Increasing the National Grid Capacity through Application of Gasification Technology: The Exploitation and Exploration of Nigeria Coal Minerals

M. N. Idris*[1], Ir. P. B. Onaji[2], B. O Aberemi[3] and U. O. Aroke[4]
[1]Department of Chemical Engineering
University of Maiduguri, Borno State, Nigeria
Email: idrismn@hotmail.com
[2]Department of Chemical Engineering
Modibo Adamawa University, Yola, Nigeria
[3]Department of Chemical Engineering
Ahmadu Bello University, ABU Zaria, Nigeria
[4]Department of Chemical Engineering
Abubakar Tafawa Balewa University, Bauchi, Nigeria

ABSTARCT
The abundance of coal and other important solid minerals in Nigeria is not only a blessing to the nation, but equally are sources of revenue that can reduce capital flight and increase the gross domestic products (GDP). Unfortunately, the technology of gasification is currently a virgin area with excellent and great potential which is yet to be harnessed. For a country like Nigeria to continue operating on a mono-economic policy and derivatives from black-gold (fossil fuel oil), is a wrong-foot which has lead us to a total halt more especially on the current-face of drastic falls in global oil prices. Coal exploration and production remains one of the main natural occurrence gifts to Nigeria. It is cheaper, easier and of high grade to power generation. Coal is highly in abundance and found in more than thirteen (13) states of the federation. Countries like the USA, China and South Africa uses coal as a primary source of electricity and energy, it has greatly sustained their economies. Nigerian coal is very good for power generation and has low sulphur content which makes it very attractive for export and domestic applications. But fortunately over the years, this sector has been neglected or left unexploited, especially after the advent of oil discovery in commercial quantities. This paper is to highlights the potentials in coal exploration, exploitation and production to becoming a major player in the energy mix of a developing nation like Nigeria. Therefore, possible usage of applicable indigenous technologies should be considered as a welcome idea which will surely assist our country toward improving the power generation for sustainable and economic development.

Keywords: *Coal, electricity, gasification technology, GDP, and sustainable development*

1.0 INTRODUCTION

Nigeria is the most populated country in Sub-Saharan Africa and the eighth most populated countries in the world, that is, the country accounts for 2.10% of the world estimated population WPR (2016). Nigeria is the largest producer of petroleum products and the 8th largest exporter of petroleum products and the 10th largest proven reserve in the world. United States of American (USA) is the largest business partner of Nigeria which account for 11% of her oil export Woytinsky and Woytinsky (1953).

Nigeria has a wide range of mineral deposits like natural gas, crude oil, coal, and bauxite, gold, tin, tantalite, limestone, lead, zinc etc., but the mining sector is still very underdeveloped. The Nigerian energy sector consists of crude oil, natural gas, coal and renewable energy. The crude oil accounts for over 95% of the nations' energy supply and other source make up 5%. The sectors being served by this energy include the transport, electricity, industrial and the residential.

Over the years, Nigerian petroleum accounts for 40% of the gross domestic products (GDP), and 80% of government earning showing that Nigeria is heavily depend on oil products. This practice of mono-economic principle has led to the neglect of all other sectors that has great potential to support and develop the nations' economy.

Coal was formed from prehistoric plants, in marshy environments, some tens or hundreds of millions of years ago. The presence of water restricted the supply of oxygen and allowed thermal and bacterial decomposition of plant material to take place, instead of the completion of the carbon cycle. Under these conditions of anaerobic decay, in the so-called biochemical stage of coal formation, a carbon-rich material called *peat* was formed Schmidt (2010). This process where the physical and chemical property of peat is changed to coal is known as *coalification*. The quality of the coal deposit is mainly determined by the following: the different types of vegetation that constitute the coal, how deep the decayed plant deposit was buried, the temperature and pressure experienced at that depth and the length of time the coal has taken to form Okolo and Mkpadi (1996).

Coal is a non-renewable source of energy and contains carbon, hydrogen, nitrogen, sulphur and oxygen. It is a fossil fuel and accounts for over 23% of the worlds' energy needs and generates over 39% of the world electricity WCI (2008). It is a cheap source of fuel, because it is found in abundance and not expensive to convert to energy. They are classified based on the level of carbon it contains and the amount of energy it can produce. Coal that contains a high amount of carbon is referred to as *high rank* coal. They have a low hydrogen and oxygen content and have a high heat value. *Low rank* coal has low carbon content, but contains a high amount of hydrogen and oxygen. The various types of coal are: lignite, sub-bituminous, bituminous, anthracite and graphite WCI (2008).

