Communication in Physical Sciences 2020, 5(3): 223-232

https://journalcps.com

Maceral Characterization of the Cretaceous Effin – Okai Coal Deposit in Northern Anambra Basin, Nigeria

***Felix B. Fatoye, Yomi B. Gideon and Joseph I. Omada**

Received 04 May 2020/Accepted 28 May 2020/Published online: 30 May 2020

Abstract *Petrographic studies have been carried out on coal samples from Effin – Okai coal deposit in northern Anambra Basin, Nigeria. The studies were designed to determine the petrographic characteristics of the coal based on its composition and vitrinite reflectance to ascertain the potential relevance of the coal to possible industrial usages. Maceral characterization reveals the presence of the three maceral groups; vitrinite, liptinite and inertinite in all the samples. Observed proportion of the vitrinites and inertinites were higher than the liptinites in the samples. Based on mineral matter-free basis, the average composition of the coal indicated 58.60% vitrinite, 8.60% liptinite and 32.80% inertinite. However, in the presence of mineral matter, the average compositions were 46.40% vitrinite, 6.30% liptinite, 28.40% inertinite and 18.90% mineral matter. Therefore, the coal contains 52.70% reactives (vitrinite + liptinite) and 47.30% inerts (inertinite + mineral matter). The mean vitrinite reflectance measurement for the coal was 0.38%* R_{omax}. *These petrographic characteristics suggest that the coal does not possess coking qualities suitable for coke making blends and for metallurgical processes such as utilization in reduction of iron ore. Therefore, the quality of the coal is low. However, it has potential values for electricity generation, in heating of boilers and for powering oven for industrial heating process.*

Keywords*: Effin-Okai, coal petrography, quality assessment, applications*.

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1.0 Introduction

Nigeria is endowed with large coal deposits. Apart from sparsely reported occurrences of lignites and minor sub-bituminous coals in the Sokoto Basin (Kogbe, 1989), in the Mid-Niger (Bida) Basin (Adeleye, 1989) and in the Dahomey Embayment (Reyment, 1965), greatest proportion of coal deposits in Nigeria is found in the Benue Trough and within the Anambra Basin.

The Anambra Basin is a major coal producing basin in Nigeria where intensive exploration and exploitation activities have been carried out since 1916 after commercial deposition of coal was discovered in Udi near Enugu in 1909 by the Mineral Survey of Sothern Nigeria (Famuboni, 1996).

