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Increasing National Energy Mix through Carbon Sequestration of Coal for Improved Power Generation

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ABSTRACT

In this paper, a novel technology of increasing national energy mix through carbon sequestration of coal has been advocated as a panacea for improving the nation's power generation for electricity utilization and consumption. Consequently, electricity and petroleum products which have become the energy forms relied upon in most economic sectors of the world significantly exist with some changes in time vis-à-vis the energy consumption due to changes in the structure of the economy, energy prices, level of production of goods and services, technology and population, etc. Also, the exclusive dependence on income from oil for infrastructural development thus became the order of the day. These, are considered unsustainable especially with the total neglect of the agrarian nature of the country and the unproductive capabilities of other goods and services derivable from electricity generated. Hence, these seriously portend that urgent and drastic engineering strategies must be introduced in the energy sector to revamp the dwindling power generation. Thus, carbon sequestration of coal is the suggested option as a clean coal energy technology for power plant optimization. In this study, some air-dried Nigerian coals collected from different coal deposits across the country were utilized for the analyses to investigate their characteristics and rheology. The result obtained shows that chemically re-characterized Enugu sub-bituminous air dried coal has the highest carbon content ranging from 3.8% to 46.27% while its calorific value was found to be also high among others at the range of 22.3 to 28.4MJ/Kg, respectively. The result also shows that increase in carbon contents for all the coal samples resulted to increase in calorific value which would reduce the accumulation of greenhouse gases in the atmosphere if released by the burning of these fossil fuels. The technology of a good sequestered carbon if adopted will help in revamping the dwindling energy sector. It will also reduce over-dependence on oil especially the petroleum products and make room for an optimal energy mix for effective diversification of the sector. This would thus increase the efficiency of power plants for improved optimization of coal for energy production and management.

Keywords: *Energy mix; Carbon sequestration of coal; Improved power generation; Effective diversification of the energy sector; Greenhouse gases.*

1. INTRODUCTION

Carbon sequestration technologies are systematic techniques of capturing, purifying and storing carbon dioxide (CO_2) in order to reduce greenhouse gas (GHG) emissions without adversely influencing energy use or hindering economic growth [1, 2]. The technologies capture and store CO_2 that would otherwise reside in the atmosphere for long periods of time to deplete the ozone layer leading to global warming [3]. This has been proposed as a way to mitigate the accumulation of GHGs in the atmosphere released by the burning of fossil fuels. These levels according to the "Integrated Partnerships for Carbon Capture" as reported by [3] are expected to be higher than today's level and will continue to be significantly on the increase. This is why The U.S Department of Energy (DOE) [2] declared that the U.S as one of the 192 countries that are signatories to the United Nations Framework Convention on Climate Change (a treaty approved in 1992) called for the stabilization of atmospheric CO_2 as the most prevalent of all gases abounding in the atmosphere. According to the source, atmospheric CO_2 is the highest contributor to the GHGs effect originating from both natural and man-made sources. In-view of this, carbon capture through coal sequestration thus, is important as an integral technique of increasing every nation's energy mix for improved power generation.

The man-made or anthropogenic sources of CO_2 are primarily the burning of various fossil fuels for power generation and transportation, although other industrial activities contribute to atmospheric CO_2 concentrations as well. This increase in atmospheric GHGs is considered to be a contributing factor to the phenomenon of global warming and a potential cause of unwelcome shifts in regional climate change.

Although, conservation, renewable energy, and improvements in the efficiency of power plants, automobiles, and other energy-consuming devices are important first steps in any GHG emissions mitigation effort [2, 4], those approaches however, cannot deliver the level of emissions reduction needed to stabilize the concentrations of GHGs in the atmosphere. This is especially in view of a growing global demand for energy and the associated increase in GHG emissions.

Succinctly, Carbon Capture and Storage (CCS) otherwise referred to as: "Carbon Sequestration" of coal, is the main technological approach required. This is effective in reducing the atmospheric GHG concentrations, which at the same time has little or no negative impacts on energy use and economic growth and prosperity. The technology to a greater dimension will provide good overall promises and potentials in reducing significantly the GHG emissions expected.

