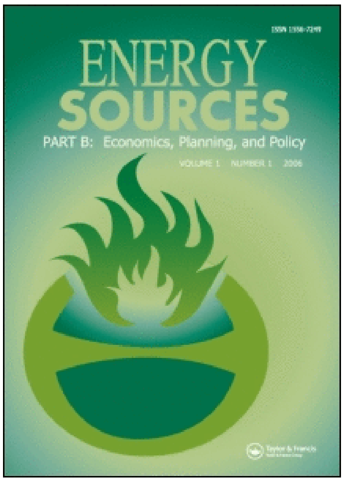

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Some Environmental Bottlenecks to Coal Utilization for Power Generation in Nigeria and Their Corrective Actions

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Abstract *Given the magnitude of the Nigerian coal reserves, the industrialization role coal played in the pre-petroleum era, and the resources conservation consideration dictating that some local resources be used so as to conserve and extend the depletion years of oil and gas, Enugu coal offers a promising alternative solution to Nigeria's power generation.*

Unfortunately, emissions from coal combination chiefly impose some environmental bottlenecks to coal utilization for power generation.

This article reviews the roles of nitrogen oxides and sulfur dioxide emissions as acid gas, as well as the activities of carbon dioxide as both acid gas and greenhouse gas. The article also examines the impact of environmental concern and legislation on the control of combustion emissions.

To ensure compliance with legislation and environmental concerns, this paper proposed fluidized bed combustion as the remedy for combustion emissions control. In this regard, two categories of FBC, namely bubbling fluidized bed and circulating fluidized bed combustors, were reviewed in conjunction with their modes of operation in the forms of:

- *atmospheric fluidized bed combustion and*
- *pressurized fluidized bed combustion.*

The review showed that the bubbling fluidized beds are more viable for retrofit applications, while the circulating fluidized bed units are more applicable in new plants.

Owing to the non inclusion of carbon dioxide parameters in the operating credentials of bubbling fluidized bed and circulating fluidized bed units, some of the known technologies for carbon dioxide scrubbing/removal were suggested as this article will show.

Keywords CO_2 scrubbing, combustion emissions, environmental bottlenecks, fluidized-bed combustion, power generation, remedy

1. Introduction

Coal was once the fuel that drove Nigeria's industrialization and socio-economic development from 1916 up to the early 1970s when crude oil began to be produced in commercial quantities in Nigeria. Between 1916 and the 1970s, coal:

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- fired the kilns at the Nigerian Cement Company Ltd., Nkalagu,
- raised the steam for driving the locomotive engines fleet of the Nigerian Railway Corporation,
- generated the steam that drove the steamers and ships in the Nigerian Marine Department,
- powered the boilers in the thermal power plants at Oji and Ijora.

These coal-utilization schemes are not currently operational.

Political, economic and environmental considerations of the military and political classes were responsible for relegating coal to the point of insignificance in Nigeria's development program. It is unfortunate that the Oji coal-fired power plant, which is situated at the heart of the Nigerian coal industry, was shut down in 1990 by federal authorities. Iwu (1998) writes that operational and maintenance cost consideration, environmental pollution, and modernization are some the reasons advanced for the shutdown.

Interestingly, overseas environmental concerns are the movers for the development of clean coal technologies that get rid of pollutants from coal utilization. The development has resulted in the accomplishment of high efficiencies that reduce emissions from coal combustion. Thus, most coal-fired power plants in advanced countries have been retrofitted or modernized for pollution control.

To give coal some relevance in the national development agenda, this article will examine some of the environmental bottlenecks to coal utilization for power generation in Nigeria and offer solutions for them.

2. Coal Reserves and Utilization

Petroleum Economist (2003) defines coal as a combustible, brittle, black or dark-brown rock rich in hydrocarbons and derived from the accumulation and transmutation of plants. Coal could be categorized as lignite (brown coal), bituminous coal (soft coal) and anthracite (hard coal). Coal, according to Miller (1998), is mostly carbon (40 to 48% depending on the type), with small amounts of water (0.2 to 1.2%) and sulphur (0.2 to 1.2%) and trace amounts of radioactive materials found in the earth. As coal ages, its carbon content increases, and its water content decreases.

The approximate percentage of the world's known coal reserves in various geographic regions is represented by Porteous (1991; Table 1).