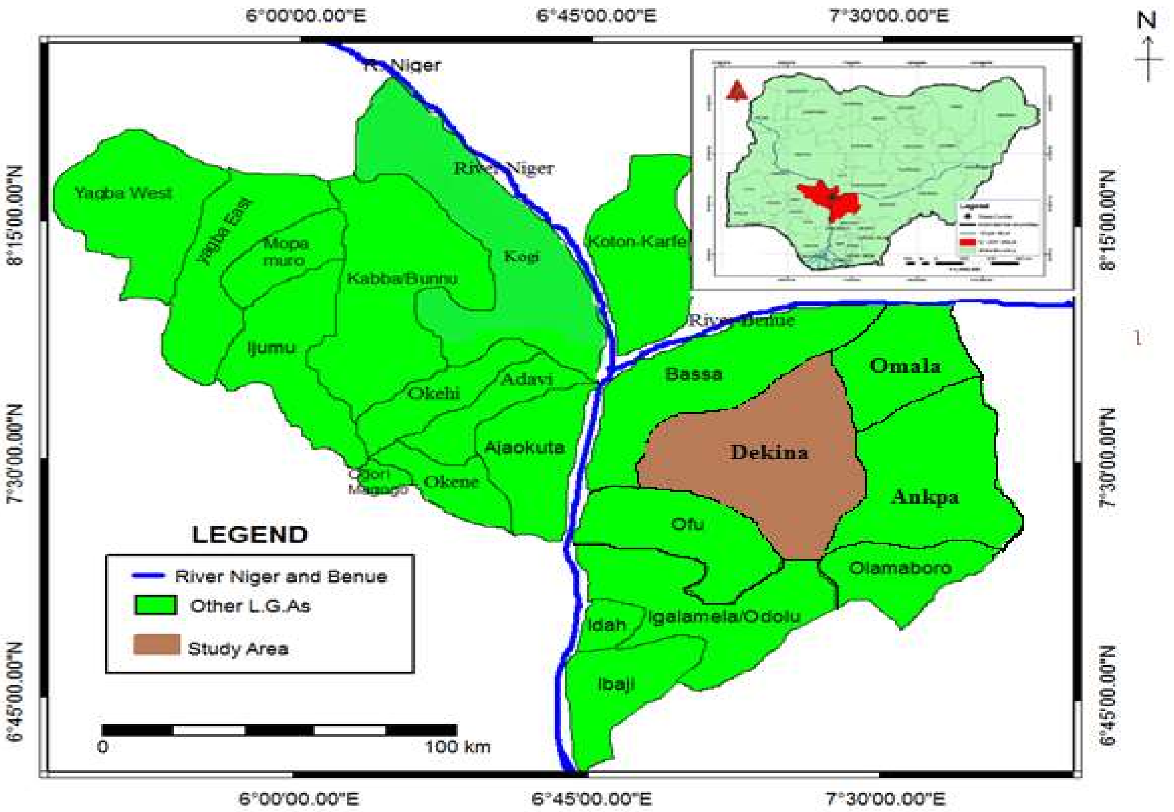
Coal mining commenced in Nigeria in 1916 at Ogbete drift mine near Enugu. Coal production was initially concentrated in Enugu where four mines (Iva Valley, Onyeama, Okpara and Ribadu) were worked by the Nigerian Coal Corporation (Orajaka *et al*., 1990). Two other mines were later opened at Okaba in Kogi State and Orukpa in Benue State. Production started from a modest beginning (24,500 tonnes in 1916) and gradually rose to an annual output of about 700,000 tonnes in 1966 just before the outbreak of the Nigerian civil war (NCC, 1982).

Although several studied have been reported for physio-chemical composition of some coal deposits in Nigeria, but little is done on Effin – Okai coal deposit and since coal deposit changes over time as it matures, the present study is designed to implement macerals (vitrinite, liptinite and inertinite) characterization and applications of Effin – Okai coal deposit.

2.0 Materials and Methods

2.1 Study Location

Effin – Okai coal deposit is situated on Latitude 7^0 37' 50.4" N and Longitude 7^0 02' 10.9" E. It is located off Olowa village along Anyigba – Olowa – Dekina road in Dekina Local Government Area of Kogi State (Fig. 1). Drainage is generally that 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 280m 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 documented by various workers (Nwajide and Reijers, 1996; Obaje *et al*., 1999; Umeji, 2005) among others. Sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine and paralic shales of the Nkporo Formation (Fig. 2), overlain by the Early – Late Maastrichtian coal measures of the Mamu Formation, comprising paralic sandstones, mudstones and coals. The Middle – Late Maastrichtian fluviodeltaic sandstones of the Ajali Formation lie on the Mamu Formation 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).

2.3 Sampling

Ten coal samples of approximately 300 g each were collected from Effin – Okai coal deposit.

Samples collected were kept in an airtight polyethylene bags prior to analyses. The coal samples were pulverized and sieved to pass through 10 mm sieve size. All sample analyses were carried out at Pearson Coal Petrography Laboratory, South Holland, Illinois, USA.

2.4. *Analysis of samples*

2.4.1 *Petrographic Analysis*

Petrographic analysis based on maceral composition and vitrinite reflectance was carried out on the coal samples.

2.4.2 *Maceral Analysis*

A Leitz MPV 2 microscope photometer was used for the petrographic work. Maceral analyses were carried out under the microscope using reflected white light with X10 ocular and X50 oil-immersion objective lenses. The maceral characterization was done by point counting using a mechanical stage attached to the microscope stage, under the reflected white light excited by ultraviolet (UV). The components V (vitrinite), L (liptinite), I (inertinite), and M (mineral matter) are expressed

in volume percent (vol. %) for V + L + I + M = 100%. Maceral analyses were carried out using International Standards ASTM D2799 and ISO7404/5.

