine calorific values of the coal samples, percentage of oxygen in the coal samples was carried out by Keljeldall method.

3.1 Proximate analysis

3.1.1 Ash content

The percentage of ash in the coal samples were determined using muffle furnace or ashing furnace at 815^{0}C for 1hour (ISO 157, 1997). The weight of the clean dry silica crusible (M1) was recorded. 1g of sample was weighed and spread out uniformly into the dish and the dish plus contents were recorded as Mass (M2) and the crucible plus ash was weighed and recorded as (M3). The percentage (%) ash was calculated as follows;

$$\% \text{ ASH} = \frac{M_3 - M_1}{M_2 - M_1} \times \frac{100}{1}$$

3.1.2 Moisture content.

The mass of the empty tray (M1) was weighed and 300g of the coal sample (M2) was also weighed. The sample was placed in drying oven at 110^0C and allowed to be deried for a period of 2 hours. The sample was removed from the oven and placed in dust free area to cool for 30 minutes. The sample will be re-weighed (i.e the tray with content) to the nearest 0.01g. The weight was recorded as (M3). The percentage of mass lost on air-drying was recorded as follows (ISO 331, 1983):

$$\% M = \frac{M_3 - M_1}{M_2} \times 100 .$$

3.1.3 Volatile Matter

The furnace was set as 900^0C ± 5^0C for 7 minutes. The crucible was removed after the 7 minutes from the furnace and allowed to cool to room temperature on a thick metal plate. Each empty crucible was weighed to the nearest 0.1mg, 1± 0.1g of test sample. The lid and tap of each crucible were replaced on a clean hard surface until the test portion forms a layer of even thickness on the bottom of the crucible. If the sample is of coke, the lid of the charged crucible will be removed and 2 to 4 drops of cyclohexane will be added and the lid replaced. The M_1 is the mass of the empty crucible and lid, M_2 is the mass, in grams of the crucible and lid and test portion before heating, M_3 is the mass, in grams of the crusible and lid and contents after heating and M is the moisture, as a percentage by mass, in the sample as analyzed (ISO 562, 1977). The volatile matter V in the sample as analyzed, expressed as percentage by mass, is given by the equation:

$$V = \frac{100\,(M_2 - M_3)}{M_2 - M_1} - M$$

3.1.4 Gross Calorific values (MJ/Kg)

The percentage of gross and net calorific values was determined using Bomb Calorimeter.

2000g of distilled water was measured and the coal was kept into the calorimeter bucket. The bucket with water was kept in position inside the calorimeter and observed for leakage. Where a leak was detected the set was discarded and the test started again. One gram of the coal sample was weighed, and transferred into the die of the manual pellet machine. Considerable pressure was applied using the plunger for 3minutes and the die was removed and turned the bottom support face down; the die was returned and gently the plunger was used to push out the pellet. The pellet was reweighed and noted the final weight. The pellet was placed in the combustion crucible. The fused wire was measured and cut exactly 10cm. The scale was used on the board supplied with the wire to make measurement. The sample holder was placed on supported and attached fuse wire to the position provided on the bomb sample holder and the crucible was placed with the sample in position (ISO 1928)

It is important to ensure that the fuse wire does not touch any part of the crucible; it can touch the surface of the sample or slightly above it. A drop of water was added about 1mL in the bomb and carefully transferred the sample holder into it, the holder was gently pressed down using both thumbs at opposite sides until it properly fit, and the valve was closed on top of the holder. The oxygen filling connection was attached to the point provided on the bomb. From the main menu of the Calorimeter display press on "Calorimeter operation" and a new window will be displayed. On the new window "O_2 fill" was pressed and the bomb will be filled with oxygen at the preset pressure on the regulator. The filling was waited to finish (about 1minute) before disconnecting the filling connector. On the same window, the "Operating Mode" key was checked at "Determination", if not the key will press again until it display "Determination". The bomb was transferred into the water with the aid of the lifting hook and fix of the power wire to the electrode terminals was done. On the same window the "Start" key was pressed and the machine will ask for the sample name which typing should done in, then "Enter" was pressed, and the machine will ask for the sample weight where typing in will be done again and "Enter" was pressed, and measuring process will automatically start. Prior to the sample ignition the machine will give 3 beeping sound, at this point the machine will give one beep sound indicating the end of the test. To view the result, the "Report" was pressed and the machine will ask for the %sulphur, which should be type in and "Enter" was pressed again and the machine will ask for the %Hydrogen, where typing should be done again and final result will be displayed.

