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Analysis of clean coal technology in Nigeria for energy generation

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ABSTRACT

An analysis of clean coal technologies for the recovery of energy from Nigerian coals was carried out. The coal mines studied are Onyeama, Ogwashi, Ezimo, Inyi, Amasiodo, Okaba, Lafia-Obi, Owukpa Owukpa, Ogboyoga and Okpara. The estimated reserves of the ten coal deposit amount to 2.1 Gt, which is about 84% of the total coal reserves of the country 2.5 Gt of coal Nigeria. The key clean coal technologies studied are Ultra-Supercritical Combustion (USC), Supercritical-Fluidised Bed Combustion (FBC), Integrated Gasification Combined Cycle (IGCC) and Coal bed Methane (CBM) and the results were compared with conventional subcritical pulverised fuel combustion (PF). The total potential energy recovery from these technologies are: PF 5800 TWh, FBC 7250 TWh, IGCC 7618 TWh, and USC 8519 TWh. This indicates an increase of about 31% in the total electricity generation if USC technology is used instead of the conventional sub-critical PF technology. About 39% of the total electricity generation of 8519 TWh from USC could come from Amasiodo coal deposit, making it the highest contributor to the total power generation. Inyi coal had a contribution of ~1.5% making it the lowest contributor. The lowest CO_2 emission factor was from Onyeama coal and was reduced from 1.0 kg CO_2/kWh in PF to 0.68 kg CO_2/kWh in USC. Oghwashi coal had the lowest energy and highest emission factor. There will be a need for the coal upgrading/beneficiation for optimal energy recovery.

1. Introduction

Nigeria has estimated coal reserves of 2.5 Gt [1]. About 90% of the coal reserves are sub-bituminous and bituminous coals with the remainder being of lignite rank [2]. These coal reserves are located in the Lower, Middle and Upper Benue Trough. Lignite and Sub-bituminous coals are mainly found in the Lower and Upper Trough and high–volatile bituminous coals in the Middle Trough [3]. Some of the notable coal mines in the Lower Trough include Onyeama and Okaba and Lafia-Obi for the Middle Trough. All in all, there are about 23 coal mines in Nigeria [1], some of which are currently not in operation [4].

Previously, coal was mainly used to power trains and also for electricity generation [5]. The peak of production and consumption was in the late 1950s when the production was about 800,000 t per year, the domestic consumption was about 700,000 t per year and the remainder was exported [5]. The Nigeria Railway Corporation consumed about 50% and the Electricity Corporation of Nigeria (ECN) consumed about 20% of the total coal produced. The remaining local coal production was consumed by the shipping industry and government agencies and other users [5].

The replacement of coal with diesel in the powering of the trains and with gas and hydro for electricity generation led to a drastic drop in coal production and utilisation. This led to the closure of the two coal power stations in Nigeria, namely the Oji coal power station in Enugu and Ijora power station in Lagos [5,6]. The present production and utilisation of coal in Nigeria is very low [7,8]. Coal is mainly used as a heat source in cement production. Other industries that use coal as heat source are the brick factories and bakeries [9].

The present electricity generation in Nigeria fluctuates between 2687 MW and 4200 MW while the estimated peak demand is 12800 MW [10]. This results in a 67-79% electricity deficit. The government plans to increase its generating capacity to 40000 MW in 2020. According to the Nigerian government power growth plan, coal is projected to contribute about 6% of the 40 GW target in 2020

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[11]. Some of the planned coal power plants will be in Enugu (1600 MW), Kogi (1000 MW) and Benue (1200 MW) [4,11]. The coal sources for the planned power stations are located at Enugu (Ezinmo, Inyi), Kogi (Okaba, Ogboyoga), and Benue (Orukpa) [4].

The technology to be applied in the proposed power plants has not been finalised. There is a need to use technologies that promote high efficiency. According to a report by the World Coal Associaion (WCA) on accelerating coal power efficiency, a 1% increase in coal-fired plant efficiency can lead to 2-3% decrease in emissions [12]. This is illustrated in Fig. 1.

Higher efficiency and low emission (HELE) coal plants are key components of clean coal technologies (CCT) [15,16]. CCT are technologies that allow the power generation industry to cleanly and efficiently use coal as an energy source [16]. Some of the notable clean coal technologies are Ultra-Supercritical Pulverised Fuel Combustion (USC), Fluidised Bed Combustion (FBC), Integrated Gasification Combined Cycle (IGCC), and Coal Bed Methane Technology (CBM) [17–19]. These clean coal technologies (USC, IGCC, FBC and CBM) and the conventional Subcritical Pulverised Fuel Technology (PF) can be applied in the recovery of energy from the coal reserves in Nigeria. USC, FBC, IGCC and PF are primarily *ex-situ* technologies that involve the mining of coal followed by combustion or gasification for energy recovery, CBM is an *in-situ* technology that involves the recovery of methane gas from coal seams prior to the mining of the coal. The methane gas can then be used in a gas turbine for electricity generation [20,21]. The recovery of the methane can also help in the mitigation of the emission of the methane in the coal mine and the fire hazards associated with the release of entrapped methane during mining and thereby increasing the safety of the miners [22].