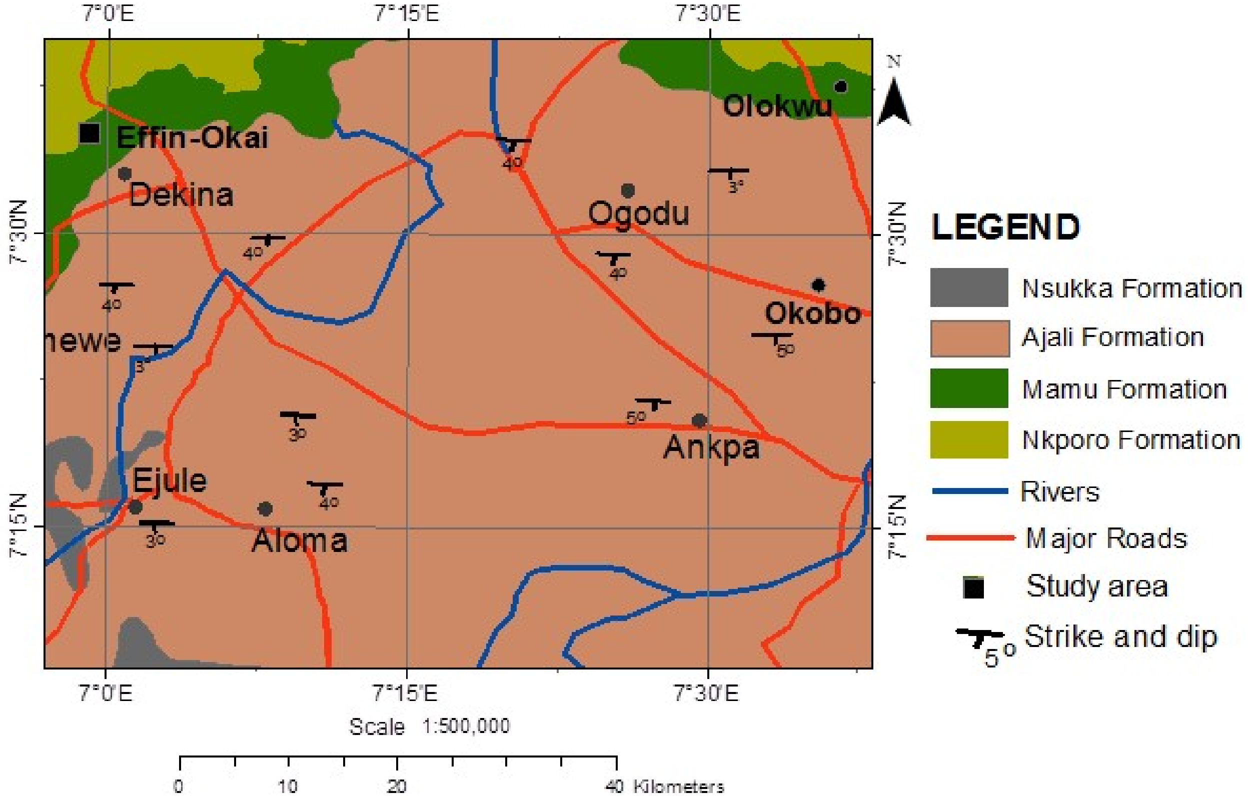


Fig. 2: Geological map of the study area

2.4.3 *Vitrinite Reflectance Analysis*

The vitrinite reflectance of the coal samples was measured under oil-immersion, using a monochromatic non-polarized light (calibrating against two sets of reference standards) in conjunction with the X10 ocular and X50 objective lenses. Measurements were made of the percentage of incident light reflected from the vitrinite particles in the samples using a wavelength of 546 nm. Mean maximum vitinite reflectance (Rm max %) determinations were carried out based on an average of at least 100 individual measurements for each studied sample. Vitrinite reflectance analyses were carried out using International Standards ASTM 2798, ISO7404.

