Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054)
Volume 8, Issue 1, 2020

A Review of Environmental Issues in Coal Processing and Utilization, and the Mitigation of the Environmental Impacts

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ABSTRACT

Coal is the most utilized primary energy source for the generation of electricity worldwide. It is also an important raw material in metallurgy in addition to being a source of many chemicals vital for the running of a lot of industries. Coal is abundant in many countries. The coal reserves are more than the oil reserves, hence can last longer. But coal is widely vilified as a dirty fuel because of the emission of environmentally unfriendly gases on coal combustion during utilization. As a result, the focus is on renewable energy at the expense of the underutilized coal. In realization of the importance of coal in sustainable development, coal cannot be ignored. This work reviews ways of utilizing coal, environmental effects and measures to mtigate eadverse environmental impact.

Key words: Coal, utilization, environmental impact.

INTRODUCTION

Coal is a combustible rock which originated from dead plants that underwent series of biochemical and geochemical transformations over millions of years resulting in a complex compound. Coal, like any particle of solid fuel can be regarded as consisting of three components: the organic matter, the moisture in the pores, and the inorganic matter

From ultimate analysis, the elements in coal are mainly carbon, hydrogen, oxygen, nitrogen and sulphur [1].

Nigeria's coal reserve is over 900 million metric tonnes with unexploited coal fields spread in several states [2, 3]. The exploitation of these coal deposits would reduce significantly the overdependence in petroleum resources for both power and income generation.

Coal has found wide applications in industrial and domestic heating, generation of electricity, production of cokes used in metallurgy and in the production of gaseous and liquid hydrocarbons of varied importance. Coal is a source of oil and major chemicals through appropriate conversion processes.

The usefulness of coal is associated with its chemical properties. Such properties include its responses to oxidation and reduction, its behaviour during pyrolysis, and its solubility or dispersibility in organic solvents. The understanding of the properties of coal provides information for the prediction of the behaviour of the coal, and hence its applications [4].

THE COAL CYCLE

It depicts the various stages in the handling of coal from reserve assessment, through mining and processing, to end use [5, 6].

The first stage of the coal cycle is the determination of coal reserves by geological assessment. The second stage of the coal fuel cycle is the mining and subsequent processing of coal from mines. This is followed by the third stage of the fuel cycle which involves the transport of the raw or processed coal. The fourth stage of the fuel cycle is the conversion of coal to other energy forms.

Each stage of the coal fuel cycle has effects on the environment.

ENVIRONMENTAL EFFECTS OF THE COAL CYCLE

Coal makes environmental impacts from the mining, the processing to the utlization stages.

AT THE MINING STAGE

Coal mining, particularly surface mining, requires large areas of land for mining activities. This leads to ecological problems, dust, noise and water pollution as the aquifer is usually affected. Another environmental problem associated with mining activities is the release of dangerous gases such as methane and lead from the mines. Accumulated Methane within coal seams in underground coal mines can sometimes cause explosion due to atmospheric oxidation or a spark from the miners' safety lamp.

As in other mining activities, a lot of dust is released into the environment. Such dusts may be carriers of toxic metals like lead, which are harmful to human health and perilous to the environment.

AT STORAGE

The storage of coal may constitute a source of environmental problem due to disasters associated with improper storage of coal. When coal is stored and exposed, a chemical change, arising from oxidation process, takes place. This is accompanied by the liberation of heat. If the heat liberated is not conducted out of the coal pile as it is liberated, it stays in the coal thereby raising its temperature. This might lead to spontaneous ignition, a hazard that would pollute the environment [3].

AT PROCESSING

Coal processing can include a variety of steps—crushing, screening, and wet or dry separations—to reduce the ash content of coal prior to transport and use [7].

These steps generate dusts which are objectionable to the environment and pollute the air.

AT UTILIZATION

This stage is dominated by the combustion of coal. The use of coal for power generation has been associated with a number of environmental challenges. Coal-based power plants emit air pollutants and create solid and liquid wastes that can adversely affect air quality, terrestrial and aquatic environments, human health, and climate.

When coal is burned, three main forms of environmental pollutants are formed [4].

These are sulphur oxides, nitrogen oxides and coal ash. Sulphur occurs in coal in different forms. One form is in combination with iron and it is known as pyrite. Another form is when it is chemically bound with the carbon molecules. This is the organic sulphur in coal. The third form is in combination with other minerals in the form of sulphates. During coal combustion, sulphur in coal is converted to sulphur dioxide (SO_2) some of which is oxidized to sulphur trioxide (SO_3). These two oxides of sulphur are conveniently called Sox. The combustion of coal in the presence of nitrogen, from either the fuel or air, leads to the formation of nitrogen oxides. During coal combustion, nitrogen in coal is oxidized to a mixture of nitrogen oxides. This mixture contains about 95% nitric oxide, NO, the rest being nitrogen dioxide, NO_2, with trace amounts of nitrous oxide, N_2O. This mixture of nitrogen oxides is conveniently called Nox [8].

