Characterization of Omelewu Coal as a Blending Stock with Naturally Occurring Bitumen (Ondo Bitumen) for Coke Production and Electricity Generation

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Abstract
To achieve high productivity, the blast furnace requires high quality coke. The coking properties of coke are directly related to coke rate. The higher coking properties, the lower the cost per tone of hot metal (pig iron). The quality of coal also determines its use for electricity generation. Analysis of available data on Nigerian coals indicates that, non is coking. In order to enhance its (Omelewu coal) properties, effect of locally available bitumen (Ondo bitumen) was investigated. Proximate analysis, Density value, Free swelling index, Gray king coke value, Dilatometry value, Calorific value, Shatter and Abradability tests were carried out on the coal sample and on the blend ratios in various percentages of the coal and the bitumen. The blend ratio of 70 - 30 % of Omelewu coal and Ondo bitumen blend show some significant improvement on the cokability of the coal and for use in electricity generation. The test confirms a reduction of high ash content of omelewu coal from 11.3% to 8.788 %, Free swelling index from ½ to 3, Gray king coke value from B to F, 17.931 M/KG calorific value to 21.700 M/KG, Dilatometry value of +23, Shatter and Abradability test of 50 % and 30% respectively, fixed carbon, volatile matter and moisture content within the acceptable range for blast furnace coke and for electricity generation for 70-30 % blend ratio of Omelewu coal and Ondo bitumen. From the research, a ratio of 70- 30 % of omelewu coal and Ondo bitumen of 250 um sieves showed that the coking properties and electricity generation properties were significantly enhanced. Based on the results of tests carried out, it was shown that the coal is of medium ash coal and suitable for pulverized coal combustion when its calorific value, ash content and moisture content were compared with the coal used for the Genessee Phase 3 power station in Canada. and is recommended for use in blast furnace coke production and for use in coal powering plant for electricity generation

Keyword: Coking properties, Omelewu coal, Ondo bitumen, Electricity generation, Coke

Introduction

The importance of coal in the energy mix of Nigeria and the entire world cannot be underestimated (Nasirudeen & Jaurro,2011). Access to energy is a driving force for economic and social development. Energy is a key factor in industrial development and in providing vital services that improve the quality of life (Sambo et al, 2009). Dependency on iron and steel for military might, technological and infrastructural development requires a viable source of energy. In the blast furnace process, high quality coke (a grayish solid fuel obtained from carbonization of coking coal) is required as a source of energy, reducing agent and a support material for furnace burden (David,2008).

Metallurgical coke is produced by heating coking coal in the absence of air, leaving a porous mass, which is very reactive at high temperature (David, 2008). Coking coal is required for coke and can serve the blast furnace of Ajoakuta Steel Company in Nigeria. But most of Nigerian coals are non-coking (Obaje,2009). As part of the Nigerian government economic reform, the Federal Ministry of Solid Minerals Development was established and coal was listed as one of the priority materials, targeted for exploration and exploitation for export and domestic consumption. Coal can transform into coke only if it softens to a plastic mass on carbonization, followed by decomposition, swelling and evolution of gas and finally solidification while gas is still being evolved (Nasirudeen & Jauro, 2011).

Not all coals will form coke and not all coking coals will give the same firm, cellular mass characteristics of metallurgical coke. Any increase in ash and Sulphur content of metallurgical coke affects pig iron production and its economies. High volatile, ash and Sulphur contents in coke in blast furnace operations result in increased slag volume, decreased productivity and difficulty in furnace control. On the other hand, electricity has been regarded as the engine of economic progress. Limited access to energy is a serious constraint to development in the developing world, where the per capital use of energy is less than one sixth that of the industrialized world (IAEA, 2015).

Nigeria is faced with acute electricity supply problems, which is hindering its development notwithstanding the availability of vast natural resources in the country (Sambo et al., 2009). There are currently 23 grid-connected generating plants in operation in the Nigerian Electricity Supply Industry (NESI) with a total installed capacity of 11,396.0 MW and available capacity of 6,056 MW. Most generation is thermal based, with an installed capacity of 8,457.6 MW (81% of the total) and an available capacity of 4,996 MW (48% of the total). Hydropower from three major plants accounts for 1,938.4 MW of total installed capacity and an available capacity of 1,060 MW (KPMG Nigeria, 2013). Total power generation at present stands at 3,385.9 MW as displayed on the website of the Federal Ministry of Power (http://www.power.gov.ng).

The Nigerian government, in a bid to fix this problem, has developed a roadmap for power sector reform in Nigeria. Some parts of the roadmap read as follows (The Presidency, Federal Republic of Nigeria, 2012): “In view of the high capital costs and long lead times required to develop commercial power generation through solar, wind, nuclear and biomass, the Federal Government is committing to focus on electricity generation in three areas, namely: Hydro, Coal and Natural Gas, of which the latter represents the largest resource for fuel-to-power. Nigeria will largely rely on hydro, coal and natural gas for generation of much of its power over the next decade".

From the foregoing, it is apparent that coal will play a significant role in the effort to achieve the much-needed improvement in electricity generation in Nigeria. Coal accounts for 41% of the world's energy source for electricity generation. This is distantly followed by gas (21%), hydro (16%), nuclear (13%), oil (5%) and other renewables (3%). Coal is the key fuel for generating electricity on almost all continents, with almost all developed and developing countries relying on coal for the stable and secure supply of electricity (World Coal Association, 2012). Therefore, full characterization of Omelewu coal and blending with naturally occurring bitumen (Ondo – bitumen) for electricity generation is therefore imperative.

Most research work on Nigerian coals is focused on their usefulness in the metallurgical industry. The few research work carried out on Nigerian coals as regards power generation have not comprehensively characterized Nigerian coals based on the contemporary requirements of power plant designers and operators. Also, Omelewu coal a newly discovered coal deposit with an area of 1,132km^2, (Wikipedia, 2016), located at Agaliga in Omelewu district of Olamaboro Local Government Area of Kogi State has not been used as a blending component with any coal for coke production and power generation.

Contemporary tests required for a comprehensive characterization of the coals for coke production and for power generation such as proximate analysis, ultimate analysis, Gray king coke type, free swelling index test, dilatometry value, caking power of coal, thermogravimetric analysis, petrographic analysis and drop tube furnace tests have not yet been carried out on Omelewu coal it is in the forgoing that this research is imperative.

Aim and Objectives

The aim of this research is to characterize Omelewu coal deposits in Nigeria thereby enriching the repository of existing data on properties of Nigerian coals and making a strong case for the utilization of the coal by blending with naturally occurring bitumen (Ondo bitumen) for metallurgical coke production and electricity generation.