Gasification is a process that converts organic or fossil fuel based carbonaceous materials into useful products: carbon monoxide (CO), hydrogen (H_2) and carbon dioxide (CO_2). This can be achieved by reacting the material at variable conditions, high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. There are different types of gasifiers available for commercial uses: (i) counter-current fixed bed, (ii) co-current fixed bed, (iii) fluidized bed, (iv) entrained flow, (v) plasma, and (vi) free-radical. The work is currently on the preliminary stage and is focused on using fluidized bed reactor (FBR) gasifier to establish some experimental ideas that could be transformed into real-life industrial applications.

Therefore, the focus of this paper is on the usefulness of coal and the technology of gasification. The main aim is to show that coal has a potential of being a major player in the Nigerian energy demand mix (locally and internationally) and can increase the nations' GDP.

2.0 LITERATURE REVIEW

2.1 Historical Formation of Coal

Although it is common to using the word '*coal*' in the singular meaning, but when we assembled a collection of coal specimens from around the world, we would find that this word is actually applicable to materials having rather a wide range of properties. One sample might be a wet, easily crumbled brown material looking like partially decayed wood. Another would be very hard, glossy black, lustrous material. The third would be soft, dull black, waxy solid. The heating values of these samples would range from about 5000 to about 15,000 BTU/Ib. In a sense, there is no such thing *coal*, as if we use the word to imply a single, uniquely defined material Okolo and Mkpadi (1996), and WCI (2008). This rather implies that they are family of substances having both similarities and differences among them.

Due to the wide variations in the composition and properties of coals, a classification system is needed to describe the different kinds available for use in homes and power plants. The coal property variation is shown in Table 1 below.

Table 1 Variation of selected coal properties with coal rank

Properties	Coal Type			
	Lignite	Sub-bituminous	Bituminous	Anthracite
Coal Ranking	low	low	high	high
% Carbon	65 - 72	72 - 76	76 - 90	90 - 95
% Hydrogen	~5	~4	~3	~2
% Nitrogen	<	1 -	2	>
% Oxygen	~30	decreases	~1	
% Sulphur	~0	increases	~0	
Heating value (BTU/Ib)	70 - 30	30 - 10	10 - 5	~5

Source: WCI (2008)

The properties of coal are broadly classified into two: physical and chemical. The chemical properties involves the constituted elements and there ratios. Carbon and hydrogen are the principal combustible elements in coal. Carbon is the dominant among the coal constituted element, most often it constitutes about 60% to 95% of the total. For most coal of 90% or less carbon, hydrogen content is generally in the range of 5%, it drops to 2% for coals having 95% carbon. Nitrogen content of almost all coals is in the range of 1 – 2%. Oxygen content is inversely related to carbon content; coal of 65% carbon may contain 30% oxygen, while coal of 95% carbon may contain only 2 – 3% oxygen; this is significant because the more oxygen coal contains, the easier it is to start to burn it, or to achieve ignition. The sulphur content of coals varies, because of the special importance of sulphur, related to the environmental consequences of burning coals.

2.2 Coal Occurrence in Nigeria

Apart from sparsely reported occurrences of lignites and minor sub-bituminous coals in the Sokoto Basin LN (2013), in the Mid-Niger Basin CCT (2015), and in the Dahomey Embayment CCT (2015), all these coal deposits occur in the Benue Trough. Mineable coal deposits in Nigeria occur at Enugu, Okaba, Ogboyaga, Orukpa, Obi-Lafia, Gombe and Chikila, LN (2013). More so, report has shown that coal are found in Ezimo, Enugu state; Iyako River, Inyi area coal deposit, east of Ukana and Egodo River near Okpatu both in Benue state. Inyi coal deposit is the only deposit that occurred in the Upper Coal Measures in Nigeria other deposits occurred in the Lower Coal Measures. Other areas where coal outcrops in Nigeria include: Jamata in Kogi state, which present as thin seams in Patti Formation of Maastrichtian-Campanian age. The coal found in Doho in Gombe state is about 1.7m in depth. They were also found in Kerri-Kerri formation of Palaeocene age. Several coal deposits were found in Gain Maiganga, south of Gombe, which is about 2 – 4.6m thick. National Steel Raw Materials Exploration Agency (NSRMEA) has been exploring for coal in this area. This coal belongs to the Gombe sandstone of Cretaceous age. The coal deposit found in Okuluku village is exposed for a distance of 4.8km near Okuluku village, a few kilometre from south of Odokpono, Kogi state. The coal in one section of this location has 1.2m thick and in the other exposures is less than 1.07m. Still from Kogi state, coal was found in Dekina area. They were also found to occur near Afikpo in Imo state. In Afuze near Auchi area of Edo state, coal seems was discovered and also at Ute near Owo in Ondo state.