3.0 Results and Discussion

The International Committee for Coal and Organic Petrology (ICCP) Handbook (1963) defined lithotypes as "the macroscopically recognizable bands of humic coals", and named four of them as vitrain, clarain, fusain and durain. Stach *et al*. (1982) gave the same definition except that the two lithotypes of sapropelic coals (cannel and boghead) were additionally included. The oldest class of humic coal were the albeit gas-proneof Devonian age, the majority of humic coals capable of generating and expelling non-volatile oil are of Cretaceous and Tertiary age (Isaksen *et al*., 1998). In this study, it was observed that the coal is banded and shows dull to shiny black in appearance. Clarain is the most common macroscopic ingredient in most of the samples followed by durain. The dominance of durain in samples 1, 5 and 10 imparts a dull appearance to the coal samples. This indicates that chemically, they have a high carbon content and flammability (Mandasini *et al*., 2018).

These organic components of coal which are called macerals are the basic and relatively homogeneous organo-petrographic entities of coal which by their chemical composition and physical characteristics determine its properties and utilization (Diessel, 1992). Many different types of macerals occur in coal. The identification of the original plants and their parts (such as bark, roots, spores, or seeds) that produced individual coal macerals is helpful in determining coal quality. In coals, they are normally classified into three groups; namely, vitrinite, liptinite, and inertinite. This classification is based either on similar origin (e.g. the liptinite group) and/or on the differences in preservation (e.g. the vitrinite and inertinite groups). Chemical and physical properties of the macerals such as elemental composition, moisture content, hardness, density and petrographic characteristics differ widely and are also subject to changes in the course of diagenesis and coalification (Bustin *et al*., 1985 and Stach *et al*., 1982).

The vitrinites are massive and cellular types with dark gray to light gray colour exhibiting moderate to low reflectivity. These are considered as telocollinite. It is frequently intermixed with exinite (liptinite), and fragmental bits of fusinite. In all the samples discrete grains of pyrite and siderite are found to be embedded in vitrinite. Telocollinite is the dominant vitrinite group in all the samples (Fig. 3). The liptinite group of macerals observed in the coal samples is mainly sporinite, cutinite and resinite. Sporinite and cutinite are the major liptinite macerals (Fig. 4). Vitrinites admixed with liptinites contain small oval bodies of resinite. Inertinites are the group of macerals which show highest reflectivity and are very bright in incident light. The micro components of the inertinite group include semi-fusinite, fusinite, macrinite, micrinite, sclerotinite, and intertodetrinite. Fusinite and semi-fusinite is by far the most dominant maceral in all the coals (Figs. 5 and 6). Semi-fusinite, macrinite, micrinite and inertodetrinite are found in decreasing order of abundance. Sclerotinite occurs as a rare component. Micrinite occurs as granular form and is opaque in transmitted light. Fusinite cell lumens are filled with inorganic minerals like pyrite, quartz and siderite. Fusinite and semi-fusinite occur as lensoid bodies and are crossed at many places (Figs. 5 and 6).

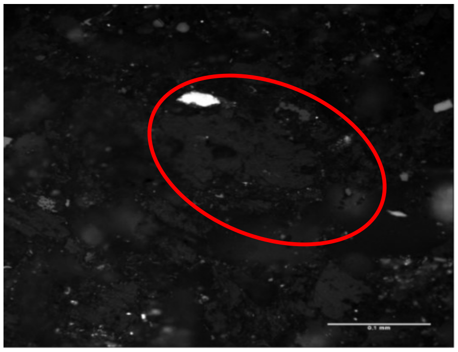


Fig. 3: Photomicrograph showing the maceral composition of Effin - Okai coal sample with dominance of telocollinite (in the circle) with spots of pyrite under reflected white light.

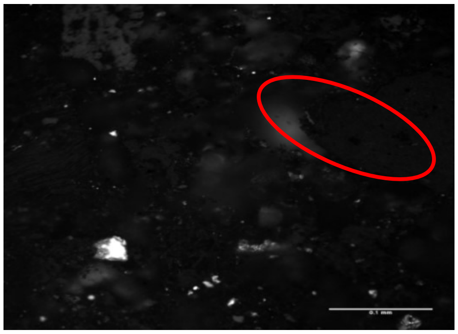


Fig. 4: Photomicrograph showing the maceral composition of Effin – Okai coal sample comprising sporinite (in the circle) with spots of pyrite under reflected white light.