2. MATERIALS AND METHODS

The technique used in this present work is $PRONO_X$ (Proactive Reduction of NOx), which utilized the principles of Orsat analyzer. PRONOx is a step ahead of $SCONO_x$ (Selective Catalytic Oxidation of NOx) because it maintains stack for NO_x and CO_x at 0.9ppm below $SCONO_x$ limit of 2ppm [5]. The experimental setup is shown in figure 1 while a typical Orsat analyzer is shown in figure 2. It incorporates a pyrometer and a VIS Spectrometer in its design to control the emission of NO_x, N_2 and CO_2, respectively.

2.1 Operating Principles of $PRONO_X$

Like $SCONO_X$, $PRONO_X$ is also a post-combustion catalytic system that removes both NO_x and CO_x from the gas turbines (GTs) but absorbs CO_2 without water/steam or ammonia injection [5]. $PRONO_X$ is fitted at the GTs exhaust. The exhaust gases flow through the pyrometer which reads the temperature before entering the Orsat analyzer incorporated into it.

The reagents normally used are a potassium hydroxide (KOH) solution, alkaline pyrogallol solution and cuprous chloride ($CuCl_2$). The KOH solution absorbs the O_2 in the exhaust gases while the $CuCl_2$ mixture is used to absorb the last trace of CO_2 gas and nitrogen. Consequently, the exhaust further flows to the reactor part of $PRONO_X$ with the N_2 still unabsorbed. Thereafter, the N_2 later reacts with potassium carbonate which is coated on the platinum catalyst surface. The NO is oxidized to NO_2 and then reacts with the potassium carbonate absorber coating on the catalyst to form potassium nitrites and nitrates at the surface of the catalyst. It reads the exhaust temperature and volume concentration with the aid of pyrometer and rotameter incorporated in it.

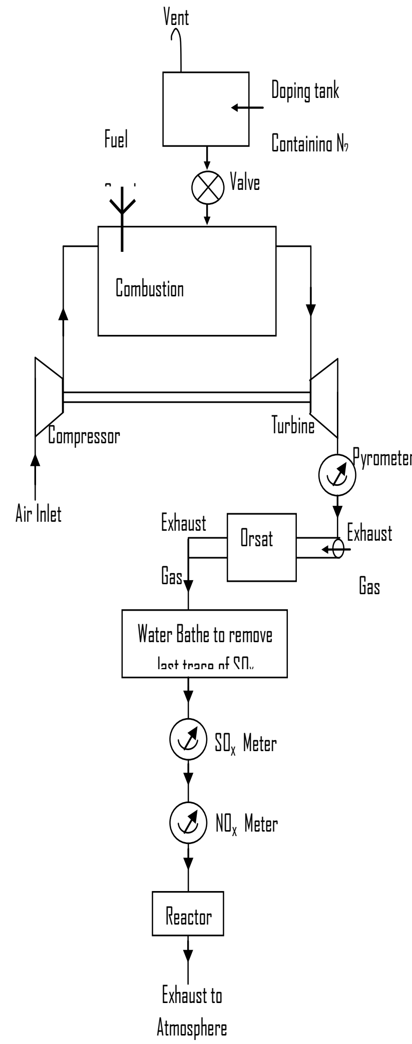


Figure 1: Schematic Experimental Setup for PRONOx
Source: [5]

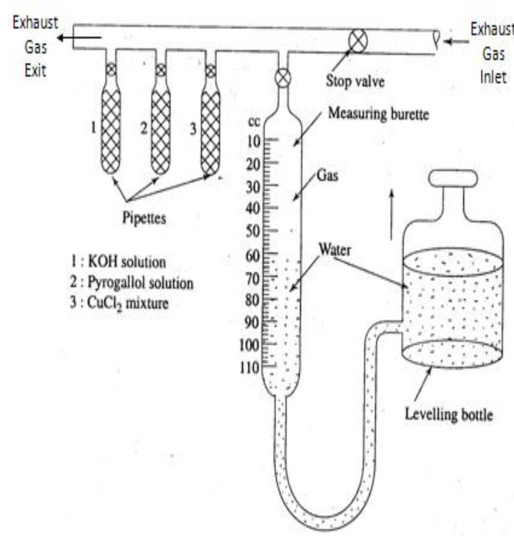


Figure 2: A Typical Orsat Analyzer
Source: [5]

