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# Thermal and Physicochemical Characterization of Locally Sourced Lignite Coal

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**ABSTRACT**

Coal as a solid mineralized substance consumed to provide was composed in ecosystems where remains of animal or plant were conserved by wood and fine-grained sediment from oxidation and decomposition by biological activities. The aim of this study is to examine the properties of locally sourced lignite coal. The characterization method used were thermogravimetric analyses and physicochemical analyses. The results of the physicochemical analyses obtained shows high carbon (C) and hydrogen (H) content of 90 % and 8.38 %; high fixed carbon of 81.3 % with low sulphur, oxygen and nitrogen content of 0.79 %, 0.67 % and 0.16 %; low moisture content, low ash content and low volatile matter of 1.45 %, 1.78 % and 15.84 % respectively. The low moisture content, ash content and volatile matter shows that the lignite coal is of good quality with 16.113 MJ/kg as the high heating value, (HHV). However, this coal has nitrogen and sulphur content less than 1 % which is an indication of the environmental friendliness of coal relative to potential NOx and SOx pollutant emissions. This coal can be used in power generation, iron and steel making, pharmaceutical industries.

**KEYWORDS:** *Lignite, Thermal, Ultimate, Proximate*

## 1 INTRODUCTION

Coal is a combustible form of rock made by the deposition and compression of small particles which contains both compounds of carbon minerals and compounds of non-carbon materials, it is the world's most sufficient and commonly dispensed mineralized energy given substance (Idris and Ahmed, 2019). Coal and coal-derived energy given substance have been used in residential, commercial, and industrial applications such as generation of electricity, iron and steel making, chemical and pharmaceutical productions, cement production and paper manufacturing (Bodude et al., 2018). Coal as a solid mineralized substance consumed to provide energy was composed in ecosystems where remains of animal or plant were conserved by wood and fine-grained sediment from oxidation and decomposition by biological activities a layer of dead plants and animals at the bottom of the wetland was covered by layers of water and dirt, snare the energy of the dead plants and animals for millions of years (Bizualem and Busha, 2017). The pressure and heat from the top layers enhanced the dead plants and animals turn into coal, it takes millions of years to form thereby became nonrenewable energy source. However, the energy in coal is obtained from the energy stored by dead plants and animals over hundreds of millions of years ago, when the earth was not completely covered with wetland forests. Coal is an easily combustible black or brownish-black form of rock made by the deposition and compression of small particles composed mainly of carbon and hydrocarbons, with little amount of other elements, like oxygen, nitrogen and sulfur (Wolde-Rufael, 2010). Coal seem to possess the most entreat of all the possible options for short-term development suitable for the national necessity of energy (Vasireddy et al., 2011). Coal and its products, play an important role in satisfying the energy necessity of the wester society. The quantity of coal deposits estimated all over the word was approximately ten times greater than that of other carbon yielding resources. The availability of coal resources was a main support to the economic expansion of many nations like the US, China, India, and Australia (Mehran et al., 2015). Coals can be classified into two: hard coals (the bituminous and anthracite) which is associated with high carbon and energy content and soft coals (the lignite and subbituminous) which is also associated with high moisture content, both hard coals and soft coals can be used in transportation, generation of electricity and cement manufacturing because quality of coals is not pre-requisite (Chukwu, 2015). Matsumoto et al., (2016), reported that researching on physicochemical characterization of coal sample would provide an enhanced information on the use and application of coal samples. The aim of this study is the thermal and physicochemical characterization of locally sourced lignite coal.

## 2 METHODOLOGY

The lignite coal was collected from Ogwashi Azagba in Delta state, Nigeria.

### 2.1 CHARACTERIZATION

Physicochemical Analyses involved ultimate and proximate analyses. The ultimate analysis was done using the method adopted from (Bodude *et al.,* 2018). Proximate analysis consists of the following parameters: moisture content, ash content, volatile matter and fixed carbon content.

**Moisture Content (MC):**

0.3 g of sample was placed on a dish. Weight of dish with sample was recorded before placing the sample in the tray dryer. Temperature of the dryer was adjusted to 60$^{O}$C, and sample was then dried to constant weight and final weight was recorded. Moisture content was calculated using:

$$MC\ (\%) = \left(\frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight}\right) \times 100\ \% \quad (1)$$

**Ash Content (AC):**

0.2 g of coal sample was placed into tarred crucible. The sample was preheated to 600 OC for 3 h. The crucibles were allowed to cool in the furnace to less than 100 ºC and then placed into desiccators with a vented top.

$$AC\ (\%) = \left(\frac{Weight\ of\ Residue}{Weight\ of\ Sample}\right) \times 100\ \% \quad (2)$$

**Volatile Matter (VM)**:

Volatile matter (VM) was determined by heating the dry sample in a covered crucible in a furnace at 930 °C for 7 min. The sample was then weighed after cooling in a desiccator. The VM was then calculated using the equation below:

$$VM\ (\%) = \left(\frac{B-C}{B}\right) \times 100\ \% \quad (3)$$

Where B is the weight of the oven dried sample and C is the weight of the sample after heating in the furnace at 930 °C.