3.1.5 Fixed Carbon

The percentages of fixed carbon (FC) in the coal samples were calculated.

The formula for calculating the fixed carbon:

FC = 100 – (moisture + ash + VM), (ISO, 1994).

3.2. Ultimate Analysis

3.2.1 Sulphur content

The percentage of carbon and sulphur in the coal samples were estimated using LECO sulphur - carbon analyzer machine, model SC - 144DR. The coal was grinded fine enough to pass through a 90 micron sieve. 0.250g weighed and placed in the combustion chamber of the analyzer. The combustion chamber was at 1350^0C temperature with pure oxygen (99% O_2) continuously pumped into it at the rate of 4L/Hr. The sample immediately burns and Sulphur and Carbon present react with the O_2 to form SO_3 and CO_2. The SO_3 and CO_2 formed were swept off by the pressure of the oxygen into a detector cell which uses infra-red radiation to detect and quantify the SO_3 and CO_2 and pass the information to computer software. The computer software converts the information to the equivalent sulphur and carbon based on previously stored calibration information (ISO 609, 1977).

3.2.2 Hydrogen

The percentages of hydrogen content in the coal samples were determined using titremetric method. For extraction; 5 – 10g of dried coal (passed through 2mm sieve) into a 45ml centrifuge tube and 30ml of 1N KCL was added. The centrifuge was covered tightly with a rubber hopper and shaken for 1 hour on a reciprocal shaker. Centrifuge the content at 2,000rpm was done for 15minutes.The clear supernatant was carefully decanted into a 100ml vol. flask and another 30ml of 1N KCL was added to the sample and shaken for 30 minutes. Flask was make up to volume and marked with 1NKCL.

For titration; Pipette 25ml of extract into a 250ml; Erlenmeyer flask (pipette 50ml if the coal pH value is above 5.0) and approximately 100ml of D/H_2O and 5 drops was added of phenolphthalein indicator and the solution was titrated with 0.05N NaOH to a permanent pink and point with alternate stirring and standing. If needed a ten more drops of indictor will be added to replace that adsorbed by the precipitate to Al $(OH)_3$.

The amount of base used is equivalent to the total amount of acidity (H + Al) in the liquid taken. To the same flask, 1 (one) drop of 0.05 HCl was added to bring the solution back to the colorless condition and 10ml of NaF solution was added. While the solution was stirred constantly while titrating the solution with 0.05N HCl until the color of the solution disappears.

1 or 2 drops of indicators were added, if the colors disappear and do not return within 2mins. The mill equivalents of acid used are equal to the amount of exchangeable Al.

This value from the mill equivalent of exchangeable H was subtracted. The exchangeable H and Al were expressed in meq/100g coal.

Note: Al in KCl extract can also be determined calorimetrically using the aluminum method. The amount of Al determined by the calorimetrically method is often larger than that determined by titration. Indicating that some Al ions may exists as

Al $(OH)_{2+}$ or Al $(OH)^+$ forms

Calculations:

$$\text{meq total acidity / 100 coal} = \frac{(a - b) \times N \times V1 \times 100}{W \times V2}$$

a = mls of sodium hydroxide used to titrate the sample, b = mls of sodium hydroxide used to titrate the blank, N = normality of the acid used, V1 = total mls of extract used, W = weight of coal used for analysis and V2 = mls of extract used for analysis

3.2.3 Nitrogen content.

The percentages of nitrogen content in the coal samples were determined using Keljedall method.