Thus, the conversion of the chemical energy to heat by complete combustion of fossil fuel using air as the oxygen source is summarized as presented below in the following chemical reactions, assuming the nitrogen remains inert; i.e. being non reactive or not readily changed by chemical or biological reaction [6, 7, 8, 9]:

$$C_xH_y + \left(x+\frac{y}{4}\right)O_2 + 3.76\left(x+\frac{y}{4}\right)N_2 \rightarrow \text{Heat} + xCO_2 + \left(\frac{y}{2}\right)H_2O + 3.76\left(x+\frac{y}{4}\right)N_2 \quad (1a)$$

Or alternatively:

$$C_xH_y + \left(x+\frac{y}{4}\right)[O_2 + 3.76N_2] \rightarrow Heat + xCO_2 + \left(\frac{y}{2}\right)H_2O + \left(x+\frac{y}{4}\right)[3.76N_2] \quad (1b)$$

This could be interpreted analytically in a simple word equation as:

Fuel+Air(Oxygen)→Heat+Carbondioxide+Water (1c)

where: stiochiometric coefficients x and y depend on the fuel type in use. It could be noted also that depending on temperature and flame parameters evolved during combustion, some of the nitrogen however, can be oxidized, thus, producing various nitrogen oxides; while some other unintended products of combustion such as sulfur dioxide (SO_2) come from sulfur impurities predominantly in coal.

Subsequently, in analyzing the work, a MATLAB computer-based methodology was invoked and used to actualize this study. The results obtained further, were used to determine which inherent characteristics in a particular type of coal sample could best be used to optimize its characteristic value. However, Artificial Intelligence/Neural Network (AI/ NN) systems could also be utilized to optimize multiple aspects of the power plant operation but great care must be taken to consider the possible negative impact on other parameters. This was accomplished by designing the software packages to communicate with each other through a management software package [10, 11] developed.

3. RESULTS AND ANALYSES

From tables 1 and 2, Schatzle [12] characterized some samples of air dried Nigerian coal. The intervals of presentation of results were such that their presentation using these data was virtually impossible. Hence, a MATLAB programming language was used in this study to re-characterize these set of tables to obtain an improved values (table 3) for the various characteristics of the coal samples investigated.

Table 1: Chemical Characteristics of Air-Dried Nigerian Coals

Chemical Characteristics	Sub –bituminous Coal					Lignite
	Enugu	Ezimo	Owukpa	Okaba	Ogboyoga	Asaba
Calorific Value (MJ/Kg)	22.3-28.4	25.4-25.6	23.0-24.9	22.9-23.5	22.7-23.9	20.9-24.0
Moisture Content (%)	2.9-11.1	10.3-13.6	11.8-16.8	8.1-12.5	12.3-15.5	Up to 40
Ash Content (%)	3.9-26.0	6.4-12.3	7.3-11.2	7.8-10.8	7.8-8.9	5-8
Volatile Matters (%)	32.5-41.8	39.6-41.3	35.3-37.8	38.9-42.7	38.8-40.9	35-39
Fixed Carbon (%)	38.6-46.3	39.2-41.0	37.8-41.4	37.8-41.4	37.8-39.8	20-26

Source: [13]

Table 2: Nigeria's Coal Resources

Location	Indicated Reserves (Million Tonnes)		Inferred Reserves X (10^6) Tonnes	Total Resources X (10^6) Tonnes
	Seams 1.07-1. 52m thick	Seams Over 1.52m thick		
Enugu/Udi	24.4	18.3	12.2	54.9
Ezimo	16.3	13.2	17.3	46.8
Inyi	10.3	-	-	10.3
Ogboyoga	28.4	54.9	31.5	114.8
Okaba	6.1	48.8	19.3	74.2
Owukpa	4.1	46.8	7.1	58.0
Total	**89.6**	**182.0**	**87.4**	**359.0**

Source: [13]

Consequently, the flowchart that enabled the program code to be written is shown in figure 3. The various tables of values generated from the MATLAB computer program based on the most important characteristics of the coals are presented in table 3 (Appendix 1). Furthermore, from the table 3, the graphs shown in figures

