Suitability Assessment of Kurumu, Garin-maiganga, Gindi-akwati and Ogboyoba Coal Deposit Properties for Power Generation

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DEPARTMENT OF MECHANICAL ENGINEERING,
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MARCH, 2016

DECLARATION

I declare that the work in this dissertation entitled “Suitability assessment of Kurumu, Garin-maiganga, Gindi-akwati and Ogboyoba coal deposit properties for power generation” has been carried out by me in the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution

Lukman Jimoh Mudashiru	……	……
Name of student	Signature	Date

CERTIFICATION

This dissertification entitled “Suitability assessment of Kurumu, Garin-maiganga, Gindi-akwati and Ogboyoba coal deposit properties for power generation” by Lukman Jimoh Mudashiru meets the regulations governing the award of the degree of Master of Science in Mechanical Engineering of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

In the quest for search of suitable coal deposits for power generation, the qualities of four Nigerian coal samples from Kurumu (Gombe State), Garin-maiganga (Bauchi State), Gindi-akwati (Plateau State) and Ogboyoba (Kogi State) deposits were analysed to assess their suitability for power generation. The coal samples were subjected to proximate analysis, ultimate analysis, calorific value determination, thermogravimetric analysis, ash fusion temperature analysis, ash composition analysis and auto-ignition temperature determination. Tests were carried out in Nigerian Geological Survey Agency, Kaduna and Beijing University of Technology (BUT), China. From the results of these analyses, Kurumu coal deposit was found to be a sub-bituminous, low ash and low sulphur coal. Garin-maiganga coal deposit was found to be a sub-bituminous, medium ash and low sulphur coal. Gindi-akwati coal deposit was found to be a lignitic, high ash and low sulphur coal while Ogboyoba coal deposit was found to be a sub-bituminous, low ash and low sulphur coal. Kurumu, Garin-maiganga and Ogboyoba coal deposits with calorific values of 25.71MJ/kg, 23.37MJ/kg and 24.78MJ/kg respectively, can be used for power generation using the integrated gasifier combustion cycle clean coal technology. However, Gindi-akwati coal deposit with a calorific value of 11.56MJ/kg can be used for power generation using circulating fluidised bed combustion technology due to its tolerance of a wide variety of coals. The self-ignition temperature and ease of combustion of the coal samples in decreasing order of their volatile ratio is Gindi-akwati (0.58), Garin-maiganga (0.49), Ogboyoba (0.48) and Kurumu (0.47).

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ABBREVIATIONS

WEO: World Economic Outlook

PFBC: Pressurized Fluidized Bed Combustion

IGCC: Integrated Gasification Combined Cycle

ASTM: American Standard of Testing and Materials

ISO: International Standard Organization

BUT: Beijing University of Technology

TGA: Thermogravimetric Analysis

DSC: Differential Scanning Calorimetry

HGI: HardgroveGrindability Index

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Adequate power supply is an unavoidable prerequisite to any nation's development. Electricity plays a very important role in the socio-economic and technological development of every nation. The electricity demand in Nigeria far outstrips the supply and the little supply is epileptic in nature. The country is faced with acute electricity problems which is hindering its development notwithstanding availability of vast energy resources in the country. It is widely accepted that there is a strong correlation between socioeconomic development and the availability of electricity in a given country. The energy woes today had

continued unabated over the years since 60 percent of Nigeria's electricity – generating capacity broke down due to decades of neglect by the government. The remainder serves only 40% of her citizens

(Essien *et al.*, 2013; Sambo *et al.*, 2010) at different degrees of black-outs, rolling black-outs and brown-outs. Another side to these woes is the fact that for more than three decades, Nigeria went for gas – fired power stations, in the days when there was still abundant cheap gas. With the present skyrocket price of gas, it has become expensive to run those plants when compared to coal – fired and nuclear plants (Oodo and Zou, 2009).

In Nigeria presently, 93% of electric power generation is provided by gas, the remainder is from hydro sources. There are over 8.6GW of installed capacity of generating plant made of government owned and independent power plant across Nigeria. Despite the large number of installed power generation capacity, Nigeria could still not meet the electricity demand of its populace which is estimated at 10GW because of old age of the power plants and lack of new generation plants addition. Actual electricity generation is only between 2.5 – 3.6GW (Ujam and Diyoke, 2013).

Even if new power plants addition were to be made, the overdependence of Nigeria's electrical system on gas which cannot guarantee longer term sustainability should be a major concern. The frequent agitation for resource control from areas with fossil fuel reserves and incessant vandalization of power plant gas supply infrastructure are threats to the continuous sustainability of the Nigeria's power system of today.

Moreover, there is an urgent need for a good energy mix in the nation's energy generation infrastructure due to the combined benefits derivable from it. Globally, the energy industry is driving towards sustainable low carbon emitting, renewable energy sources.

However, renewable as at now are still in their infant stage of commercialization and cannot help to meet Nigeria's base load electricity demand deficit. It is also

worthy of mention that even in the most envisioned grid of the 21st century otherwise called the smart grid, traditional large central power plants still form the 'nucleus' of this concept both in Europe and America
(Essien *et al*., 2013).

Coal is an important energy resource across the world, principally for electricity generation. It is the world's most abundant and widely distributed fossil fuel, with global proven reserves totaling nearly 1 trillion tonnes (Ujam and Diyoke, 2013).

Coal which is spread across Nigerian states with an estimated reserve of 2.734 billion tones
(Sambo *et al*., 2010; Ujam and Diyoke, 2013) holds the key to Nigeria's present and even future energy security. On the average, 40% of the world's electricity is generated from coal with a rather higher percentage as you move from one country to another. For instance, electricity generation in South Africa derivable from coal fuels is placed at about 93%, it is 92% in Poland, 79% in china, 69% in India, 49% in the USA (Olayande *et al*., 2012) etc as shown in Table 1.1, but most unfortunately it is 0% in Nigeria. Most developed and developing countries that has coal deposits meet their energy demands through coal based generation. Nigeria can bridge its energy demand and supply deficit by leveraging on its abundant coal deposit resources.

Nigeria cannot continue to be in the dark when there is approximately 3 billion tonnes of coal deposits spread across 22 locations in Nigeria (Kibiya, 2012) that has not been harnessed. The growing energy needs of the developing world are likely to ensure that coal remains a key component of the power generation mix in the foreseeable future, regardless of the climate change policy.

Table 1.1 Top 12 Countries that use Coal for Electricity Generation

S/No.	**Country**	**Percentages (%)**
1	South Africa	93
2	Poland	92
3	China	79
4	Australia	77

5	Kazakhstan	70
6	India	69
7	Israel	63
8	Czech republic	60
9	Morocco	55
10	Greece	52
11	USA	49
12	Germany	46

Source: Olayande et al., 2012

Developing economies have a particularly strong dependency on coal for power production, and the rate of growth in coal's contribution to electricity supply in these countries will be greatest, as shown in Table 1.2:

	Year	**2004**		**2015**		**2030**	
	Total	**TWh**	**% share**	**TWh**	**% share**	**TWh**	**% share**
Source	**Generation**	**5, 754**	**100**	**10, 749**	**100**	**17, 001**	**100**
Coal		2753	47.8	5659	52.6	8979	52.8
Oil		580	10.1	670	6.2	616	3.6
Gas		983	17.1	1955	18.2	3389	19.9
Nuclear		142	2.5	322	3.0	523	3.1
Hydro		1239	21.5	1928	17.9	2827	16.6
Renewables		56	1.0	215	2.0	668	3.9

(excluding hydro)

Table 1.2: Developing Countries Electricity Generation from Major Fuels, IEA Reference Scenario
Source: International Energy Agency, 2007

1.2 Benefits of coal as a source of power generation to the nation

The exploitation of coal for electricity generation and the production of coal briquettes for domestic and industrial heating will bring a number of benefits including;

i) Increased and more reliable electricity supply
ii) Lower cost electrical energy
iii) Expanded industrialization of the economy
iv) Increased employment and human resource development
v) Increased capacity utilization of existing industries
vi) Increased national income through taxes and
vii) Reduced deforestation and prevention of desert encroachment in the northern parts of the Country

Despite these benefits, the use of coal for electricity generation also have some short comings most of which are centered on environmental pollution. However the development of clean coal technology has considerably reduced these green house emission effects.

1.3 Statement of research problem

Since the discovery of petroleum in Nigeria, the use of coal for electricity generation, cooking, heating up houses in the cold period to create warmth, e.t.c, has been neglected in spite of its abundance in the country. This results to constant failure in power supplies, political and economical instability due to insufficiency and increase in price of petroleum product. Therefore, against the backdrop of abundant proven reserves of coal, analyses of coal properties for their suitability in power generation can significantly contribute to Nigeria's energy mix. The generation of electricity in Nigeria has suffered a major setback

due to unavailability of data on Nigerian coal for investors. To readily attract prospective investors, it is pertinent to readily make available the properties of Nigerian coals that are critical for electricity generation.

1.4 Aim and Objectives

The aim of this research is to determine the properties of coal from four deposits in Nigeria which include Kurumu (Gombe State), Garin-maiganga (Bauchi State), Gindi-akwati (Plateau State) and Ogboyoba (Kogi State) thereby enriching the repository of existing data on properties of Nigerian coals in power generation.

The specific objectives of the research are:

i) To carry out proximate and ultimate analyses of the coal samples
ii) To determine the calorific values of the coal samples
iii) To carry out thermogravimetric analysis of the coal samples
iv) To determine the ash fusion temperature, auto-ignition temperatures of coal samples and carry out ash analysis of the coal samples
v) To characterize the coal samples and To compare the results with existing standards and make recommendations on the use of the coal from each deposit for power generation

1.5 Significance of the Research

With the world's industrial giants such as the United States of America, China, Germany etc, heavily depending on coal for electricity generation, Nigeria cannot exclude herself from benefitting from this resource which she has in abundance. This research therefore has helped to determine the suitability of some of the Nigerian coals for use in coal-fired power plants not only in Nigeria, but as an export product to other coal-consuming countries around the world. This will assist potential investors in Nigerian power sector to make a decision on the profitability of using each deposit as a source for power generation.

1.6 Scope of research

This research covers analyses of coal samples from four deposits in Nigeria which include Kurumu (Gombe State), Garin-maiganga (Bauchi State), Gindi-akwati (Plateau State) and Ogboyoba (Kogi State). Analyses carried out were proximate analysis, ultimate analysis, determination of calorific value, thermogravimetric analysis, ash composition analysis, ash fusion temperature and auto-ignition temperature to assess their suitability for electric power generation. From the analyses carried out, the coal samples were characterized and the appropriate clean coal technology was recommended.

CHAPTER TWO

LITERATURE REVIEW

2.1 Availability of coal in Nigeria

Coal occurs in several areas in Nigeria and ranges from bituminous to lignite. The coal deposits of the Anambra Basin, located in southeastern Nigeria, appear to contain the largest and most economically viable coal resources (Ministry of Mines and Steel Development, 2010). This basin covers an area of approximately 1.5 million hectares and is constrained by the Niger River on the west, the Benue River on the north and the Enugu escarpment on the east. The coal is

predominantly in one seam that outcrops along the eastern side of the basin at the base of the Enugu escarpment and dips gently toward the centre of the basin. Available data shows that coal of various grades occurs in about 22 coal fields spread in over 13 States of the Nigerian Federation. The existing/potential coal mines in Nigeria are shown in Table 2.1 below:

S/N	Mines Location	State	Type of Coal	*Estimated Reserves	*Proven Reserves	Mining method
1	Okpara Mine	Enugu	Sub-Bituminous	100	24	Underground
2	Onyeama	Enugu	Sub-Bituminous	150	40	Underground
3	Ihioma	Imo	Lignite	40	N.A	Open-cast
4	Ogboyoba	Kogi	Sub-Bituminous	427	107	Opencast/ Underground
5	OgawashiAzagba/ Obomkpa	Delta	Lignite	250	63	Opencast/ Underground
6	Ezimo	Enugu	Sub-Bituminous	156	56	Opencast/ Underground
7	Inyi	Enugu	Sub-	50	20	Opencast/

			Bituminous			Underground
8	Lafia/Obi	Nasarawa	Bituminous (Cokable)	156	21,42	Opencast/ Underground
9	Oba/Nnewi	Anambra	Lignite	30	N.A	Underground
10	Afikpo/Okigwe	Ebonyi/Imo	Sub-Bituminous	50	N.A	Underground
11	Amansiodo	Enugu	Bituminous (Cokable)	1000	N.A	Underground
12	Okaba (Odagbo)	Kogi	Sub-Bituminous	250	3	Opencast/ Underground
13	Owukpa	Benue	Sub-Bituminous	75	75	Open
14	Ogugu/Awgu	Enugu	Sub-Bituminous	N.A	N.A	Underground
15	Afuji	Edo	Sub-Bituminous	N.A	N.A	Underground
16	Ute	Ondo	Sub-Bituminous	N.A	N.A	Underground
17	Doho	Gombe	Sub-Bituminous	N.A	N.A	Underground
18	Kurumu	Gombe	Sub-Bituminous	N.A	N.A	Underground
19	Lamja	Adamawa	Sub-Bituminous	N.A	N.A	Underground
20	Garin maiganga	Bauchi	Sub-Bituminous	N.A	N.A	Underground
21	GindiAkwati	Plateau	Sub-Bituminous	N.A	N.A	Underground
22	Jamata Koji	Kwara	Sub-Bituminous	N.A	N.A	Underground

Table 2.1: Existing/Potential Coal Mines/Sites in Nigeria
Source: Kibiya, 2012 ** Expressed in Million Tonnes*

The proven reserves so far in the country are 639 million tons while the inferred reserves are about 2.75 billion tones, consisting approximately of 49% sub-bituminous, 39% bituminous and 12% lignitic coals.