Thin, unworkable seems of poor quality are also known to occur around Lamja in Adamawa state. A large coal reserve probably in excess of 1,000 million tonnes is also believed to occur within the Mamu formation at depth of over 600 in Amansiodo area of Enugu state. In Gindi-Akunti of Plateau state and Janata-Koji area of Kwara state huge deposits of coal were also discovered CCT (2015). Table 2 represent the coal type in Nigeria.

Table 2 Types of coal available in Nigeria

S/No.	Coal Type	Approximate Age (Millions)	% Content (approximate)
1.	Lignite	60	65 – 72
2.	Sub-bituminous coal	1000	72 - 75
3.	Bituminous coal	300	76 - 90
4.	Anthracites	350	90 - 95

Source: CCT (2015)

3.0 COAL PROCESSING AND TECHNOLOGY

In this paper, efforts were made to present some methods on coal processing technology in order to outline the basics and good practice of coal mining and processing. More so, the technologies of coal processing and gasification would surely continue to evolving in the future of science and engineering.

3.1 Coal Processing Technologies

Several technologies are being developed in order to improve the efficiency of coal burning and reducing the negative effects it has on the environment. They include:-

3.1.1 Coal Gasification

Coal-based vapour fuels are produced through the process of gasification. Gasification may be accomplished either at the site of the coalmine or in processing plants. In processing plants, the coal is heated in the presence of steam and oxygen to produce synthesis gas, a mixture of carbon monoxide (CO), hydrogen (H_2) and methane (CH_4). This synthesis gas (syngas) can then be converted into transportation fuels like gasoline and diesel through the Fisher-Tropsch process. Currently, this technology is being used by the SASOL Chemical Company of South Africa to make gasoline from coal and natural gas. Alternatively, the hydrogen obtained from gasification can be used for various purposes such as powering a hydrogen economy, making ammonia (NH_3), or upgrading fossil fuels CCT (2015), Smith (1997).

On-site gasification is accomplished by controlled, incomplete burning of an underground coal bed while adding air and steam. In order to achieve this, the operators ignite the coal bed, pump air and steam underground into the burning coal, and then pump the resulting gases from the ground. Once the gas is withdrawn, they may be burned to produce heat or generate electricity, or may be used in synthetic gases to produce chemicals or to help create liquid fuels. In this regard, Enugu, Orukpa and Okaba coals in the Lower Benue Trough are optimum for gasification, while the high-volatile bituminous coals in the Middle-Benue Trough (Obi/Lafia coals) are sub-optimum for this purpose. Figure 1 depicts the process flow diagram of a coal gasification plant Smith (1997).

3.1.2 Flue Gas Desulphurisation

Machines are used to remove sulphur from the smoke emissions due to coal combustion. It uses a mixture of limestone and water which reacts with sulphur to form gypsum, an important raw materials in the cement industry McCartney (1989), Mathew (2013).

3.1.3 Coal Washing

Coal is grinded into small pieces and passed through a process called gravity separation, which separate the impurities. It is then pulverised and used for combustion. Figure 2 represents the process flow scheme of a coal washing plant McCartney (1989).