The specific objectives of the research are:

(i) To upgrade the physical and chemical characteristics of Omelewu coal to meet the required standard for metallurgical coke production and electricity generation.

(ii) To investigate the effect of Ondo bitumen addition on the coking properties of Omelewu coal

(iii) To carry out proximate, ultimate and ash composition analyses of the coal

Samples and the various percentage blends

(iv) To determine the calorific value of the coal samples and the various percentage blends

(v) To compare results of the above analyses with reference values of coal properties for coke

Production and electricity generation.

Omelewu coal is located between 7°11'N, 7°34' E and 7°18.3'N and 7° 56.7'E in the north central region of Nigeria, bordering Enugu State and Benue State with an area of 1,132km^2, (Wikipedia, 2016). Omelewu Coal mine site is located at Agaliga, Imane town in Olamaboro Local Government Area of Kogi State (Obaje, 2012). The coking properties of coke are directly related to coke rate. The higher the coking properties, the lower the cost per tone of hot metal (pig iron) produced. The quality of the coal used affects most of the costs associated with blast furnace productivity and with coal-fired power plants. Proper evaluation of the coking properties and combustion performance of the coal to ensure optimum utilization and minimum costs is therefore essential. This research will help determine the suitability of using Omelewu coal (Nigerian coals) and Ondo bitumen for use in metallurgical coke production and for use in coal-fired power plants, not only in Nigeria, but as an export commodity to other coal-consuming countries around the world.

This will assist the potential investor in Nigerians' Steel and power sector to make a decision on areas of coals performance that may be suspect, requiring further investigation by a larger-scale form of testing (pilot-scale simulation or full-scale testing) and also serve as a justification for investment in such a larger-scale testing. The significance of this research is further underscored by the present dependence of Nigeria on natural gas- and hydro-powered electricity. The unreliability of natural gas supply due to frequent disagreement over appropriate pricing and pipeline vandalism and the susceptibility of hydro-electric power to weather has made the inclusion of coal-fired electricity plant into Nigerian's electricity generation mix imperative. According to Green Peace International submit (http://www.greenpeace.org). The argument for nuclear power has been punctured by recent safety concerns arising from the Fukushima nuclear disaster. With world industrial giants such as the United States of America, Peoples Republic of China, Germany, Australia, India and South Africa among countries heavily dependent on coal for electricity generation, Nigeria cannot exclude itself from benefitting from this resource which it has been richly endowed with.

The utilization of Omelewu coal and Ondo bitumen by steel industries and the power sector will promote development of industries through effective supply of products to priority sector such as mining, engineering, energy, chemical, construction, transportation, communication, agriculture and agro- allied industries. It will also diversity the source of income for the nation's economy, conserve scarce foreign earnings, create employment opportunities as well as encourage development of appropriate indigenous technology.

Literature Review

Previous Research on Nigerian Coals

In the past five and a half decades, there have been researches on the characteristics of Nigeria coals. The study of the chemical and physical properties of Nigerian coals was made by Powell Duffrym technical service limited between 1947 and 1951, The obtained result was intangible and therefore further investigation was called for (Deseward & Casey, 1983). Isah (1991) carried out proximate and ultimate analysis on Enugu, Lafia and Okaba coals to determine the percentage of ash and total Sulphur. The Eschka method was used to determine the total Sulphur present. The analysis showed that Lafia coals have high ash and Sulphur contents, while Enugu coals have low ash and Sulphur contents. Others coking test were not investigated.

Suleiman (1992), analyzed the moisture content and volatile matter of some Nigerian coals. The results obtained showed that the three coal samples (Enugu, Lafia & Okaba) collected have low moisture contents, and only the Lafia coal has low volatile matter, thus satisfying the metallurgical requirement for the production of coke, but other parameters were not determined. In a research, Oyedeji (1994), Lafia coal was blended with Australian coal at different percentages of imported/ local coal; a recommendation of 60-40% was made. Based on the result of the analysis, the ash content was too high and thus falls short of the specification of the blast finance coke. Although the Sulphur content was reduced to the recommended percentage of the blast furnace specification.

In an analysis by the Steel Development Department through some foreign consultants on the ultimate and proximate analysis of Nigerian coals, a recommendation of blending ratio of 3% and 4% to 97% and 96% local – imported coal was made for Ajaokuta Steel Company. The recommendation was economically not suitable for a developing nation like Nigeria because of the huge cost of import duties (Damisa, 2001). Analysis of the blend of imported Agro – allied coal and Lafia coal done by Tyoden, (1997) gave a recommendation of 70-30% local coal but real coking properties were not achieved. At laboratory scale, National metallurgical Development Centre, Jos took a giant step forward in producing a coking blend from Nigeria coals employing the foreign Gually Eagles prime coking coal for maximum ash content of 10% specification for metallurgical coke, only 13% local (Lafia), and 28% (Enugu) coal could go into the blend with the prime coking coal (Eagle Gually). A ratio of this sort is not economically good considering the heavy charges placed on import duties (David, 2008).

The software developed for the optimization of Nigerian coal blends for making coke used in the blast furnace process by Damisa, (2001), was on-line one. The results of the input of the program in Fortran 77 environment shows that, 20% of the blend of Nigerian coals could be blended with 70% of foreign coal (prime coking coal). A ratio of this sort is not economically good considering the charges on importation. Olaleye (2003), investigated some Nigerian coals and showed that the relatively low ash and moisture contents, low Sulphur content and medium to high calorific value, make Nigerian coals compare favorably with other sub-bituminous coals in coal-producing countries of the world, thereby making them a good export commodity. They are superior as regards ease of ignition, combustion characteristics and freedom from clinker. The coals burn with a long flame and require large combustion space. They are acceptable boiler fuels if used in suitable appliances such as chain grate stokes or as pulverized fuel

Laudan (2008) analyzed coal samples from Enugu State (Okpara West Area, Okpara West Bank and Onyeama) and Gombe State (Doho & Gamawa) to determine their physical properties and to classify them by rank using proximate analysis. Auto-ignition temperatures, reactivity and activation energies of the various coal samples were also determined. Findings revealed that the reactivity and activation energies of the various coal samples depend on the coal type, source and particle size. Jauro and Chukwu (2011) investigated three Nigerian coals (Onyeama, Lafia-Obi, and Gairin, Maiganga) to determine their suitability in developing formed coke for use as blast furnace process. Parameters that were used included the shatter index, expressed as percentage stability, friability and mecum index. The highest cumulative percentage stability and the lowest cumulative percentage friability were observed in Lafia-Obi with values of 67.54% and 32.46%, followed by Onyeama with 66.92% and 33.08% and then Garin Maiganga with 55.04% and 44.96% respectively. Medium and low temperature carbonization of Onyeama and Lafia-Obi coal samples gave an improved and satisfactory percentage stability and friability for semi-cokes.

