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Quality Evaluation of Udane–Biomi Coal in the Northern Anambra Basin of Nigeria

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Abstract *Coal is a significant fuel for several industrial operations, however, its scope of application depends on some quality parameters. In this study, a geochemical investigation of Udane–Biomi (in Northern Anambra Basin) coal deposit has been carried out to ascertain its potential relevance to possible industrial applications. Results fromthe proximate analysis indicated that the average composition of the coal includes 4.49 % moisture, 76.06 % ash, 11.76 % volatile matter and 7.69 % fixed carbon. The ultimate analysis also reveals that coal consists of 10.58 % carbon, 1.66 % hydrogen, 0.29 % nitrogen, 6.82 % oxygen, 0.12 % sulphur and 0.02 % phosphorus. The average heating value of the coal is 1891Btu/1b and a free swelling index of 0.0 (zero). This observed composition of the investigated coal contradicts with data expected for cooking coals. However, coal is appropriate for electricity generation, heating boilers and ovens in industrial process heating. Coal can also be useful in the cement, glass, ceramic, paper and brick industries.*

Keywords: *Udane–Biomi coal, geochemistry, non-coking, sub-bituminous.*

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1.0 Introduction

Nigeria is endowed with large deposits of coal, which are mostly concentrated within the Benue Trough and the Anambra Basin (Fatoye*et al*., 2020). The Anambra Basin is a major coal producing basin in Nigeria where intensive exploration and exploitation activities started in 1916 with the exploration of commercial coal in Udi near Enugu in 1909 by the Mineral Survey of Sothern Nigeria (Famuboni, 1996).

Between 1909 and 1913, more coal seams were discovered within the Basin at Enugu and Ezimo in Enugu State; Orukpa in Benue State; Odokpono, Okaba and Ogboyaga in Kogi State. These seams belong to the Mamu Formation (Lower coal measures) of the Middle Campanian – Late Maastrichtian age (Simpson, 1954). Coal seams of the Nsukka Formation (Upper coal measures) of Late Maastrichtian – Paleocene age outcropped at Inyi west of the Enugu Escarpment (De-Swardt and Casey, 1963).

Coal has been found occurring in the Benue Trough of Nigeria (lower, middle and upper). It occurs in the middle Benue Trough at Obi/Lafia in Nasarawa State. The seams belong to the Awguformation of the Coniacian age which is dominantly shales, limestones, and sandstones (Obaje and Hamza, 2000). The occurrence of coal has also been reported in the Upper Benue Trough near Doho in the Gombe area and the Garin Maiganga area of Gombe State. The coal seams occur in the Kerri-Kerri Formation and Gombe sandstone formation of both Paleocene ages respectively

(Famuboni, 1996). However, Obi/Lafia coal is the only coking coal so far discovered in the country with estimated reserves of 22 million tonnes(Famuboni, 1996). Although several studies have been reported for the physicochemical composition of some coal deposits in Nigeria especially in the Anambra Basin, little is known for the Udane–Biomi coal deposit. The present study seeks, to evaluate the geochemical characteristics of coal deposits in Udane–Biomi coal to obtain parameters for characterizing the quality of the coal and suitable areas of applications.

2.0 Materials and Methods

2.1 The study area

The Udane-Biomi coal deposit is situated within Latitude 7^0 34' 54.0" N and Longitude 6^0 57' 07.5" E. It is located off Abocho town in Dekina Local Government Area of Kogi State (Fig. 1). The drainage of the study area is in the class of the dendritic pattern. The area is well drained with rivers and their tributaries occupy wide valleys. Most of these rivers are tributaries to the Anambra River. The area is generally undulating lowland with a few isolated hills. It has an average elevation of 289m above sea level.