Nigeria's coal reserves put at 5 billion tonnes (t) by RMRDC (1997) is part of the 6% coal reserves in Africa. Coal occurrence in Nigeria is spread over 13 states of the Federation, and so far 21 mine sites have been identified. Iwu (1998) states that in over

Table 1
World coal reserves and their make-up

Geographic locations	Percent occurrence
Former USSR, Eastern Europe and China	48
North America	26
Western Europe	9
Australia and Asia	9
Africa	6
Latin America	1

Table 2
Ultimate analysis of washed Enugu coal

Constituent (%w)	As received	Dry	Dry ash free
Carbon	65.40	71.90	79.40
Hydrogen	—	—	5.20
Sulfur	0.62	0.58	0.75
Oxygen	0.03	0.03	0.04
Phosphorus	—	—	12.70
Chlorine	0.007	0.008	0.008
Carbon dioxide	0.35	0.038	0.042
Nitrogen	1.60	1.80	1.90
Mineral matter	9.50	10.40	11.50

Source: Ugwu, 1996.

76 years of coal mining in Nigeria only about 25 million tonnes have been exploited, mainly from the Enugu mines. It therefore leaves much to be desired about the relegation to the background of Enugu coal, whose quality properties are shown in Table 2.

Oguejiofor (2003) writes that with 40% contribution to the total electricity utilization in the world, coal is the most widely utilized resource for electricity generation, as Table 3 shows.

Unfortunately with a reserve level of 5 billion t, coal utilization for electricity generation in Nigeria is 0 as shown in Table 4.

3. Emissions From Coal Combination

When utilized as fuel, coal is the dirtiest of the fossil fuels. Coal combustion in the conventional method releases carbon dioxide (CO_2), carbon monoxide (CO, sulphur dioxide (SO_2), nitrogen oxides (NO_x; namely nitrious oxide [N_2O], nitrogen monoxide [NO] and nitrogen dioxide [NO_2]), particulates (fly ash), and toxic metals (lead, arsenic, nickel and cadmium). The magnitude of pollutants emitted from coal combustion depends on the capacity of the power boiler/plant. Miller (1998) writes that without expensive air

Table 3
World electricity generation resource

Energy resource	Percentage utilization
Coal	40
Hydroelectric	21
Nuclear	17
Oil	11
Gas	10

Source: Oguejiofor, 2003.

Table 4
Percentage contribution of coal in power generation

Country	Percentage contribution
China	90
India	90
UK	60
USA	50
Nigeria	0

Source: Oguejiofor, 2003.

pollution control devices, burning coal produces more air pollution per unit of energy than any other fossil fuel.

3.1. CO_2 Emission and Their Environmental Impacts

Porteous (1991) reports the following facts about CO_2:

- the generation of 1 kilowatt-hour (kWh) of electricity from a coal-fired power station produces 1 kg of CO_2 (1000 kg = 1 t; 1 kWh = 1000 watt (W) of electricity supplied for 1 h or a 100 W bulb lit for 10 h),
- the burning of 1 therm (thm) of natural gas produces 6 kg of CO_2 (1 thm = 105.51 megajoule [MJ]),
- the combustion of 1 l of gasoline produces around 2.5 kg of CO_2,
- for the same amount of useful energy, oil emits 38 to 43% more CO_2 than natural gas and coal emits 72 to 95% more CO_2.

Data of this nature can form the basis of a carbon tax. On this basis, coal would be taxed more than oil, which would be taxed more than gas (Porteous, 1991).

Carbon dioxide emission into the atmosphere functions as a greenhouse gas and an acid gas. As a greenhouse gas, Miller (1998) explains that CO_2 is responsible for 50 to 60% of the global warming from greenhouse gases produced by human activities since pre-industrial times; CO_2 remains in the atmosphere for 50 to 200 years. As an acid gas Oguejiofor (2000) reports that carbon dioxide is carbonic anhydride and combines with atmospheric water to form carbonic acid as shown by the chemical equation:

$$CO_2 + H_2O(l) \rightarrow H_2CO_{3(aq)}$$

The atmospheric acid falls as rain, dew, fog or smog, causing harm to steel structures, masonry work and vegetation.

3.2. NO_x Emissions and Their Environmental Impact

Nitrogen oxides are made up of N_2O, NO and NO_2. Nitrogen oxides in flue gas are a product of oxidizing either:

- nitrogen in the combustion air supply referred to as thermal NO_x,
- nitrogen in the fuel supply, which is referred to as fuel NO_x.