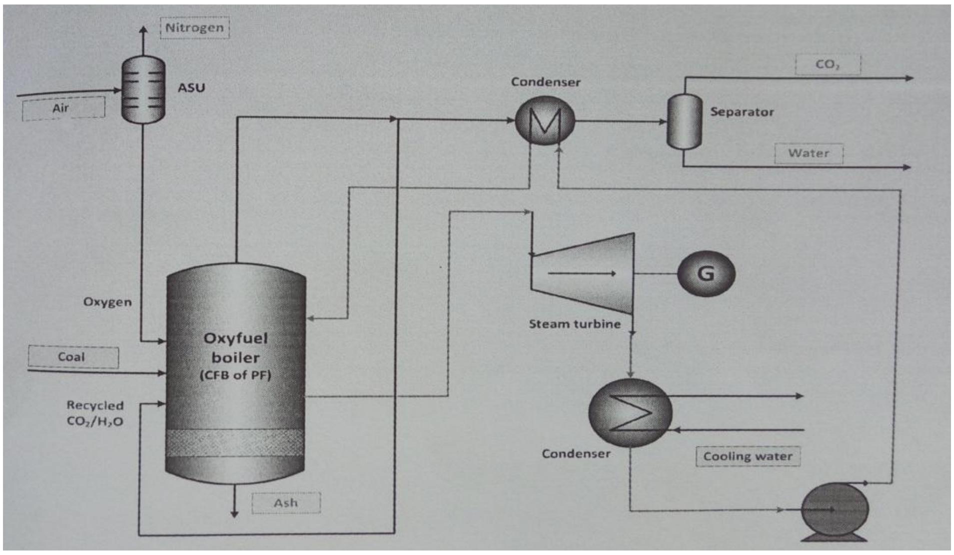

Figure 1 Process flow scheme of a coal gasification plant Mathew (2013)

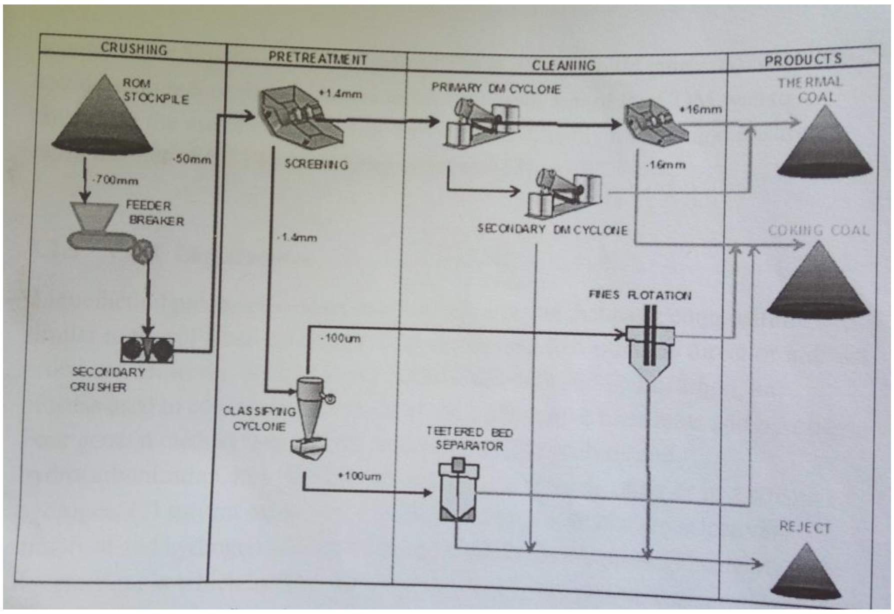

Figure 2 Process flow scheme of a coal washing plant Mathew (2013)

3.1.4 Carbon Capture and Sequestration (CCS)

CCS involves the capture of carbon (IV) oxide (CO_2) from a concentrated steam. The CO_2 is converted to liquid and injected into the ground where it is predominantly stored. More so, it is heavily monitored to avoid it seeping back into the atmosphere or contaminating the water supplies. Clean coal technology (CCT) is been promoted so that the large supply of coal deposit can be exploited without affecting global warming. Coal is an economic source of energy and has s stable supply. Large amount of CO_2 are emitted, but coal can be made clean and efficient DME SA (2010). To achieve this there should be a transfer of technology from the developed to the developing countries. This was the plan according to the Kyoto Protocol of clean development mechanism (CDM) to allow developed countries sponsor and carry out projects that reduce green-house-gas (GHG) emissions in the developing countries. This was to encourage the developed countries invest in countries like Nigeria and the incentives was that they would gain credits they could use to reduce their emission levels. The main aim of CDM was to encourage the use of coal in a more environment-friendly manner and ensure the rapid transfer of CCT to developing nations Lomax (2011).