**Percentage Fixed Carbon**:

The percentage fixed carbon (FC) was computed by subtracting the sum of VM and AC from 100 as shown in
the equation below:

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

**Determination of Calorific Value**

1.0g of coal sample in a nickel-chromium crucible was placed in an atmospheric environment of high-pressure known as Combustion Vessel, surrounded by water. The sample was then ignited. The calorimeter jacket was held at a constant temperature by regulating the fan speed while the heat produced by the burning sample caused the bomb and bucket temperature to increase. The temperature of the water was determined by an electronic thermometer with a resolution of 1/10000 of a degree. Any minute heat flow between the jacket and the surrounding during the test was continuously monitored by a microprocessor and necessary corrections of any heat leak applied automatically. Heat evolved is proportional to the gross calorific value (air-dried basis) of the sample and displayed automatically by the instrument. Duration of each run was 10 min.

**Thermogravimetric Analysis**

The lignite coal was heated from 25 ºC to 1000 ºC in air with an an air flow rate of 50 ml/min at a heating rate of 10 ºC/min. The weight change of the sample was recorded automatically until there was no further weight change. The residue in the crucible represents the ash content of the sample. Typical run time of the test was about 3.5 h.

## 3 RESULTS AND DISCUSSION

### 3.1 PHYSICOCHEMICAL ANALYSES AND THERMOGRAVIMETRIC ANALYESS

**Ultimate Analyses:** The data generated from ultimate analysis, were elemental parameters (such as carbon, hydrogen, sulphur, oxygen and nitrogen), which are used to determine the quality of coal. From Table 1, the coal sample possess high carbon content followed by hydrogen content of about 90 % and 8.38 % with low values of sulphur, oxygen and nitrogen content of about 0.79 %, 0.67 % and 0.16 % from the elemental analysis obtained. Among these elements, the carbon and hydrogen content of coals determines the maturity (rank), calorific value and chemical reactivity during thermal conversion of coals. From this analysis, the sulphur and nitrogen contents of the lignite coal examined were very low, are such, little or no $NO_x$ and $SO_y$ gases will be released during combustion to the environment (Bodude *et al.,* 2018). However, this lignite coal will be friendly to the environment and the equipment because of the little percentage composition of sulphur and nitrogen contents obtained from the analysis.

**Table 1:** Ultimate Analyses of Lignite Coal

| Parameters | Values (%) |
|---|---|
| Carbon | 90.00 |
| Hydrogen | 8.38 |
| Sulphur | 0.79 |
| Oxygen | 0.67 |
| Nitrogen | 0.16 |

Carbon and hydrogen are the main combustion constituents of coal and these two constituents are high in this lignite coal as compared with other elements such sulphur, oxygen and nitrogen. The type and ranking of coal are determined by the amount of carbon, from lignite to anthracite. Meanwhile, the carbon content in coal is used for classifications of coal, the higher the carbon content, the higher is the calorific value and the better is the quality of the coal. Hydrogen is commonly attached with volatile matter to determine the use to which the coal will be engaged. (Solomon and Aliyu, 2013), also concluded, that a good coal sample should possess high carbon content as compared with quantity of hydrogen, nitrogen and oxygen, as in the case of the result obtained for this lignite coal in Table 1.

The moisture content is a useful property of coal as all coals are mined wet. The groundwater and other non-essential moisture which are known as external sourced moisture is easily evolved while the moisture held within the coal itself is inherent moisture that is analyzed quantitatively. Most coals, as they are dug from the ground, have some quantity of moisture associated with them. The degree of maturity of coal, depends on the quantity of moisture content (Idris and Ahmed., 2019). The quality of coal is also determined by moisture content because it affects the calorific value, the higher the moisture content, the lesser the calorific value which causes reduction of the coal capacity and the lower the moisture content, the higher calorific value. 1.5 % moisture content is required in a good coking coal (Solomon and Aliyu., 2013). The value recorded for moisture content of this lignite coal in Table 2 was very closed to the stipulated value (1.5 %) for a good coking coal, this is an indication that the coal is a good coking coal which can be used for different applications where coking coal are needed. The ash content of coal is the remains residue that will not readily ignite left after the burning of coal, this represent the size of mineral matter when the Volatile Matter, moisture content, carbon, oxygen and sulphur are burnt off during combustion, it also indicates the rank of coal. The ash content of this coal used in this research work is about 1.78 % from the proximate analysis carried out (Table 2).