Up to the early 1960s, coal production was significant and dominated the commercial energy supply in some countries. It was also the predominant source of energy for rail transportation and electricity generation.

Coal presently does not contribute to Nigeria's electricity generation. Of the new generation stations under construction, only the Oji River Power Plant with a planned capacity of 20 MW is coal-fired (Sambo *et al*., 2010).

2.2 Previous Research on Nigerian Coals

Kibiya (2012) collected and analysed five 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 coals, while Okaba coal was found to be sub-bituminous B coal. Lamja coal was found to be lignite A coal. Findings also revealed a dependence of coal density, reactivity and activation energies on coal type and particle size. The study concluded that Lafia-Obi, Okpara and Onyeama coals may be used for power generation. Lamja and Okaba coals were not recommended for power generation because of their low calorific values.

Laudan (2008) analyzed coal samples from Enugu State (Okpara West Area, Okpara West Bank and Onyeama) and Gombe State (Doho and Gamawa) to determine their physical properties and to classify them by rank using proximate analysis. An electric furnace fitted with a 3KW heating element capable of generating heat to a temperature of 900^{o}C was constructed and used to determine the auto-ignition temperatures, reactivity and activation energies of the various coal samples.

Findings revealed that the reactivity and activation energies of the various coal samples depend on the coal type, source and particle size. While for some coals, the reactivity and activation energies increase with decrease in particle size (Okpara West Bank coal), in others, reactivity and activation energies decrease with decrease in particle size (Onyeama, Okpara West Area and Doho coals). However, in all cases, reactivity increases with increase in temperature.

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 coke. Parameters that were used include the shatter index, expressed as percentage stability and friability and mecum index. The highest cumulative percentage stability and the lowest cumulative percentage friability was 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 carbonisation of Onyeama and Lafia-Obi coal samples gave an improved and satisfactory percentage stability and friability for semi-cokes.

Suleiman (1992) analysed the moisture content and volatile matter of some Nigerian coals. The results obtained showed that the three sample locations (Enugu, Lafia and 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.

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. The Okaba coals have a little bit higher ash and sulphur contents than the Enugu coals but much lower values when compared to Lafia coals.

2.3 Classification of coal

There are four main classifications of coal, arising from progressive variation in their carbon content.

i. Peat: contains about 60% carbon.

ii. Lignite coal: contains about 65% carbon.

iii. Sub bituminous coal: contains about 70% carbon.

iv. Bituminous coal: contains about 85% carbon.

v. Anthracite coal: contains about 94% carbon.

The American Standard for Testing and Materials (ASTM D388) classification system distinguishes among four coal classes, each which is sub-divided into several groups as shown below:

Table2.2: ASTM Coal Classification by Rank

Class/Group	***Fixed Carbon[a]*** ***(%)***	***Volatile Matter[b]*** ***(%)***	***Heating Value[b]*** ***(Btu/Ib)***
Anthracitic			
Meta-anthracite	> 98	< 2	–
Anthracite	92 – 98	2-8	–
Semi-anthracite	86 – 92	8 – 14	–
Bituminous			
Low-volatile	78 – 86	14 – 22	–
Medium-volatile	69 – 78	22 – 31	–
High-volatile A	< 69	>31	> 14,000
High-volatile B	–	–	13,000-14,000
High-volatile C	–	–	10,500-13,000[c]
Sub-bituminous			
Sub-bituminous A	–	–	10,5000-11,500[c]
Sub-bituminous B	–	–	9,500-10,500
Sub-bituminous C	–	–	8,300-9,500[c]
Lignitic			
Lignite A	–	–	6,300-8,300
Lignite B	–	–	< 6,300

[a]Calculated on dry, mineral-matter-free coal. Correction from ash to mineral matter is made by means of the Parr formula: mineral matter – 1.08[percent ash + 055[percent sulfur]]. Ash and sulfur are on a dry basis.
[b]Calculated on mineral-matter-free coal with bed moisture content.
[c]Coals with heating values between 10,500 and 11,500Btu/lb are classified as high volatile C bituminous if they posses caking properties or as sub-bituminous A if they do not.
Source: Miller, 2005.

Classification of coal samples according to the ash and sulphur contents is show in the table below:

Table 2.3: Ash and Sulphur classification of coals

Classification	**Composition range (%)**
Ash content	
High ash	>15.0

Medium ash	8.0-15.0
Low ash	<8.0
Sulphur content	
High sulphur	>3.0
Medium sulphur	1.0-3.0
Low sulphur	<1.0

Source: Tavoulareas et al., 1995

2.4 Clean Coal Technology

The clean coal based generation technologies include circulating fluidized bed combustion (CFBC), pressurized fluidized bed combustion (PFBC), integrated gasification combined cycle (IGCC) and top cycle, as would be considered in this work must be critically analyzed to know which ones are most suitable in the Nigerian scenario. For Nigeria to meet both domestic and industrial energy demand with minimal environmental consequences, clean coal power generation should be integrated in the Nigerian electricity mix (Essien and Igweonu, 2014).

2.4.1 Circulating Fluidized Bed Combustion (CFBC)

This offers a viable alternative to conventional pulverized fuel – flue gas desulphurization (PF - FGD). It is particularly suitable for plants rating below 200MW. As the name implies, coal is burnt with air in a circulating fluidized bed. Crushed coal and limestone are fed into the fluidized bed, where the limestone exposed to the heat of coal combustion undergoes calcinations to produce lime. The flue bed consists mainly of coal, limestone reaction products and ash. Circulating fluidized bed operates at relatively low temperatures, which favors low NOx formation while SO_2 is captured by the lime. Due to the relatively low temperatures at which the bed operates, circulating fluidized bed unit with rating higher than 500MW is yet to be constructed.

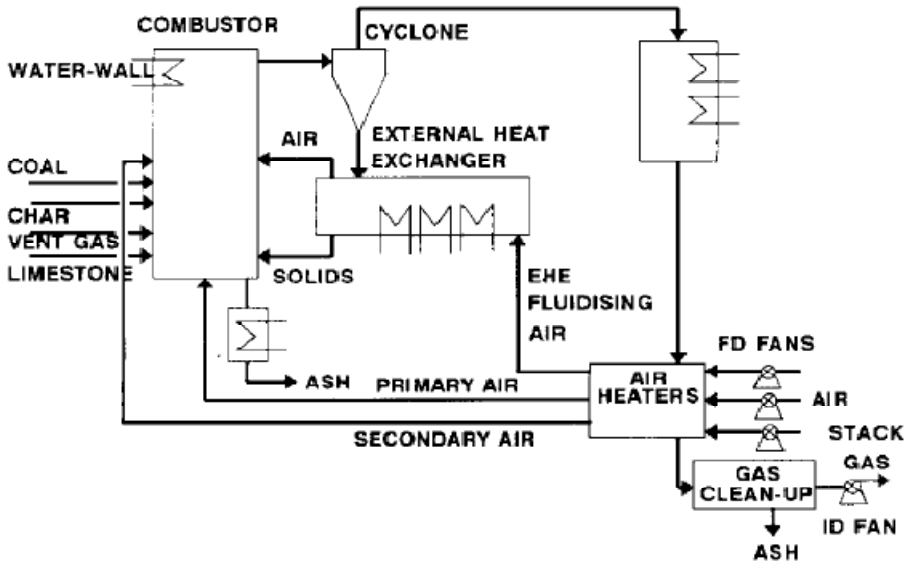


Figure 2.1: Circulating Fluidized Bed Combustor (Essien and Igweonu, 2014)

2.4.2 Pressurized Fluidized Bed Combustion (PFBC)

Here, coal is burnt at elevated pressure in a deep bubbling bed. It is just a modified CBFC. As in CBFC, the fluidized bed contains sorbent – limestone which when exposed to heat undergoes calcinations to produce lime for SO_2 retention. Flue gas at a high temperature coming out of the combustor is passed through a gas turbine to produce electricity.

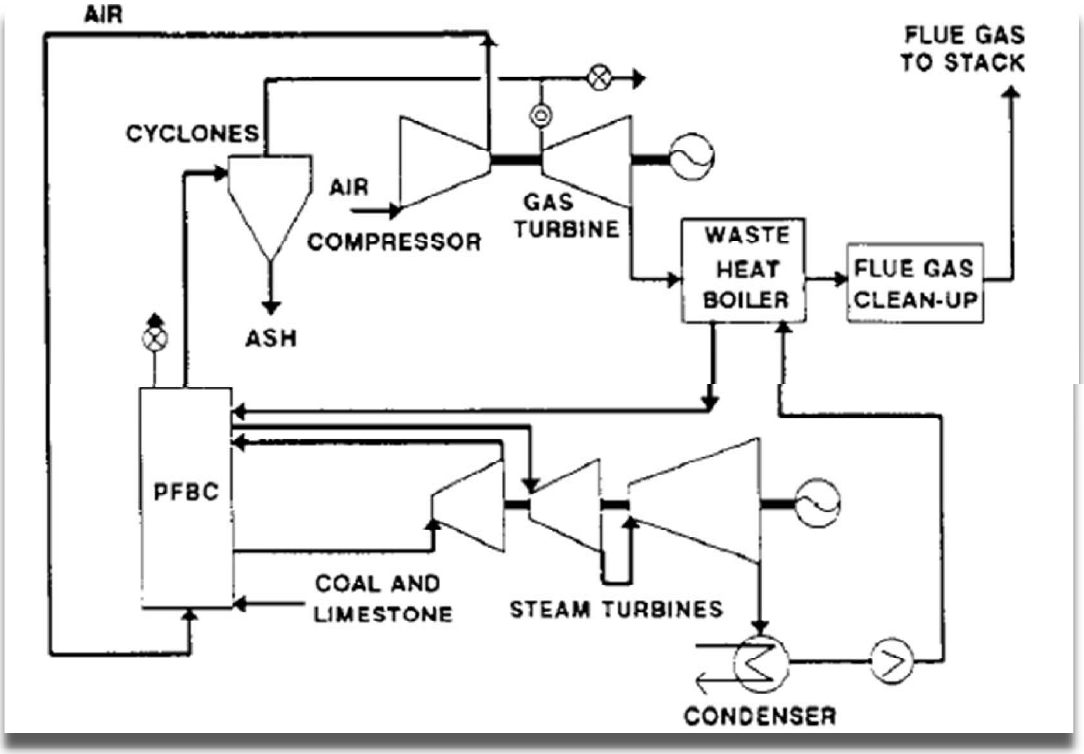


Figure 2.2: Pressurized Fluidized Bed Combustor (Essien and Igweonu, 2014)

2.4.3 Integrated Gasification Combined Cycle (IGCC)

The IGCC technologies offer utility a flexible design option and can be adopted to meet current and future needs. The gasification of coal has been a popular technology in the production of chemicals from coal, synthesize gas (syngas) and as fuel in power plants. Synthesize gas from the gasifier can be cleaned of particulate and sulphur and either used as fuel for electricity production in gas turbine or further processed to create methane and put into a pipeline to replace natural gas.

Alternatively, syngas also can be sent to a chemical processing unit to produce fertilizer, clean transportation fuels, and hydrogen as final product.

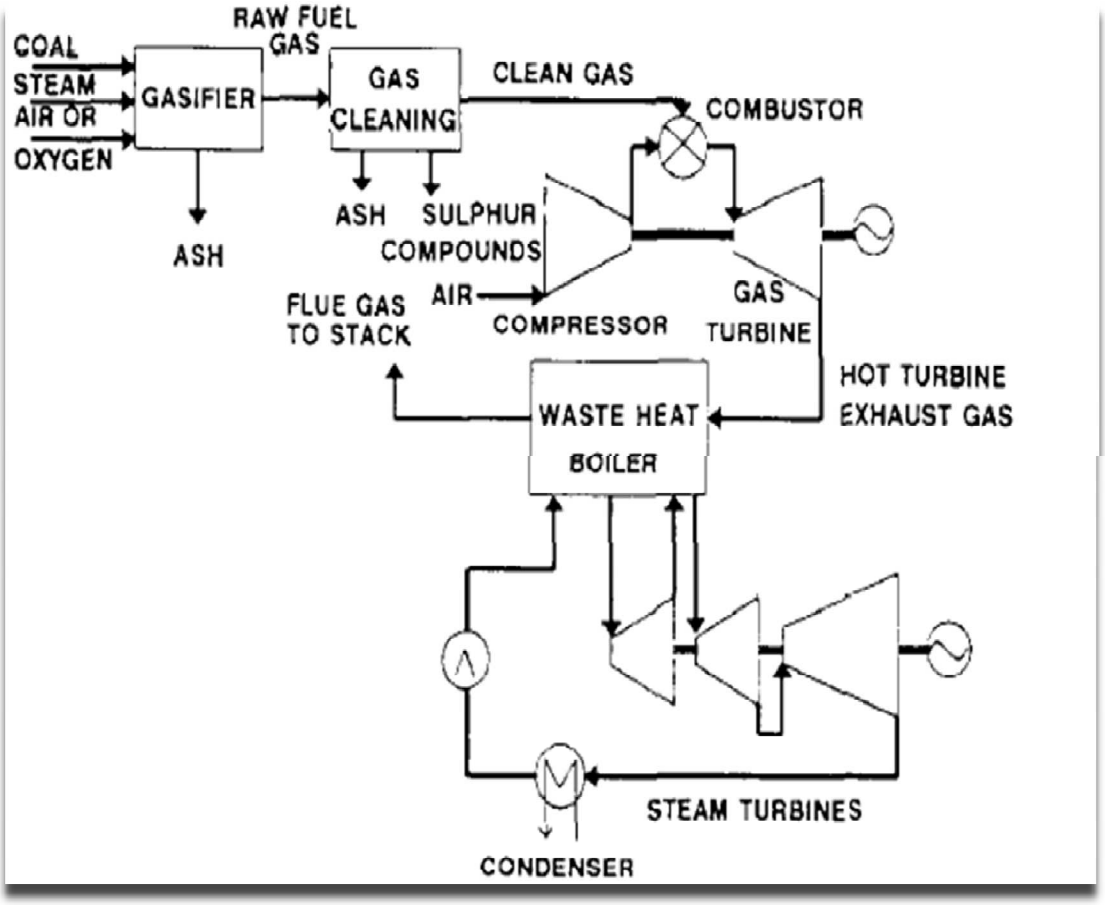


Figure 2.3: Basic Feature of IGCC (Essien and Igweonu, 2014)

Finely ground coal is mixed with oxygen or air and steam in a gasifier. The oxygen is provided by air separation unit, and the partial oxidation of coal raises the temperature to assure complete carbon conversion with steam to form a gas mixture that is largely hydrogen and carbon monoxide which is the syngas. The gas is cleaned and burned in a combustor of gas turbine to produce electricity. Hot exhaust from the gas turbine raises steam in a waste heat boiler which is sent to a steam turbine in the combine – cycle power block for additional electricity production.