3.1.5 Coal Liquefaction

Coal liquefaction is a process of converting coal into liquid fuel that has a composition similar to that of crude petroleum. There are two methods of coal liquefaction: (i) direct and (ii) indirect processes. However, since coal is a hydrogen-deficient hydrocarbon, any process used to convert coal to liquid or other alternative fuels must add hydrogen. Four general methods are used for liquefaction:

1. *Pyrolysis* and *hydrocarbonisation* – is a process where coal is heated in the absence of air or in a stream of hydrogen.
2. *Solvent extraction* – this in which coal hydrocarbons are selectively dissolved and hydrogen is added to produce the desired liquids.
3. *Catalytic liquefaction* – in which hydrogen takes place in the presence of a catalyst; and
4. *Indirect liquefaction* – in which CO and hydrogen are combined in the presence of a catalyst.

Alternatively, coal can be converted into a gas first, and then into a liquid using Fischer-Tropsch process. In the Bergius process, coal is liquefied by mixing it with hydrogen gas and heating the system (hydrogenation). This process was used by Germany during World War I and II and has been explored by SASOL Chemical Company in South Africa. The effectiveness of coal conversion depends on the total reactive macerals of low- to medium-ranking coals. In this regard, the high-volatile Obi/Lafia bituminous coal in the Middle Benue Trough is best suited for liquefaction, while the Onyeama coal in the Lower Benue Trough is better for this purpose. Although Orukpa and Gombe coals in the Lower and Upper Benue Trough respectively have adequate proportions of total reactive macerals, they are lower in rank for optimum liquefaction. The Okaba coal is low in rank and has too much inertinite macerals, making it unsuitable for liquefaction NEIC (2007).

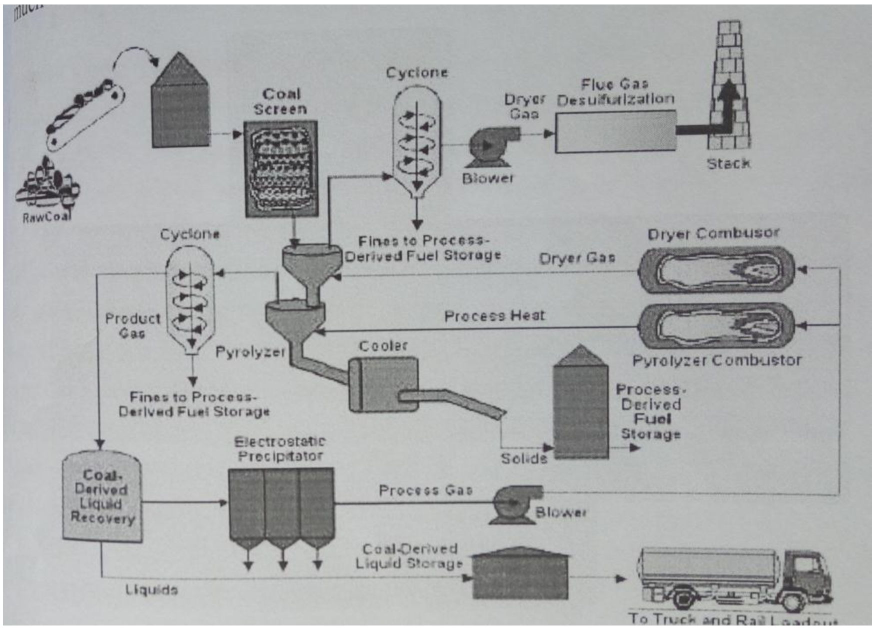

Figure 3 Process flow diagram of a coal liquefaction plant DME SA (2010), Lomax 2011

3.2 Methods of Mining and Extraction

The most economical method of coal extraction from coal seams depends on the depth and quality of the seams, the geology and environmental factors. Coal mining processes are differentiated by whether they are operating on the surface or underground. Many coals extracted from both surface and underground mines require washing in a coal preparation plant. Technical and economic feasibility are evaluated based on the following: (a) regional geological conditions, (b) overburden characteristics, (c) coal seam continuity, (d) thickness, (iv) structure, (v) quality, and (vi) depth. Others are the strength of materials above and below the seam for roof and floor conditions; topography (especially altitude and slope); climate, land ownership as it affects the availability of land for mining and access; surface drainage patterns, ground water conditions, availability for labour and materials; coal purchaser requirements in terms of tonnage, destination and capital investment requirements. The two (2) methods of mining are (i) surface and (ii) deep underground mining. The choice of mining depends on burial depth, density of the overburden and thickness of the coal seam. Seams relatively close to the surface, at depths less than approximately 180 ft. (50 m), are usually surface mined.

