ABUAD Journal of Engineering Research and Development (AJERD)
Volume 2, Issue 1, 20-25

ISSN: 2645-2685

Proximate, Ultimate Analysis and Industrial Applications of Some Nigerian Coals

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Date Submitted: 28/06/2018
Date Accepted: 16/11/2018
Date Published: 23/04/2019

Abstract: *The physico-chemical, thermal and mechanical properties were used to evaluate coal samples from Udane-Biomi, Emewe-Efoppa and Okobo, Kogi state, Nigeria. The results of the proximate analysis of the coals showed higher ash content for Udane-Biomi (75.23%) than Emewe-Efoppa (6.86%) and Okobo (3.32%) coal deposits. The Net Calorific Values (NCV) obtained from Bomb Calorimetry test indicated that the heating value of Emewe-Efoppa (25.25 MJ/Kg) and Okobo (26.53 MJ/Kg) coal samples were eight times higher than Udane-Biomi (3.2 Kcal/kg) sample. The chemical composition of the coal got from the ultimate analysis test showed that the carbon contents were between 10.40 – 68.59%. The sulphur and nitrogen contents in all coals were similar and significantly low. Based on the analyses of the results obtained, Emewe-Efoppa and Okobo coals may be used for different purposes such as power generation, fuels, feedstock for chemicals and Udane-Biomi coal is best for cement production.*

Keywords: *coal reserve; net calorific value; proximate analysis; ultimate analysis*

1. INTRODUCTION

Worldwide, coals are used for various purposes such as generation of electricity, iron and steel making, cement production, paper manufacturing and chemical and pharmaceutical productions [1]. However, the application of coals in manufacturing industries depend on its types, grades and quality, which are function of temperature and pressure and the length of time of its formation [2]. There are two classes of coals: low rank coals (the lignite and subbituminous) and hard coals (the bituminous and anthracite). Low rank coals are characterised with high moisture content and hard coals with high carbon/energy content. Both low rank and hard coals can be used in railway transportation, power generation and cement manufacturing because high quality coals is not pre-requisite. Thus, little or no laboratory analysis may be required after exploration and prior to the usage. However, in iron and steel making industries, smokeless fuel manufacturing industries and town gas supply, high quality coal is needed. This implies that there is a need for coal analysis to meet the desire objectives. Nigeria as a developing country needs a high quality coal for technological advancement in the field of iron and steel making industries. Studies have shown that Nigeria coals are more of low rank coals [3, 4] than hard coals. Hence, quest for continuous research for high quality coals is imperative.

Olaleye investigated some notable Nigerian coal deposits [5]. He observed that the quality of the coals studied was comparable with other sub-bituminous coals in coal-producing countries of the world, due to its low ash, sulphur and moisture contents and medium to high calorific value. Ndagana *et al.*, also demonstrated that Okaba coal deposit is a sub-bituminous coal, hence, a low rank coal [6]. Ernest and Onyeka (2016) investigated coals from different parts of the countries [7]. They concluded that the Enugu and Benue coal samples are sub-bituminous while the Delta coal sample is lignite. There is a need for further examination of Nigerian coal deposits for the industrial applications, especially in iron and steel production. In this study, three types of coals from Udane-Obiomi, Emewe-Efoppa and Okobo coal reserves were analysed to suggest their possible applications.

2. MATERIALS AND METHODS

2.1 Materials

Coal samples were obtained from three different locations namely: Udane-Biomi, Emewe-Efoppa and Okobo. The samples were stored in appropriately labelled air-tight containers to retain their as-received conditions. A known weight of each pulverized sample of coal from each of the sites was taken for different analyses.