2.4.4 Top Cycles

The top cycle as shown in figure 2.4 has a pressurized fluidized bed gasifier and a CFBC compartment for burning of residual char.

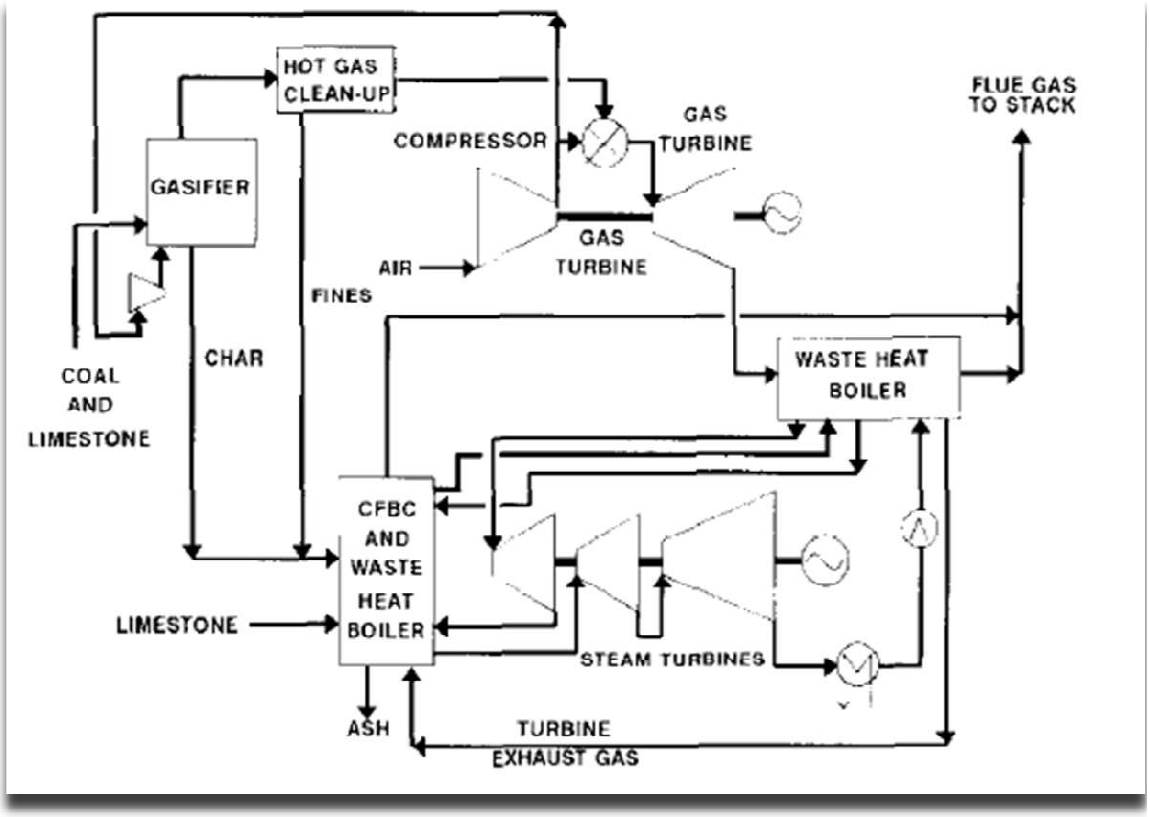


Figure 2.4: Basic Features of Top Cycle (Essien and Igweonu, 2014)

The gasifier is pressurized and is designed to operate at a high temperature of about 950^0C – 1000^0C. Here, about 80% of the mass of the coal is converted into gas of low calorific value and about 90% of the sulphur content in the coal is retained using limestone.

The low calorific value gas is fired in a high efficient turbine, and exhaust gas is used in a waste heat boiler integrated into the steam system. The residual gasifier char is fed to the CFBC unit to raise steam for a reheat steam cycle. Reheating, single or double, increases the cycle efficiency by raising the mean temperature of heat addition to the cycle.

Clean coal based generation has been a major source of power in so many countries with coal deposits like Nigeria. The economic growth of countries like the USA, China, South Africa, Australia, India, Germany, to mention just a few has correlation with their level of generation which is boosted by clean coal based generation (Essien and Igweonu, 2014).

Nigeria with estimated coal reserve of 2.734 billion tones spread across 22 locations cannot continue to solely depend on oil and hydro sources for its power needs in the midst of continuous widening of the gap between Nigeria's electricity demand and supply.

Nigeria must key into one or more of these clean coal generation technology options if it is to come out of the dark that it has been for over a century. To reinforce its economic and social development and compete economically with the developed countries of the world, the integration of clean coal power generation in the Nigerian electricity mix is imperative. This will not only guarantee the steady power supply that has eluded it for over a century, but will also ensure security of energy supply and stability in energy price which are recipes for economic development.

Both the CFBC and IGCC are recommended technology for electricity generation with Nigerian coals. Gindi-akwati coal deposit was characterized as a low grade coal with relatively low calorific value. The CFBC technology can be utilized by the Gindi-akwati coal deposit due to the relatively low temperature at which the bed operates and suitable for plants rating below 200MW.

Kurumu, Garin-maiganga and Ogboyoba coal deposits on the other hand were found to have high calorific values and hence IGCC technology is recommended for these coal deposits. This is because IGCC offers flexibility in design and in addition to generating electricity, syngas which can be used in fertilizer production could also be processed.

2.5 Terms and Significance of Various Parameters in Proximate Analysis

2.5.1 Fixed carbon

Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough heating value of coal.

2.5.2 Volatile Matter

Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal. Thus the volatile matter is an index of the gaseous fuels present. Typical range of volatile matter is 20 to 35%.

Volatile Matter,

i) Proportionately increases flame length, and helps in easier ignition of coal.
ii) Sets minimum limit on the furnace height and volume.
iii) Influences secondary air requirement and distribution aspects.
iv) Influences secondary oil support

2.5.3 Ash Content

Ash is an impurity that will not burn. Typical range is 5 to 40%

Ash,

i) Reduces handling and burning capacity.
ii) Increases handling costs.
iii) Affects combustion efficiency and boiler efficiency
iv) Causes clinkering and slagging.

2.5.4 Moisture Content

Moisture in coal replaces combustible matter; it decreases the heat content per kg of coal. Typical range is 0.5 to 10%

Moisture,

i) Increases heat loss, due to evaporation and superheating of vapour
ii) Helps, to a limit, in binding fines.
ii) Aids radiation heat transfer.

2.6 Ultimate Analysis

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc. The ultimate analysis of coal involves determination of the weight percent carbon as well as Sulphur, nitrogen and oxygen (usually estimated by difference). Trace elements such as chlorine, mercury and other elements that occur in coal are often included as part of this analysis.

Carbon determination includes carbon present as organic carbon occurring in the coal substance and any carbon present as mineral carbonate. The hydrogen determination includes hydrogen present in the organic materials as well as hydrogen in all of the water associated with the coal.

In the absence of evidence to the contrary, all of the nitrogen is assumed to occur within the organic matrix of the coal. On the other hand, Sulphur occurs in three forms in coal: as organic Sulphur compounds; as inorganic sulphides that are, for most part, primarily the iron sulphides pyrites and marcasite (FeS_2); and as inorganic sulphates (e.g. Na_2SO_4, $CaSO_4$).

2.7 Calorific Value

Calorific value is a measure of the energy that a given quantity of coal will produce when burned, expressed in Joule/Kilogram (J/kg). Calorific value determines quantity of coal per unit of output and coal mass flow. It also affects the capacity of the furnace, pulverizer, burners, feeding systems, fans, pollution control equipment and coal and ash handling systems (Carpenter *et al.*, 2007).

2.8 Thermogravimetric analysis

Thermogravimetric analysis (TGA) is an analytical technique used to determine materials stability and its fraction of volatile component by monitoring the weight change that occurs as the material is heated.

In most cases, TGA is performed in an oxidative atmosphere with a linear temperature ramp. The maximum temperature is selected so that the specimen weight is stable at the end of the experiment. This implies that the reaction is completed by burning off all the moisture and volatile matter leaving only the ash behind.

In cases where various weight losses are not completely discrete, use of a derivative thermogravimetric curve is recommended. In DTG, the rate of weight loss of the sample is recorded as a function of temperature. The DTG curve consists of series of peaks, corresponding to the various steps in the decomposition of the sample. The area under each peak is proportional to weight loss.

TGA and DTG studies are useful tools for the determination of combustion characteristics e.g peak temperature, burnout temperature and activation energy of coals and chars as well as other combustible materials (Kizgut *et al*., 2003).

Peak temperature of maximum weight loss rate (Tp) is usually considered as the most important feature of DTG profiles. Coals with lower peak maxima temperatures are generally ignited and burned easily (Marinov *et al*., 2009).

In addition to weight changes, some instruments also record the temperature difference between the specimen and one or more reference pans (Differential Thermal Analysis, DTA) or the heat flow into the specimen pan compared to that of the reference pan (Differential Scanning Calorimetry, DSC). Differential Scanning Calorimetry is used to measure the heat of combustion.

2.9 Fusibility of coal ash

The tendency of coal ash to slag under high temperatures is a serious matter of concern for companies that utilizes gasifiers and boilers. Melting of the inorganic material in coal is responsible for the slagging and clinker formation that is observed when coal is subjected to high temperatures.

Clinker formation can lead to channel burning, resulting in pressure drop within a gasifier, which ultimately results in an unstable gasifier (Van Dyk *et al*., 2005). Slagging occurs when the ash heats up to a point where particles within the ash start to sinter and fuse. Eventually, a liquid slag is produced (Wall *et al*., 1996).

Removal of slag within a non-slagging gasifier, as well as clinkers, forces the gasifiers out of production, resulting in a loss of production time which in turn results in profit loss.

It is thus critically important to determine the fusing characteristics and potential of the coal source being used. The temperature range to determine the AFT of a coal sample lies between 1000 and 1600°C. During the heating process the four different temperatures will be measured. These four temperatures are:

i) Initial deformation temperature (IDT)

ii) Softening temperature (ST)

iii) Hemispherical temperature (HT)

iv) Flow temperature (FT)

The temperature at which the tip of the pyramidal coal ash sample deforms and the rounding of the apex takes place is known as the **deformation temperature.** This temperature is also known as the initiation of the ash melting process. The second temperature, or **softening temperature,** is reached when the width of the heated pyramidal coal sample, is equal to its height. At this point the critical viscosity is reached.

The **hemispherical temperature** is the next temperature and can be identified by the shape of the sample deformed up to a point where the height of the sample is half of its width. The last temperature is the **flow temperature** and at this point the ash is supposed to be completely molten and freely fluid.

2.10 Ash Composition Analysis

The ash remaining after coal has burned, consists of different mineral species. As part of the characterization of the coal samples the ash must also be analysed in order to gain insight into the types of minerals present because these minerals also affects the ash fusion temperature. The compositions of the ashes are in terms of the oxides of Si, Al, Fe, Ti, P, Ca, Mg, Na, K and S.

2.11 Auto-Ignition temperature and coal storage

Uncertainty in the availability and transportation of fuel necessitates storage. Stocking of coal has its own disadvantages like build-up of inventory, space constraints, deterioration in quality and potential fire or explosion hazards. Other minor losses associated with the storage of coal include oxidation, wind and carpet loss. A 1% oxidation of coal has the same effect as 1% ash in coal, wind losses may account for nearly 0.5 – 1.0% of the total loss.

The main goal of good coal storage is to minimise carpet loss and the loss due to spontaneous combustion. Formation of a soft carpet, comprising of coal dust and soil causes carpet loss. On the other hand, gradual temperature builds up in a coal heap, on account of oxidation may lead to spontaneous combustion of coal in storage.