Procedure

Two grams of each sample was weighed into a digestion tube and one tablet of Keljeldall was added, 20mls of sulphuric acid (conc H_2SO_4) was added into the tube and digested at 420°C for 3 hours. After cooling, 80mls of distilled water was added into digested solution. 50mls of 40% caustic soda (NaOH) was measured onto 50mls of digested solution and then placed on heating section of distillation chamber, 30mls of 4% boric acid was added, plus boromocresol green and methyl red indicator, and transferred into conical flask and placed underneath distillation chamber for collection of ammonia. The solution changed from orange to green color. 0.1 normal solution of HCl was weighed into burette. The conical flask containing the solution was titrated until the color change from green to pink. The burette reading was taken and the Nitrogen calculated using the formula below:

$$\% N = \frac{(A - B) \times 6.25 \times 100}{\text{Mg of sample}}$$

A = ML of acid for titrating the samples, B = ML of acid for titrating blank sample (O), N = Normality of acid used for titration, F = Factor – 6.25 and 100 = Conversion to percentage.

3.2.3 Oxygen content

The percentages of oxygen in the coal samples were calculated (ISO 1994):

O = 100 – (moisture + ash + N + S+H)

3.3 Major and trace elements contents

Major and minor elements in the ash samples were determined using X-Ray fluorescence (XRF). The elements determined include Si, Al, Fe, Ca, Mg, K, S, Na, Ti, P, Mn, Sr, Cr, Zn, Zr, V and Ba.

IV. Results And Discussion

4.1 Lithological Description of core samples

Three boreholes were drilled at suitable sites for coal in the study area. The exercise revealed the presence of coal bodies. Lithological sections of the boreholes are presented in figures 2 - 4 while the descriptions are given below. Borehole No. 1 (Figure 2): The borehole is located at latitude $10^0 25^l 44.99^{ll}$N and longitude $11^0 17^l 13.54^{ll}$E. From the top of the borehole, Topsoil: Brown Sand with thickness range from 0.00 meters to 1.00 meters, were observed followed by the Shale with grey colour and the thickness ranges from 1.00 meters to 10.00 meters, and followed by Sandy clay with dark grey colour at 10.00 meters to 26.00 meters. Below the Sandy clay, a thin coal seam was discovered with thickness of 0.62 meter at depth of 29 meters and followed by Shale with 0.18 meter thick at depth of 29 meters, and followed by Coal seam with thickness of 2.25 meters. At 31 meters depth, a coal seam with the thickness of 4 meters was discovered and followed by shale bed within the range of 35.84 meters to 38.89 meters. Another coal seam was observed from the bore core samples at depth of 38.89 meters to 41. 53 meters, followed by black shale and sand bed 16.47 and 2.10 thick respectively.