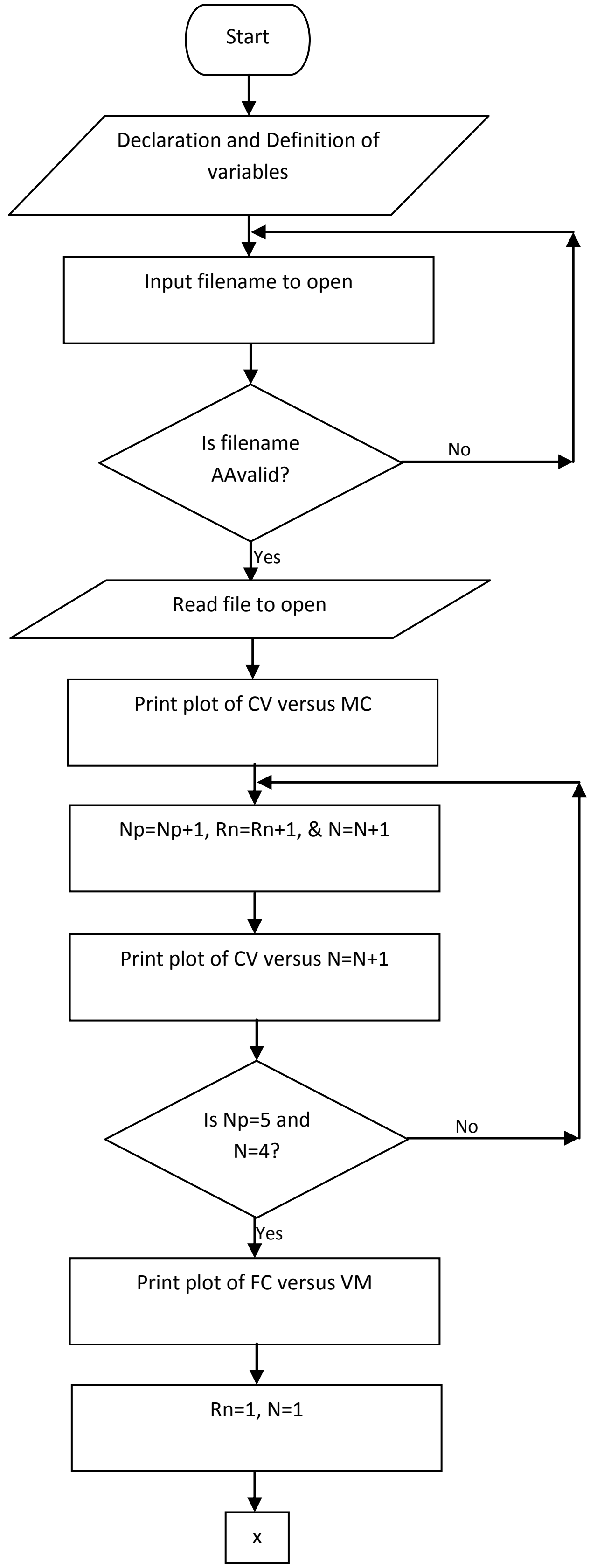
4 to 13 were plotted while their trends are discussed as follows:

3.1 Calorific Value versus Moisture Content, Ash Content, Volatile Matters and Fixed Carbon

The graphs of the influence of moisture content, ash content, volatile matters and fixed carbon on calorific values of the coal samples studied are presented in figures 4 to 7 respectively. Even though these parameters seem to be by-products of the coals, the experimentations carried out in tables 1 and 2 that generated the graphs, show that they are of importance in the performance of the coals.

From the analysis in figure 10, the presence of moisture has to be guarded against in any of the coals. This is so as a slight increase in moisture content brings about a rapid change in fixed carbon content. Figure 11 further shows that ash content does not almost have any impact on water content for Asaba coal. However from figure 12, moisture content presence does not steeply affect the quantity of volatile matter in any of the Nigeria's air-dried coal. This has the same trend in figure 13 where ash content and volatile moisture percentages are analyzed.

Generally, from figure 4, it is noticed that slight increase in moisture content brings about a steep increase in calorific value for all Nigerian air-dried coals. Similarly, a slight increase in fixed carbon brings about a remarkable increase in calorific value as captured in figure 7. This implies that increase in quantity of moisture and fixed carbon content respectively are necessary for high calorific values of air-dried Nigerian coals. The less steep nature of the curve for the other parameters affecting the quantities of the coals shows that these constituents like volatile matters, and ash contents are not of immense significance to the quantities of the coals except in Owukpa coal.