The measures that would help in reducing the carpet loses are as follows:

i) Preparing a hard ground for coal to be stacked upon.

ii) Preparing standard storage bays out of concrete and brick.

Coal for power generation has to be stored in various capacities before usage. Storage conditions affect self-ignition of the coal without external aid.

The lowest temperature at which this ignition takes place is the auto-ignition temperature. The storage condition such as particle size and temperature affects auto-ignition temperature.

There is no definite temperature at which coal bursts into flame, it depends on the surrounding conditions. The phenomenon of flame from coal is due to the combustion of volatile matter driven off from the coal, the character of such matter varying under different conditions. Hence, the temperature at which the coal flames varies widely and is dependent upon surrounding conditions.

The volatile ratio of coal also determines the tendency of coal to explode. Volatile ratio is defined as the ratio of volatile matter divided the summation of volatile matter and fixed carbon. Coals having volatile ratio less than 0.12 do not present explosion tendencies. However, coals with volatile ratio above 0.12 present explosion hazards.

The glow Point of coal is also Ignition Temperature of coal. If a sample of coal is heated carefully so that the rate of heating is uniform throughout the sample it will be found that at a certain very definite temperature the sample will start flaming and assume a uniform glow. This is known as the ignition temperature of the coal. The glow point is the self ignition temperature of coal (Arms, 2007).

2.12 Coal quality requirements for coal-fired plants

Boiler design is not an exact science, and operators tend to establish optimum coal and operating conditions based on operational experience. Specification values derived from both the literature and survey of power-plant are shown in table 2.3 (Carpenter *et al*., 2007). These properties act as a guide or reference for coal to be used in generating power.

Table 2.4: Some typical bituminous coal quality requirement for pulverized coal-fired plant

Parameter	Desired values	Typical limits
Heating value, MJ/kg ar	High	Min 24-25 (23)
Moisture, % ar	4-8	Max 12
Volatile matter, % mf	20-35	Min 20 (side-fired furnace)
	15-20	Max 20 (down-fired furnace)
Ash, % mf	Low	Max 15-20 (max 30)
Sulphur, % daf	Low	Dependent on local pollution regulation
Nitrogen, % daf	Low	(0.8-1.1), dependent on local pollution regulation
Chlorine	Low	Max 0.1-0.3 (max 0.5)
HGI	High	Min 50-55 (min 39)
Ash Analysis, wt % ash		
Silicon dioxide		(45-75)
Aluminum oxide		(15-35)
Titanium oxide		(0.4-2.2)
Ferric oxide		(1-12)
Calcium oxide		(0.1-2.3)
Magnesium oxide		(0.2-1.4)
Sodium oxide		(0.1-0.9)
Potassium oxide		(0.8-2.6)
Sulphite		(0.1-1.6)
Phosphorus pentoxide		(0.1-1.5)
Ash fusion temperature, ^{0}C		
Initial Deformation	High	(>1075)
Softening	High	(>1150)
Hemispherical	High	(>1180)
Fluid	High	(>1225)
Maceral Analysis, %		
Vitrinite		55-80
Exinite		5-15
Inertinite		10-25

**Typical limits refer to those normally quoted; those in brackets indicate outer limits acceptable in some cases.*
Source: Carpenter et al., 2007

2.13 Power generation from low grade coals

Table 2.4 above specifies the ideal qualities of coals typically for bituminous pulverized coal power generation; however, low grade coals (of high ash, high sulphur and high moisture contents) are successfully being used for power generation. The usual practice is internationally is to trade high quality coals while low grade coals are used for power generation and other uses. Table 2.5 summarises the characteristics of low grade, high ash coals used by some recently constructed pulverized-coal fired plants located in different geographical locations across the world. This was extracted from results of the case studies of recently constructed coal and gas-fired power plants carried out by IEA and published in 2007.

Table 2.5: Characteristics of low grade coals used by some power stations

	Power stations			
Parameters	**Niederausseum**	**Genese phase 3**	**Suratgarh unit 5**	**Majuba**
Location	Germany	Canada	India	South Africa
Coal type	Lignite	Sub-bituminous	Bituminous blend	Bituminous
Gross calorific value (MJ/kg)	12.24	17.9	14.7*	21.8
Ash, %	2-12*	19.4	30(45*)	18.6-39.8
Moisture, %	51-58*	20	10*	1.7-4.4
Sulphur, %	0.2	0.2	0.5*	0.7-1.7
Gross power output at MCR, MW	1012	495	250	Units 1-3: 657 Units 4-6: 713

Source: International Energy Agency, 2007
*Note: All values as received, MCR: Maximum Continuous Rating, *Design values/range*

2.14 Research Gap

Most of the researches conducted on Nigerian coals is focused on metallurgical applications. The few research work carried out on Nigerian coals have not comprehensively characterized all the coal deposits based on the contemporary requirements for power generation. The usual tests such as proximate and ultimate analysis have extensively been carried out.

However, contemporary tests required for comprehensive characterization of Nigerian for power generation such as thermogravimetric and differential scanning calorimetry, ash fusion temperature and auto-ignition temperature analysis have rarely been carried out.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Coal Samples

Samples, each weighing 3kg, were obtained from the four coal deposit mine sites in Nigeria: Kurumu (Gombe State), Garin-maiganga (Bauchi State), Gindi-akwati (Plateau State) and Ogboyoba (Kogi State) deposits. These samples were stored in appropriately labeled air-tight containers to retain their as-received conditions.

Coal samples from each site were used at the laboratory of the Nigerian Geological Survey Agency, Kaduna for proximate analysis, ultimate analysis, determination of gross calorific values, ash fusion temperature, ash composition and auto-ignition temperatures.

Thermogravimetric analysis was conducted in the laboratory of Beijing university of technology, China.

3.2 General Sample Preparations

The principle of mixing and then dividing, using mechanical and manual method as described in ISO 13909-4:2001 was used to generate a representative pulverized sample of each coal, and then preparing each sample to the desired analytical specifications using an array of sample preparation equipment. Crushing of the samples from a top-size of 150mm to a suitable size distribution range of 12.5 – 50.0mm was carried out using a crusher.

An automatic sieve shaker was used for sieving the samples to the desired size distribution required for each test. A hand rifler was then used to split the samples into sub-samples.

3.3 Proximate Analysis

3.3.1 Moisture Content

The air-oven method was used to analyze for moisture content. Coal samples passing a 212µm test sieve was stored in the proximate analysis room for 30 minutes before the start of the test. Crucibles with lids were heated for 1.5 hours before the start of the test.

The crucibles and lids were cooled for 10 minutes and then put in a desiccator cabinet for 10 minutes. An electronic balance was then used to weigh the crucibles before uniformly spreading 1.000g of conditioned sample and recording the mass of the crucibles and contents. The crucibles and contents were then loaded into the air oven at a temperature of 105^{o}C for 1.5 hours, and such that the atmosphere or flow within the oven was changed at a rate five times per hour.

The crucibles with dried samples was removed from the oven, the lids replaced and allowed to cool for 10 minutes, and then placed in the desiccator cabinet for another 10 minutes before being weighed. The moisture content of the coal was calculated from the loss in mass. This was as specified in ASTM D3173.

3.3.2 Volatile matter

Coal samples passing a test sieve with an aperture of 212µm was stored in the proximate analysis room for at least 30 minutes before commencement of the test. The crucibles and lids (crucibles uncovered) were placed in the volatile furnace. When the furnace attained a temperature of 905^{o}C, the crucible and lids were removed and allowed to cool for 60 minutes to room temperature. 1.000g of coal samples were put into each crucible. Each crucible was lightly tapped on a clean hard surface a few times to form an even layer on the bottom. The crucibles were then loaded into the furnace with temperature maintained at 905^{o}C and timing with a stopwatch immediately commences. A calibrated type-K thermocouple was used to verify the temperature range and was positioned in the middle of the samples. After 7 minutes, the crucibles were removed from the furnace and placed on an asbestos sheet and allowed to cool for 60 minutes to attain room temperature. Each crucible was then weighed and the difference calculated to determine volatile matter. This was in accordance with the method specified in ISO 562:1998.

3.3.3 Ash Content

Ash is simply the non-combustible inorganic residue which remains after coal is completely burned. Coal samples passing a test sieve with an aperture of 212µm sieve size was stored in the proximate analysis room for 30 minutes before the test commenced. After the crucibles and lids were conditioned in the furnace and allowed to cool to room temperature, 1.000g of coal samples were placed into each crucible. The crucibles were loaded into the furnace equipped with a pre-programmed temperature controller. The furnace temperature was ramped to 500^{o}C over a period of 60 minutes; held at 500^{o}C for 30 minutes; ramped to 815^{o}C over a period of 60 minutes; and held at 815^{o}C for 60minutes. The temperature was verified with an external type-K thermocouple when the furnace stabilized at 815^{o}C. At the end of this cycle, the crucibles were removed and placed on an asbestos slab to cool down for 10 minutes. At the end of 10 minutes, the crucibles were transferred to a desiccator cabinet and allowed to further cool down for 10 minutes. After this period, the crucibles were removed and weighed, with difference calculated to determine ash content. This was in accordance with the ISO 1171:1997.

3.3.4 Fixed carbon

This was calculated from the formula:

%Fixed Carbon= 100 – (%Moisture+ %Ash+ %Volatile matter) ……. (3.1)

3.4 Ultimate Analysis

Coal passing through a sieve having an aperture of 212µm was used for this analysis. Ultimate analysis was carried out making use of the TRUSPEC CHN Elemental determinator. The equipment was supplied with a reference material with known ultimate analysis result.

This reference material (Prox-Plus) was used to determine the accuracy of the CHN Elemental determinator before commencing the tests. 1.0g of sample was loaded into porous crucibles and subjected to combustion in an oxygen-rich environment. Typical run duration was about 10 minutes.

The system converts the coal catalytically to Nitrogen, CO_2 and water, which are separated with a gas chromatographic column and detected through a sensor. The results were displayed on the computer monitor in terms of percentage carbon, hydrogen and nitrogen on an air dried basis. This was based on ISO 12902 – CHN instrumental method.

Oxygen was calculated by difference on an air-dried basis as follows:

$$O_2\,(\%) = 100 - (C + H_2 + N_2 + \text{Ash} + \text{Moisture}) \quad \ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

3.5 Determination of Total Sulphur Content

Total sulphur was determined using infra-red spectroscopy method. Coal samples passing through a test sieve with an aperture of 212µm was used for determination of total sulphur content. The samples were conditioned in a dry oven at a temperature of 105^{o}C for 60 minutes, transferred into a dessicator cabinet and allowed to cool for 30 minutes. 0.35g of the coal sample was placed in a combustion system to burn in a stream of pure oxygen at a temperature of 1350^{o}C. This oxidises the sulphur content and break down the sulphur bearing compounds to form SO_2. All other infrared energy was eliminated from reaching the detector by precise wavelength filter. Thus absorption of infrared energy was attributed to only sulphur. Anhydrous magnesium perchlorate removes all the moisture, and the SO_2 flows to the infra-red detection cells where sulphur was measured by infra-red absorption detectors. SO_2 absorbs infra-red energy at a precise wavelength within the infra-red spectrum. Average run time was 3 minutes. Results were displayed automatically on the computer monitor in percentage sulphur on an air-dried basis. This was in accordance with the procedure laid down in ASTM D4239.

3.6 Determination of Calorific Value

Coal samples passing a sieve with an aperture of 212µm were used for this analysis. The calorific values of the samples were determined by burning 1.000g of coal sample in a controlled environment using the bomb calorimeter. Certified benzoic acid tablet was used to calibrate the calorimeter before starting the test.

1.000g of coal sample in a nickel-chromium crucible was placed in a high pressure atmospheric environment called a Combustion Vessel, which is surrounded by water. The sample was then ignited. The calorimeter jacket was held at a constant temperature by modulating the fan speed while the heat generated by the burning sample caused the bomb and bucket temperature to rise. The temperature of the water was measured 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 released was proportional to the gross calorific value of the sample. This was in accordance with ISO 1928:1995 specification.

3.7 Thermogravimetric and differential scanning calorimetry analyses

The thermal stability of the various phases in the samples was analysed by TG/DSC under air flow of 50mL/min. Coal samples passing through a test sieve with an aperture of 212µm were used for the test. The samples were thermally analysed by placing 25 mg of the specimens in an alumina (Al_2O_3) crucible (100mg capacity), subjected to a linear heating ramp between 200°C and 1000°C at a rate of 10°C/min and a cooling rate of 50°C/min, using a standard NETZSCH, STA 449 C Jupiter TG/DSC instrument. The test measurements were made for the mass change (loss) of the sample as a function of the temperature and the phase changes by the absorption or the emission of energy. This was in accordance with ASTM E1131 and ISO 11358.

3.8 Determination of Ash Fusion Temperature of Coal Samples

This was based on the thermal deformation of pyramid-shaped coal ash sample. Coal ash was manually shaped into pyramids and then heated in the carbolite furnace with a maximum operating temperature of 1500^0C.

Four temperatures were obtained during this test which are the;

i) Initial deformation temperature (IDT)
ii) Softening temperature (ST)
iii) Hemispherical temperature (HT)
iv) Flow temperature (FT)

The test was conducted in accordance with the ISO 540 and ASTM D1857 standards.