2.2 Methods

2.2.1 Coal preparation

Figure 1 shows all the three coal samples used for this study. Manual method, with the aid of hammer was used for the crushing and milling of the coal samples to meet International Organisation for Standardisation (ISO) 13909-44:2001 specifications. Subsequently, sieving of the coal samples was carried out with an automatic sieve shaker to a size of 212 µm (Retsch Mill, USA). Prior to each test, a known weight of each of the samples was air-dried with an electrothermal blast drying box at 40° C. This is to bring the moisture content of the samples to approximate equilibrium with the laboratory atmosphere in order to minimize gain or loss during sampling operations in accordance with American Society for Testing and Materials [8] All the tests were repeated three times to enhance the reliability of the results.

Figure 1: Pictures of (a) Udane-Biomi, (b) Emewe-Efoppa and (c) Okobo coal sample

2.2.2 Proximate analysis

The proximate analysis of Udane-Biomi, Emewe-Efoppa and Okobo coal reserves was carried out according to American Society for Testing and Materials Standard. For Moisture Content (MC), 10 g of each of the coal samples was kept in a silica crucible and heated in a muffle furnace at 110° C for one hour. Thereafter, the silica crucible was taken out of the muffle furnace, cooled in a desiccator and weighed. The process of heating, cooling and weighing was repeated until a constant of coal (anhydrous) was achieved (ASTM D3173). The % MC was determined according to Eqn. 1. ASTM D3175 procedure was used for Volatile Matter (VM). The previous moisture free samples were covered and placed in a muffle furnace and heated at 950° C for 7 minutes. The VM was determined according to Eqn. 2. The Ash Content (AC) was determined according to the ASTM D3174. The 10 g of coal samples were placed in a crucible and heated and the residue obtained were used to obtain the % AC (Eqn. 3). The fixed carbon was determined as in Eqn. 4. The procedures and Eqns. 1 to 4 were -obtained from [8 - 10]. Eqn. 5 was used to determine the Mineral Matter [11].

$$\% MC = \frac{Loss\ in\ weight\ of\ coal}{Weight\ of\ coal\ initially\ taken} * 100 \qquad (1)$$

$$\% VM = \frac{loss\ in\ weight\ of\ moisture\ free\ coal}{Weight\ of\ moisture\ free\ coal} * 100 \qquad (2)$$

$$\% AC = \frac{Weight\ of\ residue\ ash\ formed}{Weight\ of\ coal\ initially\ taken} * 100 \qquad (3)$$

$$\% FC = 100 - (\% MC + \% AC + \% VM) \qquad (4)$$

$$MM = 1.08\,AC + 0.55S \qquad (5)$$

$$(where\ S\ is\ the\ sulphur\ content)$$

2.2.3 Ultimate analysis

The nominal chemical composition of the coal samples was carried out at Pedagogic Consulting Lagos, Nigeria. Leibig-Pregle chamber containing magnesium percolate and sodium hydroxide was used. Carbon (C) content was determined according to ASTM D5373-02, hydrogen (H) and nitrogen (N) according to ASTM D4239-02 and sulphur (S) according to ASTM D5142-02 specifications. The oxygen content (O) was obtained according to Eqn. 6 [12].

$$\% O = 100 - \%(C + S + N + H + ash) \qquad (6)$$

2.2.4 Calorific value

XRY-1A Di-thermal Oxygen Bomb Calorimeter was used to determine the Gross Calorific Value (GCV) and Net Calorific Value (NCV) of the coals according to ISO 1928:1995 specification.

2.2.5 Hardness test

The microhardness characteristic of the coal samples was analysed with Microvickers Hardness Tester. A well-polished surface test sample was prepared from each of the coal reserves. Subsequently, a load of 100 g was applied. This is to enable the comparison of the coals from different locations.