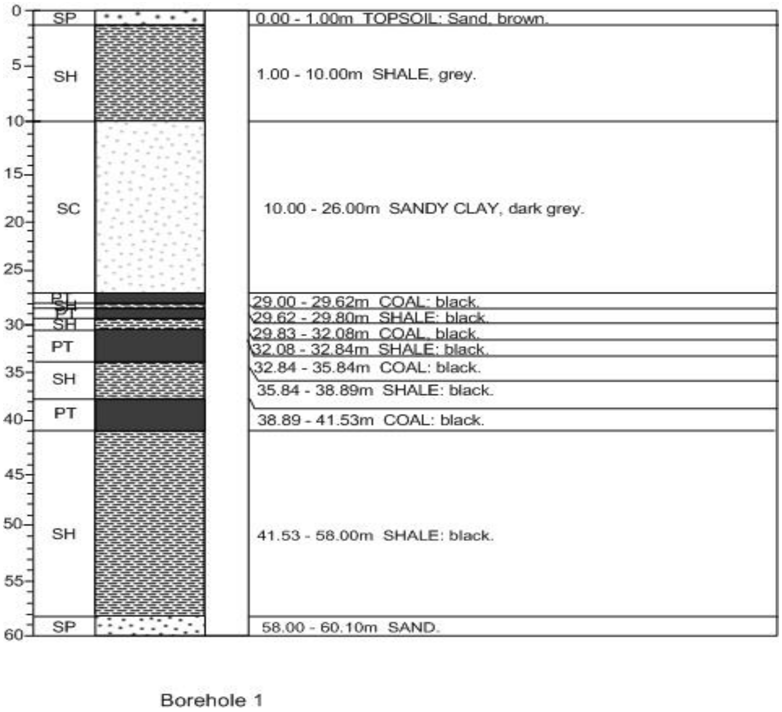
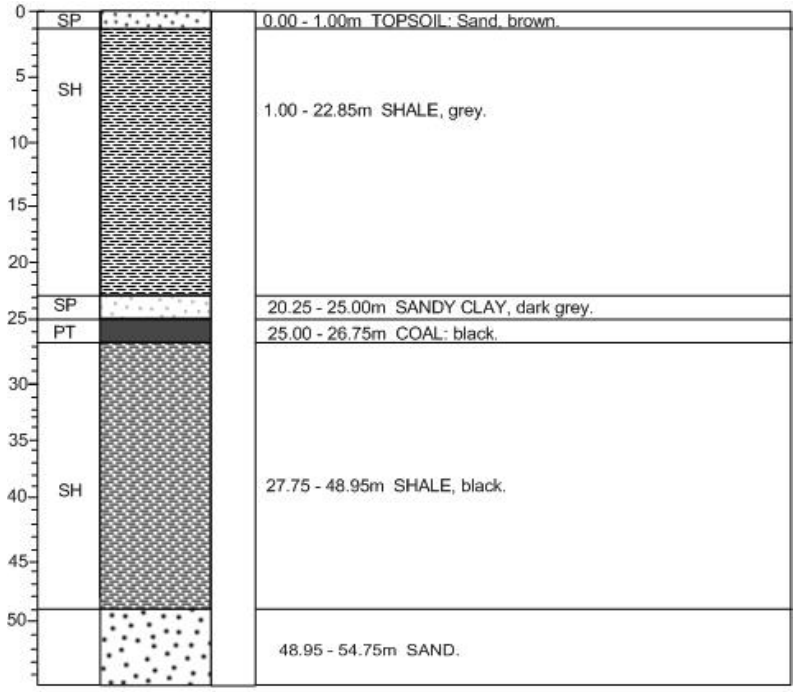


Figure 2: Lithostratigraphy column of the drill hole BH1 around Molko area, North-eastern Nigeria.

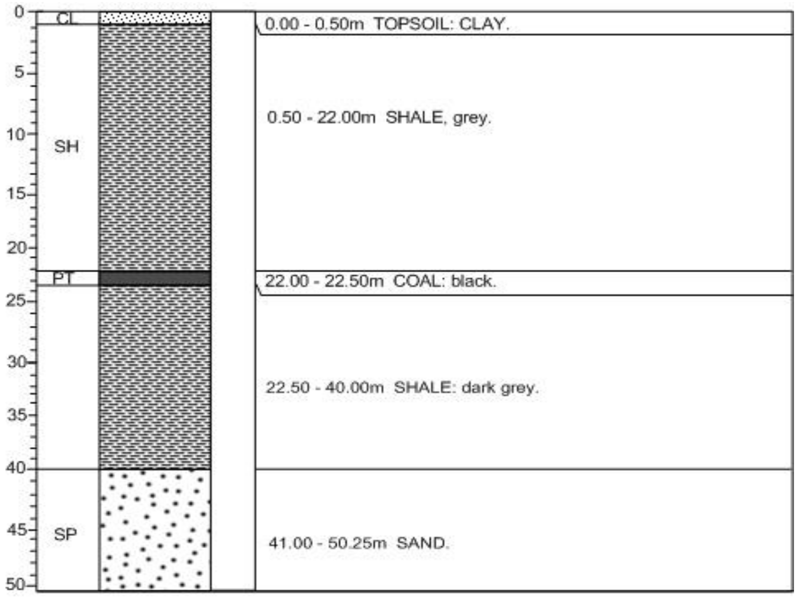
Borehole No. 2 (Figure 3): The borehole is located on latitude $10^0 25^l 55.27^{ll}$ N and longitude $11^0 17^l 45.12^{ll}$ E. This borehole was drilled up to 55m depth where sandstone bed with brownish colour were discovered at 0.00 meter to 1.00 meter, followed by grey shale bed with thickness of 21.85 meters. Within 20.25 to 25.00 meters Sandy clay with dark grey colour was observed. Coal seam was discovered at depth from 25.00 to 26.75 meters and followed by black shale with 21.20 meters thick and at the bottom sand bed within the range of 48.95 to 54.75 meters was identified.