3.9 Ash composition analysis

The ash remaining after the coal samples have been combusted consists of mainly mineral species. As part of the determination of suitability of the coal samples for power generation, the ash must also be analysed in order to gain insight into the types of minerals present. The procedures as set out in standard ASTM D3682, 2001 was used to obtain the composition of the ash in terms of the oxides of Si, Al, Fe, Ti, P, Ca, Mg, Na, K and S. The compositions determined in percentages via the XRF- minipal 4 instrument.

Coal samples were heated to form ash. The ash was then fused with lithium tetraborate. The fused ash was place in the XRF-minipal 4 and the percentage composition of each oxide was displayed on the monitor.

3.10 Experimental procedure for determination of auto-ignition temperatures

Coal samples were crushed and pulverized into smaller particles and sieved with the automatic sieve shaker to different grades, using two sets of sieves for fine and coarse sample sizes.

1.0- 1.6mm (fine)

2.0 - 3.5mm (coarse)

Each grade of coal was weighed with an electronic weighing balance and loaded into the furnace.

The coal sample was heated and its temperature was continually monitored until smoking and flaming started. The temperature when the flaming was uniform and the coal sample began to glow was noted. The glow point was used to establish and analyze the self ignition temperature of the coal samples. This was in accordance with ASTM E2021.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Results of the analyses conducted on the four coal deposits in Nigeria, to determine their properties using the proximate and ultimate analyses, the calorific value, ash analysis, ash fusion temperature and auto-ignition temperature were carried out in the Nigerian Geological Survey Agency, Kaduna and the thermogravimetric analysis conducted in BUT university laboratory Beijing, China are presented in this chapter:

4.2 Proximate Analysis

4.2.1 Result of proximate analysis obtained from the four coal samples are shown in the table below:

Table 4.1: Results of proximate analysis of the coal samples in percentage

PARAMETERS	KURUMU	GARIN-MAIGANGA	GINDI-AKWATI	OGBOYOBA
Moisture content	3.93	6.24	8.41	10.27
Ash content	7.99	13.43	41.68	6.59
Volatile matter	41.63	39.12	28.69	39.87
Fixed carbon	46.45	41.21	21.22	43.30

4.2.2 Result of volatile ratios obtained from the four coal samples are shown in the table below:

Table 4.2: Results of volatile ratio of the coal samples

COAL SAMPLES	VOLATILE RATIO
Kurumu	0.47

Garin-maiganga	0.49
Gindi-akwati	0.58
Ogboyoba	0.48

4.3 Ultimate analysis

Results of ultimate analysis obtained from the four coal samples are shown in the table below:

Table 4.3: Results of ultimate analysis of the coal samples in percentage

PARAMETERS	KURUMU	GARIN MAIGANGA	GINDI AKWATI	OGBOYOBA
Carbon	72.36	62.96	38.98	64.96
Hydrogen	5.13	3.94	2.66	4.74
Oxygen	9.09	11.91	6.47	11.82
Nitrogen	1.27	1.15	1.53	1.30
Sulphur	0.20	0.37	0.27	0.31

4.4 Calorific values

Results of the calorific values of the coal samples are shown in the table below:

Table 4.4: Results Calorific values of the four coal samples

Gross calorific value	Coal samples			
	Kurumu	Garin Maiganga	Gindi Akwati	Ogboyoba
MJ/kg	25.71	23.37	11.56	24.78
Btu/lb				

(1MJ/kg=429.923Btu/lb)	11,053.32	10,047.30	4,969.91	10,653.49

4.5 Thermogravimetric and differential scanning calorimetry analyses

4.5.1 Results of thermogravimetric and differential scanning calorimetry analyses of Kurumu coal deposit as shown graphically in the figure below:

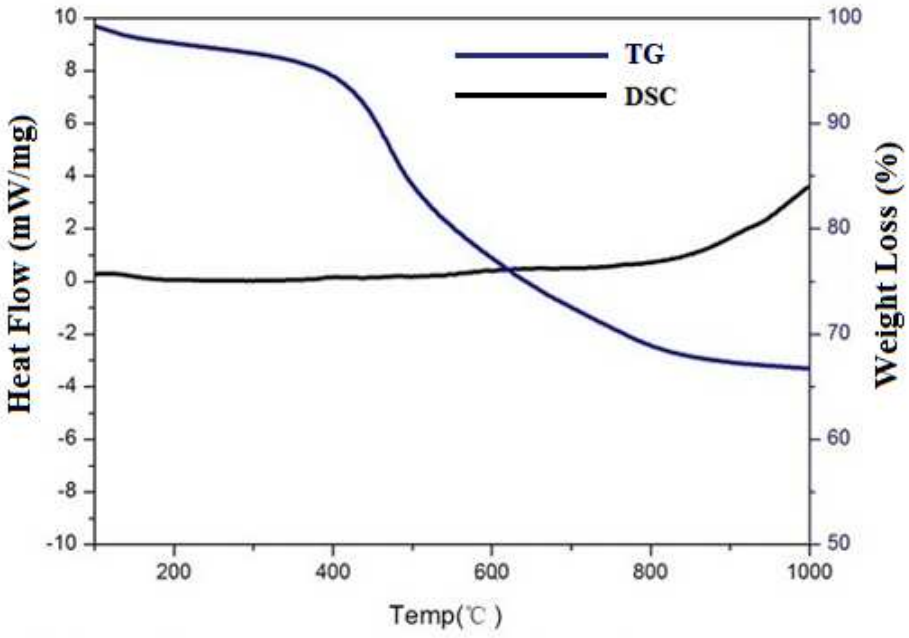


Figure 4.1: TG-DSC of Kurumu Coal Deposit

4.5.2 Results of thermogravimetric and differential scanning calorimetry analyses of Garin maiganga coal deposit as shown graphically in the figure below:

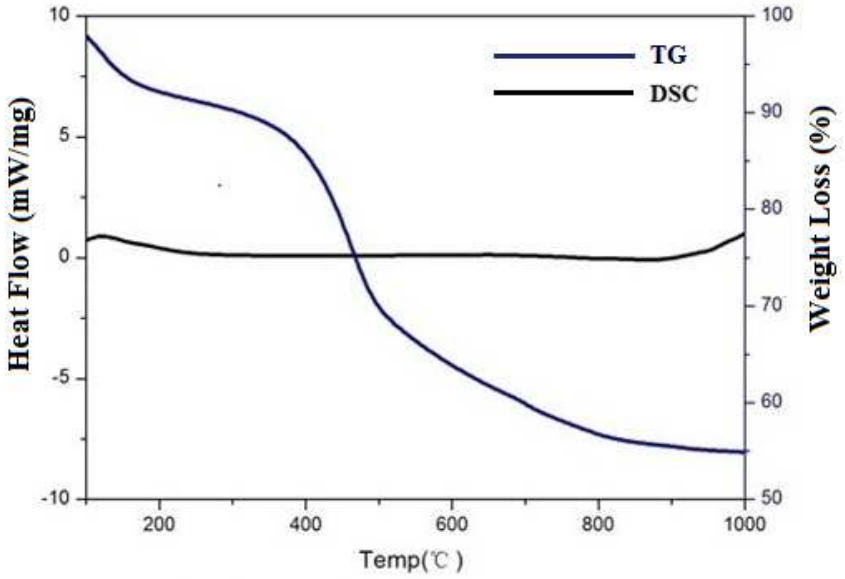


Figure 4.2: TG-DSC of Garin Maiganga Coal Deposit

4.5.3 Results of thermogravimetric and differential scanning calorimetry analyses of Gindi akwati coal deposit as shown graphically in the figure below:

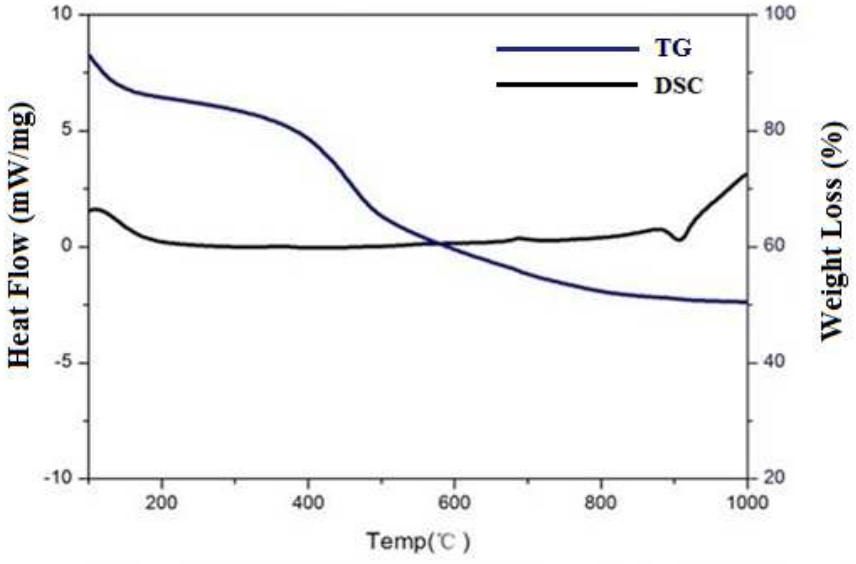


Figure 4.3: TG-DSC of Gindi Akwati Coal Deposit

4.5.4 Results of thermogravimetric and differential scanning calorimetry analyses of Ogboyoba coal deposit as shown graphically in the figure below:

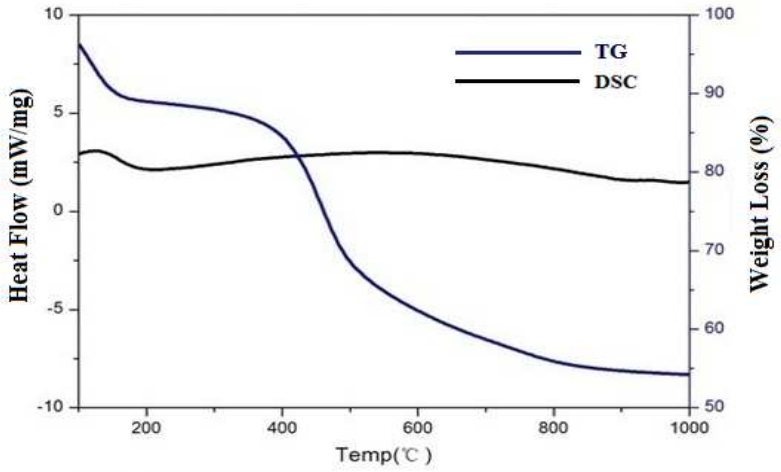


Figure 4.4: TG-DSC of Ogboyoba Coal Deposit

4.6 Ash Analysis

The results obtained from ash composition analysis of the four coal samples using XRF technique are listed in the table below:

Table 4.5: Ash composition analyses of the four coal samples

Oxide (%)	Kurumu	Garin-Maiganga	Gindi-Akwati	Ogboyoba
Silicon dioxide	61.41	66.73	71.84	69.11
Aluminium oxide	28.00	19.40	9.20	17.0
Titanium oxide	1.77	0.90	0.48	1.70
Ferric oxide	5.65	7.48	11.39	5.43
Calcium oxide	1.52	3.41	3.70	1.94
Magnesium oxide	0.40	0.74	0.60	1.15
Sodium oxide	0.10	0.18	0.15	0.33
Sulphite	1.06	1.12	1.41	2.40
Phosphorus pentoxide	< 0.001	< 0.001	1.10	< 0.001
Potassium oxide	0.09	0.03	0.13	0.94

4.7 Ash Fusion Temperature

The results obtained from ash fusion temperature analysis of the four coal samples are shown in the table below:

Table 4.6: Ash fusion temperatures of the four coal samples

Parameters	Coal samples			
	Kurumu	**Garin-maiganga**	**Gindi-akwati**	**Ogboyoba**
Initial deformation **(**^{o}C**)**	1055	1025	805	1045
Softening **(**^{o}C**)**	1148	1133	990	1136
Hemispherical **(**^{o}C**)**	1176	1156	1000	1164
Fluid **(**^{o}C**)**	1198	1185	1050	1191

4.8 Coal Auto-Ignition Temperature

The results obtained from auto-ignition temperature analysis of the four coal samples are shown in the table below:

Table 4.7: Auto-ignition temperatures of the four coal samples

Sample size	Coal sample			
	Kurumu (^{o}C**)**	**Garin-maiganga (**^{o}C**)**	**Gindi-akwati (**^{o}C**)**	**Ogboyoba (**^{o}C**)**
Fine (1.0mm-1.6mm)	340	330	336	330
Coarse (2.5mm-3.5mm)	360	340	360	370

4.9 Discussion of results

4.9.1 Proximate analysis

The moisture content ranges from 3.93% to 10.27%. Coal sample from Kurumu deposit has the lowest moisture content of 3.93% and Ogboyoba has the highest moisture content

with 10.27%. Coal samples from Garin-maiganga and Gindi-akwati deposits both have moisture content of 6.24% and 8.41% respectively.

Coal sample from Kurumu deposit has the lowest ash content while samples from Garin-maiganga, Gindi-akwati and Ogboyoba all have ash contents of 13.43%, 41.68% and 6.59%respectively.

Volatile matter of Kurumu sample was found to be the highest with a value of 41.63% while that of Gindi-akwati deposit was the lowest and determined to be 28.69%. Garin-maiganga and Ogboyoba both have values of 39.12% and 39.87% respectively. However, volatile ratio of the coal samples are 0.47, 0.48, 0.49 and 0.58 for Kurumu, Ogboyoba, Garin-maiganga and Gindi-akwati coal deposits respectively.