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis

This study aimed at comparing properties of the Udane-Biomi, Emewe-Efoppa and Okobo coal reserves and comments on their possible applications. Figures 2 - 6 show the results of the proximate analysis carried out on the three coal reserves. Figure 2 shows the percent composition of the air dry and inherent moistures present in the coal samples. It can be seen that the inherent moisture content of Emewe-Efoppa and Okobo coal reserves was nearly the same and significantly higher than that of Udane-Biomi coal sample. Similarly, the air-dry moisture content demonstrated similar trend. Okobo coal reserve had the highest moisture content followed by Emewe-Efoppa coal reserve and the least by Udane-Biomi coal reserve. Udane-Biomi coal reserve is characterised with low volatile matter of 13 %, compared to Emewe-Efoppa and Okobo coal reserves of 45 and 42 % respectively (Figure 3). The results of the ash content for three coal reserves are presented in Figure 4. Udane-Biomi, Emewe-Efoppa and Okobo coal reserves contain 75, 6.86 and 3.32 % of ash contents, respectively. This implies that Udane-Biomi has the characteristic of being able to retain enough heat for efficient melting due to its least danger of spontaneous combustion (low volatile matter) [2, 12]. However, the ash content of Udane-Biomi coal reserve is observed to be very high. Previous study has shown that ash content affects the composition, volume and performance of blast furnace coke negatively [13]. Thus, Udane-Biomi coal can be said to have limited applications because of its higher incombustible and higher cost of handle and processing of the ash [2]. Emewe-Efoppa and Okobo coal reserves exhibited lower ash content, thus, cheaper to process and handling. The grade of coal refers to the amount of carbon and mineral matter that is present in the coal and is a measure of coal heating value and quality [2]. Figure 5 shows the percent fixed carbon in each of the coal reserves studied. The highest fixed carbon content of 44.84 % was recorded in Okobo coal sample,

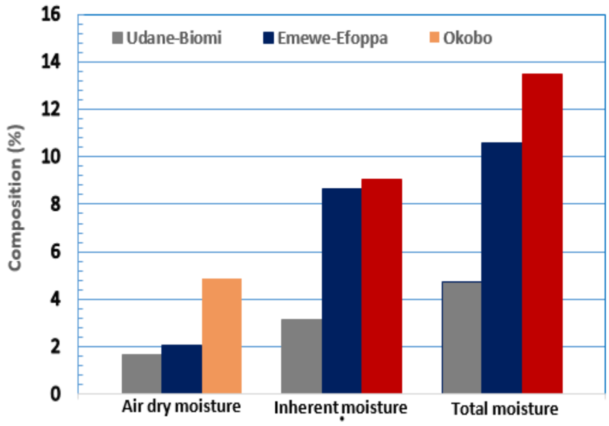

Fig. 2. Percent compositions of air dry and inherent moistures present in Udane-Biomi, Emewe-Efoppa and Okobo coal samples

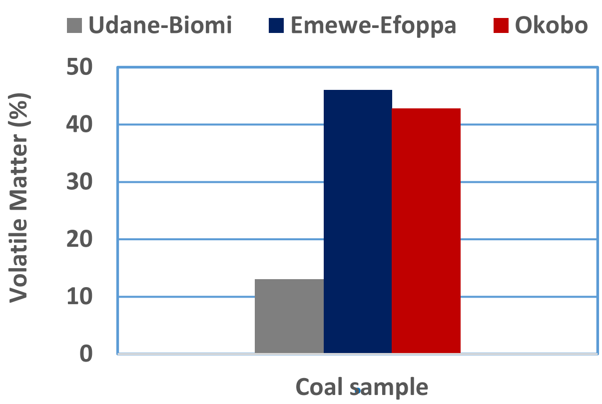

Fig. 3. Percent compositions of volatile matter present in Udane-Biomi, Emewe-Efoppa and Okobo coal samples