Generally, when burning coal, less than 25% of the NO_x produced is thermal NO_x and the balance is fuel NO_x (Lavely and Ferguson, 2001).

Nitrogen monoxide is a colourless gas, formed during high temperature combustion of fuels which allow the nitrogen in the air to combine directly with oxygen at temperatures above 1600°C, and thermal NO_x is formed as expressed by the following chemical equation:

$$N_{2(g)} + O_{2(g)} \rightarrow 2NO_{(g)}$$

If the fuel also contains nitrogen, nitrogen monoxide will be produced at temperatures above 1300°C, giving rise to fuel NO_x. When cooled rapidly on exiting from the stack into the atmospheres, NO can form NO_2 as shown below:

$$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$$

Nitrogen dioxide is a reddish-brown gas with pungent odor and can impact on the environment and ecosystem in various forms, namely as acid gas and a reagent for photochemical smog formation. As an acid gas, Oguejiofor (2000) expresses that NO_2 dissolves in atmospheric water to produce nitrous acid and nitric acid in accordance with the chemical equation:

$$2NO_{2(g)} + H_2O_{(l)} \rightarrow HNO_{2(aq)} + HNO_{3(aq)}$$

These atmospheric acids fall as acid rain in the form of dew, fog, smog or conventional rain, which attack almost everything in the environment and ecosystem. Nitrogen dioxide, according to Porteous (1991), is extremely poisonous and forms nitrous acid (HNO_2) and nitric acid (HNO_3), both of which attack the mucous lining of the lungs. Nitrogen dioxide is also thought to act as a plant-growth retardant at normal atmospheric concentrations (Porteous, 1991).

3.3. Emissions and Their Environmental Impact

Like CO_2 and NO_x, SO_2 is an acid gas, which contributes significantly to acid rain phenomenon. Sulfur dioxide was a contributor to the massive smog that engulfed London in 1952 for four days and killed 3,000 people, including the elderly, the sickly and the young (Acid Rain Information Centre, 1986).

According to Oguejiofor (2000) SO_2 as an acid gas reacts with atmospheric water to form the unstable aqueous sulphurous acid as shown:

$$SO_{2(g)} + H_2O_{(L)} \rightleftarrows H_2SO_{3(aq)}$$

Sulfurous acid is oxidized by atmospheric oxygen to form sulfuric acid as shown:

$$2H_2\ SO_{3(aq)} + O_{2(g)} \rightleftarrows 2H_2SO_{4(aq)}$$

By the process of precipitation, the acid descends on the human environment and impacts negatively on the human habitat. Fortunately, Nigeria's coal, particularly the Enugu coal, has low sulphur content (see Table 2).

4. Concerns About Emissions Control

The section will examine the legislative responses and environmental concerns about controlling emissions from combustion processes.

4.1. Legislative Responses

One of the corrective actions taken as a result of the London smog of 1952, which killed 3,000 people, was the enactment of legislation for the control of combustion emissions into the environment. Some of these pieces of the United Kingdom (UK) legislation are:

- Clean Air Act 1956 and 1968
- Control of Pollution Act 1974
- Health and Safety at Work Act 1974
- Environmental Protection Act 1990.

A major piece of the UK legislation enacted in 1990 was the Integrated Pollution Control (IPC) Act. Porteous (1991) explains that IPC was introduced in the UK environmental protection bill so that all major emissions to land, air, and water are considered simultaneously and not in isolation, i.e., the reduction of pollution in one environmental medium can have effects in another.

In the UK, while the administrative control of pollution is by the previously listed pieces of legislation, the enforcement and implementation of these laws/legislation are the responsibilities of statutory bodies such as Her Majesty's Inspectorate of Pollution, the Department of the Environment, and the Health and Safety Executive. The Warren Spring Laboratory coordinates the UK smoke and SO_2 Monitoring Network to ensure compliance with the European Union air quality limits.

In the USA, the clean Air Act was amended in 1990, which required the installation of NO_x combustion control equipment on the existing coal-fired plants (Stallard and Jonas, 2001). In compliance with this amended act, NO_x emission consideration became significant in the design/construction of new fossil-fuel-fired power plants and in the retrofitting of existing coal-fired plants.