**Table 2:** Proximate Analyses on Coal Sample

| Parameters | Values (%) |
|---|---|
| Moisture Content | 1.45 |
| Ash Content | 1.78 |
| Volatile Matter | 15.84 |
| Fixed Carbon | 81.30 |
| HHV | 16.113 MJ/kg |

The high yield of ash content is usually a signed by the mutually sufficient supply of disintegrated materials in wetland, while the fusing materials govern mainly with low yield ash content of coals, whereas the part of disintegrated materials increases and the organically bound elements concentration decreases with increased ash yield. However, these observations seem valid majorly for coals ranking, lignite majorly consist of fusing mineralization, moisture, pyrite and calcite and organically bound C and S are common (Rasheed et al., 2015). This observation is also in agreement with the statement that some low yield ash content (<10%) coals contain mainly fusing and biogenic inorganic matter, whereas those with higher ash yield (>10%) show simultaneous enrichment in disintegrated and fusing inorganic matters (Sahni et al., 2013). The volatile matter is also a coal component which are evolved at high temperature when air is absence, at the temperature where volatile matter is evolved, the moisture content is as well totally liberated. Except for the fixed carbon and ash content which exceed that temperature, thereby required more high temperature. Volatile matter is mostly a combination of short and long chain hydrocarbons, aromatic hydrocarbons and some Sulphur. Volatile matter ranging from 2 % to about 50 % (Rasheed et al., 2015). in this research work, the volatile matter of the coal sample used is found to be about 15.84 % from the proximate analysis carried out (Table 2). The coal that contain high volatile matter are readily ignite, it burns fast and freqently burn with a long smoky fire because of high percentage of a combination of short and long chain hydrocarbons, aromatic hydrocarbons and some Sulphur present, the high volatile matter of coal is an indication of low ranked coal while low volatile matter content in a coal is more typical of higher-rank coal (Speight, 2013). In coal, the carbon found remaining after which volatile materials are driven off is known as fixed carbon content of coal. Fixed carbon is determined by subtracting the mass of volatiles material from the original mass of the coal sample, it helps in estimating the quantity of coke that will be produced from a coal sample. The fixed carbon contents are different from carbon content determined from ultimate analysis, because some carbon is evolved in hydrocarbons with the volatiles. The fixed carbon content of coals, excluding the ash and moisture, ranges from 50 % to about 98 % (Rasheed et al., 2015). However, the value of carbon content of coal determines the fixed carbon value of coal, in this research work, the fixed carbon of this lignite coal used is found to be about 81.30 % from the proximate analysis carried out (Table 2). Heating Value indicates the extent of heat content of coal this lignite coal is good for heating and power generation.

Table 3 shows the comparisons between this work and other reported work in literature. The present work has high carbon and hydrogen content as compared with the previous work, the more the carbon content, the better the quality of coal. Meanwhile, the previous work has high oxygen and nitrogen content as compared with the present work.

**Table 3:** Comparative Ultimate Analyses between this and previous work

| | A | B | C | D |
|---|---|---|---|---|
| **Parameters** | **Values (%)** | **Values (%)** | **Values (%)** | **Values (%)** |
| Carbon | 90.00 | 70.42 | 68.24 | 60.21 |
| Hydrogen | 8.38 | 5.42 | 6.48 | 5.89 |
| Sulphur | 0.79 | 0.88 | 0.97 | 0.58 |
| Oxygen | 0.67 | 10.48 | 10.43 | 9.46 |
| Nitrogen | 0.16 | 1.09 | 1.67 | 1.07 |

A (present study); B, C and D-(Idris and Ahmed., 2019)

**Table 4:** Comparative Proximate Analysis between this and previous works

| | A | B |
|---|---|---|
| **Parameters** | **Values (%)** | **Values (%)** |
| Moisture Content | 1.45 | 12.78 |
| Ash Content | 1.78 | 19.83 |
| Volatile Matter | 15.84 | 41.24 |
| Fixed Carbon | 81.30 | 26.15 |
| HHV | 16.113 MJ/kg | 16.02 MJ/kg |

A (present study) and B-(Mehran *et al.,* 2015).