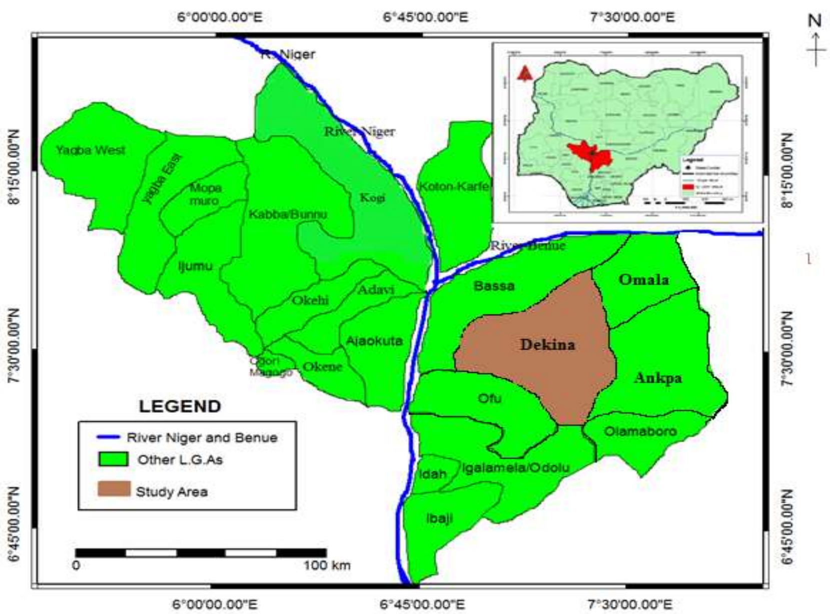

Fig. 1: Location map of the study area (modified from map of Nigeria)

2.2 Regional Geological Setting

The study area lies within the Anambra Basin of Nigeria. The structural setting and general geology of the Anambra Basin have been widely reported (Nwajide and Reijers, 1996; Obaje*et al*., 1999; Umeji, 2005). Sedimentation in the Anambra Basin commenced with the Campanian–Maastrichtian marine and paralic shales of the Nkporoformation (Fig. 2), overlain by the Early–Late Maastrichtian coal measures of the Mamuformation, comprising paralic sandstones, mudstones and coals. The middle-late Maastrichtianfluviodeltaic sandstones of the Ajali Formation lie on the Mamuformation and constitute its lateral equivalents in most places. In the Paleocene, the marine shales and paralic coaly sequence of the Nsukka Formation were deposited to complete the succession in the Anambra Basin (Umeji, 2005).