Coal that occurs at depths of 180 – 300 ft. (50 – 100 m) are usually deep mined, but in some cases surface mining techniques can be used, open pit methods can be used for those that are 200 ft. (60 m). More so, open pit mining operations are used for coal seams form 1000 – 1500 ft. (300 – 450 m) below ground level. Figure 4 represents the underground coal mining process as shown below.

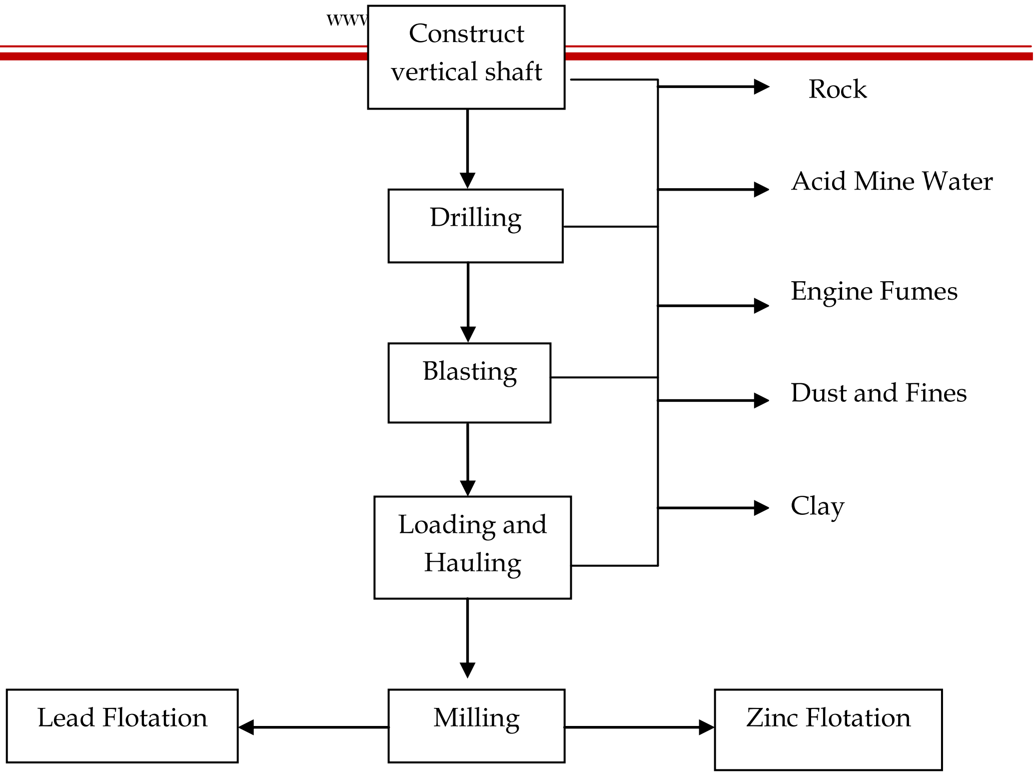

Figure 4 Underground mining schematic processes WCI (2008)

3.3 Danger and Safety in Mining

Historically, coal mining has been a very dangerous activity and list of reported disasters is a long one. In the twentieth century, over 100,000 coal miners lost their lives in the USA, 90% of the fatalities occurring in the first half of the century.

3.4 Environmental Impacts

Surface mining of coal completely eliminates existing vegetation, destroys the genetic soil profile, displaces or destroys wildlife and habitat, degrades air quality, alters current land uses, and to some extent permanently changes the general topography of the area mined.

