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Physical and Plastic Properties of Three Nigerian Coals

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ABSTRACT

The present global concern for new sources of energy has kindled a renewed interest in coal. In the option for maximizing the use of low grade coals in the production of metallurgical grade coke and various coal conversion processes, the qualities of three Nigerian coal samples, Onyeama, Garin Maiganga and Lafia-Obi, were assessed for their potential utilization in a blast furnace. Several parameters that determine coke ability, such as moisture content, ash content, volatile matter, apparent specific gravity, porosity, X-ray fluorescence and fluidity were investigated. Results obtained revealed that the moisture content of Onyeama, Lafia-Obi and Garin Maiganga coal are 3.03, 2.93 and 6.35%, respectively with corresponding ash content of the semi-coke as 25.10, 28.54 and 42.01% in that order. x-ray fluorescence revealed high mineral matter content with highest concentration of copper and lead (10400 and 32500 ppm) for Onyeama, iron and silicon (40830 and 48500 ppm) for Lafia-Obi while Garin Maiganga had iron and silicon in the order of 60900 and 44800 ppm, respectively. Apparent porosity shows that Onyeama has a value of 63.07% while Lafia-Obi and Garin Maiganga have values of 57.78 and 27.27%, respectively. These results show that the coal samples are suitable for use in low shaft furnace for pig iron production.

Key words: Coal, metallurgical coke, blast furnace, iron ore, Nigeria

INTRODUCTION

The Nation's oil crisis is quite foreseeable and there are warnings about the "evil days" when the bonanza from oil would be no more (NCC, 1988; Ikoku, 1984). Nigeria is blessed with a large coal deposit but most of them non coking (Jauro *et al*., 2008). If our indigenous coal deposits can be explored and exploited, Nigerian economy can be diversified, leading to a smooth industrial and technological transformation from the present petroleum based economy (Afonja, 1996). Coal can be converted into liquid fuel in the process of low-temperature carbonization (Hook and Aleklett, 2010; Chen and Ma, 2002). Rank and types of coal are fundamental factors that determine suitability of coal for applications like coking, liquefaction etc. (U.S. Energy Information Administration, 2008; Obaje, 1997). Coal liquification is one of the basic technologies that limit escalation of crude oil and mitigate the effect of energy shortage (Chen and Ma, 2002). Coking coals are coals that when heated, softens, fuses and re-solidifies to form a porous carbon rich material called coke (Obaje, 1997). Coking properties are dependent upon the porous structure of coal (Sato *et al*., 1998). These improves as maximum fluidity and swelling number increases (Coal Utilization Research Unit, 1987). Metallurgical coke of relative size is employed globally in blast furnaces for the reduction of iron ore to iron. It acts as a reducing agent, reducing the iron ore to its elemental form.

This study investigates the apparent porosity, apparent specific gravity, proximate analysis, fluidity and X-ray fluorescence of three Nigerian coals obtained from Onyeama (Enugu State), Garin Maiganga (Gombe State) and Lafia-Obi (Nasarawa State) in order to ascertain the potential performances of the coal in a blast furnace.

MATERIALS AND METHODS

Research duration: This research was carried out at the Chemistry programme laboratory, Abubakar Tafawa Belewa University Bauchi from 2007-2009.

Collection and preparation of materials: Lafia-Obi and Onyeama coal samples were collected from the National Metallurgical Development Centre, Jos. while sample from Garin Maiganga was collected from the mine site around Gombe, Gombe State. Samples collected were kept in an airtight polyethylene bags prior to analyses. The coal samples were air dried, pulverized and sieved to pass 200 mm sieve size. All analytical determinations were done according to ASTM (1987) standards methods.

Determination of moisture ash and volatile matter in samples:

- **Determination of moisture content:** Exactly 1.0 g of the powdered sample of each coal was placed in separate pre-weighed silica crucibles and subjected to a temperature of 105-110°C for 1 h in the absence of air, until a constant weight was attained
- **Ash content:** Exactly 1.0 g each of pulverized samples were weighed into three separate platinum crucibles and subjected to a temperature of 825°C in a muffle furnace for about 4 h until a constant weight was attained
- **Volatile matter:** One gram of powdered sample of each coal was weighed and covered in a 10 mL platinum crucible. The sample was subjected to a temperature of 925°C in a muffle furnace for 7 min

X-ray fluorescence of samples: Twenty gram of powdered sample of each coal was weighed and dried at 105°C for 1 h in an oven and then cooled. It was intimately mixed with organic binder at a ratio of 5:1 g and then pelletized at pressure of 10 metric tones in a pelletizing machine. The palletized samples were stored in desiccators for analysis.