Kibiya (2012) collected and analyzed five (5) coal samples from Lafia-Obi (Nasarawa State), Okaba (Kogi State), Lamja (Adamawa State), Okpara and Onyeama (Enugu State) to determine their properties and classify them by rank using proximate analysis. Auto-ignition temperatures, reactivity and activation energies of the various coal samples were also determined. Results obtained showed that Lafia-Obi coal could be ranked the highest as bituminous (low volatile) coal. Okpara and Onyeama coals both were both bituminous A coals, while Okaba coal was found to be sub-bituminous B coal. Lamja coal was found to be a lignite A coal. The study concluded that Lafia-Obi, Okpara and Onyeama coals may be used for power generation if improvement treatment is given to the coals. Lamja and Okaba coals were not recommended for power generation because of their low calorific values. In a research, David (2008) blended Lafia coal with Naturally occurring bitumen (Ondo bitumen), the ash content was little higher in percentage of the blast furnace specification, although the Sulphur content was reduced to the recommended percentage of the blast furnace recommendation, thus real coking properties were not achieved.

All these deficiencies open way for further researches on the possible way of upgrading the coking and energy generation properties of Nigerian coals.

Coal and its Formation

According to David (2008), coal consists of complex mixture of organic chemical substance with small amount of nitrogen and Sulphur. The organic materials are derived mainly from plants remains, which have undergone various degree of decomposition, physical and chemical alteration after burial in peat and swamp (David, 2008) Coal is a solid, brittle, combustible, carbonaceous rock formed by the decomposition and alteration of vegetation by compaction, temperature and pressure. It varies in colour from brown to black and is usually stratified (Speight, 2005).

Coal can be defined as a chemically and physically heterogeneous combustible, sedimentary rock consisting of both organic and inorganic material. (Afu etal, 2018). Coal consists primarily of carbon, hydrogen and oxygen with lesser amount of Sulphur and nitrogen. Coal is considered the cheapest and most widely abundant fossil fuel in the world (Ye et al, 2013). Inorganically coal consists of a diverse range of ash –forming compounds distributed throughout the coal (Miller, 2005). Coal is not one material but many, and it did not form all by itself but in the presence of a great many other geometrical, mechanical, thermal and chemical processes (David, 2008).
According to Chung and Geer (2005), coal formation may have been influence by bacteria, temperature, time and pressure.

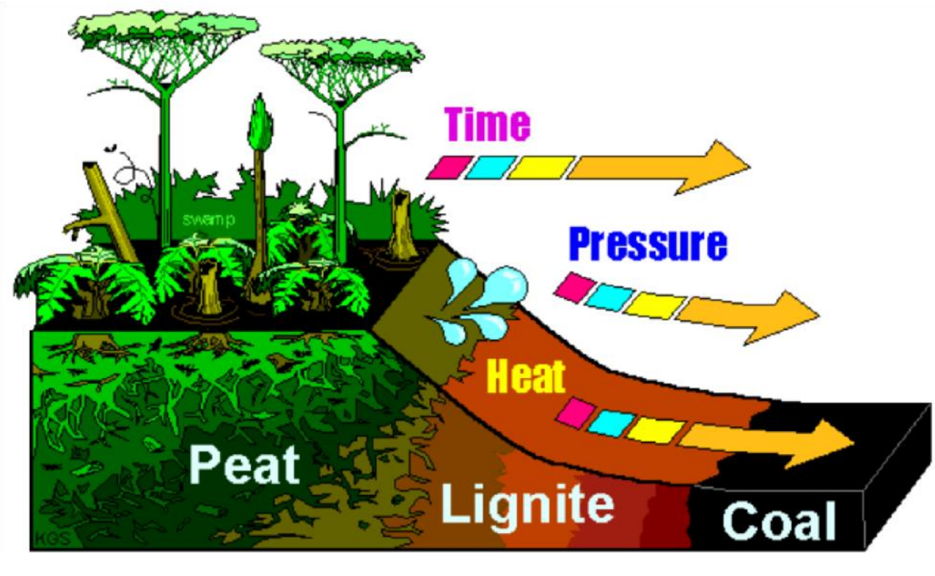

Figure 1: The Formation of Coal (Brian & Marty, 2008)

Rank of Coal

Coals are classified according to RANK, TYPE and GRADE. Brian & Marty (2008) concluded that the degree of 'metamorphism' or coalification undergone by a coal, as it matures from peat to anthracite, has an important bearing on its physical and chemical properties, and is referred to as the 'rank' of the coal.

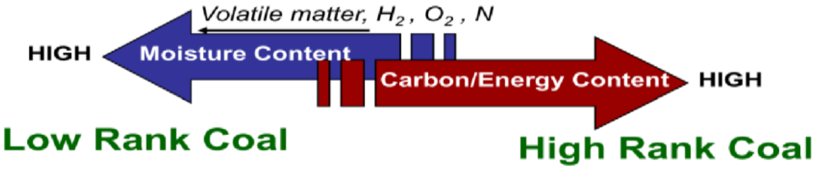

Figure 2: Coal Ranking (Brian & Marty, 2008)

The stages of carbonization reached by a coal determine the rank of the coal. Rank of a coal can therefore be defined as the degree of its alteration, starting from the decomposition of materials to the formation of solid blocks. Determination of rank of coal is based upon chemical composition and proximity value for mineral matter free coal (Afonga, 1991, & Damisa, 2001).

According to Brian and Marty (2008), Coals are classified according to Rank, Type and Grade. Brian & Marty (2008) concluded that the degree of 'metamorphism' or coalification undergone by a coal, as it matures from peat to anthracite, has an important bearing on its physical and chemical properties, and is referred to as the 'rank' of the coal. The rank of coal is its degree of maturation and is an indication of the extent of metamorphism the coal has undergone. Rank is also a measure of carbon content as the percentage of fixed carbon increases with the extent of metamorphism. Lignite and sub-bituminous coals are referred to as being low in rank, while bituminous coals and anthracites are classified as high-rank coals. The heating value of coals increases with increasing rank but begins to decrease in higher rank coals due to significant increase in volatile matter (Brian & Marty, 2008).

The American Standard for Testing and Materials (ASTM) classification system (ASTM D388) is very important in the coal industry. The ASTM D388 distinguishes among four coal classes, each of which is subdivided into several groups shown in Table 1 (Miller, 2005).