In Nigeria, the legal system is British-oriented and the new-found awareness of environmental quality led to the establishment in 1988 of the Federal Environmental Protection Agency (FEPA). FEPA (usually cited as FEPA Act 1988) was charged with the responsibility for the protection and development of the Nigerian environment including policy initiation in relation to environmental research and technology.

In 1989 FEPA's responsibilities were translated into the National Policy on Environment. As part of the implementation on the national environmental policy, interim guidelines and standards for environmental control in Nigeria were developed in 1991 (also called FEPA 1991). By 1992, an amendment was made on the FEPA Act 1988, resulting in the Federal Environmental Protection Agency (Amendment) Decree 1992 (Decree No. 59 of 1992).

Also in 1992, the Environmental Impact Assessment Decree No. 86 was promulgated. This solely gave legal muscle for the enforcement of the various policy provisions on the need for studies of the environmental impact on both public and private sector projects as such projects are being planned.

The enforcement and implementation of the stipulations of these laws lie with the Federal Ministry of Environment and, at the state level, the State Waste Management Authorities. However, these Ministry and Authorities focus more on solid waste management and control, with little or no efforts on gaseous emissions. This may be because they are yet to attract the multidisciplinary scientists and specialists required for the compliance of the laws on emission.

4.2. Environmental Concerns

Environmentalists believe in a holistic or global approach that integrates broad strategies in solving the problems of emission from human activities. To this end, some of the global environmental concerns striving for emission reductions in greenhouse gases are:

- conferences of the Intergovernmental Panel on Climate Change 1990, 1992, 1994, 1995 etc.,
- the 1992 UN Earth Summit held in Rio de Janeiro, Brazil,
- the 1997 UN Convention on climate change, dubbed the "Kyoto Protocol."

The Earth Summit produced the five Rio documents in the name of biodiversity, climate, deforestation, financing and population. The Kyoto Protocol pledged the signatories of industrialized nations to specified, binding reductions in emissions of six greenhouse gases, namely CO_2, methane (CH_4), NO_x, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_7). However, the Kyoto Protocol is not working because the George W. Bush administration rejected the treaty on the grounds that the Protocol will harm the US interest and should include developing nations like China and India whose industries contribute significantly to greenhouse gas emissions.

4.3. Lessons for Nigeria

Given the forgone submissions, Nigeria has some lessons to learn from both legislative responses and environmental concerns about fossil-fuel emissions.

Despite the London smog disaster of 1952, coal utilization continues to contribute about 50% to the UK power generation. Administrative controls through legislative enactments/amendments, their enforcement by statutory inspectorate bodies, and their compliance by the UK power-generating industries continues to make coal a usable energy-generating resource, despite the rich oil/gas reserve in the North Sea. Porteous (1991) shows that as of 1991 the UK natural gas reserve was put at 83.8 trillion cubic feet. Secondly, despite the US signing of the Kyoto Protocol, the George W. Bush administration is shielding the coal-fired power generators and playing for time that would enable fossil fuel plants to find better ways of reducing emissions to meet Kyoto requirements. Thus, while the UK and the US are striving to continue keeping coal relevant for power generation in the face of challenges, Nigeria relegated her coal when she witnessed commercial-scale petroleum.

5. Remedies for Coal Combustion Emissions: Fluidized Bed Combustion

Environmental concerns and various governments' legislations have encouraged the development of clean coal technologies that reduce combustion emissions. This section discusses some of the available technologies for controlling the emissions from coal combustion to ensure environmentally friendly coal utilization and compliance with the relevant legislations, environmental concerns and of course the International Standards Organization (ISO) 14001. ISO 14001 is an international certification standard for health, safety and environment (HSE) management and performance.

For solid-fuel combustion, fluidized bed combustion (FBC) emerged in the late 1980s as a viable technology alternative over stoker fired/pulverized coal-fueled combustors. By

1991, FBC has transited from small industrial-size boilers to the size range of 100 to 165 megawatt (MW) boilers. By the year 2001, manufacturers of FBC were willing to offer full commercial guarantees for boilers in the 250 to 300 MW size range (Habiger, 2001).

In FBC, a stream of hot air is blown into a boiler to suspend a mixture of powered coal and crushed limestone. This method removes most of the SO_2, sharply reduces emissions of NO_x, and burns the coal more efficiently and cheaply than conventional combustion methods (Miller, 1998). This is corroborated by Habiger (2001), who writes that SO_2 emissions could be controlled from FBC units without the use of external scrubbers (i.e., flue gas desulfurization system), and NO_x emissions from FBC units are inherently low.