The lowest percentage of fixed carbon was determined to be 21.22% from Gindi-akwati coal sample. The coal samples from Kurumu, Garin-maiganga and Ogboyoba have percentage of fixed carbon determined to be 46.45%, 41.21% and 43.30% respectively.

Moisture content affects coal handling and storage (coal flow properties, behaviour in frost, dust emissions), and pulveriser capacity. An increase in moisture increases the flue gas volume flow rate and influences the excess air requirements with consequent effect on fans, air pre-heater and pollution control equipment. Increased moisture lowers thermal efficiency of boiler and can influence burner design (Carpenter *et al.*, 2007). kurumu coal sample with the lowest inherent moisture content (3.93%) would be the easiest to handle and store followed Garin-maiganga (6.24%), gindi-akwati (8.41%) and then Ogboyoba (10.27%).

Ash content affects coal and ash handling systems, pulverisers (abrasion), furnace, superheater, reheater, economiser,sootblowing intervals (slagging and fouling propensity, erosion, corrosion), pollution control equipment and unburnt carbon in ash (Carpenter *et al.*, 2007). Ogboyoba coal sample with the lowest ash content (6.59%) would cost less in terms of investment in ash handling equipment and pulveriser abrasion followed by Kurumu (7.99%), Garin-maiganga (13.43%) and Gindi-akwati (41.68%) coal samples.

The volatile matter content and volatile ratio of coal affects storage behaviour (oxidation, danger of spontaneous combustion, loss of heating value), pulverizer outlet temperature and required fineness for pulverisation, burner settings, furnace, combustion behavior and efficiency (ignition, flame shape and stability, burnout and carbon content of fly ash) (Carpenter *et al.*, 2007). Kurumu coal sample with the lowest volatile ratio (0.47) would have the least danger of explosion. This is followed by Ogboyoba (0.48), Garin-maiganga (0.49) and Gindi-akwati (0.58) coal samples.

The fixed carbon is the solid fuel in the coal and gives a rough estimate of the heating value. The lowest percentage of fixed carbon was determined to be 21.22% from Gindi-akwati coal sample, followed by Kurumu, Garin-maiganga and Ogboyoba with 46.45%, 41.21% and 43.30% of fixed carbon respectively. Hence, the heating values of the coal samples in decreasing order will be Kurumu, Ogboyoba, Garin-maiganga and Gindi-akwati.

4.9.2 Ultimate analysis

The elemental composition of Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur were shown in figure 4.3. Kurumu has the highest Carbon content of 72.36% followed by Ogboyoba, Garin-maiganga and Gindi-akwati with 64.96%, 62.94% and 38.98% respectively.

Hydrogen content ranges from 2.66%, 3.94%, 4.74% and 5.13% for coal samples of Gindi-akwati, Garin-maiganga, Ogboyoba and Kurumu respectively.

The composition of oxygen in the four samples was determined to be 9.09% for Kurumu deposit, 11.91% for Garin-maiganga, 6.47% for Gindi-akwati and 11.82% for coal deposit from Ogboyoba.

The nitrogen content ranges from 1.15% for Garin-maiganga to 1.53% for Gindi-akwati. Kurumu and Ogboyoba both have nitrogen composition of 1.27% and 1.30% respectively.

All the four coal samples have low sulphur content with Kurumu deposit having 0.20%, Garin-maiganga, Gindi-akwati and Ogboyoba having 0.37%, 0.27% and 0.31 percent respectively.

Carbon and hydrogen are the major combustible constituents of coal, and both of them are high in the coal samples. The higher the carbon content, the higher the calorific value and the better the quality of the coal for power generation.

4.9.3 Calorific value

Caloric value gives the heating value of the coal sample. Calorific value of Kurumu coal deposit was the highest out of the four coal samples that was analysed with a value of 25.71MJ/kg. Gindi-akwati coal sample has a very low calorific value of 11.56MJ/kg. Garin- maiganga and Ogboyoba coal deposits both has calorific values of 23.37MJ/kg and 24.78MJ/kg respectively.

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 are in the range of 9.5 MJ/kg to 27 MJ/kg (Zactruba, 2009). Thus, all the coal samples would be suitable for power generation. The kurumu coal sample, with the highest heating value of 25.71MJ/kg, would be the best for heating and power generation.

4.9.4 Thermogravimetric (TGA) and Differential scanning calorimetry (DSC) analyses

From the thermal profiles of the four coal samples, the peak temperatures at maximum weight loss rate obtained during thermogravimetric analysis of the four coal samples are as shown in figures 4.1 to 4.4. This can be read at the points where mass depletion is noticed for the coal samples. Accordingly, the points where a decline of profile is noticed is of interest in all of the temperature profiles.

It was found that the peak temperatures are as follows: Gidin-Akwati; 360^{o}C, Garin-maganga; 370^{o}C, Ogboyoba; 380 ^{o}C and Kurumu; 400^{o}C. This is in increasing order of peak temperature profiles, which is also in decreasing order of ease of combustion. This correlates with the volatile ratio. From these results Gidin-Akwati with a peak temperature at maximum weight loss of 360^{o}C has the least characteristic of combustion, followed by garin-maiganga (370^{o}C), ogboyoba (380^{o}C) and kurumu (400^{o}C). This is in agreement with the findings of Marinov *et al.,* 2009, that coals with lower peak maxima temperatures (T_p) can generally be ignited and burned easier.

From the differential scanning calorimetry profiles of the four coal samples, it can be observed that for Kurumu coal deposit, a huge exothermic profile was noticed as the differential thermal curve reaches the end of the oxidation state between 920^{o}C -1000^{o}C which is in line with the results obtained for calorific value of the Kurumu coal.

Garin-maganga coal deposit DSC curve on the other hand shows a small endothermic peak at 40^{o}C, which signifies that samples absorbed water and other organic impurities. Also a huge exothermic profile was noticed as the differential thermal curve reaches the end of its oxidation state between 960^{o}C -1000^{o}C. This is also in line with the results obtained for the calorific value of the fuel.

Gindi-akwati coal deposit shows an endothermic peak at 170^{o}C, this is of the obvious reason that samples absorbed water and other organic impurities. At 880^{o}C, another endothermic peak was observed which was due to the fact that at this high temperature, Gindin-akwati coal sample still had some physi-absorbed water and other organic impurities. This may have affected some of the properties of this coal sample in terms of its power generation potential.

It was observed that for Ogboyoba coal deposit, at temperature of 90^{o}C, an exothermic peak was observed which shows that sample released heat at this point. Also, an endothermic peak was observed at 200^{o}C, which is an indication of samples absorbing

water and organic impurities at this point. It was also be observed that at the points between 200^{o}C-700^{o}C, an exothermic profile was observed meaning sample released heat at this temperature range.

However, an endothermic peak was also observed from 700^{o}C- 880^{o}C which was also of the obvious reason that sample absorbed water. It is interesting to note that an exorthermic profile was observed from 880 ^{o}C and afterwards the profile remained stable. This explains its potential and thermal stability in generating power from this coal sample.

It is worth noting that the differential calorimetry curves for all the profiles did not show significant endothermic and exothermic curves. This could be as a result of samples not absolutely green at the time of thermogravimetry measurement.

4.9.5 Coal ash analysis

The analysis of the ash constituents of the four coals samples shows that in all the samples silica accounts for the highest percentage in the ashes while percentage of phosphorus pentoxide was the lowest with less than 0.001% for the entire samples except for Gindi-akwati which has 1.1% of phosphorus pentoxide. The lowest constituent in Gindi-akwati coal ash was potassium oxide with 0.13%.

4.9.6 Ash fusion temperature

The ash fusion temperatures of the entire coal samples were above 1000^{0}C except for the coal deposit of Gindi-akwati which had its initial deformation and softening temperatures to be 805^{0}C and 990^{0}C respectively. This shows that of all the fours coal samples analysed, Gindi-akwati coal sample has the lowest ash fusion temperature.

This temperature at which the ash melts to form slag and clinker if of great importance because clinker formation results in pressure drop and leads to unstable gasifier. The temperature range of AFT is usually between 1000^{0}C to 1600^{0}C. The circulating

fluidized bed combustion technology is therefore recommended for Gindi-akwati coal deposit. IGCC clean coal technology is recommended to be utilized by the other samples.

4.9.7 Coal auto-ignition temperature

The temperature of coal samples when it started glowing for fine coal particle size was determined to be 330^0C for both deposits of Garin-maiganga and Ogboyoba while Gindi-akwati and Kurumu both have ignition temperatures of 336^0C and340^0C respectively.

Ignition temperatures of coarse coal particle size was also determined to be 360^0C for both Kurumu and Gindi-akwati coal samples while Garin-maiganga and Ogboyoba both had 340^0C and 370^0C respectively.

This shows that coal self-ignition temperatures are also affected by particle size. Hence, it is desirable for coal to be stored in larger sizes.

Heating value	Coal samples (heating value, Btu/lb)

4.9.8 Ranking of the analysed coal samples using ASTM D388 classification criteria

With reference to table 2.2 (page 12), the results obtained from the proximate analysis and calorific values were used in the classification of the four coal samples. All the analysed coal samples have fixed carbon less than 69% and volatile matter greater than 39% except for the coal sample of Gindi akwati deposit. Hence, the samples from Kurumu, Gindi-akwati, Garin-maiganga and Ogboyoba will be ranked based on the heating values.

Table 4.8: Ranking of the four coal samples using the ASTM classification

		Kurumu (11,053.32)	Garin-maiganga (10,047.30)	Gindi-akwati (4969.91)	Ogboyoba (10,653.49)
Bituminous high volatile B	13,000-14,000				
Bituminous high volatile C	10,500-13,000				
Sub-bituminous A	10,500-11,500	✓			✓
Sub-bituminous B	9,500-10,500		✓		
Sub-bituminous B	8,300-9,500				
Lignite A	6,300-8.300				
Lignite B	< 6,300			✓	

4.9.9 Ash and Sulphur classification of the analysed coal samples

Classification of the coal samples for ash and sulphur contents based on the result obtained from proximate and ultimate analyses is shown in the table below:

Table 4.9: Ash and Sulphur classification of the four coal samples

		Coal samples			
Classification	**Composition range (%)**	**Kurumu**	**Garin-maiganga**	**Gindi-akwati**	**Ogboyoba**
Ash content					
High ash	>15.0			✓	
Medium ash	8.0-15.0		✓		

Low ash	<8.0	✓			✓
Sulphur content					
High sulphur	>3.0				
Medium sulphur	1.0-3.0				
Low sulphur	<1.0	✓	✓	✓	✓

0 Suitability of analysed coal samples for power generation

Table 2.3 shows typical requirements for coal fired plants. Based on the results obtained from the four coal samples analysed and comparing with table 2.4 (page 24), Kurumu, Garin-maiganga and Ogboyoba coal deposits meets most of the requirements except for Gindi-akwati coal deposit which has the lowest calorific value, high ash content and also has lowest ash fusion temperatures. Chlorine content, Hardgrove Grindability Index (HGI) and petrographic analyses were not carried out so no comparison was made these.

However, the characteristics of low grade coals for power generation in some power plants are shown in table 2.5 (page 25). Hence with reference to table 2.5, Gindi-akwati coal deposit could still be used for power generation.

The following tables show the comparison between the analysed coal samples and standard requirements for coal-fired plants**.**

Table 4.10: Comparison of properties of Kurumu coal with typical bituminous coal quality requirement for pulverized coal-fired plant (Based on Table 2.4)

Parameter	**Desired values**	**Typical limits**	**Kurumu coal**
Heating value, MJ/kg ar	High	Min 24-25 (23)	25.71
Moisture, % ar	4-8	Max 12	3.93
Volatile matter, % mf	20-35	Min 20 (side-fired furnace)	41.63
	15-20	Max 20 (down-fired furnace)	41.63
Ash, % mf	Low	Max 15-20 (max 30)	7.99
Sulphur, % daf	Low	Dependent on local pollution regulation	0.2
Nitrogen, % daf	Low	(0.8-1.1), dependent on local pollution regulation	1.27
Chlorine	Low	Max 0.1-0.3 (max 0.5)	Not analysed
HGI	High	Min 50-55 (min 39)	Not analysed
		Ash Analysis, wt % ash	
Silicon dioxide		(45-75)	61.41
Aluminum oxide		(15-35)	28.00
Titanium oxide		(0.4-2.2)	1.77

Ferric oxide		(1-12)	5.65
Calcium oxide		(0.1-2.3)	1.52
Magnesium oxide		(0.2-1.4)	0.40
Sodium oxide		(0.1-0.9)	0.10
Potassium oxide		(0.8-2.6)	1.06
Sulphite		(0.1-1.6)	< 0.001
Phosphorus pentoxide		(0.1-1.5)	0.09
Ash fusion temperature (^{0}C)			
Initial Deformation	High	(>1075)	1055
Softening	High	(>1150)	1148
Hemispherical	High	(>1180)	1176
Fluid	High	(>1225)	1198
Maceral Analysis, %			
Vitrinite		55-80	Not analysed
Exinite		5-15	Not analysed
Inertinite		10-25	Not analysed

Legend: Acceptable Allowable Not acceptable

Table 4.11: Comparison of properties of Garin-maiganga coal with typical bituminous coal quality requirement for pulverized coal-fired plant (Based on Table 2.4)