Table 1: ASTM Coal Classification By Rank (ASTM D388)

Class/Group	Fixed Carbon (%)	Volatile Matter(%)	Heating Value (Btu /Ib)
Anthracite			
Meta Anthracite	>98	< 2	-
Semi Anthracite	92-98	2-8	-
Bituminous			
Low – volatile	78- 86	14	-
Medium -volatile	69-78	22	-
High- Volatile A	< 69	22—31	> 14,000
High- Volatile B	-	>31	13,000 - 14,000
High – Volatile C	-	-	10,500 -13,500
Sub- Bituminous			
Sub – bituminous A	-	-	9,500 – 10,500
Sub- bituminous B	-	-	9,500 – 10,500
Sub – bituminous C	-	-	8,300- 9,500
Lignite	-		
Lignite A	-		6300-8300
Lignite B	-		< 6300
Peat	-	-	-

TABLE 2: Countries Using Coal in Electricity Generation

Country	Coal usage for Electricity (%)	Country	Coal usage for Electricity (%)
Botswana	100	Zimbabwe	46
Mongolia	93	USA	45
South Africa	93	Germany	42
Poland	88	United Kingdom	29
PR China	78	Turkey	28
Australia	77	Japan	23
Kazakhstan	75	Netherland	21
India	68	Vietnam	18
Czech Republic	56	Russia	16
Morocco	50	Canada	15
Denmark	49	France	5

(***SOURCE: WORLD COAL ASSOCIATION, 2012)***

Coal resources in Nigeria.

There are five economically important seam of sub – bituminous coal so recognized in Nigeria. And are located in the south and middle belt of the country. Nigeria is blessed with over 2.5 million tons of coal with proved reserved of about 639millon tones out of which about 25millon tones have been mined (David, 2008). Analysis of some Nigerian coal deposit is shown in Table 4

TABLE 3: Proximate Analysis of Some Nigerian Coal

Coal Resources	Proven Reserve (Million tones)	% Moisture	% Volatile matter	% Ash	% Fixed Carbon	% Sulphur	% phosphorus
Enugu	254	6.65	44.56	11.19	53.35	0.75	0.0012
Okaba	323	9.56	42.33	10.12	50.05	0.72	0.0013
Owukpa	132	4.06	40.16	10.35	50.65	0.55	0.0012
Lafia	222	8.99	32.61	17.82	52.65	4.02	0.0081
Omelewu		-	-	-	-	-	-

Source: Nigerian Coal Corporation (2011)

Investigation and test carried out on Nigerian coal revealed some distinct characteristics. Some of the coals examined are Enugu, Okaba, Owukpa and Obi coals (David, 2008).

Enugu Coal

The coal deposit is predominantly sub – bituminous, of medium quality and non – coking. it is friable and susceptible to weathering. The coal cannot produce metallurgical coke of high quality on its own. It has high moisture and volatile matter contents and very high characteristic for low rank coal with high resinous and waxy materials but contains low Sulphur, but is also non agglomerating in character (David, 2008)

Okaba Coal

The coal deposit belongs to the sub- bituminous type of medium quality and non-coking with low Sulphur and ash contents .it reacts to weathering, not easy to grind, non – caking, rich in resinous and waxy materials and gives high yield of tart and oil tar and oil gas of high calorific value .it is self-binding under pressure (Damisa, 2001)

Owukpa Coal

The deposit possesses virtually the same characteristics with Okaba coal, except that it has less moisture content (Damisa, 2001)

Lafia –Obi Coal

This coal proved to be the best because of its coking and caking abilities. its Sulphur and ash content are high, hence limit its use for production of blast furnace coke of acceptable quality. The coal deposit is bituminous in nature, it has the lowest moisture about 1.4%, medium volatile content of about 29.4% and less susceptible to weathering (oxidation process). when heated, it passes through plastic stage and cake or stick together into a mass and as a result does not combust fully and clogs the production system (Chathlety and Akonlolu,2001).

Omelewu Coal

It is located between 7°11'N, 7°34' E and 7°18'3''N and 7° 56'7''E in the southeast region of Nigeria, bordering Enugu State and Benue State with an area of 1,132km^2, (Wikipedia, 2016). Omelewu Coal mine is located at Agaliga, Imane town in Olamaboro Local Government Area in Kogi State.

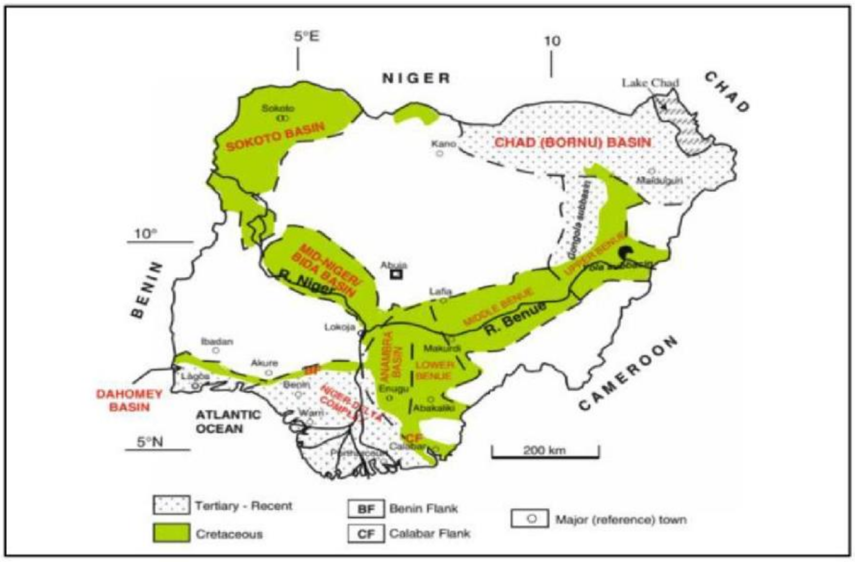

FIGURE 3: Sedimentary Basins of Nigeria (Obaje, 2009).