Determination of porosity: About 1.5×1.5 cm^2 of cut samples of semi-coke were dried in an oven at 110°C to constant weight, it was rapidly transferred into vessel of boiling water with specimen immersed in the boiling water and boiling continued for 10 min. Heating was discontinued and the hot water was displaced by a continuous replacement with cold water for about 30 min. The weight of specimen suspended in cold water was recorded. It was then removed from water and its weight, when suspended in air was also recorded. The process was repeated three times for each sample and mean values recorded.

Determination of apparent density: Fifteen gram of each powdered sample dried at 110°C was introduced into density bottle and the weight, W_2 of the sample with bottle recorded. The weight, W_1, of empty density bottle was earlier recorded. Then 30 cm^3 of water was introduced into the bottle by means of pipette to eliminate splashing till bottle was filled with water. Total weight of bottle, sample and water, W_3 and that of bottle filled with water alone W_4 was taken. The process was repeated three times for each sample and their mean values recorded (ASTM, 1992).

Low temperature carbonization (LTC) of coal: Exactly 27.5 kg weight of each coal sample (about 50 mm sized, coal) was taken in a rectangular mild steel retort. The retort was sealed with gas outlet at the top walls in the oven. Electrical heating element was provided in both the top walls on the front and rear walls. When the oven walls attain 100°C the retort was introduced into the oven and carbonization was carried out at 650°C for LTC carbonization. When the gas evolution tapered off, the retort was taken out, cooled, cut open and the resultant coke from each sample tested.

Determination of plasticity of samples: Exactly 5 g of each powdered sample was weighed into a metal crucible equipped with a motorized stirrer. Each sample was stirred as it was heated at a rate of 1°C min^{-1} to a final temperature of 300°C. Stirring force required as phase changes was recorded by the rate of stirrer's rotation.

RESULTS AND DISCUSSION

Table 1 shows the results of proximate analysis and plasticity (fluidity) obtained from coal samples while Table 2 shows the results of proximate analysis, apparent specific gravity and porosity of semi-coke from coal samples. Lafia-Obi has the lowest moisture content of 2.90% followed

Table 1: Proximate analysis and plasticity of some Nigerian coals

	Sample identity		
Parameter	Onyeama	Lafia-Obi	Maiganga
Moisture content (wt.%)	3.03	2.93	6.35
Ash (%dB)	13.38	21.04	32.05
Volatile matter (%dB)	34.97	22.25	37.05
Fixed carbon	48.62	53.78	24.55
Fluidity (ddpm)	0.0012	9.00	0.00

ddpm: Dials division per min

Table 2: Proximate analysis, apparent specific gravity and apparent porosity of semi-coke from coal samples

	Sample identity		
Parameters	Onyeama	Lafia-Obi	Maiganga
Moisture (%)	1.8	1.35	3.0
Ash (%)	25.10	28.54	42.01
Volatile matter (%dB)	3.71	2.42	5.21
APG (%)	32.05	38.69	51.29
Porosity (%)	63.07	57.78	27.27

APG: Apparent specific gravity

by Onyeama with a value of 3.03% and Garin Maiganga with the highest value of 6.35%. High moisture content would result in a decreased plant capacity and an increase in operating costs (Jauro *et al.*, 2008) with consequent decrease in the calorific value and the concentration of other constituents (IEA/OECD, 2002). The moisture content required for good coking coal is 1.5% (Obaje, 1997). However, the Central Fuel Research Institute, India (CFRI) stipulated a range of 1-4% moisture for semi-coke used in low shaft furnace. Therefore, the values recorded in these coals are within the stipulated range except for Garin Maiganga (Gombe) with slight difference. Low temperature carbonization of the samples gave semi-coke with 1.8, 1.4 and 3.0% moisture for Onyeama, Lafia-Obi and Maiganga, respectively.