FBC units could be distinguished into two classes, namely:

- the bubbling fluidized bed (BFB), operated at the velocities in the range of 3 ft/s (0.91 m/s) to 10 ft/s (3.048 m/s),
- the circulating fluidized bed (CFB), operated at the velocities ranging from 13 ft/s (3.96 m/s) to 22 ft/s (6.71 m/s).

The primary use of BFB units in the electric utility industry has been in retrofit applications (Habiger, 2001). The CFB units are considered commercially available and compete in the marketplace in size up to about 250 MW (Habiger, 2001) for new plant applications.

Any of these classes of FBCs can be operated under atmospheric and pressurized conditions. When the coal, biomas, sorbent ($CaCO_3$) in the fluidized vessel are maintained at atmospheric pressure, then atmospheric fluidized bed combustion (AFBC) is obtained. However, when the coal and sorbent are subjected to 10 to 15 atmospheres in a pressurized vessel, this results in pressurized fluidized bed combustion (PFCB).

Clean coal technologies have been undergoing development. Over the years, legislation has continued to change and environmental concerns have also continued to step up pressure. In response, coal combustion technologies have also continued to improve, resulting in the decline in the rates of combustion emissions. Tables 5 and 6 show the performance data of BFB and CFB coal combustors.

These operating credentials offer promise and hope for the rebirth of the Oji-River Coal-fired Power Station in Nigeria, which utilized the Enugu coal for power generation from its commissioning in 1956 to its shutdown in 1990. Despite the fact that Tables 5 and 6 fail to illuminate the CO_2 parameter, interestingly, the technologies for knocking off CO_2 from flue-gas stream are well known:

- aqueous absorption in a counter-current flow of CO_2 and water maintained at a pressure of about 30 atmospheres,
- amine absorption in a counter-current flow of CO_2 and amine solution,
- adsorption by zeolite solids,
- separation of CO_2 from flue-gas stream and the storage in the deep sea.

Nonetheless, further development trends about FBC systems can be obtained from leading manufacturers of coal-fueled fluidized bed boilers such as Alstom, Switzerland; ABB Combustion Engineering Inc., USA; Lurgi, Germany; M.W. Kellogg, USA; Babcock and Wilcox; Foster Wheeler Energy Corporation; British Coal; and Sasol, South Africa.

Table 5
Typical BFB operating parameters

Bed temperature (°C)	843–900
Superficial velocity (m/s)	0.91–3.048
Bed depth (m)	0.61–1.83
Freeboard height (m)	2.44–6.10
Coal feed particle size:	
(i) Overbed feed (microns)	31,750 × 0
(ii) Underbed feed (microns)	12,700 × 0
Sorbent feed particle size (microns)	3,175
Calcium/sulfur ratio	2.5–4.0
SO_2 removal (%)	90
Combustion efficiency (%)	90–98
Recycle ratio	0–5
Excess air (%)	20–35
NO_x emissions (ppm)	150–350

Source: Habiger, 2001.

Table 6
Typical CFB operating parameters

Bed temperature (°C)	843–900
Superficial velocity (m/s)	4.6–9.14
Coal feed particle size (microns)	1,563–9,525
Sorbent feed particle size (microns)	1,000
Recycle ratio	10–100
Calcium/sulfur ratio	1.5–4.0
SO_2 removal (%)	90–95
Combustion efficiency (%)	90–98
NO_x emissions (ppm)	10–100

Source: Habiger, 2001.

6. Conclusion

The control of pollution from coal utilization in power-generating plants begins from process selection, through plant construction/operation, to plant maintenance. Given the magnitude of coal reserves in Nigeria, it is important that the overdependence on oil and gas be reduced by diversification to solid fuel resources. Consistent with this is the fact that resource conservation consideration may dictate that some coal be used in order to conserve oil and natural gas and extend their depletion years. Interestingly, this work has illuminated the alternative FBC technologies to enable investors and end-users to make informed decisions about the choice/selection of coal-fueled power generators.

It is expected that this would encourage the rebirth of Nigeria's coal-utilization industry, and create investment/employment opportunities for the teeming population of Nigeria.

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