Borehole 2

Figure 3: Lithostratigraphy column of the drill hole BH2 around Molko area, North-eastern Nigeria.

Borehole No. 3 (Figure 4): The drill hole is centred on latitude $10^{0}\,25^{l}\,28.74^{ll}$N and longitude $11^{0}\,17^{l}$ 29.99^{ll} E. From the top of the drilled hole, top soil and clay were identified with thickness of 0.00 and 0.50 meters respectively, followed by grey shale (0.50 to 22.00 meters). Pure black coal seam was discovered at depth of 22 meters with thickness of 0.50 meters followed by dark grey shale at depth of 22.50 to 40.00 meters. At bottom of the borehole sand bed with 9.25 meters thick was discovered.



Borehole 3

Figure 4: Lithostratigraphy column of the drill hole BH3 around Molko area, North-eastern Nigeria.

4.2 Proximate Analysis

Results of the geochemical analysis of proximate, ultimate, major and trace elements of coals are presented below. Results of the proximate analyses were used to establish the rank of coal and show the ratio of combustible to incombustible constituents. It gives the basis for selling and buying and evaluation for beneficiation or for other purposes of the coals (ASTM, 1989). The results of the proximate analyses of the Molko coals are shown in Table 1.

Table 1: Results of proximate Analyses of the Molko coal samples.

Boreholes		Borehole - 1				Borehole - 2		Borehole - 3	Average
Items	Unit	S1	S2	S3	S4	S1	S2	S1	
Depth	m	29	29.83	32	38	25.00	26.75	22	28.94
Air Moisture	%	0.00	0.05	0.00	0.00	0.25	0.00	0.00	0.04
Inherent Moisture	%	4.07	5.10	4.80	3.70	1.66	4.88	5.11	4.18
Total Moisture	%	4.07	5.15	4.80	3.70	1.91	4.88	5.11	4.23
Ash content	%	37.35	13.56	22.07	44.55	72.53	18.90	10.65	31.37
Volatile matter	%	39.64	50.35	43.83	35.40	18.74	46.10	50.80	40.69
Fixed Carbon	%	18.89	31.00	29.26	16.32	7.05	30.05	33.44	23.71
Gross Calorific value	j/g	16821	24449	21961	14411	7101	22821	25471	19005

Coal ranking standard value (Raymond, 19), the Anthracite coals have 81.8% Fixed carbon, 7.7% Volatile matter, Moisture 4.0 %, Ash content 1.0%, Hydrogen 3.6%, Oxygen 2.5%, Nitrogen 1.4%, Sulphur 0.7%, and Heating value 36.2 MJ/Kg. The Bituminous coal: Fixed carbon 54.9%, Volatile matter 35.6%, Moisture content 5.3%, Ash 6.0%, Hydrogen 5.1%, Oxygen 10.1, Nitrogen 1.4%, Sulphur 0.6% and Heating value 36.1 MJ/Kg. Sub-bituminous coals: Fixed carbon 43.6%, Volatile matter 34.7%, Moisture 10.5%, Ash 10%, Hydrogen 5.6%, Oxygen 14.9%, Nitrogen 1.7%, Sulphur 0.4% and Heating value 31.8 MJ/Kg. Lignite coals: Fixed carbon 27.8%, Volatile matter 24.9%, Moisture 36.9%, Ash 13%, Hydrogen 4.3%, Oxygen 23%, Nitrogen 1.1%, Sulphur 0.4%, and Heating Value 26.7 MJ/Kg.

The total moisture percent of the analyzed Molko coals ranges from 1.66 - 5.11% while the average is 4.18% (Table 1) which indicates as lower rank, possibly the rank of sub-bituminous to lignit grade. For the application; the coal may be suitable for the blast furnace, especially in production of cement clinker due to its moisture content. When compared with Maiganga coals, its moisture average value is same. The Maiganga coal has the average moisture content of 4.18% (Usman, 2014). Moisture content is an significant parameter of coal since all coals are mined wet. Chemically and physically bound water can contribute to total moisture. Groundwater and other moisture is define as adventitious moisture and is readily evaporated. Moisture held within the coal itself is called as inherent moisture and is analysed quantitatively. The moisture content decreases with maturity and ranking of coal due to the decrease of porosity (Stach et al. 1982).