The lowest ash content of 13.38% was observed in Onyeama coal, followed by Lafia-Obi with a value of 21.04%. Garin Maiganga has the highest ash content of 32.05%. 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). Ash reduces plasticity and determines the behavior of slag and fouling in combustion chamber (ASTM, 1987). An ash content of less then 10% is recommended for good coking coals (Akpabio *et al.*, 2008; Averitt, 1974). The ash content of Onyeama, Lafia-Obi and Garin Maiganga semi-coke are 25.1, 28.54 and 42.01%, respectively (Table 2). Industrial experience indicates that a 1% weight increase of ash in the coke reduces metal production by 2 or 3% weight (Diez *et al.*, 2002). Lafia-Obi coal has the lowest volatile matter of 22.25%, followed by Onyeama Sample with values of 34.97% and Garin Maiganga (Gombe) with 37.05% while percentage volatile matter for semi-cokes are 3.71% for Onyeama, 2.42% for Lafia-Obi and 5.21% for Garin Maiganga. High volatile non-coking or weakly coking coals are known to have volatile matter content of 36% and above (Li and Fan, 2008). 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). The results are in consonance with the reports of (Okolo, 1988) who observed that Nigerian coals have high volatile matter and as such are potential sources of energy and feedstock for the chemical and allied industries. The fixed carbon content of the coal samples revealed that Lafia-Obi sample has the highest carbon content of 53.81%, followed by Onyeama coal with 48.62% and Garin Maiganga coal with 24.55%. The fixed carbon content determines the coke yield of coal samples (Diez *et al.*, 2002; Schobert, 1987).

The apparent specific gravity and porosity of 32.05 and 63.07% was observed for coke from Onyeama, 38.69 and 57.78% for coke from Lafia-Obi while 51.29 and 27.27% was observed for coke from Garin Maiganga (Table 2). This show that porosity increases as apparent specific gravity decreases. The presence of mineral matter in coal closes pore spaces and affects the specific gravity (Ward, 1984). Also the specific gravity of the organic phase of coal is partly dependent upon its porosity (Mahajan and Walker, 1978) and coking properties are governed by the porous structure (Sato *et al.*, 1998; Oshinowo and Ofi, 1987).

The results presented in Table 1 also show the fluidity of the three coal sample. Garin Maiganga coal gave a zero dial division per min (ddpm) while Onyeama coal sample gave a maximum fluidity of 0.0012 ddpm and Lafia-Obi gave the highest rotation and maximum fluidity of 9 ddpm. However, the fluidity of Onyeama and Lafia-Obi coals are insignificant compared to the required minimum value of 60 dial division per minute and thus characterizes non-coking behavior (Jauro *et al.*, 2008). But if a single coal is to be used in coke manufacture, an intermediate value for this parameter is probably desirable (Oshinowo and Ofi, 1987; Laditan, 1988).

Table 3: Distribution of some elements in Onyeama, Lafia-Obi and Garin Maiganga coal samples expressed in part per million (ppm)

Element	Onyeama	Lafia-Obi	Maiganga
Al	8470	24300	31553
Si	18666	48500	44800
K	6638	13525	2572
Ca	9142	8571	24785
Ti	10260	9720	13500
Cr	1437	479	616
Mn	3950	232	2634
Fe	14140	46830	60900
Ni	1416	393	472
Cu	10400	720	1760
Zn	1340	1288	1123
Mg	900	960	780
Na	742	371	1113
As	2273	Nil	Nil
Zr	3625	296	814
Sn	27031	Nil	Nil
Pb	32580	Nil	Nil

Table 3 show the results of the X-ray fluorescence analysis of Onyeama, Lafia-Obi and Garin Maiganga coal samples. The results revealed large amounts of inorganic, heavy metals and rare-earth metals. The lowest iron content of 14140 ppm was observed in Onyeama sample, followed by Lafia-Obi with values of 46830 and 60900 ppm recorded for Maiganga.

However, Onyeama coal contain such elements as arsenic 227, tin 27031, tungsten 12372 and lead 32580 ppm which are absent in both Lafia-Obi and Garin Maiganga coal samples. The release of some of these elements in to the environment poses serious environmental problem (Skodras *et al.*, 2002). Also the degree of fouling is determined by the amount and composition of mineral matter in Coal (Barriocanal *et al.*, 1998; Paulson *et al.*, 1972). The presence of some of these minerals around Lafia-Obi-belt however, is a good pointer to the numerous mining activities around Lafia belt (Afonja, 1996). It should be noted that high mineral matter in coal is detrimental because mineral matter reduces coal plasticity (Afonja, 1996). However, it can be reduced to acceptable level through proper preparation of coal before utilization (Adeleke and Onumanyi, 2007).

CONCLUSION

The studies conducted reveal that Lafia-Obi coal has the lowest moisture content, volatile matter and highest fixed carbon content, followed by Onyeama and then Maiganga. The volatile matter in coal samples from Lafia-Obi lies in the medium-volatile bituminous rank while Onyeama and Garin Maiganga are classed as high-volatile bituminous. Their porosity increases as the density decrease with Onyeama having the highest porosity and Garin Maiganga lowest. The composition of ash and the X-ray fluorescence show that the coals from Onyeama and Lafia-Obi can be considered suitable for use in low shaft furnace for pig Iron production while Garin Maiganga could be used only after some treatment.

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