The evaluation of the use of advanced clean coal technologies such as USC, FBC, IGGC and CBM on the recovery of energy and emissions reduction from Nigerian coal reserves has not been carried out in detail.

Sambo [23] reported that about 3500 MW of electricity can be generated from coal deposits in Orupka and Ezimo coals in Benue State without specifying the type of coal power technology. Chukwu [24] reported that coals from five coal mines (Odagbo, Owukpa, Ezimo, Amansiodo and Inyi) are suitable for power generation using pulverised fuel technology and fluidised bed technology based on their coal properties.

Amoo [25] also reported that Lafia-Obi coal can be used for electricity generation using fluidised bed technology. He evaluated the fluidised bed properties of Lafia-Obi under air and oxy-combustion conditions using a CFD model.

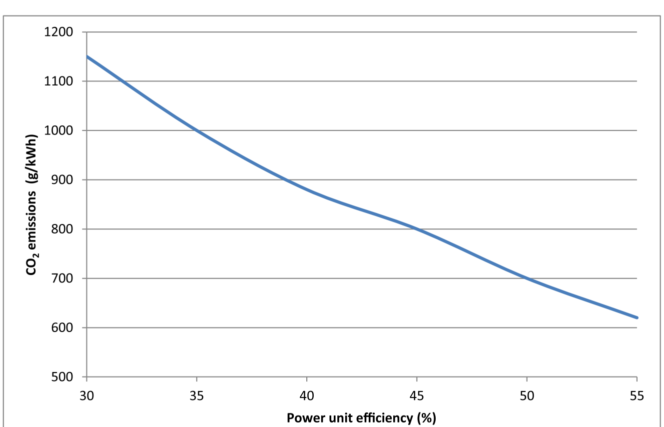

Fig. 1. Reduction of emissions through efficiency improvements [13,14].

Adeyinka [26] reported on the gasification properties of a Nigeria bituminous coal, but there was no mention of the evaluation of power production through an Integrated Gasification Combined Cycle (IGCC) process for the particular coal.

This study aims to evaluate the coal consumption rate, emission factor and total energy recovery for USC, FBC, IGGC and CBM technologies and compare them with those from a conventional low efficiency subcritical pulverised fuel (PF) for several coals from ten different coal mines in Nigeria, namely Onyeama, Ogwashi, Ezimo, Inyi, Amasiodo, Okaba, Lafia-Obi, Owukpa Owukpa, Ogboyoga and Okpara. The estimated reserves of these coal mines are 2.1Gt, i.e. about 84% of the total estimated reserves of the 2.5 Gt of coal. The coal mines are open cast (surface mining) and underground [1]. An overview of the mines is presented in Table 1. The proximate and ultimate analyses of the different coals is presented in Table 2 and are obtained from the literature [27–31].

The potential energy recovery, emission factors and overall efficiency for PF, USC, FBC, IGGC, were evaluated as follows:

The overall efficiency is a function of the technology, thus: PF is 28–32%, USC is 45–47%, FBC 35-40% and IGCC is between 35 and 42% [18]. In this study, we used the maximum value for each of these technologies.

Heat Rate required to produce one 1 kW = 3600 kJ/h /Overall efficiency (1)

Coal energy generation rate = Heat rate/ Heating value of the coal (HV) MJ/kg (2)

Total Energy recovery = Total coal reserves xCoal energy generation rate (3)

CO_2 Emission factor = Carbon Content x Combustion efficiencyx 44/12 × 1/HV (4)

Combustion efficiency for the different coals was derived from their fuel ratios. A lower fuel ratio would result in a higher combustion efficiency [32]. The combustion efficiency for all the coals was in the range of 0.88–0.96.

For the CBM technology, the total energy recovery is derived by multiplying the volume of methane in the coal mines and the energy density by the volume of Methane. The energy density by volume of Methane is 9.8 kWh/m^3 [33].

The volume of the methane gas in the coal mines was evaluated by Kim correlation [34], and it is expressed as a function of the coal properties such as the fixed carbon, volatile matter, ash yield and moisture. The volume of methane gas in the coal mines is a function of the depth of the coal seam. The volume of methane gas in the coal mines can be calculated by using Equation (5) [19].

$$V_{gas} = \frac{(100 - \%M - \%A)\left(\frac{V_m}{V_d}\right)\left[K_o(0.096h)^{n_o} - 0.014\left(\frac{1.8h}{100}\right) + 25\right]}{100} \quad (5)$$

V_{gas} is the volume of methane capacity of the mine, h is the depth of the mine, M: moisture, A; ash yield, V_m is the volume of wet coal and V_d is the volume of dry coal. The volume ratio V_m/V_d is the adsorption capacity of the methane gas in the coal mine/seam and is related to moisture of the coal and is given in Equation (6) [19].

$$\frac{V_m}{V_d} = \frac{1}{C_o M + 1} \quad (6)$$

C_o is a constant and it is 0.25