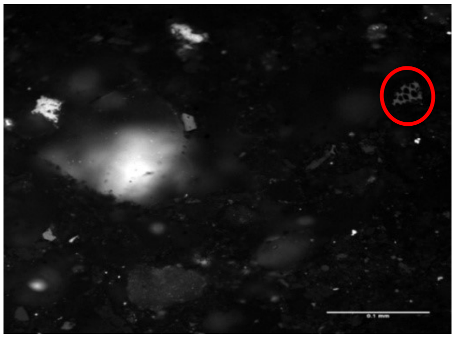


Fig. 5: Photomicrograph showing the maceral composition of Effin – Okai coal sample with fusinite (in the circle) and dots of pyrite under reflected white light.

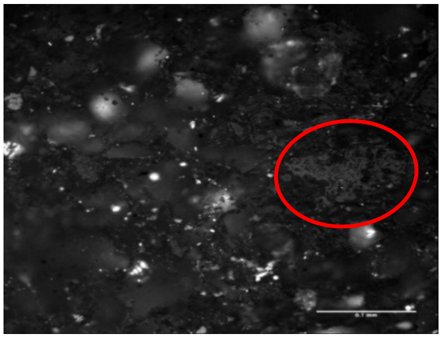


Fig. 6: Photomicrograph showing the maceral composition of Effin – Okai coal sample comprising of semi-fusinite (in the circle) with specks of pyrite under reflected white light.

Table 1 Petrographic composition (maceral) of Effin – Okai coal samples

Sample Number	Vitrinite (%)	Lipnite (%)	Inertinite (%)	Total macerals (%)
Effin – Okai 1	57.8	6.4	35.8	100
Effin – Okai 2	59.5	10.1	30.4	100
Effin – Okai 3	58.5	7.6	33.9	100
Effin – Okai 4	58.9	7.9	33.2	100
Effin – Okai 5	57.8	7.8	34.4	100
Effin – Okai 6	59.1	11.3	29.6	100
Effin – Okai 7	59.7	10.3	30	100
Effin – Okai 8	58.5	8.7	32.8	100
Effin – Okai 9	58.3	8.5	33.2	100
Effin – Okai 10	57.9	7.4	34.7	100
Average	58.6	8.6	32.8	100
X	53.0	17.0	30.0	100
Y	80.5	10.2	9.3	100
Z	80.0	0.0	20.0	100

X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

The three maceral groups namely, vitrinite, liptinite and inertinite were represented in all the samples. The mineral matter content was also considered in conventional maceral analysis. Vitrinite, however, is the predominant group in the samples (Tables 1and 2). On mineral matter-free basis, the coal, on average, contains 58.60 % vitrinite, 8.60 % liptinite and 32.80 % inertinite (Table 1). With mineral matter counted, on average, it consists of 46.40 % vitrinite, 6.30 % liptinite, 28.40 % and 18.90 % inertinite (Table 2).

Generally, the coal is characterized by low vitrinite content and high inertinite content to satisfy Mackowsky (1982) rating of 60 – 80 % vitrinite and 5 – 15 % inertinite for coking potential. However, it satisfies the rating of 30 – 60 % vitrinite and less than 40 % inertinite proposed for steam or thermal coals by Mackowsky (1982). These imply that Effin– Okai coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries.

Table 2: Petrographic composition (maceral and mineral matter) of Effin – Okai coal samples

Sample Number	Vitrinite (%)	Lipnite (%)	Inertinite (%)	Total macerals (%)	Total minerals (%)
Effin – Okai 1	49.9	5.1	26.1	77.1	22.9
Effin – Okai 2	46.3	7.5	24.9	78.7	21.3
Effin – Okai 3	46.7	6.5	29.6	82.8	17.2
Effin – Okai 4	47.1	5.8	35.5	88.4	11.6
Effin – Okai 5	46.8	7.1	28.6	82.5	17.5
Effin – Okai 6	45.7	6.4	26.6	78.7	21.3
Effin – Okai 7	47.4	5.5	32.4	85.3	14.7
Effin – Okai 8	46	6.7	26.7	79.4	20.6
Effin – Okai 9	46.6	6.4	32.1	85.1	14.9
Effin – Okai 10	45.5	6	21.5	73	27
Average	46.4	6.3	28.4	81.1	18.9
X	51.0	17	29	97	3
Y	80.07	10.23	9.3	99.6	0.4
Z	79.7	0	19.9	99.6	0.4