Parameter	**Desired values**	**Typical limits**	**Garin-maiganga coal**
Heating value, MJ/kg ar	High	Min 24-25 (23)	23.37
Moisture, % ar	4-8	Max 12	6.24
Volatile matter, % mf	20-35	Min 20 (side-fired furnace)	39.12
	15-20	Max 20 (down-fired furnace)	39.12
Ash, % mf	Low	Max 15-20 (max 30)	13.43
Sulphur, % daf	Low	Dependent on local pollution regulation	0.37
Nitrogen, % daf	Low	(0.8-1.1), dependent on local pollution regulation	1.15
Chlorine	Low	Max 0.1-0.3 (max 0.5)	Not analysed
HGI	High	Min 50-55 (min 39)	Not analysed
Ash Analysis, wt % ash			
Silicon dioxide		(45-75)	66.73
Aluminum oxide		(15-35)	19.40

Titanium oxide		(0.4-2.2)	0.90
Ferric oxide		(1-12)	7.48
Calcium oxide		(0.1-2.3)	3.41
Magnesium oxide		(0.2-1.4)	0.74
Sodium oxide		(0.1-0.9)	0.18
Potassium oxide		(0.8-2.6)	1.12
Sulphite		(0.1-1.6)	< 0.001
Phosphorus pentoxide		(0.1-1.5)	0.03
Ash fusion temperature (^{0}C)			
Initial Deformation	High	(>1075)	1025
Softening	High	(>1150)	1133
Hemispherical	High	(>1180)	1156
Fluid	High	(>1225)	1185
Maceral Analysis, %			
Vitrinite		55-80	Not analysed
Exinite		5-15	Not analysed
Inertinite		10-25	Not analysed

Legend: Acceptable Allowable Not acceptable

Table 4.12: Comparison of properties of Gindi-akwati coal with typical bituminous coal quality requirement for pulverized coal-fired plant (Based on Table 2.4)

Parameter	**Desired values**	**Typical limits**	**Gindi-akwati coal**
Heating value, MJ/kg ar	High	Min 24-25 (23)	11.56
Moisture, % ar	4-8	Max 12	8.41
Volatile matter, % mf	20-35	Min 20 (side-fired furnace)	28.69
	15-20	Max 20 (down-fired furnace)	28.69
Ash, % mf	Low	Max 15-20 (max 30)	41.68
Sulphur, % daf	Low	Dependent on local pollution regulation	0.27
Nitrogen, % daf	Low	(0.8-1.1), dependent on local pollution regulation	1.53
Chlorine	Low	Max 0.1-0.3 (max 0.5)	Not analysed
HGI	High	Min 50-55 (min 39)	Not analysed
Ash Analysis, wt % ash			
Silicon dioxide		(45-75)	71.84
Aluminum oxide		(15-35)	9.20
Titanium oxide		(0.4-2.2)	0.48

Ferric oxide		(1-12)	11.39
Calcium oxide		(0.1-2.3)	3.70
Magnesium oxide		(0.2-1.4)	0.60
Sodium oxide		(0.1-0.9)	0.15
Potassium oxide		(0.8-2.6)	1.41
Sulphite		(0.1-1.6)	1.10
Phosphorus pentoxide		(0.1-1.5)	0.13
Ash fusion temperature (^{0}C)			
Initial Deformation	High	(>1075)	805
Softening	High	(>1150)	990
Hemispherical	High	(>1180)	1000
Fluid	High	(>1225)	1050
Maceral Analysis, %			
Vitrinite		55-80	Not analysed
Exinite		5-15	Not analysed
Inertinite		10-25	Not analysed

Legend: Acceptable Allowable Not acceptable

Table 4.13: Comparison of Properties of Ogboyoba Coal with typical bituminous coal quality requirement for pulverized coal-fired plant (Based on Table 2.4)

Parameter	**Desired values**	**Typical limits**	**Ogboyoba coal**
Heating value, MJ/kg ar	High	Min 24-25 (23)	24.78
Moisture, % ar	4-8	Max 12	10.27
Volatile matter, % mf	20-35	Min 20 (side-fired furnace)	39.87
	15-20	Max 20 (down-fired furnace)	39.87
Ash, % mf	Low	Max 15-20 (max 30)	6.59
Sulphur, % daf	Low	Dependent on local pollution regulation	0.31
Nitrogen, % daf	Low	(0.8-1.1), dependent on local pollution regulation	1.30
Chlorine	Low	Max 0.1-0.3 (max 0.5)	Not analysed
HGI	High	Min 50-55 (min 39)	Not analysed
Ash Analysis, wt % ash			
Silicon dioxide		(45-75)	69.11
Aluminum oxide		(15-35)	17.0

Titanium oxide		(0.4-2.2)	1.70
Ferric oxide		(1-12)	5.43
Calcium oxide		(0.1-2.3)	1.94
Magnesium oxide		(0.2-1.4)	1.15
Sodium oxide		(0.1-0.9)	0.33
Potassium oxide		(0.8-2.6)	2.40
Sulphite		(0.1-1.6)	< 0.001
Phosphorus pentoxide		(0.1-1.5)	0.94
Ash fusion temperature (^{0}C)			
Initial Deformation	High	(>1075)	1045
Softening	High	(>1150)	1136
Hemispherical	High	(>1180)	1164
Fluid	High	(>1225)	1191
Maceral Analysis, %			
Vitrinite		55-80	Not analysed
Exinite		5-15	Not analysed
Inertinite		10-25	Not analysed

Legend: Acceptable Allowable Not acceptable

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Four coal samples from Kurumu (Gombe State), Garin-maiganga (Bauchi State), Gindi-akwati (Plateau state) and Ogboyoga (Kogi State) have been characterised to assess their suitability for power generation. Specifically, tests carried out on the coal samples include proximate, ultimate, ash composition and thermogravimetric analyses. Calorific value, ash fusion temperatures and auto-ignition temperatures were also determined. Results obtained were compared with requirements published by pulverised coal power

plant operators around the world. kurumu coal sample had the highest gross calorific value of 25.71MJ/kg, followed by ogboyoba, garin-maiganga and gindi-akwati coal samples with 24.78MJ/kg, 23.37MJ/kg and 11.56MJ/kg, respectively. Results of proximate analysis shows that kurumu coal had the highest volatile matter content of 41.63% and also had the lowest moisture content of 3.93%. The highest fixed carbon content of 46.45% was recorded in kurumu coal. Elemental carbon was highest in kurumu coal (72.36%).

Thermogravimetric analysis results show that Gindi-akwati recorded the lowest peak temperature (360^0C) while the differential scanning calorimetry showed that all the coal samples reached the end of their oxidation states at 1000^0C.

The lowest ash fusion temperature recorded from analysis of all the samples was in Gindi-akwati coal with initial deformation, softening, hemispherical and fluid temperatures as 805^0C, 990^0C, 1000^0C and 1050^0C respectively.

The auto-ignition temperature of the coal samples shows that the smaller the particle size the lower the auto-ignition temperature in all the coal samples.

5.2 Conclusion

1. Result of proximate analysis show that Kurumu coal had the highest volatile matter content of 41.63%, followed by Ogboyoba, Garin-maiganga and Gindi-akwati with 39.87%, 39.12% and 28.69% respectively. the moisture content of the coal samples is 3.93%, 6.24%, 8.41% and 10.27% for Kurumu, Garin-maiganga, Gindi-akwati and Ogboyoba coal samples respectively. The highest fixed carbon content of 46.45% was recorded in Kurumu coal, while Gindi-akwati coal sample has the lowest with 21.22%. However, Gindi-akwati coal sample has the highest composition of Ash with 41.68%.

2. The result of ultimate analysis also shows that all the coal samples have low sulphur content. The carbon content ranges from 72.36% for Kurumu coal sample, 62.96% for Garin-maiganga, 38.98% for Gindi-akwati and 64.96% for Ogboyoba coal samples.

3. Calorific values correlates with the fixed carbon, elemental carbon and hydrogen which are the major combustible elements in coals and the coals have high carbon and hydrogen content which accounts for their high calorific values except for Gindi-akwati coal deposit which has low carbon content and hence low calorific value.

4. The thermogarvimetric analyses also shows that the ease of combustion and peak temperatures of the coal samples in decreasing order is Gindi-akwati, Garin-maiganga, Ogboyoba and Kurumu.

5. All the analysed coal samples have acceptable ash fusion temperature except Gindi-akwati coal sample.

6. The auto-ignition temperatures of the coal samples decrease with increasing volatile ratio and particle size.

7. Percentage of silicon dioxide is the highest in all the coal samples from the ash analysis.

8. Classification of the coal samples in terms of rank, grade and type show that Kurumu, Garin-maiganga and Ogboyoba coal samples were found to be sub-bituminous coals while Gindi-akwati coal was a lignitic coal. Kurumu and Ogboyoba coals were high grade, low suphur and low ash coals. Garin-maiganga was also high grade, low suphur but medium ash coal while Gindi-akwati coal was a low grade, low sulphur and high ash coal.

9. Comparison of the properties of the analysed coal samples with standard requirements for coal plants show that Kurumu, Garin-maiganga and Ogboyoba are suitable for power generation having met most of the requirement for coal fired power plants as shown in table 2.4 (page 24). Gindi-akwati coal deposit on the other hand can also be used for power generation in some plants as shown in table 2.5 (page 25).

Finally, Kurumu, Garin-maiganga and Ogboyoba coals can be used for power generation using the IGCC coal technology while Gindi-akwati coal sample can be used for power

generation using circulating fluidised bed combustion (CFBC) technology. CFBC technology was developed to burn low grade and/or difficult-to-burn fuels and can therefore tolerate a wide variety of coals and particle sizes.

5.3 Recommendations

Clean coal technology is highly needed in Nigeria for power generation as the only feasible solution to the power supply problems bedeviling the country. It is therefore necessary for the government to aggressively exploit the country's abundance coal reserves for this purpose.

Hardgrove Grindability Index (HGI), Chlorine content and petrographic analysis should be carried out on the analysed coal samples to further enrich the data available on the deposits.

Coal samples to be used for various analyses should be on as received basis as these also goes in a long way to affect results as was specifically observed in the thermogravimetric curves.

Lastly, characteristics of different ratio of blends of these coals are also recommended.

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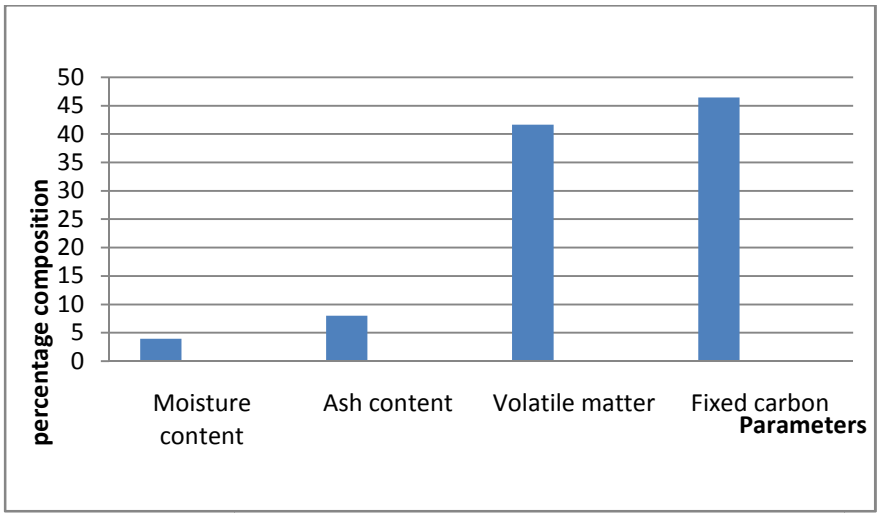
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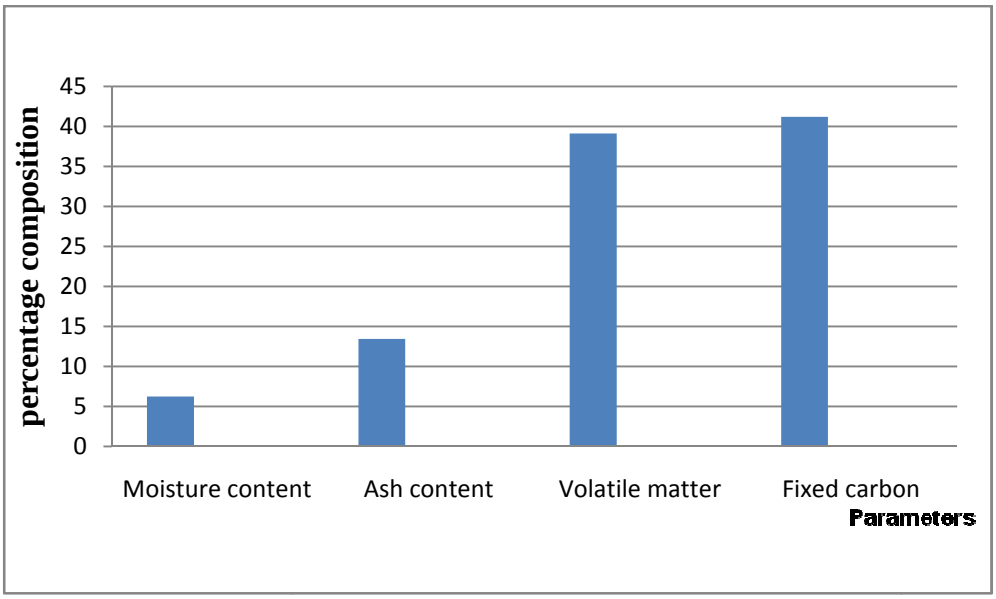
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APPENDICES