Bitumen

Bitumen is a generic term defined by American Society for Testing and Material (ASTM) as a class of black or dark colored solid, semi-solid or viscous substances, natural or manufactured, composed principally of high molecular weight hydro- carbon of which asphaltic tars, pitches and asphaltenes are typical. The British standard defined bitumen as a ductile viscous liquid or solid material, black or brown in color having adhesive properties, consisting essentially of hydro-carbons derived from petroleum or occurring in natural asphalts and soluble in carbon disulphides or carbon tetrachloride (BS 892, 1989). According to Anil and Ronald (2000), bitumen is a complex mixture of molecules of predominantly hydro- carbon in nature. The chemical composition of bitumen according to Anil and Ronald (2000) can be further subdivided into:

(i.) asphaltenes (ii) resins (iii) aromatic (iv) saturates

These groups are called "SARA" fractions (Anil and Ronald, 2000). The properties of bitumen are dependent on the properties of these four components and can vary depending on the deposit. Asphalteness are a product or resin development by geological or processing effects. They are the thickening agent of bitumen; Resins are chemically very similar to the asphaltenes. They consist of mainly polycyclic molecules containing saturated aromatic atoms. The aromatic contribute to the ductility of bitumen. The fluidity of bitumen is imparted by saturates and aromatic fraction, which in combination with the asphaltenes produce complex flow behavior (Branthanver etal 2005).

The chemical composition of bitumen maybe controlled by crude source, manufacturing processes or by additive system. This has the effect of improving performance to a desired optimum based on field or performances design (Halleran, 2005). According to Branthanver and Halleran (2005), bitumen contains 83.0-87.0% carbon 10.0-14.0% hydrogen, 0.1-2.0% nitrogen 0.05-15% oxygen 0.05-60% Sulphur and (Ni and V) metal > 1000ppm.

A notable deposit of natural bitumen in Nigeria which has been reported as the second largest in the world is located spanning from Ijebu-ode of Ogun State to Okitipupa of Ondo State to the western margin of Edo/Delta States. The bitumen-bearing zone is about 120km long and 6km wide, and the thickness ranges from 0.5 to over 40m with an average of about 6m (Adegoke etal, 1980). A lot of effort had been made to carry out research work on the Nigerian bitumen of which greater attention was focused on the tar sand deposit of western Nigeria by same groups; Organization and individuals (Owolabi, 1979). The earlier research includes Cousey D.G and Hubbard (1963) in conjunction with Hitch L.S road research laboratory England. Cousey etal (1963) collected four samples of bitumen and investigated its composition and physical properties. Results obtained showed that the material (bitumen) may be suitable for use as a binder.

Recent work which are considered to be the most intensive were carried out by the geological consultancy unit of Obafemi Awolowo University lle – ife and led by professor Adegoke Led group was mainly exploratory and geological in nature while that of Adedimola involved engineering investigation. In Adedimola (2002) investigation were carried out in order to analyze the chemical composition and the engineering properties of Ondo – Bitumen. It was found that, Ondo bitumen contain 85.5% of carbon, 13.14% hydrogen, 0.50% nitrogen 0.80% oxygen and 0.06% Sulphur, & that it can be used as a pavement material.

Characterization of Coal

Characterization of coal is a vital procedure for the production of coke for efficient operation of blast furnace process of pig iron production which is an intermediate material for steel making and also for power plant generation of electricity. Various methods are used for this purpose, e.g. proximate analysis, ultimate analysis coking and caking analysis, petrographic constituent's analysis, reflectance analysis and thermal analysis. These analyses are also used for solving operational problems. There is a wide range of testing and evaluation procedures used to evaluate the performance of coals for pulverized coal combustion and for coke production. These procedures range in scale from:

(i) Standard laboratory analysis.

(ii)Bench-scale testing to simulate some aspect(s) of the coals impact on power plant processes.

(iii) Pilot-scale simulation of power plant.

(iv) Testing in full-scale boilers.

Standard laboratory analyses of coal are often reliable predictors of power plant performance and blast furnace coal quality test. Laboratory data is very valuable as an indicator of areas of the coal performance that may be suspect, requiring investigation by a larger-scale form of testing. It also gives a measure of the variability of the coal's quality over the mine. It is difficult to justify the cost of pilot scale tests on samples that represent every quality. For these reasons, extensive use is made of laboratory analysis as a preliminary predictor (Damisa,2001).

In addition, the standard tests reflect the average composition of the coal. However, coal is a heterogeneous, complex material, during combustion the coal particles, which have varying organic and inorganic (mineral-matter) compositions, can behave in completely different ways. It should be emphasized that a coal (or blend) being evaluated must truly represent the mass of material from which it was taken. (\Damisa.2001).

Research Methodology

Materials and Method

Location of the Coal

The study area is located between 7°11'N, 7°34' E and 7°18'3''N and 7° 56'7''E in the southeast region of Nigeria, bordering Enugu State and Benue State with an area of 1,132km^2, (Wikipedia, 2016). Omelewu Coal mine site is the study location, located in Agaliga, omelewu district of Olamaboro Local Government Area, Kogi State.

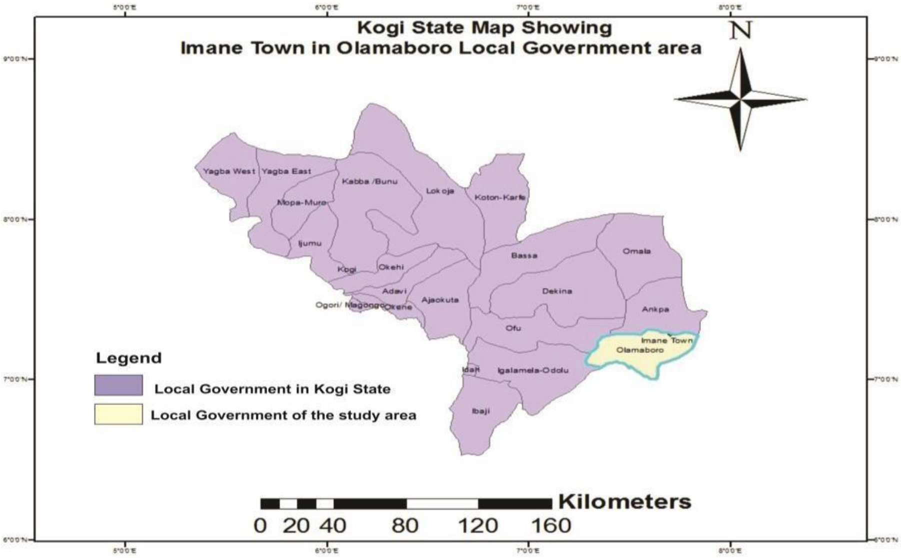

Figure 4: ***Map of Olamaboro Local Government Area in Kogi State.***

Location of the Bitumen

The naturally occurring Bitumen (Ondo Bitumen) **is** located around lamudifa village, north of Agbabu in Odigbo local government area of Ondo State. The samples of bitumen were collected with improvised open drive samplers.

Field Materials/ Equipment: The field materials and equipment used are global positioning system (GPS), polythene bag, paper tape, measuring tape, permanent maker, hammer, digger and chisel. A total of 10 different coal samples were collected from the mine site and were tested in the laboratories.