 ISSN: 2645-2685

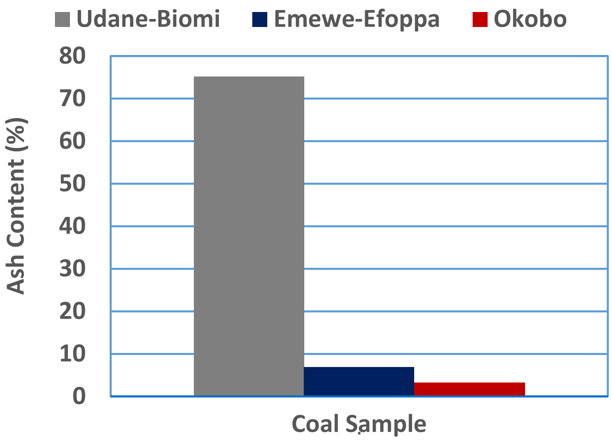

Fig. 4. Percent compositions of ash content present in Udane-Biomi, Emewe-Efoppa and Okobo coal samples

followed by Emewe-Efoppa and Udan-Biomi coal samples with values of 38.49 and 8.58 % respectively. Udane-Biomi coal sample is characterised with high mineral matter and that of Emewe-Efoppa and Okobo coal samples is very low, as shown in Figure 6. This implies that Emewe-Efoppa and Okobo coal samples have better heating value and high quality [14].

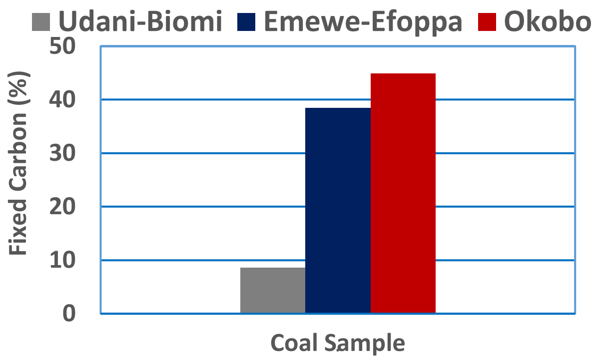

Fig. 5. Percent compositions of fixed carbon present in Udane-Biomi, Emewe-Efoppa and Okobo coal samples

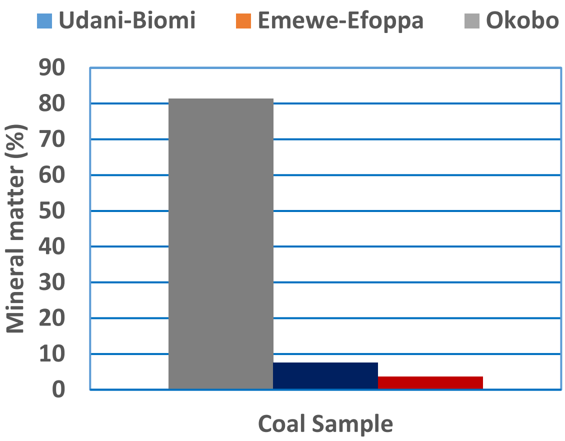

Fig. 6. Percent compositions of mineral matter present in Udane-Biomi, Emewe-Efoppa and Okobo coal samples

3.2 Calorific Value

The results of calorific values are shown in Figure 7 respectively. Calorific value indicates the degree of heat content of the coals. Bomb calorimetry was used to determine the Net Calorific Value. Okobo coal reserve exhibited highest NCV of 26.53 MJ/kg followed by Emewe-Efoppa of 25.25 MJ/kg and least by Udane-Biomi 3.27 MJ/kg coal reserve. All the three coal reserves are good for heating and power generation. However, the higher calorific values of Emewe-Efoppa and Okobo coal reserves would be the best.

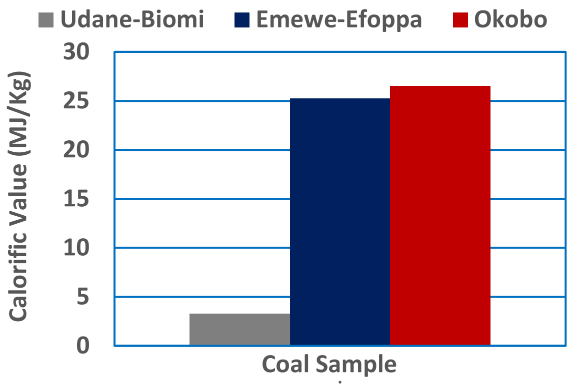

Fig.7. Udane-Biomi, Emewe-Efoppa and Okobo coal samples as function calorific value.