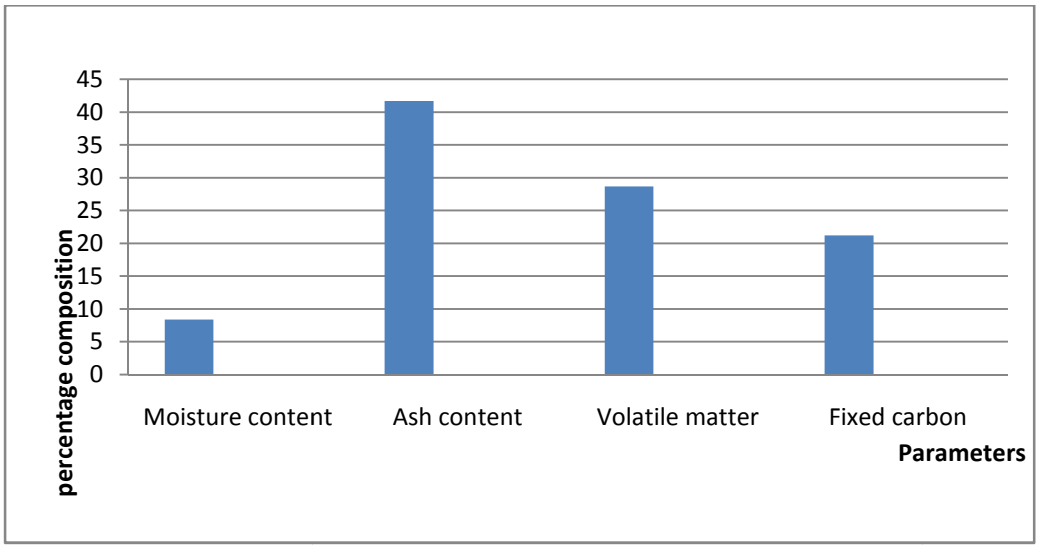
APPENDIX I: Proximate analysis of Kurumu coal sample



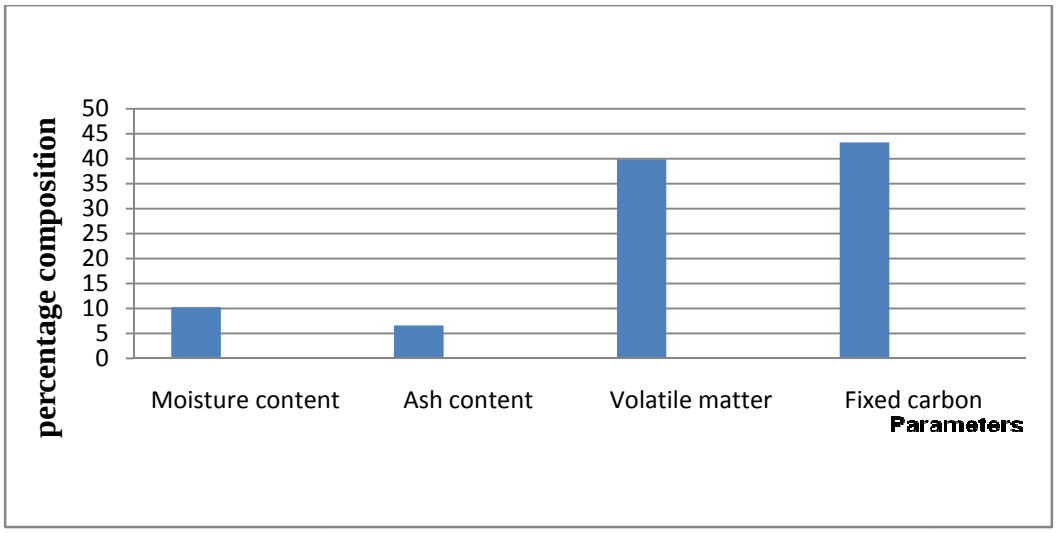
APPENDIX II: Proximate analysis of Garin-maiganga coal sample



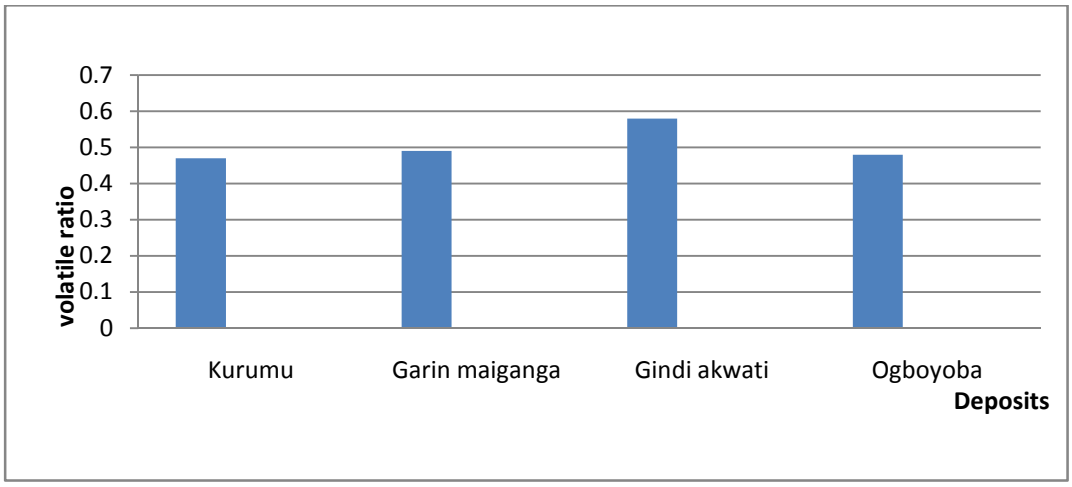
APPENDIX III: Proximate analysis of Gindi-akwati coal sample



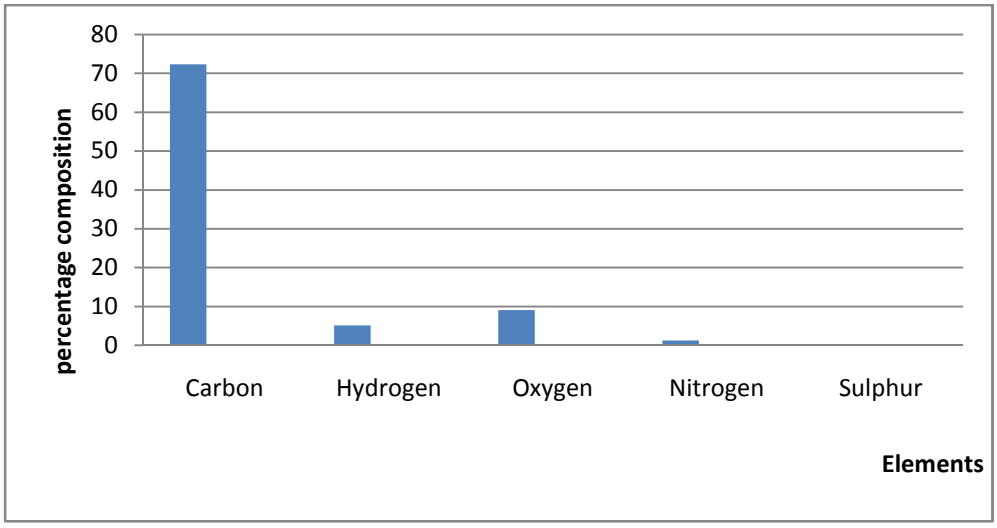
APPENDIX IV: Proximate analysis of Ogboyoba coal sample



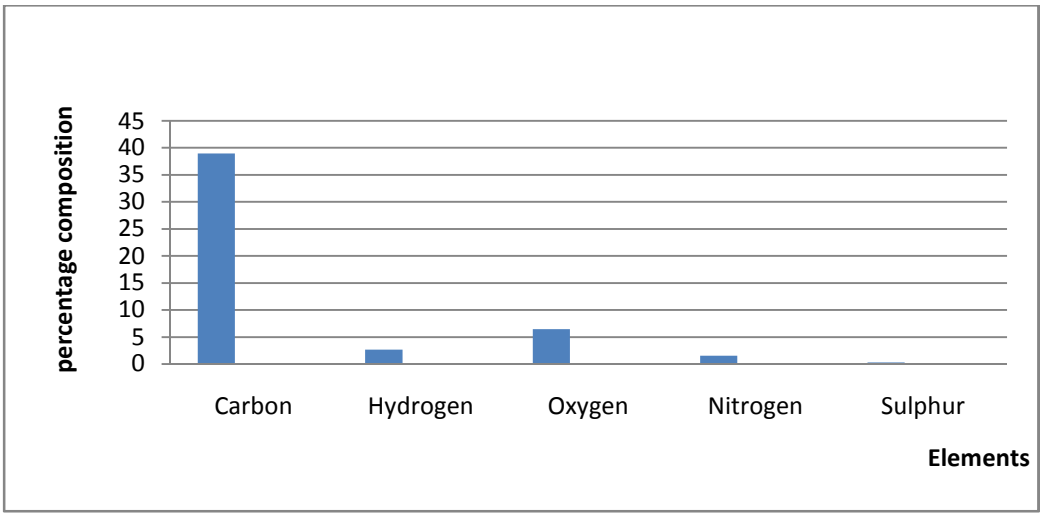
APPENDIX V: Volatile ratios of the coal samples



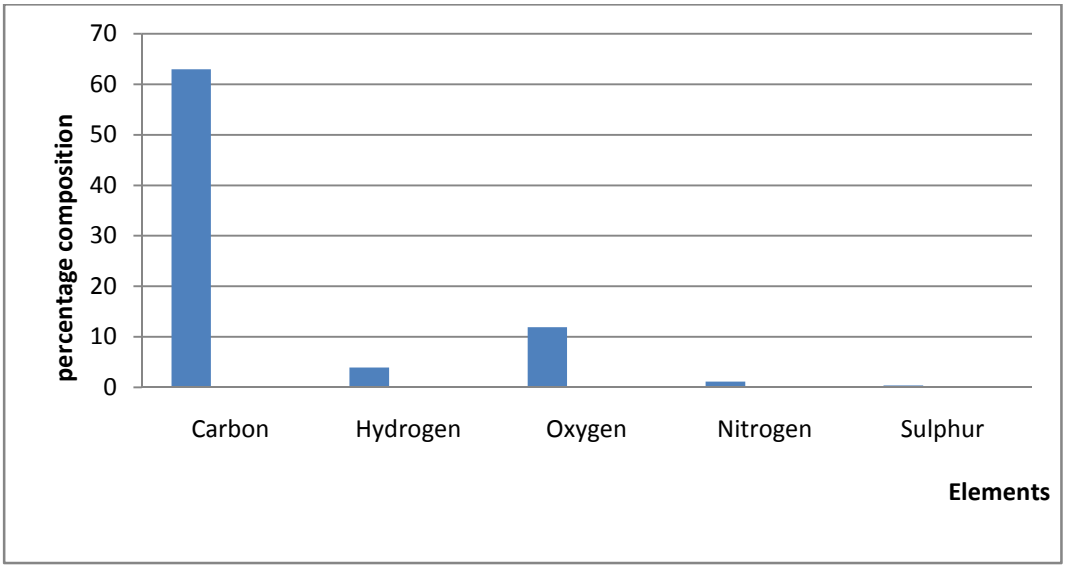
APPENDIX VI: Ultimate analysis of Kurumu coal sample



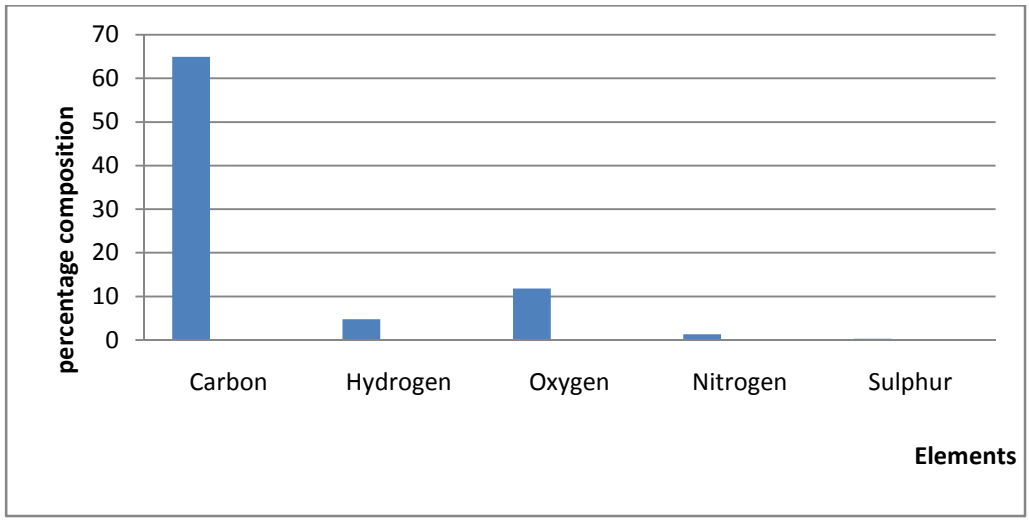
APPENDIX VII: Ultimate analysis of Gindi-akwati coal sample



APPENDIX VIII: Ultimate analysis of Garin-maiganga coal sample



APPENDIX IX: Ultimate analysis of Ogboyoba coal sample



APPENDIX X: Calorific values of the coal samples