Sample Collection

The coal samples used for this research work were obtained from the underground mines and outcrop of Omelewu coal. From the underground mines, coal cutting saw was used to obtain the samples by cutting out a full column about 10cm square between roof and floor. A hard anger was employed to obtain samples from the out crop. The coal sample is prepared using both the mechanical and manual methods so as to meet the desired analytical specifications using an array of sample preparation equipment. The samples are assumed as representatives of the bulk. Samples of plain Bitumen in semi-solid form and black in colour, was collected from two wells located around lamudifa village, north of Agbabu in Odigbo local government area of Ondo State. The samples of bitumen were collected with improvised open drive samplers.

Sampling Method

The chute sampling techniques was used. The samples were poured gradually into the sampler hopper along its length. The sampler splits into two portions A and B. Portion A was spited into two sub samples C and D using the chute riffler. Similarly Portion B was splitted into two sub – samples E and F . C and E were combined and passed through the sampler to obtain B1, B2, and B3, B4. D and F were combined and passed through the sampler to obtain two –portions J and K to obtain B5, B6 and B7, B8. Any of the samples (B1 – B8) can be taken; in this case B1 was weighed, placed and screened in the mesh (250 µm) screen.

Sample Cleaning:

The samples were washed thoroughly using heavy media separation (Ferro silicon) to remove all dirt's and debris of sand that might be attached with the coal and bitumen from the mines.

Grinding /Blending

The samples were grinded using a metallic mortar and piston. It was properly grounded. Blending of the coal sample and the bitumen was done using the various weights of the sample at the ratios required in grams. The various grams which were calculated in percentages, were strickly adhered to. The mixing was properly done using spatula to avoid samples concentrating in one place. The weights are 90-10 % 85-15% 80-20%, 75- 25% 70 – 30% 60-35% 60-40%, 55-45% 50-50% of coal and bitumen. The various test to prove its coking properties and electricity generation properties were carried out on each of the blends.

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Plate 1. 250µm coal sample

Plate 2: *Sample of Ondo Bitumen*

Equipment

Equipment used for this research work include, XRD, XRF, SEM/EDS, Pycnometer, Bomb calorimeter, Crawford Strand Burner, Heating furnaces, Muffle Oven, Scrubber, Blending machine, Jones Sampling Device, Froth flotation, Ceramic Crucible and C/H/N Analyzer

Test Schedule

The coal, bitumen and the blended samples are analyzed in the laboratories of the Department Mineral Resources Engineering, Kaduna polytechnic Kaduna, the Department of Chemistry Kogi State College of Education Technical Kabba, Department of Metal Works Technology, kogi state college of Education Technical kabba, The Geological Survey Laboratories Banawa, Kaduna and the Laboratories of National Metallurgical Centre Jos. The tests conducted on the samples includes; Density determination, Proximate analysis (Volatile matter, Moisture content, Fixed carbon, Ash content), Calorific value, Free swelling index, Gray –king coke type, Dilatometry value, determination of Carbon, Hydrogen, Nitrogen and Sulphur in bitumen samples, Shatter and Abradability test.

Determination of density of the Coal Samples:

The density was determined by weighing the mass (mg) of the coal sample on the weighing balance to know the weight of the coal sample. A 250ml measuring cylinder was filled with distilled water (initial volume, Vi). Grain Coal sample was gently and carefully put into the measuring cylinder containing distilled water and change in volume was recorded (Final volume, Vf). Then the density is being determined using the equation below.

$$\text{Density} = \text{Mass/ volume} = \frac{\text{Mass}}{V_f - V_i} \times 100$$

Proximate Analysis:

Determination of Moisture Content

(ASO 1038.3, ISO 11722 and ASTM D3173) standards was used for the moisture content determination.

It was carried out on the coal sample and the various percentages blend of coal samples and bitumen.

Thus:

$$\text{Moisture content of coal} = \frac{\text{weight of coal sample - weight of dried coal sample}}{\text{Weight of coal sample}} \times 100$$

For the various percentage blends.

$$M_3 = M_2 / M_1 \times 100$$

Where M_3 = % weight of moisture

M_2 = Weight of blend after Heating

M_1 = Weight of Blend before Heating

Determination of Volatile Matter Content

(ISO 562, ASTM D3175, and ASO1038.3) specifications was used to determine the volatile matter.

$$\text{Volatile Matter} = \frac{\text{Weight of coal sample - Weight of dried coal sample}}{\text{Weight of coal samples}} \times 100$$

For the various percentage blends

% Volatile matter (W_a = $W_b / W_c \times 100$

% Volatile matter (D.A.B.) = $Wc \times 100 / 100 - M_3$

Where

W_a = Weight of the blend before heating

W_b = Weight of blend after heating

W_c = Percentage Weight of volatile matter

M_3 = Percentage weight of moisture content.

Measurement of Ash Content

(ASTM D5142, ISO 172, 46) standard was used to determine ash content for the coal sample and the various percentage blends

Percentage Ash (A3) = A2 /A1 X 100.

A1 = Average weight of Sample.

A2 = Average weight of ash.

A3 = Average % weight of ash on D.A.B

Determination of Fixed Carbon Content

Determination of fixed carbon is carried out using the equation below:

Fixed Carbon (FC) = 100 – (% Moisture + % Volatile matter (d.a.b) + % Ash (d.a.b)

Where (d.a.b) = Dried Air Base.

Determination of Free Swelling Index

This is an important parameter in selecting a coal for use in the blast furnace. The purpose of this test is to access the swelling properties of the coal s when heated in a covered crucible under standard condition to a final temperature of 820 ^{o} C. 1 g of air dried coal and the blend (coal and bitumen) was grounded to pass 0. 2mm sieve and was heated for thirty minutes. The coke button obtained by heating the finely ground coal to 820 ^{o} C was classified by comparing it with the outlines of asset of standard profiles. The number of the profile most closely corresponding to the coke button is the crucible swelling number.

Determination of Gray – King Coke Type

This involves carbonization of the blends to high temperature in an oxygen deficient atmosphere in order to concentrate the carbon. The coke residue from the carbonization of finely mixed blend at 600° c was classified by comparism with series of proscribed coke type. 10 grams of the blend was air dried and grounded to pass 0.2 mm sieve. The blend was weighed and transferred to the main body of the retorts which was held almost vertically. The retort was turned into a horizontal position with the side arm downward and distance rod inserted so that the face of the piston was from the closed end of the retort. When the temperature reaches 600^{0} c, the retort was retracted from the furnace to cool. When it was cool enough to handle, the tar receiver and bung were removed and the traces of tar fouling the mouth and side arm of the retort were removed by solvent. The carbonized residue was then slid out of the retort for examination.