X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

Comparing the values of maceral composition of the studied coal with those reported for other coals, Effin – Okai coal is similar to sub-bituminous coal in Ib-Valley (India) reported by Senapaty and Behera (2015) but contrast with the values of bituminous coals in North-East (India) and Obi-Lafia (Nigeria) reported by Sharma *et al*., (2012) and Afonja (1996) respectively (Tables 1 and 2) thereby placing Effin – Okai coal in sub-bituminous rank. Vitrinite is the most abundant material group in most coals and hence plays an important role in determining the properties of the coal. Vitrinite and liptinite are both reactives. They enhance the rate of combustion. Inertinite has a low reactivity, which retards combustion (Schapiro, *et al.,* 1961). The studied coal, on average, contains 52.70% reactives (vitrinite + liptinite) and 47.30% inerts (inertinite + mineral matter) (Table 3).

Generally, the studied coal contains low amount of reactives and high amount of inerts to agree with Composition Balance Index (CBI) of reactives greater than 70 % and inerts lesser than 30 % stated by Schapiro *et al*. (1961) and Rentel (1987) for coking coals (Table 3). However, it satisfies the Composition Balance Index (CBI) of reactives greater than 40 % and inerts lesser than 60 % for steam or thermal applications also proposed by Schapiro *et al*. (1961) and Rentel (1987). These imply that Effin – Okai coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries. The cement, glass, ceramic, paper and brick industries can use it for this purpose. Mackowsky (1982) proposed greater than 30 % vitrinite and lesser than 40 % inertinite for coals used in the manufacture of organic chemicals. Based on this proposal, Effin – Okai coal with 58.60 % vitrinite and 32.80 % inertinite can also be used in the manufacture of products such drugs, dyes, plastics, synthetic rubbers, insecticides, antiseptics, paint products, solvents, synthetic fibres, flavourings, perfumes, varnishes, adhesives and numerous other organic chemicals.

The mineral matter content of the coal was observed to range from 11.60 % (in sample 4) to 27.00 % (in sample 10) with average value of 18.90 % (Table 2). Mineral matter in coal are inorganic content that are associated with macerals. Mineral matter is an undesirable constituent of coal as it contributes to producing brittle steel, causes slagging and fouling in the boilers thereby impeding their function, reduces the calorific (heating) values of coal and reduces coal plasticity.

Table 3: Percentage reactives and inerts components of Effin – Okai coal samples

Sample Number	Reactives (V+L) (%)	Inert (I+M)(%)	Total (V+L+I+M)(%)
Effin – Okai 1	51	49	100
Effin – Okai 2	53.8	46.2	100
Effin – Okai 3	53.2	46.8	100
Effin – Okai 4	52.9	47.1	100
Effin – Okai 5	53.9	46.1	100
Effin – Okai 6	52.1	47.9	100
Effin – Okai 7	52.9	47.1	100
Effin – Okai 8	52.7	47.3	100
Effin – Okai 9	53	47	100
Effin – Okai 10	51.5	48.5	100
Average	52.7	47.3	100
X	68	32	100
Y	90.3	9.7	100
Z	79.7	20.3	100

V = Vitinite, L = Liptinite, I = Inertinite M = Mineral matter
X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