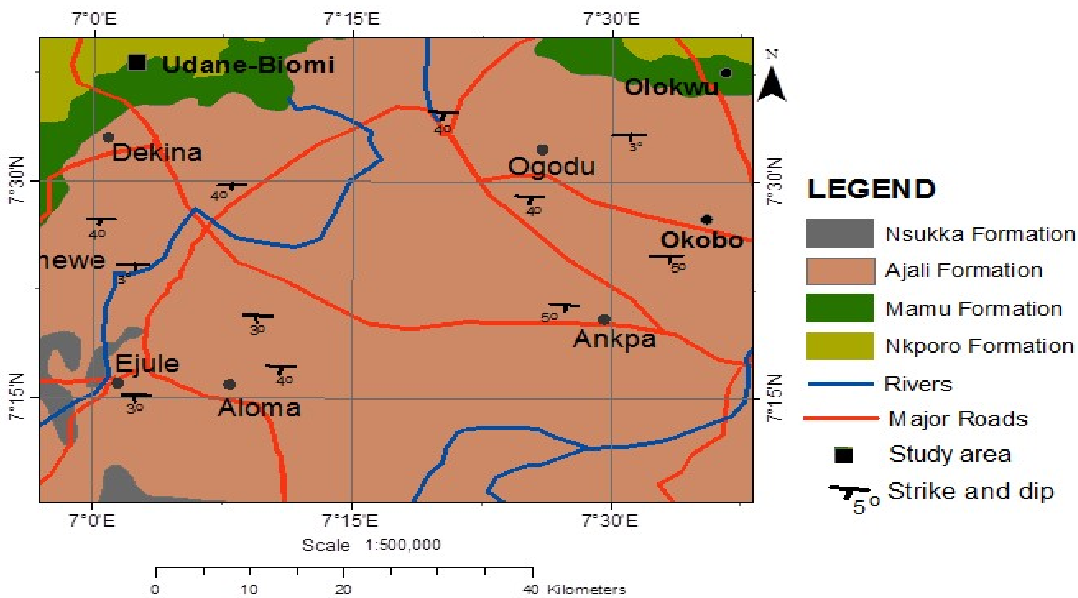

Fig. 2: Geological map of the study area.

2.3 Sampling

Ten coal samples were collected from the Udane–Biomi coal deposit. The samples were taken from the coal outcrops and kept in labeled airtight polyethylene bags to retain their as-received condition. Sample preparations were done according to the American Standard for Testing Materials, ASTM D2013 and ASTM D5198 methods. All analyses were carried out at Mineral Laboratory, Kentucky, USA.

2.4 Proximate Analysis

The parameters of proximate analysis of coal are moisture, volatile matter, ash, and fixed carbon.

2.4.1 Determination of moisture content

1.00 g of pulverized coal sample was thinly spread on a previously dried crucible placed in an oven whose temperature was maintained at 105 ^{0}C for 3 hours. The difference in weight before and after the period was measured as the moisture content.

2.4.2 Determination of ash content

1.0 g of pulverized coal sample was weighed into a platinum crucible and in a muffle furnace at a temperature of 750 ^{0}C for about 2 hours until a constant weight was attained. The ash content was evaluated through the difference in weight before and after combustion.

2.4.3 Determination of volatile matter

1.00 g of pulverized coal sample was weighted and covered in a 10ml platinum crucible. The same combusted to a temperature of 950 ^{0}C in a muffle furnace for 7 minutes after which the sample was removed, allowed to cool in a desiccator and re-weighed to obtain weight loss, which was estimated as the percentage volatile matter.

2.4.4 Determination of fixed carbon

The fixed carbon was estimated as the difference between 100 and the total sum of moisture, ash and volatile matter.

Fixed Carbon (%) = 100 – (% moisture content + % ash content + % volatile matter content).

2.5 Ultimate Analysis

The ultimate analysis is dependent on quantitative analysis of various elements present in the coal samples, such as carbon, hydrogen and oxygen (the major components) as well as nitrogen, sulphur and phosphorus.

2.5.1 Determination of carbon and hydrogen

1.00 g of coal was burnt in a current of oxygen to convert the C and H to CO_2 and H_2O respectively. The products of combustion (CO_2 and H_2O) were passed overweighed tubes of anhydrous $CaCl_2$ and KOH which absorbed H_2O and CO_2 respectively. The increase in the weight of $CaCl_2$ tube was used as an estimate for the weight of water (H_2O) formed while an increase in the weight of KOH tube represented the weight of CO_2 formed. The percentage of carbon and hydrogen was then calculated.

2.5.2 Determination of nitrogen

Nitrogen was determined by Kjeldahl's method. 1.00 g of pulverized coal was heated with concentrated H_2SO_4 in the presence of potassium sulphate and copper sulphate in a long necked flask thereby converting nitrogen of coal to ammonium sulphate. When a clear solution was obtained it was treated with 50 % NaOH solution. The ammonia thus formed was distilled over and absorbed in a known quantity of standard sulphuric acid solution. The volume of unused H_2SO_4 was then determined by titrating against a standard NaOH solution. Thus, the amount of acid neutralized by liberated ammonia was determined.

2.5.3 Determination of oxygen

The concentration of oxygen was estimated by subtracting the amount of the other elements, carbon, hydrogen, nitrogen, sulphur, moisture and ash from 100%.