Determination of Strength of Coke by Shatter Test

Coke larger than 50.8 mm was dropped from a height of 1.83m to a steel plate four times in succession and the broken coke was then screened. The shattered coke is screened through 3.8mm screen. The weight of fractured coke retained on the 3.8mm screen sieve is the shatter index. This then is a measure of its resistance to breakage and that passing 12. 7mm indicate Abradability.

Determination of Sulphur in the Bitumen Sample

Eschka method for the determination of Sulphur was used. 1 g of air dried sample of bitumen was mixed with 3- 4 g of Eschka mixture (2 part calcined MgO and 1 part anhydrous Na_2CO_3). The mixture was placed in a platinum crucible and was covered with about 2g of more Eschka's mixture. The mixture was heated gradually to drive off the volatile matter with frequent stirring of charge by a platinum wire to allow free access of air. After the Oxidation was completed the crucible was removed and cooled. Based on B.S.1015 Pt. 2015). The sulphate in the filtrate were then precipitated as $BaSO_4$ by adding 10% solution of $BaCL_2$ (10ml) to the hot solution and then filtered and washed with hot water 5-6 times. The barium sulphate was then ignited and weighed. A blank test was conducted with the same amount of Eschka mixture and other reagent as used in the actual experiment and under exactly the same conditions.

Percentage of Sulphur was then calculated as follows.

Sulphur (%) = (A- B) X 13.735/C

Where, A + weight of $BaSO_4$ precipitated from sample in g

B= weight of $BaSO_4$ precipitated from blank ion g

C = weight of sample of bitumen in g

Determination of Calorific Value of the Coal Sample and the Various Percentage Blend

ASTM D5865, ISO 1928: ASO1058.5 specifications was used to determine gross calorific value. In determining the calorific value, coal samples of aperture size of 250μm were used for this analysis. The calorific value of the samples is determined using the e2k combustion bomb calorimeter. The heat released is proportional to the calorific value of the substance (Michael, 2015).

Determination of Carbon and Hydrogen in Bitumen

About 0.2 g of finely ground air dried bitumen was burnt in a stream of oxygen in a silca tube at 800 ^{0}c. The resulting water and carbon dioxide were absorbed in $CaCL_2$ (B.S.1016 pt, 2014).

$$\text{HYDROGEN } \% = \frac{\text{Weight of } H_2O \text{ X } 1119}{\text{Weight of bitumen sample}} \text{ X } 100$$

$$\text{CARBON } \% = \frac{\text{Weight of } CO_2 \text{ X } 0.2728}{\text{Weight of bitumen sample}} \text{ X } 100$$

Determination of Nitrogen in the Bitumen Sample

The percentage Nitrogen was calculated by subtracting % carbon. % hydrogen and % Sulphur from 100. % Nitrogen = 100 - (% carbon + % hydrogen + % sculpture)

Note: The % Nitrogen will contain some elemental loss on ignition (L.O.I)

Results and Discussion

Results

Result of the chemical and physical tests carried out on Omelewu coal, Ondo bitumen and the various % blend of Omelewu coal and Ondo bitumen are presented in the tables below. The following abbreviations are used and their meaning are as follows.

OC - Omelewu coal
OB – Ondo bitumen
D.A.B - Dry Air Base
G.K.- Gray king coke type.
F.S. I – Free Swelling Index

Table 4: (Chemical Composition of Ondo Bitumen)

Constituents	**C**	**H**	**N**	**S**	**ASH**	**VOLATILE MATTER**	**MOISTURE**
% Composition	70.59	4.44	0.67	1.78	4.45	14.52	1.29

Table 5: Proximate Analysis Result, Free Swelling Index and Gray King Coke Type

Samples	% Moisture content	% Ash content	% Volatile content	% Fixed Carbon	Free Swelling index	Gray – king Coke Type.
OMELEWU	13.18	11.32	39.71	39.28	½	B
% **Blends of coal** OM – OB						
90 - 10	8.96	6.21	32.32	52.51	1	B
85- 15	7.95	7.12	31.69	53.24	1 ½	C
80 - 20	6.34	7.84	30.54	55.28	2	D
75 - 25	5.15	8.21	29.89	56.75	2	E
70 - 30	4.45	8.78	26.12.	60.65	3	F
65 - 35	4.40	9.10	25.76	60.74	3	F
60 - 40	3.96	9.31	25.88	60.85	3	F
55 - 45	3.53	9.69	25.45	61.33	3	F
50 - 50	3.12	10.14	24.69	62.05	3	F

Blast Furnaces Specification.

Moisture content should be below 5% (Damisa, 2001). Ash content of blend used for blast furnace specification should be between 5.0- 8.5 % (D.A.B) The volatile matter content of coal/blends for blast furnace specification ranges between 23- 32 % (D.A.B) Wilson and wells (2008). For percentage Fixed carbon it ranges between 60 – 90% (D.A.B) The Free Swelling index of coal / bends used in the blast furnace ranges between 3- 4 (Wilson and wells (2001), The Free Swelling index is between 3 – 4 and Gray –king coke type ranges from G and above for blast furnace specification (Wilson and Wells, 2008).

Table 6: Density Value

SAMPLE	DENSITY KG/M^3
OMELEWU COAL	1.25
OMELEWU COAL AND ONDO BITUMEN % BLEND	
OC - OB	1.26
90 - 10	
85 - 15	1.27
80 - 20	1.28
75 - 35	1.29
70 - 30	1.30
65 - 35	1.31
60 - 40	1.32
55 - 45	1.34
50 - 50	1.35

TABLE 7: Calorific Value Result

SAMPLES	CAORIFIC VALUE M/Kg
OMELEWU COAL .	17.931
OMELEWU COAL AND ONDO BITUMEN % BLEND	
OC - OB	20. 241
90 - 10	
85 - 25	21.371
80 - 20	21.396
75 - 25	21.495
70 - 30	21.700
65 - 35	22.834
60 - 40	22.912
55 - 35	23.013
50 - 50	23.101

Note: OC = OMELEWU COAL, OB = ONDO BITUMEN

Table 8.: Comparism of the 70 -30 % blend Omelewu Coal Sample and Ondo bitumen with characteristics of Coal used by the Genessee Phase 3 power station in Canada.