Table 4 shows the comparisons between this work and other reported work in literature. However, the HHV were similar, the previous work has high volatile matter, ash content and moisture content as compared with the present work.

**Thermogravimetric Analyses**

The decomposition curves of TG and DTA of the locally sourced lignite coal from Ogwashi Azagba in nitrogen atmosphere determined at the heating rates of 10.00 oC /min are shown in Figures 1 and 2, respectively. The TG curve indicates the percentage weight loss of a coal sample at the temperature range from 27.00 oC to 950 oC. The rate at which weight is loss depends on temperature: the more the temperature, the more the weight is loss because, pyrolysis process proceeds slowly at lower temperatures. There were three stages involved in TG curve shown in Figure 1, the first stage characterized by weight loss at the temperature range (27–266) oC was ascribed to the loss of moisture or water vapor. The second stage characterized by weight loss at the temperature range (266-580) oC was typically ascribed to the loss of volatile matter or devolatilization process. The last stage characterized the degradation from temperature range (580-820) oC was attributed to the slow process of coke formation.

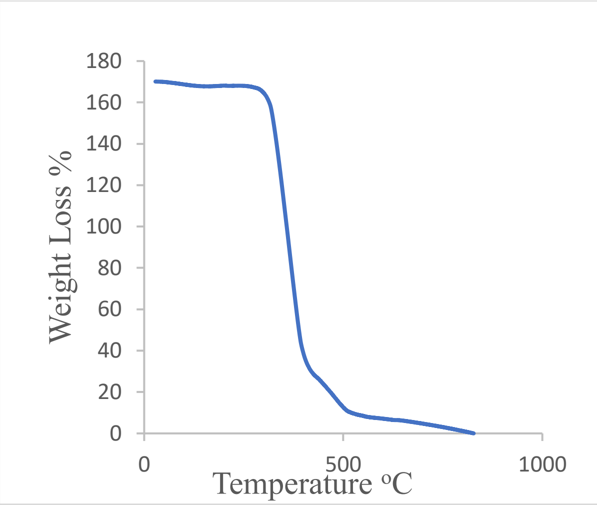


**Figure 1:** TGA properties of Lignite Coal

The DTA curve of sample at the heating rates of 10.00 °C /min is shown in Figure 2.

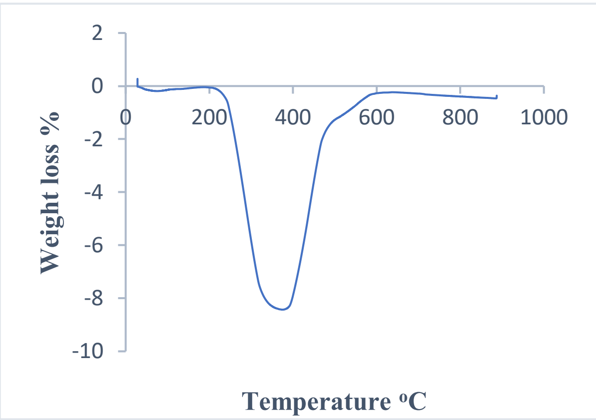


**Figure 2:** DTA properties of Lignite Coal

This DTA curve display two peaks which described evaporation of moisture and primary breakdown, and secondary breakdown. The small peak represents the evaporation of moisture content which take place at temperature between 30-183.92 oC. The second peak occurred at the temperature between 183.92 - 576.02 oC indicating devolatilization process in this coal sample which involved the liberation of volatile matter content and thermal breakdown of some covalent bond like ether bonds and methylene group which will produce gases like hydrogen, carbon monoxide, and lighter hydrocarbons. This region is the most important region to investigate since the main weight loss and complicated chemical reaction, like release of tar and gaseous products and semi coke formation, take place in this temperature range (Aboyade et al., 2013). The peak temperature (TP) from Figure 2 is 379.88 oC which is the main important point on the DTA curve. In addition, the peak temperature represents where the rate of weight loss is at a maximum. This parameter is used in the assessment of combustibility (Mehran et al., 2015).

## 4 CONCLUSION

The physicochemical analyses carried out shows high carbon content of the locally sourced lignite coal. The carbon content and HHV indicate its use in generation of electricity, iron and steel making, cement production and raw material for chemicals. This analysis also shows that the coal sample possess relatively low sulphur, oxygen and nitrogen contents which is an indication of environmental friendliness of coal relative to potential NOx and SOx pollutant emissions. However, the locally sourced lignite coal sample is easy to process, it burns slowly and does not burn with long smoky fire because of its low percentage of a combination of short and long chain hydrocarbons, aromatic hydrocarbons and some sulphur present.

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