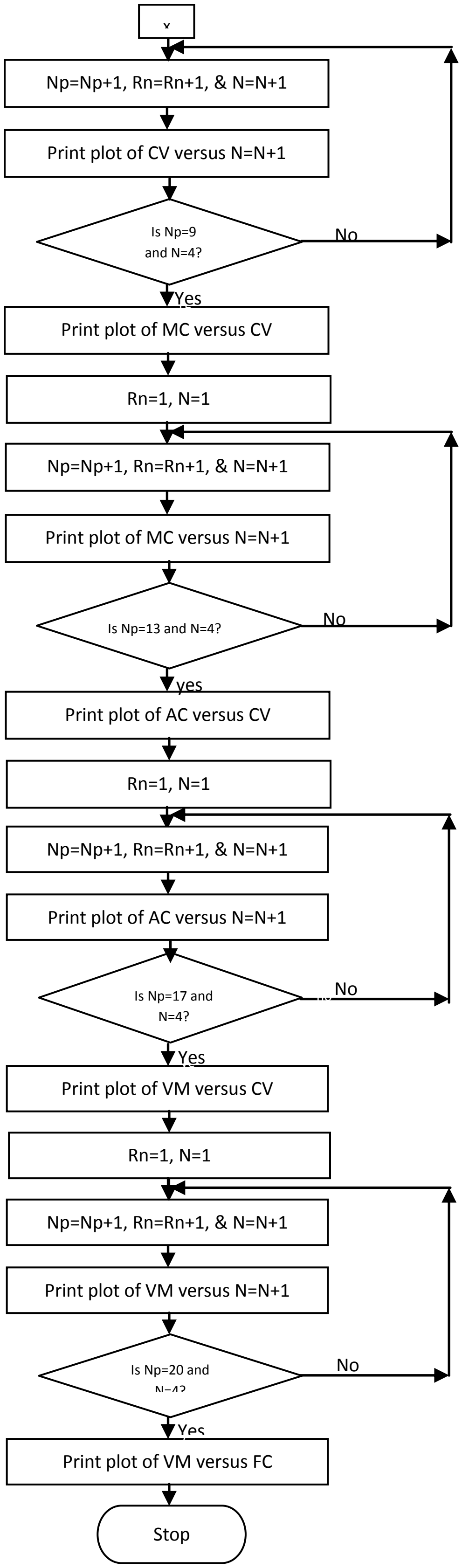


Figure 3: Flow Chart for Producing Improved Chemical Characteristics of Air-dried Nigerian Coal from Table 1