Volatile matter content in a coal known as gaseous products in coal (except for moisture vapor) which are liberated at high temperature in the absence of air. And is mixture of short and long chain hydrocarbons, some sulfur and aromatic hydrocarbons. Along with ranks, volatile matter is constantly used to assess the coke yield on carbonization and burning characteristics. The volatile matter content analysed in the studied Molko coals varies from 18.74 - 50.80% with an average of 40.69% (Table 1). It is fairly high in the investigated coals which indicate high volatile bituminous coal (Stach et al. 1982) and is considered near optimum value and this is an indication of the maturity of the coaland will likely have an appreciable coking characteristics. The average value is much higher than 31.11% as reported by Usman (2014), for the Maiganga coal located 70km South - West of Molko. Ash is the non-combustible residue remaining after burning the coal. Ash obtained differs from in composition from the inorganic constituents present in the original coal. The Molko coal contains a relatively high ash (31.37%) as compared to the low ash value required for prime coking coals. The ash in the Molko coal samples range from 10.65% to 72.53% with an average value of 31.37%. This average value is lower than 49.00% as published by Usman (2014) for the same Maiganaga coal. The lower the ash content of a coal, the better is its application as a source of fossil fuel especial in the steel industry (Wessiepe, 1992). Incineration causes an expulsion of all water, the loss of carbon dioxide from carbonates, the conversion of iron pyrites into ferric oxides and other chemical reactions (ASTM 1989). However, coking coal with ash content up to 20% are being used for smelting iron in some parts of the world (Afonja, 1974). It is advisable that the ash content of Molko coal be reduced considerably by washing.

The Fixed carbon in coal is solid residue (other than ash) which is obtained by destructive distillation (after volatile are driven off). It is made up principally of carbon, but may contain appreciable amounts of sulfur, hydrogen and oxygen (ASTM 1989). Fixed carbon differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles. Fixed carbon is used as an estimate of the amount of coke that will be yielded from a coal sample. The result of the fixed carbon content carried out on coal samples show a range between 7.06% to 33.44% with an average value of 23.71%. This average value is much higher than 15.64% as reported by Usman et. al., (2014), for the Maiganga coal located 70km away from Molko coal field. The average carbon content of Molko coal was considered low. The coal at an advantage in terms of usage either as coking or non-coking coal since the environment will be less polluted as consequence of burning the coal. Caloric value in this research ranges from 14411j/g to 25471j/g with an average value of 19005j/g. However, the Maiganga's coal average value is greater than compared to Molko coal. Calorific value is the amount of heat per unit mass of coal when combusted. The combustion properties of the coal; The determination of the effects of combustion on coal influences the selection of coals for particular industrial uses. The Gross calorific for this research indicates that the coal is of lower grade coal.

4.2 Ultimate Analysis

Ultimate Analysis, the results of analyzed parameter Hydrogen, Nitrogen, Sulphur and Oxygen are tabulated in Table 2. The results of each element are discussed below in detail. Oxygen content in the samples ranges between 20.16% to 78.36% with an average of 60.42%. This result average value is much higher than 37.86% and 21.36% for seam A and B respectively as analysed by Baba and Usman (2012) for the Maiganga coal. The increased content of Oxygen is characteristic of low rank coals, while the decreased concentration is typical of low rank coals. The increased oxygen is in accordance with greater contents of moisture and hydrated minerals or as a result of advanced coal weathering. While the loss of oxygen occurs in the later stages of metamorphic development of coal due to the well-known decrease in oxy-containing functional groups as carboxylates and increase in aromaticity (Stach et. al., 1982). The hydrogen content is found varying from 4.21% to 5.10% with an average value of 4.59%. This average value is much higher than 0.7 and 1.47 for seam A and B respectively as reported by Baba and Usman (2012). The increased content of hydrogen is normally more characteristic of low rank coals.