Parameters of coal type	Unit	Genesssee phase 3, Canada	70- 30 % blends Of omelewu coal and Ondo bitumen
Heating value	M/kg	17.9	21.70
Moisture content	%	19.4	4. 45
Ash	%	19.4	8. 78

The result shows that the 70 -30 % Omelewu coal/ Ondo bitumen blend/ is very suitable for coal-fired power generation

Table 9: Dilatometry Value Determination Of Omelewu Coal and Ondo Bitumen

S/N	SAMPLE	MAXIMUM CONTRACTION	SOFTENING TEMP	AMOUNT OF DILATATION
1	Omelewu (O_1)	-14	180	0
2	Omelewu (O_2)	-13	182	0
3	Omelewu (O_3)	-12	186	0
4	O_1 + 20% OB	-10	203	+5
5	O_2 + 25% OB	-8	210	+15
6	O_3 + 30% OB	-7	216	+23

NOTE: O_1 = 80% Omelewu Coal, O_2 = 75 % Omelewu Coal, O_3 = 70 % Omelewu Coal
OB = Ondo Bitumen.

Shatter and Abradability Test for 70 - 30 % Blend Ratio of Omelewu Coal and Ondo Bitumen

Shatter test - 50%

Abradability - 10%

Discussions

Moisture Content

From the result obtained, the moisture content of the blend of Omelewu coal and Ondo bitumen between 85-15% and 50-50 % blend of the coal and the bitumen fall with the acceptable range of moisture content of coal for blast furnace coke production and also for electricity generation. As more bitumen was added to the coal, moisture content is reduced. This is attributed to the fact that bitumen contains little or no water. (Owolabi 1997).

The values are less than the blast furnace specification which is (maximum of 1.9%) on (D.A.B), hence any given ratio could be used in the blast furnace based on moisture content. It is pertinent to note that moisture is present in the following forms, surface, inherent and combined.

Volatite Matter Content

Analysis of the blend of Omelewu coal and the bitumen showed that the percentage of volatile matter decreased from 6.o % to 4.o % as the quantity of bitumen was increased from 10 % to 50% this could be attributed to the fact that bitumen contains little volatile matter. It has earlier been stated that volatile matter content in coal should not be greater than 32%. thus all ratios (Omelewu coal – Ondo bitumen) met the requirement of Blast furnace specification and electricity generation.

Ash Content

Ash is the incombustible material that remain after a coal is burnt. It lowers the calorific value of coal (Damisa,2001). Ash may be inherent or accidental depending on the source from which it is derived. Inherent ash is present in the original vegetable matter from which the coal is formed and is inseparable from the coal substance. It consists of oxides of potassium, sodium magnesium calcium and silicon. The ash content of 70-30% blend is in the acceptable range for blast furnace use and for electricity generation.

Fixed Carbon

From the obtained result, the fixed carbon content increased as the bitumen in the blend increases. The increase in fixed carbon content of the blend could be attributed to the carbon present in the bitumen. The value of carbon content from 70- 30% ratios of the coal and bitumen blend down to 50 -50 % blend fall within the acceptable range for coal used in blast furnace coke (Wilson and Wills,1975) and for use in power generation (Obaje 2017)

Free Sweeling Index

This is another important parameter in selecting a coal for use in the blast furnace. Addition up to 30% also improved the free swelling index of omelewu coal from ½ to 3, thus increasing its cokability, hence any given ratio from 30 % to 50% could be used in the blast furnace based on free swelling index. value (David, 2008).

Gray King Coke Value

This value shows whether a coal is coking or not. Addition of bitumen up to 30% improved the Gray- king coke value from B to F thus enhancing its coking properties. The coke produced from 30% to 50% of bitumen were slightly shrunken and hard. this is because bitumen provides the coal a plastic phase to overcome any diffusional restriction. (David 2008)

Dilatometry Value

This is also an important property to be considered for selecting a coal for use in blast furnace. From the obtained results addition of up to 30% increased the dilatometry value from flat dilation value of 0 to +23 for 70 -30% ratio. This is because bitumen possesses good coefficient of volume expansion. The dilatometry value of + 23 is within the blast furnace specification (20 to 27%) for good coking coal. (David 2009).

Calorific Value

The calorific value gives the heating value or the heat of combustion of a substance. It has been suggested that the calorific value of power plant coals is in the range of 9.5 MJ/kg to 27 MJ/kg (Zactruba, 2009). Thus, considering the result of calorific values of the blended samples, it can be deduced that all the % blends of Omelewu coal and Ondo bitumen would be suitable for power generation. From results of proximate analysis, the ash content of the 70 - 30 % blend samples indicates that the ash content of the percentage ratio is within the accepted value of coal blends used for coke production and for coal fired power generation as compared to that Genessee Phase 3 Power Station in Canada. Omelewu coal deposit contains medium-ash that ranges between High ash content and Low Ash content. The medium ash coal is also suitable for electricity generation. (IEA, 2010**)**. Pulverized Coal Combustion is the most commonly used method in coal-fired power plants.

This technology is well developed, and there are thousands of units around the world, accounting for well over 90% of coal-fired capacity. Pulverized Coal Combustion can be used to fire a wide variety of coals, although it is not always appropriate for those with a high ash content (IEA, 2010). Omelewu coal is a sub-bituminous coal. Comparison of Coal Samples were drawn with Characteristics of coal used by the Genessee Phase 3 Power Station in Canada to determine its suitability with typically published requirements for pulverized sub-bituminous coal-fired power generation. and its suitable for electricity generation for 70- 30 % of the Coal and Ondo bitumen.

Conclusion

The properties of Omelewu coal and Ondo bitumen were characterized. Proximate analysis, density value, calorific values, Free swelling index, Gray king coke type, dilatometry value, shatter test and Abradability test were all determined for the various percentage blends. From the result the blend ratio of 70- 30% blend of Omelewu coal and Ondo Bitumen blend shows some improvement upon the addition of bitumen on the cokability of the coal and its usefulness in electricity generation. The improvement of the property of omelewu coal from Flat dilation value of 0 to +23 for 70- 30 % ratio blend, showed clearly the significant improvement in the cokability of the coal upon the addition of bitumen.

The utilization Omelewu coal and Ondo bitumen by steel industries and the power sector will promote development of industries through effective supply of products to priority sector such as mining, engineering, energy, chemical, construction, transportation, communication, agriculture and agro- allied industries. It will also diversity the source of income for the nation's economy, conserve scarce foreign earnings, create employment opportunities as well as encourage development of appropriate indigenous technology. Hence this research work is of great importance and essentially justifiable.

Recommendation

In order to obtain more detailed information on the study areas, it is highly recommended that further research should be done on Ultimate Analysis, (Petrographic Analysis (PGA) and Thermo-gravimetric analyses (TGA) .

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