Impacts of Coal Combustion on Air Quality

Atmospheric emissions of SO_x, NO_x, and particulate matter (PM) from coal combustion are significant sources of air pollution that have been linked to respiratory and other human health problems [9, 10] as well as stunt vegetation. SOx and NOx are also major factors in formation of smogs.

Impacts of Coal Combustion on Terrestrial and Aquatic Environments

When coal burns, some impurities like sulphur and nitrogen are released into the air. These substances can combine with water vapour (for example, in clouds) and form droplets that fall to earth as weak forms of sulphuric and nitric acid, called acid rain. As acid rain, they can seriously damage soil productivity, destroy vegetation and aquatic life, and attack man-made structures.

Coal combustion and gasification processes generate ash and other solid residues, as well as liquid effluent. The coal ash retains the trace elements that were originally present in the coal, and some of these elements have the potential to impact negatively on human health and the environment. Leaching of ash and slag, and the water used for handling ashes as slurries, can create water pollution problems [1, 4, 8].

Impacts of Coal Combustion on Global Climate

Burning coal and other fossil fuels releases carbon dioxide to the atmosphere. These increased levels have been linked to an overall warming of the earth's surface global climate change [11, 12].

Mitigation of coal's environmental impacts

Coal mines must be properly constructed and managed to avoid erosion, especially after coal excavation. It is desirable to have appropriate drainage channels that allow for collection of runoff water over mines into artificial lakes where the water will be treated before it becomes avalable for further use.

The adverse consequence of improper coal storage can be mitigated by limiting the access of air and moisture to the coal in a pile. Every precaution should be taken to exclude air. The coal can be parked carefully in a pile as the best preventive technique to avert spontaneous heating. This can be helped by packing the coal uniformly and avoiding segregation of different sizes [13].

Like in all industrial operations, wastes are generated in the course of the coal cycle. If the coal power plant is more efficient, there will be a decrease in waste volumes or the concentrations of hazardous components from the plants. Efficient plants burn less coal per unit of energy produced with reduced environmental pollution [1].

During coalification, minerals are deposited in coal or embedded in it. These minerals may come from the dead plants or from the swampy water where the coal was formed. It is easy to remove such minerals by physical means if the minerals are embedded. However, some minerals were incorporated in coal as the coal formed, or chemically bound to the coal structure. The removal of such minerals by physical coal cleaning processes is virtually impossible. As such the success of cleaning depends on the way in which the minerals are incorporated in the coal. Some of the physical processes for removing mineral impurities from coal are based on the difference in specific gravity between coal and the minerals. The specific gravity of mineral free coal varies with rank but generally ranges from 1.2 to 1.5. The specific gravities of minerals found associated with coal are much higher. When crushed coal is placed in a fluid whose specific gravity is intermediate between those of coal and minerals, the coal floats and the minerals sink. The coal is then mechanically separated from the minerals. The behaviour of raw coal in a wet washer can be predicted from laboratory simulation tests known as 'Foat and Sink tests, and Washability tests [8, 13].

Mined coal is associated with mineral and chemical materials including clay, sand, and trace elements. Coal cleaning by washing and beneficiation removes these materials.

The combustion of coal generates liquid, gaseous and solid wastes. The production of this waste can be minimized by coal cleaning prior to combustion. This is an important step in reducing emissions from coal use. Coal cleaning reduces the ash content of coal by over 50% resulting in less waste, lower sulphur dioxide (SO_2) emissions and improved thermal efficiencies, leading to lower CO_2 emissions [1].

Trace elements

Coal is a chemically complex substance, naturally containing many trace elements. A number of technologies are used to limit the release of trace elements including coal washing, particulate control devices, fluidized bed combustion, activated carbon injection and Flue-Gas Desulphurisation.

Coal ash is safely disposed of by burying them in mined-out pits or sending them, slurried with water, to lagoons, where solid matter can settle out and later be recovered for final disposal.

Particulates

Particulate emissions are finely divided solid and liquid (other than water) substances that are emitted from power stations. Particulates can affect people's respiratory systems, impact local visibility and cause dust problems. A number of technologies have been developed to control particulate emissions using collecting systems such as Electrostatic precipitators [ESP], Fabric filters, Scrubbers and Hot gas filtration systems. Both ESP and fabric filters are highly efficient, removing over 99.5% of particulate emissions [13].