3.5 Marketing Value for Coal

Electricity is the most efficient method of transferring energy to the final consumer. Nigeria is a country that has other potential source of energy like hydro, nuclear, biomass, solar and wind; but the cost of these ventures and other economic variables act as a limiting factor in this respect. Nigerians has been experiencing severe power outage, this has increased the cost of production and businesses to close down. This power outage has continuously increasing the operating cost of business and thus slowing down the growth of the economy. The instability and constant interruption in the oil supply due to Niger Delta problems, mismanagement of funds and severe dry season has been a source of limitation to all efforts of the government to making electricity at affordable cost. Therefore, coal is the best alternative to cushion these effects and in turn safe forex to the government. It cost of production is quite attractive and the infrastructures are nearly in place for transportation and distribution, this make it relatively cheaper than other options. In fact, coal is the energy source that drives great economies like USA, China, South Africa and Australia. In 2005, the feasibility report from BehreDolbear and Company projected that the electricity demand in Nigeria would rise to about 15GW in 2025 from the current 3.5GW, with coal providing over 6GW Lomax (2011), Chirons (2008).

4.0 THE TECHNOLOGY OF COAL PROCESSING

The cost of coal power plants depends on location, the type of technology being used and the regulations being enforced in that country. The environmental effect associating with energy source is the major cost attached to the use of coal for generating electricity. The burning of coal produces emissions that make up the ozone depletion substances (ODS) and green-house-gas (GHG). Globally, various technologies are being initiated to improving the burning efficiency of coal and reducing the negative effects it has on the surrounding environment Hughes (2005), NEIC (2007). Figures 1 – 4 shown above depicts some coal technologies that are currently in use for exploitation and production. The Kyoto protocol was enacted to promoting the transfer and development of CCT to developing countries Henning, D., (1999). Table 3 represents the characteristic of coal showing the proximate weight and ultimate weight analysis of the constituted parameters.

Table 3 Coal characteristics

S/No.	Parameter	Units	Coal
Proximate weight (% wt.)			
1.	Moisture		8.10
2.	Volatile matter		28.51
3.	Ash		14.19
Ultimate analysis (% wt. dry)			
4.	Carbon	% wt.	72.04
5.	Hydrogen	% wt.	4.08
6.	Nitrogen	% wt.	1.67
7.	Oxygen	% wt.	14.17
8.	Sulphur	% wt.	0.65
9.	Chlorine	% wt.	0.02
10.	Lower heating value	LHV (MJ/kg a.r.)	27,803.29

Source: Victoria et al., (2010)

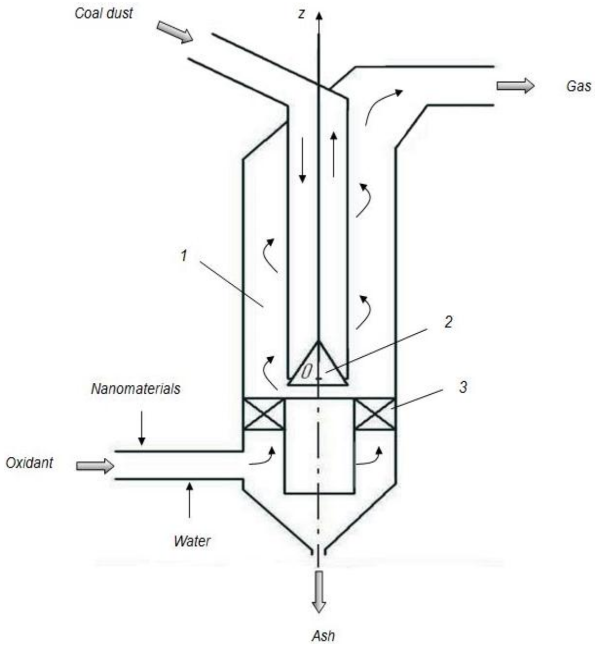

Figure 5 Schematic diagram of a jet-vortex coal gasification: 1 − gasification chamber; 2 – divider; 3 – Swirler. Source: Nikolai (2015)