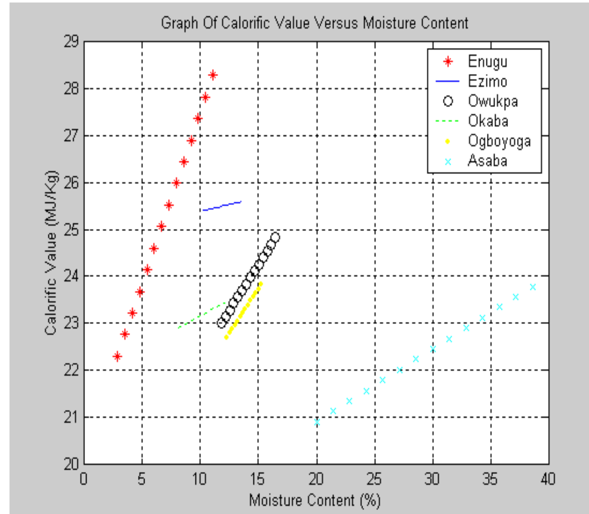


Figure 4: Calorific value versus moisture content

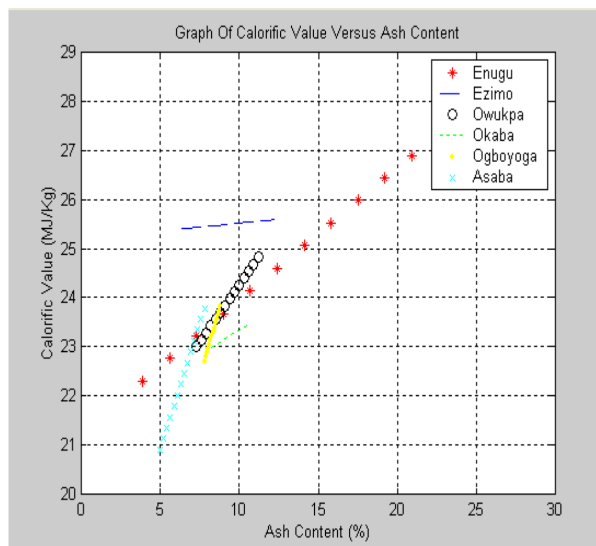


Figure 5: Calorific value versus ash content

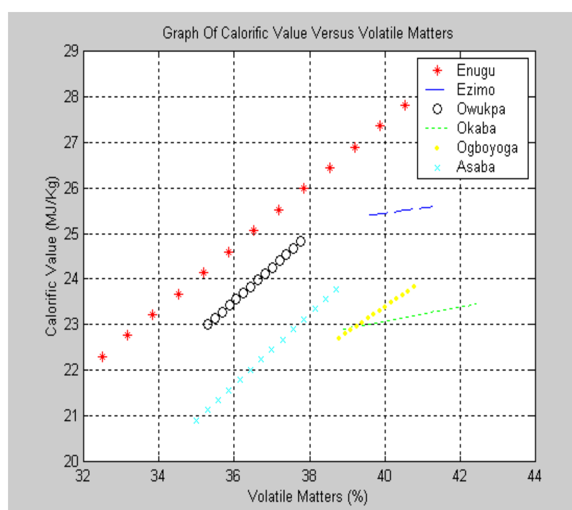


Figure 6: Calorific value versus volatile matters

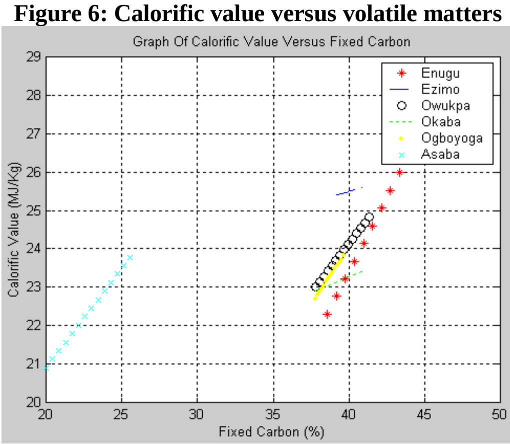


Figure 7: Calorific value versus fixed carbon

3.2 Impact of Other Constituents on Themselves

Figures 8-13 respectively illustrate the impact of volatile matters on fixed carbon; ash content on fixed carbon; moisture content on fixed carbon; ash content on moisture content; volatile matter on moisture content and volatile matter on ash content. The influence of these parameters is more pronounced on specific value which is the principal quantity of any coal.