3.3 Ultimate Analysis

The results of ultimate analysis carried out on Udane-Biomi, Emewe-Efoppa and Okobo coal reserves were evaluated on air-dried basis. The elemental compositions of the coal samples are presented in Table 1. It can be observed that Okobo coal with 68.59 % C, 42.78 % VM, 0.29 % S and 26.53 MJ/kg is a high-volatile C bituminous coal [2]. Similarly, Emewe-Efoppa coal with 64.60 % C, 45.95 % VM, 0.28 % S and 25.25 MJ/kg is also a high-volatile C bituminous coal [2]. Udane-Biomi coal is a lignite B due to its low calorific value of 3.28 MJ/kg [2]. Among the parameters that influences the maturity (rank), calorific value and chemical reactivity during thermal conversion of coals are carbon and hydrogen contents [15]. The obtained carbon content is within the ranges of hard coal, which suggest that the coals obtained from Okobo and Udane-Biomi might be used for applications that required high quality. The sulphur and nitrogen contents are very low for all coal samples studied. As such, limited NO_a and SO_b gases will be released to the environment during combustion. Thus, the coals are friendly to the environment. Previous study by Ryemshak and Jauro has shown that the sulphur content obtained for Okobo and Udane-Biomi coals conforms within the range required for power generation, fuels, feedstock for chemicals [15].

3.4 Hardness Test

Figure 8 shows the relationship between the hardness of each of the coal reserves. Udane-Biomi coal exhibited highest hardness followed by Emewe-Efoppa and Okobo coal reserves. Generally, the difference in their hardness value is les than 20 %.

Table 1: Ultimate analysis of three coal reserves from Kogi State, Nigeria

S_N	Elements	Udane-Biomi Coal (%)	Emewe-Efoppa Coal (%)	Okobo Coal (%)
1	C	10.40	64.60	68.59
2	H	9.50	5.06	5.03
3	O	2.75	21.99	21.53
4	N	1.84	1.20	1.24
5	S	0.28	0.29	0.29
6	Ash content	75.23	6.86	3.32
7	Calorific Value (MJ/kg)	3.28	25.25	26.53

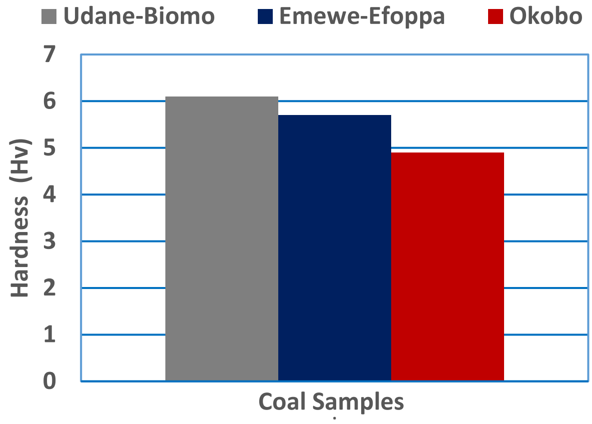

Figure 8: Udane-Biomi, Emewe-Efoppa and Okobo coal samples a as function hardness

4. CONCLUSION

The physicochemical, thermal and mechanical properties of three Nigerian coals from Kogi State were characterised to know and compare their ultimate and proximate analyses, hardness and calorific values. The ultimate analysis indicated the coal samples possess high carbon and hydrogen and relatively low sulphur and nitrogen contents. The calorific value of Emewe-Efoppa and Okobo coal samples is very high and within the range of hard coals. It was also observed that the ash content of Udane-Biomi coal sample is very high. Thus, by comparing the properties of the coals, Emewe-Efoppa and Okobo coal samples are suitable for power generation, iron and steel making, cement production and feedstock for chemicals. Udane-Biomi coal sample is best for cement production due to their high volatile and mineral matters.

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