The reactions mechanism of gasification of low-reactive coal number of chemical reactions takes place, of which the most important are the following [18]:

$$C + O_2 \rightarrow CO_2 + Q_1 \quad (1)$$

$$2C + O_2 \rightarrow 2CO + Q_2 \quad (2)$$

$$C + H_2O \rightarrow CO + H_2 - Q_3 \quad (3)$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2 - Q_4 \quad (4)$$

$$C + CO_2 \rightarrow 2CO - Q_5 \quad (5)$$

$$C + 2H_2 \rightarrow CH_4 + Q_6 \quad (6)$$

$$CO + H_2O \rightarrow CO_2 + 2H_2 + Q_7 \quad (7)$$

$$2CO + O_2 \rightarrow 2CO_2 + Q_8 \quad (8)$$

$$2H_2 + O_2 \rightarrow 2H_2O + Q_9 \quad (9)$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + Q_{10} \quad (10)$$

Where *Qi*, i = 1 … 10 – absolute value of heat effects of corresponding reactions kJ/kmol; For reactions (1) - (6) heat effect corresponds to the carbon kmol, for reactions (7)-(8) – to CO kmol, for (9) – to H_2 kmol, for (10) – to CH_4 kmol.
The developed model is open for other reactions that can make a significant contribution to the results of the gasification process. The main correlations in the mathematical model are ordinary differential equations, reflecting the law of conservation of energy and mass conservation law for the seven components involved in the reactions (1) - (10). In its turn, the corresponding equations of conservation of mass are based on the kinetics of the processes (1) - (10). The equations of motion in this model are absent because of the small pressure changes by height of the gasification chamber.

4.1 Benefits and Foreign Investment Packages on Coal Powered Electricity

Currently, Nigeria is generating about 3,000MW while energy demand is above 20,000MW of electricity. There is no best alternative source of energy for a developing economy like Nigeria than coal source. Coal production would a reliable means, positively affects the GDP, increase employment, increase government revenue and efforts to reducing dependency on oil. Coal emits a lot of heat especially the sub-bituminous type. The government is encouraging the use of this major energy source to boost the country’s power generating capacity and attract foreign investors. The authority has put several incentives to encourage foreign investors. This includes: (i) a 3 – 5 years tax holiday, (ii) royalty payment is deferred, (iii) 100% ownership of mining company and generating plant, (iv) extension of infrastructure to the mining site, (v) export processing and free trade zones, (vi) capitalisation of initial expenses on survey and exploration is possible, (vii) presence of domestic market for industrial commodities, (viii) there are stock exchange readily available and (ix) presence of the national electrical power grid.

4.2 The National Electric Power Grids (NEPG)

Since the cost of electricity is agreeably high in Nigeria at the moment, because domestic refined oil methods being used to power the thermal stations is expensive. Therefore, coal is considered the best alternative to power production. When Nigeria succeeds to exploiting her coal potentials, these will greatly contribute to the national grids power capacity and capability, which in turn reduce the cost of purchasing electricity and energy in the country.

5.0 CONCLUSIONS

The Nigerian coal is mainly sub-bituminous in nature and is deposited in over thirteen (13) states of the federation. Coal is a major player in the world's energy mix and generate over 40% of the world electricity and makes up to 23% of the energy consumed in the world. Fortunately, coal is found in abundance in Nigeria, the benefits are enormous but yet unexploited. The strength of a fuel in a country's energy mix is dependent on how important that fuel is to the nation. Coal is one fossil fuel that could be the answer to Nigeria's bid to boost the power sector of the economy. It plays a major role in the energy mix of the future, and the challenges of green-gas emissions (GHG) are being addressed. The carbon capture consequestration (CCC) are been improved upon and will be used to critically reduce the carbon (IV) oxide ($C0_2$) emissions from coal combustion. Therefore, the quest to developing the indigenous technology must be considered as a welcome idea which will surely assist our country in improving power generation for sustainable and economic development.

ABBREVIATIONS

CCS	-	Carbon capture sequestration
CCT	-	Clean coal technology
ODS	-	Ozone depletion substances
CDM	-	Clean development mechanism
CPE	-	Coal power electricity
GDP	-	Gross domestic products
GHG	-	Greenhouse gases
NEPG	-	National electric power grid
NSRMEA	-	National Steel Raw Materials Exploration Agency

RECOMMENDATIONS

The Kyoto protocol tries to promote the transfer and development of CCT to developing countries. These transfer of technology should involves the development of personnel and innovative technical know-how that will enable coal play its role in Nigeria's energy mix and also foster a partner with other developed countries.

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