% of oxygen in coal = 100 – (% C + % H + % N + % S + % M + % A)

2.5.4 Determination of sulphur

A 1.00 g sample of coal of 0.2mm particle size was heated with Eschka mixture (which consists of 2 parts of MgO and 1 part of anhydrous Na_2CO_3) at 800 ^{0}C. After combustion, the amount of sulphur present in the mix was retained as oxides and it was precipitated as sulphate. The sulphate formed was precipitated as $BaSO_4$ (by treating with $BaCl_2$). The percentage of sulphur in coal was calculated from the weight of the coal sample taken and the weight of $BaSO_4$ precipitate formed.

2.5.5 Determination of phosphorus

Phosphorus was determined by treating 1.00 g of the coal ash with a hot mixture of HNO_3, H_2SO_4 and HF acids. This volatilized the phosphate and dissolved the phosphorus to precipitate a complex phospho-molybdate from which the phosphorus content was estimated.

2.6 Calorific Value Analysis

A bomb calorimeter was used to measure the calorific value of the coal. Electrical energy was used to ignite the coal and the hot air generated from the heating was used to raise the temperature of the water, through which the calorific content of the coal was estimated.

2.7 Determination of free swelling index

10.00 g of finely grounded coal sample was weighed into a dry platinum crucible. The crucible was placed in a muffle furnace and the temperature was raised to 800 ^{0}C until all volatiles were driven off. The crucible was removed from the furnace and allowed to cool. The cross-section of the coke “button’ was compared with a series of standard profiles (chart) to determine the free swelling index.

3.0 Results and Discussion

Table 1 shows values for the proximate contents of the coal, including moisture content, ash content, volatile matter and fixed carbon contents while Table 2 contains records obtained from the ultimate analysis of the coal including percentage carbon, hydrogen, nitrogen, oxygen, sulfur and phosphorus.

The moisture content of the coal varied from 3.14 % in sample 9 to 5.66 % in sample 3 with a mean value of 4.49 % (Table 1). The measured moisture content of the coal is high compared with high-rank coals (Table 1). Moisture is an undesirable constituent of coals because it reduces the heating value (water does not burn!) of coal. The moisture content required for good coking coal is 1.5 % (Obaje, 1997). Therefore, the average value of 4.49 % recorded for coals from Udane–Biomi coal is above the stipulated rating for coking coal.

Table 1: Proximate analysis results of the Udane-Biomi coal samples

Sample number	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)	Total (%)
Udane-Biomi 1	5.28	75.15	11.86	7.71	100
Udane-Biomi 2	4.61	76.61	11.35	7.43	100
Udane-Biomi 3	5.66	75.83	11.43	7.08	100
Udane-Biomi 4	3.23	77.06	11.87	7.84	100
Udane-Biomi 5	4.36	75.51	12.17	7.96	100
Udane-Biomi 6	4.37	75.97	11.41	8.25	100
Udane-Biomi 7	4.72	75.48	12.39	7.41	100
Udane-Biomi 8	5.05	75.24	12.35	7.36	100
Udane-Biomi 9	3.14	77.20	11.06	8.60	100
Udane-Biomi 10	4.48	76.55	11.71	7.26	100
Average	4.49	76.06	11.76	7.69	100
X	15.10	12.35	46.10	26.45	100
Y	4.31	0.20	31.26	64.23	100
Z	3.15	1.32	21.63	73.90	100