It has been found that the calorific values of coals decrease with increasing mineral matter content because of the endothermic reactions required to decompose the mineral matter as well as the heat capacities of such minerals. The resulting combustion energy loss can be very large hence the quality of the coal will be low since coal quality is related based on its calorific value (Shirazi, 1995). Peng (2002) also stated that the lower the amount of mineral matter in coal, the better its quality. The studied samples are characterized by relatively high mineral matter compared with known high rank coals (Table 2). According to Thomas (2002) recommendation which suggested that the mineral matter in coal suitable for coking purpose should be less than 5 %. Therefore, Effin – Okai coal with 18.90 % mineral matter may not be suitable for the manufacture of coke meant for reduction of iron ore in the blast furnace. Although Thomas (2002) gave a rating of less than 15 % mineral matter content for steam or thermal coals but Adeleke and Onumanyi (2007) stated that mineral matter content less than 25 % in steam or thermal coals can be reduced to acceptable level through proper preparation before utilization. This implies that Effin – Okai coal is also good for generation of electricity and heating purposes when properly prepared. The cement, glass, ceramic, paper and brick industries can use it for this purpose. Comparing the values of the mineral matter composition of the studied coal with the values of other coals elsewhere, Effin – Okai coal is similar to sub-bituminous coal in Ib-Valley (India) reported by Senapaty and Behera (2015) but contrast with bituminous coals reported in North-East (India) and Obi-Lafia (Nigeria) by Sharma *et al*., (2012) and Afonja (1996) respectively (Table 2). Vitrinite analysis is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a coal. The reflectance of vitrinite in coals is dependent on the level of coalification. The level of coalification dictates economic potential and technological applications of the coal. The mean vitrinite reflectance measurements of the studied coal samples ranged from 0.37 % R_{omax}(in samples 2, 3 and 8)to 0.39 % R_{omax}(in samples 1, 5 and 7) as shown in Table 4.According to Thomas (2002) and Taylor *et al*. (1998), vitrinite reflectance rating of 0.10 – 0.60% $R_{omax}$is applicable to sub-bituminous coals. This rating therefore placed Effin - Okai coal in sub-bituminous rank. By comparison, the vitrinite reflectance value of the studied coal is similar to that of sub-bituminous coal in Enugu (Nigeria) reported by Ugwu (1988) but contrast with the value of bituminous coal in Obi-Lafia (Nigeria) reported by Obaje (1997).

Table 4: Mean Vitrinite reflectance values (R_{o-max} %) of Effin – Okai coal samples

Sample Number	**R_{omax} (%)**
Effin – Okai 1	0.39
Effin – Okai 2	0.37
Effin – Okai 3	0.37
Effin – Okai 4	0.38
Effin – Okai 5	0.39
Effin – Okai 6	0.38
Effin – Okai 7	0.39
Effin – Okai 8	0.37
Effin – Okai 9	0.38
Effin – Okai 10	0.38
Average	0.38
X	0.5
Y	0.88

****X: Enugu (Nigeria) Sub-bituminous coal (Ugwu, 1988)**
Y: Obi/Lafia (Nigeria) Bituminous coal (Obaje, 1997)

Based on vitrinite reflection classification, Effin – Okai coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries such as cement, glass, ceramic, paper and brick industries. The coal can also be used in the manufacture of products such drugs, dyes, plastics, synthetic rubbers, insecticides, antiseptics, paint products, solvents, synthetic fibres, flavourings, perfumes, varnishes, adhesives and numerous other organic chemicals. It can as well be used for the production of gas and automotive fuel.

4.0 Conclusion

Petrographic studies in terms of maceral and mineral matter composition as well as vitrinite reflectance revealed that Effin – Okai coalis generally low in vitrinite, low in reactive, high in mineral matter and low in vitrinite reflectance. These characteristics suggest that the coal does not possess significant qualities that make it suitable for coke making blends thereby placing it on low quality, non-coking and sub-bituminous rank. However, it is good for electricity generation. The coal is also appropriate in heating for manufacturing processes. For example, it can be used to heat kilns in the production of cement, glass, ceramic, paper and bricks. In addition to generating electricity and heating, the coal is important source of raw materials for manufacturing. Its destruction distillation (carbonization) can produce hydrocarbon gases and coal tar, from which Chemists can synthesize drugs (such as aspirin), dyes, plastics, synthetic rubbers, insecticides, antiseptics, paint products, solvents, synthetic fibres (such as rayon and nylon), flavourings, perfumes, varnishes, adhesives and numerous other organic chemicals. The coal isa good producer of gas fuel, and is suitable for complete gasification using oxygen enriched steam blast process. It can also be processed to produce automotive fuel. The coal and its by-products can as well be used as components of many different products like soaps, detergents, fertilizer, shampoo, etc

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