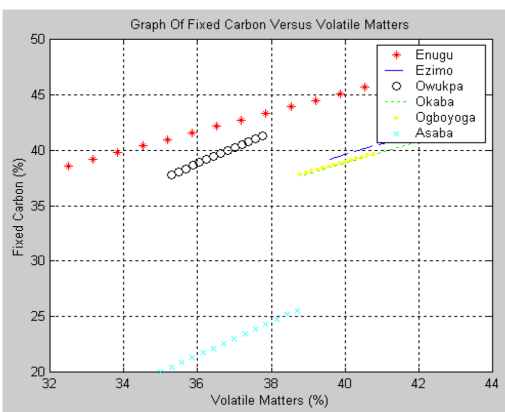


Figure 8: Fixed carbon versus volatile matter

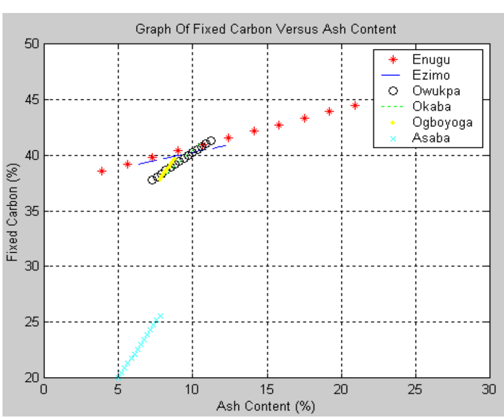


Figure 9: Fixed carbon versus ash content

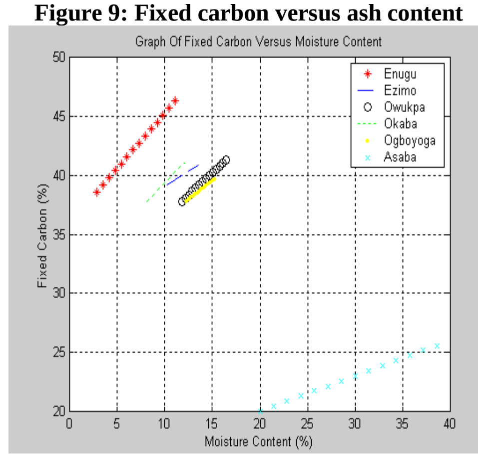


Figure 13: Ash content versus volatile matters

4. CONCLUSIONS

Analyses have been conducted through this paper to ascertain the quality of Nigerian air-dried coals. The work shows that Nigeria has abundant reserve of coal resources in five locations. However, these coals have high carbon contents and carbon dioxide released from them need to be sequestrated after they have been burnt. This is mostly to reduce the amount of GHGs that could increase the ozone depletion layer of the atmosphere.

However, the analyses revealed that these coals are highly rich in calorific value. The low moisture and ash contents make them comparable to other foreign coals. The coals can therefore earn much revenue for the country thereby reducing over-dependence on oil which is the present trend in the country. Evidently, the measure will make room for the diversification of the energy sector for proper national energy mix.

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APPENDIX 1:

Table 3: Re-characterization of Chemical Characteristics of Air-Dried Nigerian Coals (Improved Values)