Table 2: Ultimate Analysis of Molko coal samples

Ultimate Analysis		Borehole - 1				Borehole - 2		Borehole - 3	Average
Items	Unit	S1	S2	S3	S4	S1	S2	S1	
Hydrogen	%	4.59	4.30	4.35	4.21	4.65	4.92	5.10	4.59
Sulphur	%	0.36	0.40	0.41	0.28	0.10	0.34	0.39	0.32
Nitrogen	%	0.33	0.70	0.98	0.99	1.0	0.86	0.78	0.80
Oxygen	%	53.66	76.34	67.80	56.55	20.16	70.44	78.36	60.42

The Nitrogen content in the coal samples of the study area ranges between 0.33% to 1.0% with an average value of 0.80%. This average value is slightly higher than seam A (0.77%) and lower than 1.28% for seam B as studied by Baba and Usman (2012) for the Maiganga coal deposit. The increased contents of nitrogen are normally more characteristic of high - rank coals, while the decreased values of this element are commonly more typical of lignites. The sulphur content in the coal samples ranges between 0.10% to 0.41% with an average value of 0.32%. Therefore, the Maiganga's coal average value of 0.50% and 0.72% (Baba and Usman, 2012) for seam A and seam B respectively are higher than compared to Molko coal deposit.

According to ASTM standards (1989, 1990), the total sulfur content obtained by this ultimate analysis is used to serve different interests such as: evaluation of coal quality in relation to contract specification, evaluation of coal preparation, evaluation of potential sulfur emissions from coal combustion or conversion processes, and other purposes of commercial or scientific interests. The high presence of sulfur in coal can cause acid rain which is very harmful for the environment and human being. The most commonly found forms are sulfate sulfur and pyritic sulfur along with minor presence of organic sulfur. The sulfur percentage in the studied Molko coal is very low and it is less than 1, and therefore points to a freshwater depositional environment.

4.3 Associations of Major and Minor Elements in the coals

The major and minor elements are here described as those that are stable (Ca, Mg, Si, Al, Ti and Fe); partially vaporise (Na, K and Cr); easily vaporised (Zn) and fully vaporise (S, C, N and H) elements (Baba and Usman, 2012). The stable mineral elements (less volatile) such as Ca, Mg, Si, Al, Ti and Fe (Table 3) were analysed in ash coal samples of Molko. The result reveals that the stable volatile mineral element contents (Si, Al and Ca) in Molko coal are higher compared to Maiganga coal (Baba and Usman, 2012) while Fe, Mg and Ti content in Maiganga coal are slightly higher than Molko coal. For the partially vaporize elements (medium volatile) K and Cr contents are much lower in the molko coals compared to Maiganga coals while K content is higher in the Molko coal. Easy vaporize element (more volatile) Zn as reported in Table 3. The volatile element like Zn in Molko coal are lower compared to Maiganga coal which are in same region.

Table 3: Major and minor element compositions of Molko ash coal samples.

Ash Chemistry		Borehole - 1				Borehole - 2		Borehole - 3	Average
Items	Unit	S1	S2	S3	S4	S1	S2	S1	
Ash content	**%**	**37.35**	**13.56**	**22.07**	**44.55**	**72.53**	**18.90**	**10.65**	
SiO_2	%	64.29	52.85	58.40	60.32	83.64	66.75	55.09	63.04
Al_2O_3	%	22.90	19.49	23.95	28.91	9.25	13.49	16.00	19.14
Fe_2O_3	%	6.63	8.10	5.44	3.27	2.25	4.32	8.55	5.50
CaO	%	1.70	9.50	5.30	2.17	0.54	6.40	8.60	4.88
MgO	%	0.65	2.02	1.69	1.00	0.10	1.64	2.26	1.33
SO_3	%	1.06	5.59	3.20	1.30	0.19	4.16	7.21	3.24
K_2O	%	1.07	0.41	0.75	0.92	2.20	0.55	0.41	0.90
Na2O	%	0.08	0.10	0.08	0.12	0.10	0.09	0.10	0.09
TiO_2	%	1.47	1.94	1.84	1.67	1.35	1.95	1.71	1.70
P_2O_5	%	0.06	0.23	0.07	0.08	0.06	0.05	0.19	0.10
Mn_2O_3	%	0.30	0.40	0.07	0.03	0.07	0.23	0.16	0.18
SrO	%	0.04	0.11	0.07	0.05	0.01	0.07	0.14	0.07
Cr_2O_3	%	0.02	0.01	0.01	0.02	0.01	0.00	0.01	0.011
ZnO	%	0.01	0.00	0.01	0.02	0.01	0.01	0.11	0.02
ZrO_2	%	0.03	0.04	0.03	0.00	0.11	0.12	0.01	0.04
V_2O_5	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
BaO	%	0.05	.0.07	0.08	0.07	0.06	0.08	0.06	0.06
Sum		100.36	100.79	100.99	99.95	99.95	99.91	100.61	