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

Table 2: Ultimate analysis results of the Udane -Biomi coal samples

Sample Number	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulphur (%)	Phosphorus (%)	Total (%)
Udane–Biomi 1	9.91	1.56	0.40	8.12	0.13	0.018	20.14
Udane–Biomi 2	10.26	1.75	0.31	6.72	0.13	0.017	19.19
Udane–Biomi 3	9.57	1.60	0.27	7.23	0.11	0.018	18.80
Udane–Biomi 4	11.32	1.59	0.21	6.31	0.10	0.014	19.54
Udane–Biomi 5	11.15	1.58	0.24	6.35	0.11	0.013	19.44
Udane–Biomi 6	10.44	1.78	0.30	6.53	0.13	0.015	19.20
Udane–Biomi 7	10.74	1.70	0.23	7.05	0.12	0.014	19.85
Udane–Biomi 8	10.53	1.60	0.32	6.87	0.12	0.014	19.45
Udane–Biomi 9	11.58	1.72	0.30	6.40	0.13	0.012	20.14
Udane–Biomi 10	10.30	1.73	0.32	6.62	0.12	0.015	19.11
Average	**10.58**	**1.66**	**0.29**	**6.82**	**0.12**	**0.015**	**19.49**
X	**67.60**	**4.80**	**1.20**	**17.70**	**0.80**	**0.06**	**92.16**
Y	**83.47**	**6.68**	**0.59**	**8.00**	**0.20**	**0.04**	**98.98**
Z	**91.44**	**3.36**	**0.09**	**2.70**	**0.09**	**0.03**	**97.71**

***X: Wyoming (USA) sub-bituminous coal (after Spath and Amos, 1995), Y: Newcastle (England) bituminous coal (after Jensen and Bateman, 1979)andZ:South Wales (Britain) anthracite (after Jensen and Bateman, 1979)**

Table 3: Calorific value results of the Udane–Biomi coal samples

Sample Number	Calorific Value	
	(Btu/1b)	(Kj/Kg)
Udane-Biomi 1	1789	4161.21
Udane-Biomi 2	1834	4265.88
Udane-Biomi 3	1750	4070.50
Udane-Biomi 4	2007	4668.28
Udane-Biomi 5	1941	4514.77
Udane-Biomi 6	1793	4170.52
Udane-Biomi 7	1897	4412.42
Udane-Biomi 8	1903	4426.38
Udane-Biomi 9	2115	4919.49
Udane-Biomi10	1881	4375.21
Average	1891	4398.47
X	8683	20196.66
Y	12000	27912.00
Z	15700	36518.20

X: Wyoming (USA) sub-bituminous coal (after Spath and Amos, 1995), Y: San Pedro (USA) bituminous coal (after Warwick and Hook, 1995) and Z:Barakar (India) Anthracite (after Sethi, 2014)

However, based on the work reported by Gunn *et al*. (2012),a recommended range of 18 – 30 % was accepted for the moisture content of thermal coals. Therefore, the analysed coal is suitable for the generation of electricity and heating for the manufacturing of cement, ceramics, glass, paper, bricks, etc.

The ash content of the analysed coal varied from 75.15 % in sample 1 to 77.20 % in sample 9 with a mean value of 76.06 % (Table 1). Lower ash content is an essential requirement for coke-making coals because some of the ash would end up in the coke on carbonization and in the blast furnace (Akpabio, 1998). The lower the ash content of any coal, the better is the expected advantages of coal as a source of fossil fuel especially in the steel industry (Wessiepe, 1992). Ash reduces plasticity and determines the behavior of slag and fouling in the combustion chamber (ASTM, 1987). The measured high ash content is also an indication of a low degree of coalification and hence immaturity of the coal. Ash content of less than 10 % is recommended for good coking coals (Averitt, 1974; Bustin *et al.,* 1985; Akpabio *et al*., 2008). A range of 10 – 20 % is recommended by Thomas (2002) for good coking coals. Coal with higher ash contents can reduce the efficiency of the blast furnace. In steam coal, high ash content will effectively reduce its calorific value. Recommended maximum ash content for steam coals serving as pulverized fuel is around 20 % (Thomas, 2002). These imply that the Udane–Biomi coal is unsuitable for metallurgical processes such as applications in iron and steel production. The high ash content of 76.06 % in the coal can be reduced to an acceptable level through proper preparation before utilization. This implies that Udane–Biomi coal if properly prepared can be used for the generation of electricity and for heating purposes. The cement, glass, ceramic, paper and brick industries can use it for this purpose.