Chemical Characteristics	**Enugu Sub – bituminous Coal**														**Interval**
Calorific Value (MJ/Kg)	22.3000	22.7600	23.2200	23.6800	24.1400	24.6000	25.0600	25.5200	25.9800	26.4400	26.9000	27.3600	27.8200	28.2800	0.46
Moisture Content (%)	2.9000	3.5300	4.1600	4.7900	5.4200	6.0500	6.6800	7.3100	7.9400	8.5700	9.2000	9.8300	10.4600	11.0900	0.63
Ash Content (%)	3.9000	5.6000	7.3000	9.0000	10.7000	12.4000	14.1000	15.8000	17.5000	19.2000	20.9000	22.6000	24.3000	26.0000	1.70
Volatile Matters (%)	32.5000	33.1700	33.8400	34.5100	35.1800	35.8500	36.5200	37.1900	37.8600	38.5300	39.2000	39.8700	40.5400	41.2100	0.67
Fixed Carbon (%)	38.6000	39.1900	39.7800	40.3700	40.9600	41.5500	42.1400	42.7300	43.3200	43.9100	44.5000	45.0900	45.6800	46.2700	0.59
Chemical Characteristics	**Ezimo Sub – bituminous Coal**														**Interval**
Calorific Value (MJ/Kg)	25.4000	25.4150	25.4300	25.4450	25.4600	25.4750	25.4900	25.5050	25.5200	25.5350	25.5500	25.5650	25.5800	25.5950	0.015
Moisture Content (%)	10.3000	10.5500	10.8000	11.0500	11.3000	11.5500	11.8000	12.0500	12.3000	12.5500	12.8000	13.0500	13.3000	13.5500	0.25
Ash Content (%)	6.4000	6.8500	7.3000	7.7500	8.2000	8.6500	9.1000	9.5500	10.0000	10.4500	10.9000	11.3500	11.8000	12.2500	0.45
Volatile Matters (%)	39.6000	39.7300	39.8600	39.9900	40.1200	40.2500	40.3800	40.5100	40.6400	40.7700	40.9000	41.0300	41.1600	41.2900	0.13
Fixed Carbon (%)	39.2000	39.3300	39.4600	39.5900	39.7200	39.8500	39.9800	40.1100	40.2400	40.3700	40.5000	40.6300	40.7600	40.8900	0.13
Chemical Characteristics	**Owukpa Sub – bituminous Coal**														**Interval**
Calorific Value (MJ/Kg)	23.0000	23.1400	23.2800	23.4200	23.5600	23.7000	23.8400	23.9800	24.1200	24.2600	24.4000	24.5400	24.6800	24.8200	0.14
Moisture Content (%)	11.8000	12.1600	12.5200	12.8800	13.2400	13.6000	13.9600	14.3200	14.6800	15.0400	15.4000	15.7600	16.1200	16.4800	0.36
Ash Content (%)	3.9000	5.6000	7.3000	9.0000	10.7000	12.4000	14.1000	15.8000	17.5000	19.2000	20.9000	22.6000	24.3000	26.0000	0.30
Volatile Matters (%)	32.5000	33.1700	33.8400	34.5100	35.1800	35.8500	36.5200	37.1900	37.8600	38.5300	39.2000	39.8700	40.5400	41.2100	0.19
Fixed Carbon (%)	38.6000	39.1900	39.7800	40.3700	40.9600	41.5500	42.1400	42.7300	43.3200	43.9100	44.5000	45.0900	45.6800	46.2700	0.27
Chemical Characteristics	**Okaba Sub – bituminous Coal**														**Interval**
Calorific Value (MJ/Kg)	22.9000	22.9430	22.9860	23.0290	23.0720	23.1150	23.1580	23.2010	23.2440	23.2870	23.3300	23.3730	23.4160	23.4590	0.043
Moisture Content (%)	8.1000	8.4150	8.7300	9.0450	9.3600	9.6750	9.9900	10.3050	10.6200	10.9350	11.2500	11.5650	11.8800	12.1950	0.315
Ash Content (%)	7.8000	8.0150	8.2300	8.4450	8.6600	8.8750	9.0900	9.3050	9.5200	9.7350	9.9500	10.1650	10.3800	10.5950	0.215
Volatile Matters (%)	38.9000	39.1720	39.4440	39.7160	39.9880	40.2600	40.5320	40.8040	41.0760	41.3480	41.6200	41.8920	42.1640	42.4360	0.272
Fixed Carbon (%)	37.8000	38.0580	38.3160	38.5740	38.8320	39.0900	39.3480	39.6060	39.8640	40.1220	40.3800	40.6380	40.8960	41.1540	0.258
Chemical Characteristics	**Ogboyoga Sub – bituminous Coal**														**Interval**
Calorific Value (MJ/Kg)	22.7000	22.7860	22.8720	22.9580	23.0440	23.1300	23.2160	23.3020	23.3880	23.4740	23.5600	23.6460	23.7320	23.8180	0.086
Moisture Content (%)	12.3000	12.5290	12.7580	12.9870	13.2160	13.4450	13.6740	13.9030	14.1320	14.3610	14.5900	14.8190	15.0480	15.2770	0.229
Ash Content (%)	7.8000	7.8790	7.9580	8.0370	8.1160	8.1950	8.2740	8.3530	8.4320	8.5110	8.5900	8.6690	8.7480	8.8270	0.079
Volatile Matters (%)	38.8000	38.9520	39.1040	39.2560	39.4080	39.5600	39.7120	39.8640	40.0160	40.1680	40.3200	40.4720	40.6240	40.7760	0.1520
Fixed Carbon (%)	37.8000	37.9430	38.0860	38.2290	38.3720	38.5150	38.6580	38.8010	38.9440	39.0870	39.2300	39.3730	39.5160	39.6590	0.143
Chemical Characteristics	**Asaba Lignite Coal**														**Interval**
Calorific Value (MJ/Kg)	20.9000	21.1220	21.3440	21.5660	21.7880	22.0100	22.2320	22.4540	22.6760	22.8980	23.1200	23.3420	23.5640	23.7860	0.222
Moisture Content (%)	20.0000	21.4290	22.8580	24.2870	25.7160	27.1450	28.5740	30.0030	31.4320	32.8610	34.2900	35.7190	37.1480	38.5770	1.429
Ash Content (%)	5.0000	5.2150	5.4300	5.6450	5.8600	6.0750	6.2900	6.5050	6.7200	6.9350	7.1500	7.3650	7.5800	7.7950	0.215
Volatile Matters (%)	35.0000	35.2860	35.5720	35.8580	36.1440	36.4300	36.7160	37.0020	37.2880	37.5740	37.8600	38.1460	38.4320	38.7180	0.286
Fixed Carbon (%)	20.0000	20.4290	20.8580	21.2870	21.7160	22.1450	22.5740	23.0030	23.4320	23.8610	24.2900	24.7190	25.1480	25.5770	0.429