Fully Vaporize elements (Combustible) S, C, N and H (Table 1 & 2). These elements have been treated earlier in Proximate and Ultimate analysis section (Section 4.1 and 4.2). The major elements in the Molko coal are dominated by SiO_2, Al_2O_3 and Fe_2O_3 in the ash samples (Figure 4). The main carriers of these elements are quartz, clay minerals and pyrite (Zhao et. al., 2013). The coal of Molko have SiO_2, Al_2O_3 and Fe_2O_3 ranging from 52.85wt% to 83.64wt% with an average value of 63.04wt% for Silica; 13.49wt% to 28.91wt% with the average of 19.14wt% and 2.25wt% to 8.55wt% with an average value of 5.50wt% for Fe_2O_3 respectively as shown in Table 3.

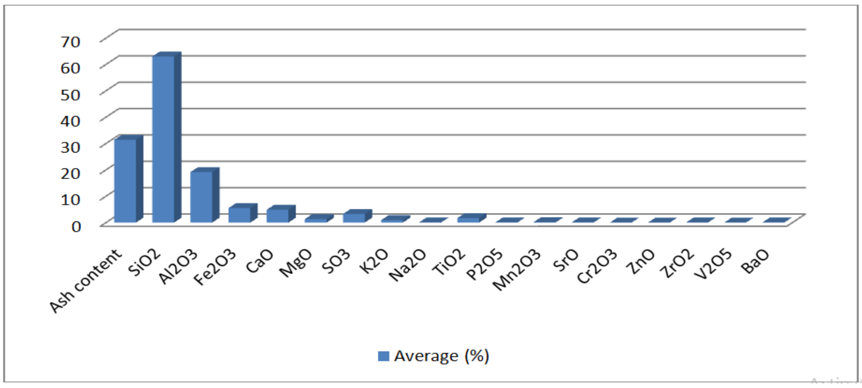


Figure 4: Elemental ash composition of Molko coal field.

The concentrations of most minor element in the Molko coal are unremarkable, falling well within the range of U.S and world coals (Orem and Finklam, 2003). As expected, the concentrations of the most of the elements in the high grade coal are considerably higher than the Molko coal. The data do not indicate any potential for high quality coal. Minor elements are present in coal in either organic or inorganic forms, and probably most of them occur in both forms. The relationship between selected minor elements and ash yield are illustrated in figure 4. Many elements in most coals are derived from the detrital input to the precursor swamp and many chalcophile elements are associated with sulphide minerals that may have formed syngenetically or epigenetically (Finkelman, 1982).

V. Conclusions

Based on the proximate analysis, the studied Molko coals of the Gongola basin th categorized by high volatile, low ash and sulfur contents. The heat value (GCV) is fairly high (14411j/g to 25471j/g). It seems that as a part of the clean coal technology (CCT), the studied Molko coal has the potential for coal liquefaction (coal to liquids: CTL) which is evidenced by the fairly high of fixed carbon and favourable amount of hydrogen. Nevertheless it requires additional study on CTL. The carbon content of the studied coal range from 7.06wt% to 33.44wt% with an average value of 23.71wt% which qualified the coal as lignite coals. The chemical analysis also indicates that the major oxides in these samples are SiO_2 and Al_2O_3 indicating the prevalence of quartz and clay minerals likely derived from a detrital source. The concentrations of most trace elements in these coals are not falling well within the range of high grade coal, the data of trace elements indicates as lower rank coals because of the lower concentrations than the high grade coals.

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