The volatile matter content of the coal varied from 11.06 % in sample 9 to 12.39 % in sample 7 with an average value of 11.76 % (Table 1). The volatile matter apart from its use in coal ranking is one of the most important parameters used in determining their suitability and applications (U.S. Energy Information Administration, 2008; Chen and Ma, 2002). In coke production, a volatile matter range of 20 – 35 % is expected (Thomas, 2002). In pulverized fuel firing for electricity generation, most boilers are designed for a minimum volatile matter of 20 – 25 % (Thomas, 2002). In stoker firing for electricity generation, the recommended range for the volatile matter is 25 – 40 %. Although the average value of 11.76 % was recorded for Udane–Biomi coal is within the proposed rating for coking coal, however, the high values of moisture and ash contents in the coal make it unsuitable for coke making in the generation of substantial heat for the working of blast furnace for iron smelting, however, it is appropriate for electricity generation and heating for manufacturing processes. The cement, glass, ceramic, paper and brick industries can use it for this purpose

The fixed carbon content of the coal varied from 7.08 % in sample 3 to 8.60 % in sample 9 with a mean value of 7.69 % (Table 1). Coal can be characterized by low fixed carbon content compared with high-rank coals (Table 1). The fixed carbon content of coal has a direct relationship with its moisture and volatile matter, therefore, the low fixed carbon content in the coal is a consequence of its high moisture and volatile matter. Fixed carbon content determines the coke yield of coal samples (Diez *et al*., 2002 and Schobert, 1987). High carbon content is essential for coke-making coal because it is the mass that forms the actual coke on carbonization (Diez *et al*., 2002). A range of 46 – 86 % is recommended by Lowry (1945) as suitable for coking coals. Therefore, the coal samples from Udane–Biomi coal with has an average value of 7.69 % fixed carbon content is not suitable forcoking. However, it could be utilized in thermal power plants and other small industries for combustion processes.

The results representing the proximate analysis generally revealed that the studied coal is characterized by high moisture, high ash and low fixed carbon contents. Comparing these characteristics with other coals (X, Y and Z in Table 1), the studied coal is similar to Saar (Germany) sub-bituminous coal but contrary with Newcastle (England) bituminous coal and South Wales (Britain) anthracite all reported by Jensen and Bateman (1979). Therefore, the analysed coal sample is in the sub-bituminous rank.

The carbon content of the coal varied from 9.57 % in sample 3 to 11.58 % in sample 9 while the concentration of hydrogen ranged from 1.56 % in sample 1 to 1.78% in sample 6 (Table 2). The ranges of 75 – 90 % carbon and 4.5 – 5.5 % hydrogen are recommended by Lowry (1945) for good coking coal. Based on these recommendations, the studied coal with an average carbon content of 10.58 % has no coking value. However, it may be appropriate for electricity generation and heating for manufacturing processes.

The nitrogen content of the coal varied from 0.21 % in sample 4 to 0.40 % in sample 1 while the oxygen content of the coal ranged from 6.31 % in sample 4 to 8.12 % in sample 1 (Table 2). The lower the oxygen content of a coal the better the suitability of the coal for heating and other purposes.. As oxygen content increases, moisture-holding capacity increases and caking power decreases. Oxygen is an important indicator for ranking coal. A range of 5 – 20 % is recommended by Lowry (1945) for the oxygen content of coking coals while Gunn *et al*. (2012) proposed 16 – 20 % for thermal coals. Though the coal is moderate in nitrogen and oxygen contents yet it is not suitable for the production of coke for metallurgical processes (such as iron and steel manufacture) because of its low carbon content which is a principal combustible element. However, coal is appropriate for electricity generation and heating for manufacturing processes. The cement, ceramics, glass, paper and bricks industries can use it for this purpose.