Gaseous pollutants from coal combustion

A way to mitigate the impact of gaseous products from coal combustion is to clean the coal before it burned. This can be achieved by crushing the coal and thereafter washing the small parts.

Oxides of sulphur

Coal Cleaning: Sulphur occurs in coal in different forms. Sulphur can occur in form of pyritic sulphur in which sulphur is combined with iron pyrite. This can be washed out of the coal by coal cleaning. In this process, the coal is placed in a large water-filled tank. The coal floats to the surface while the sulphur impurities sink. This can then be separated. Some other forms of sulphur such as the organic sulphur may not be removed from coal by washing. In these forms, sulphur is chemically connected to the carbon molecules, and may have to be removed by using suitable technologies such as flue-gas desulphurization. Generally, through cleaning of coal before use, the total sulphur content can be reduced by up to 40%. Thus, when coal is thoroughly cleaned, its combustion introduces less sulphur oxides into the environment.

Flue-Gas Desulphurisation: Oxides of sulphur are soluble in water. They are also reactive to basic compounds such as suspension of lime or limestone in water. This fact is used to capture the sulphur oxides in coal power plants before they escape into the air. The process for doing this is called flue-gas desulphurization (FGD) and is carried out in units called scrubbers. The flue-gas is bubbled through the slurry. The sulphur oxides dissolve in the basic slurry, forming a sludge which contains calcium sulphate and calium sulphite.

The reactions are represented below:

$$CaO + SO_2 \longrightarrow CaSO_3$$

$$CaO + SO_3 \longrightarrow CaSO_4$$

The sludge can be removed by physical means and may be used for its other benefits such as in making boards.

Use of Low-Sulphur Coal: By carrying out ultimate analysis on the coal, it will be possible to note the sulphur content of a particular coal. This consideration might be used to choose coal for combustion such that coal having low sulphur content (e.g.1% sulphur or less) would be preferred on environmental factor. This type of coal introduces less sulphur oxides into the environment.

Oxides of Nitrogen

One of the best ways to reduce NOx is to prevent it from forming in the first place. This could be achieved by burning coal in burners where there is more fuel than air in the hottest combustion chambers. These burners can reduce the amount of NOx released into the air by more than half. Some of these devices use special chemicals called 'catalysts' that break apart NOx into non-polluting gases. These devices can remove up to 90 percent of NOx pollutants.

Technologies to reduce NOx emissions include primary abatement measures such as the use of low NOx burners. The burner can also be optimized to minimize the formation of NOx during combustion. Technologies such as Selective Catalytic Reduction (SCR) remove between 80-90% of NOx emissions at a given plant [14].

One other method of reducing thermal NOx is to design boilers in which the combustion gases are held up for a long time to allow NOx to decompose back to N_2 and O_2. In such boilers, coal is burned in a fuel-rich which is later made air-rich by delaying the mixing of secondary air and allowing only small amounts of excess air.

Another way of reducing the NOx is by reacting the nitrogen oxides with ammonia, in the presence of catalysts, to give nitrogen and water. Therefore, by reaction with ammonia, NOx can be rendered harmless.

Use of fluidized Bed Boilers: The result is that a fluidized bed boiler can burn very dirty coal and remove 90% or more of the sulphur and nitrogen pollutants while the coal is burning.

Gasification of coal is one of the best ways to clean pollutants out of coal. There are various ways of gasifying coal. One method is by passing a mixture of air and steam through a bed of coal. Gasification is based on chemical reactions between carbon and one or more of the three gases, oxygen, steam or carbon dioxide [3]. The result is a mixture of carbon monoxide and hydrogen- a gas. The impurities in coal, like sulphur, nitrogen, and many other trace elements, can be almost entirely filtered out when coal is changed into a gas (a process called gasification) [14].

Capturing and sequestering (storing) CO_2 produced by fossil fuel combustion or gasification. The technologies currently offered commercially to capture power plant CO_2 emissions can achieve net emission reductions of 85 to 90 percent at new PC or IGCC power plants [12]. Such technologies are widely used in a variety of industrial processes, mainly in the petroleum and petrochemical industries, but are not yet deployed commercially in the electric power sector.

CONCLUSION

Coal is an important primary fuel, used extensively for the generation of electricity. Like in any industrial operation, the utilization of coal would generate liquid, gaseous and solid wastes. But the wastes can be minimized by cleaning the coal before use. At the combustion of coal, the coal plant should be fitted with suitable technologies such as flue gas desulphurization devices that could reduce emission of sulphur oxides and nitrogen oxygen oxides. It has been found that gasification of coal can remove almost all the pollutants associated with coal. Coal can therefore be utilized with minimal adverse environmental effects.

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