The sulphur content of the coal varied from 0.10 % in sample 4 to 0.13 % in samples 1, 2, 6 and 9 (Table 2). The average sulphur content of 0.12 % in the coal is low and within the rating of less than 1.0 % recommended by Bustin *et al*. (1985) for coke-making, but its pyritic nature makes it unsuitable for coke making. Pyritic coal and coal with higher values of sulphur (greater than 1.0 %) contribute to producing brittle steel, causing slagging and fouling in the furnace thereby reducing its efficiency and causing corrosion of the furnace. The total sulphur content in steam coals used for electricity generation should not exceed 0.8 – 1.0 %; the maximum value however depends upon local emission regulations (Thomas, 2002). Therefore, the coal is suitable for electricity generation and heating for manufacturing processes.

The phosphorus content of the coal ranged from 0.012 % in sample 9 to 0.018 % in sample 1 (Table 2). Phosphorus is another element with an adverse effect on iron quality. Unlike sulphur, its final placement in the iron product is not easily controlled by the adjustment of slag volume. Care must therefore be taken that the coals used in coke-making have low initial phosphorus content. Zimmerman (1979) stated 0.05 % to 0.06 % as a safe limit for coking coals while Gray *et al*. (1978) quoted a lower limit of 0.03 % for the same type of coals. According to Thomas (2002) coking coals should have a maximum phosphorus content of 0.1 %. Based on phosphorus content, coal is better used in electricity generation and heating for manufacturing processes.

The results obtained from the ultimate analysis indicated that the studied coal is also characterized by very low carbon content. Comparing the characteristic with other coals (X, Y and Z in Table 2), the studied coal is similar to Wyoming (USA) sub-bituminous coal reported by Spath and Amos (1995) but in contrast with Newcastle (England) bituminous coal and South Wales (Britain) anthracite both reported by Jensen and Bateman (1979) thereby placing Udane-Biomi coal in sub-bituminous rank.

The calorific value of the coal varied from 1750 in sample 3 to 2115 Btu/1b in sample 9 (Table 3). The average calorific value of the coal (1891 Btu/1b) is low compared with high-rank coals (Table 3). Mineral matter, moisture and ash contents of a coal help in determining its calorific (heating) value. The less these contents the better the calorific value. Bustin *et al*. (1985) recommended 14499 Btu/1b for good metallurgical coal while Wendy (2017) proposed a minimum calorific value of 8500 Btu/1b for heating. Based on these recommendations, the studied coal is not suitable for metallurgical purposes. However, it is suitable for electricity and combustion purposes.

The calorific value of Udane-Biomi coal compares favouably with the value reported by Spath and Amos (1995) for Wyoming (USA) sub-bituminous coal but in contrast with those reported by Warwick and Hook (1995) and Sethi (2014) for San Pedro (USA) bituminous coal and Baraka (India) anthracite respectively (X, Y and Z in Table 3) thereby placing the studied coal in sub-bituminous rank.

Free swelling index (FSI) is a measure of the plasticity and devolatilization characteristics of a coal. The higher the FSI for coal, the more suitable is the coal for coke manufacture. Values of FSI greater than 4 are recommended for coal required for coke manufacturing (Blackmore, 1979). Based on this recommendation, the studied coal with zero (0) FSI is unsuitable for coke production. However, Blackmore (1979) stated that the higher the FSI for steam coal, the lower the efficiency of combustion. This implies that the Udane–Biomi coal is good for steam coal suitable for the generation of electricity and for heating in the manufacturing industries.

4.0 Conclusion

Proximate, ultimate and calorific value analyses as well as free swelling index test revealed that the coal has high moisture, high ash, low carbon, low calorific values and zero (0) free swelling index.

All these characteristics suggest that Udane–Biomi coal is medium quality, non-coking and sub-bituminous. Though the sulphur content is low, its pyritic nature makes it non-coking and therefore not suitable to be employed in the generation of substantial heat for the operation of the blast furnace for iron smelting. However, it is suitable for electricity generation. The coal is appropriate in heating boilers and ovens in industrial process heating.

The cement, glass, ceramic, paper and brick industries can use it for this purpose.

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Conflict of Interest

The authors declared no conflict of interest