

ENVIRONMENTAL PROBLEMS ARISING FROM COAL HANDLING AND PROCESSING

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Keywords: coal, environment, atmospheric pollution, particulate matter, sulfur dioxide, nitrogen oxides, greenhouse gases, trace elements, wastewaters, acid mine drainage, emission standard, pollution control, coal dust, coke oven, fly ash, acid rain, sulfur content, pyritic sulfur, organic sulfur, combustion, methane, aqueous pollutants, regulation, pretreatment, operation modifications, flue gas cleaning, sorbent injection, handling, processing

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Summary

Coal production and utilization is an important industrial source of extensive environmental pollution. Over the last decades, attention has focused on the atmospheric pollution caused by coal combustion processes. Sulfur dioxide, particulate

matter and nitrogen oxides are the pollutants that have received worldwide public concern owing to their environmental impacts. Various technologies have been developing to control the emissions of these pollutants, with the enforcement of increasingly stringent emission standards in most countries. At present, there are no specific emission standards for the control of greenhouse gases and trace elements in coal combustion plants, perhaps because there remain many uncertainties regarding their environmental impacts. However, there are increasing public concerns about many potential environmental impacts related to the emissions of greenhouse gases and trace elements from coal combustion, and thus a number of related research subjects are under study.

1. Introduction

Coal is one of the most important energy sources supporting modern human activity. It is estimated that coal will still be a major part of fossil fuels for many decades to come. Coal is economically amiable, but it is most unclean. It contains numerous impurities, such as mineral matter, sulfur, nitrogen, trace elements, and interior water; this feature of coal is the main cause of a number of troubles with the environment. Coal holds less hydrogen and more oxygen than oil and natural gas; this is also environmentally unfriendly.

Public concern on the obvious threats to human safety and health caused by coal mining and coal firing emerged when coal came into industrial use. However, only since the 1960s has considerable concern centered worldwide on various aspects of the environmental protection associated with the huge production and utilization of coal. With the enforcement of more and more stringent legislation, advanced clean coal processing technologies are under development or coming into application in many nations. Perhaps the most salient shift in coal processing over the past decades has been in the area of environmental control.

Each segment of the coal system has some kind of environmental problem—from coal extraction, via preparation, to processing and utilization. Coal utilization processes in industry mainly include combustion and gasification for generating electricity, process heat and residential heat as well as carbonization for making metallurgical coke, and chemical materials. Of these, electricity generated by coal combustion is by far the largest consumer. In recent years there has been increasing environmental concern related to the pollutant emissions from coal combustion. Not only are large amounts of pollutants discharged from coal combustion, but there are diverse pollutants produced, covering gaseous, liquid, and solid forms. It has increasingly been recognized that these pollutants pose various adverse impacts to the environment, harming public health and reducing the quality of life.

2. Origins, Modes of Occurrence, and Emissions of Pollutants

Pollutants discharged into the air are called atmospheric pollutants. Atmospheric pollutants arising from the coal system mainly include particulate matter, SO₂, NO_x, hydrocarbons, CO₂, and trace elements. Water pollutants can be broadly categorized as

inorganic pollutants like acids, metal ions and suspended solids, as well as organic pollutants like phenols and oils.

2.1. Atmospheric Pollutants

2.1.1 Particulate Matter

Particulate matter (or particulates), is generally identified as any dispersed matter, solid or liquid, whose individual aggregates are larger than a single small molecule. Particles less than or equal to 10 micron in diameter are called PM₁₀, whose concentration in the air is conventionally monitored and regulated. In 1997, the USA Environmental Protection Agency (EPA) promulgated a new air quality standard for the first time in control of PM_{2.5}, those in diameter less than or equal to 2.5 micron. Particulate matter of most concern in the coal system, includes coal dust, fly ash, smoke or soot, and acidic aerosols.

Coal dust is airborne particles from coal, coal refuse, etc. Particle sizes of dust range generally from 1 to 100 micron or larger. In coal transportation, storage, handling, preparation, and processing, any exposure of coal to the air can cause coal particles to be picked up by wind. Open coal stockpile on the ground is an obvious source of coal dust if no measure like surface solidification by water or reagent spraying is taken for control. The dust is severe in windy and dry weather. This nuisance particularly offends nearby residents. In coal or coke grinding, screening and handling, the fine coal particles produce a dust sedimentation by the mechanical action in a local area, if particle leaks are not eliminated in the operations.

Coke oven plants may suffer the worst local dust pollution out of coal processing. Several operations, charging coal into the coke oven, coke pushing, and coke handling, can cause dust and volatile particles to escape. In the conventional process of coke quenching, the hot coke is moved by the quench car and then cooled underneath the quench tower by water spraying. The strong steam lifting action forces coke dust to be blown out. In a modern coke oven, complex suction lines and modified quench process are constructed to minimize dust and volatile emissions. The capital cost of coke ovens is estimated to increase by twenty percent due to the installation of environmentally protective equipment.

Fly ash is the principal particulate matter emitted from the flue gas in coal combustion or gasification, which is mainly derived from mineral matter present in coal. Fly ash has a wide particle size ranging from 0.01 to 100 micron. Under the circumstance of incomplete coal burning, for example in residential stoves, the released substances significantly consist of hydrocarbon constituents and acidic components. Such particles are called smoke or soot, generally in diameter ranging from 0.01 to 1 micron. Primary pollutants, SO₂ and NO_x, may react in the atmosphere to form sulfate and nitrate aerosols, called secondary particulate matter.

The content of mineral matter in coal ranges between two and forty percent, averaging about ten percent by weight. Most mineral matter is transformed into ash during coal combustion. In the industrial firing furnace, part of the ash is discharged from the

bottom and the other emitted from the flue gas as fly ash. Typically, fly ash accounts for about fifty to eighty percent of the total ash.

Fly ash loading in the flue gas depends on the grade of coal and furnace type, which increases when low-grade coal (which contains more mineral matter) is used. Furnace configuration and bottom ash tapping types influence fly ash loading. Uncontrolled particulate emissions from the flue gas are $0.5\text{--}1.5\text{ g m}^{-3}$ for cyclone, $1\text{--}5\text{ g m}^{-3}$ for stoker, and $8\text{--}20\text{ g m}^{-3}$ for pulverized coal firing. Wet bottom furnaces usually have a lower fly ash loading than dry bottom furnaces. Although most fly ash may be settled in a line of post-treatments downstream of a combustor, it was reported that in 1990 coal combustion accounted for 32 percent of global PM_{10} emissions from human activities, with the annual emissions of 111 million tons.

In coal gasification, fly ash emissions occur especially in entrained flow or fluidized bed gasifiers. Uncontrolled particulate loading in the effluent gas can be more than 20 g m^{-3} for entrained gasification. However, the figure varies with the compositions of coal and operation parameters. In fixed- or moving-bed gasification, gasifying agents (steam and air) flow slowly through the coal or coke bed, thus fly ash emissions are low.

2.1.2 Sulfur Oxides

Apart from particulates, another pollutant, which has for a long time been an important environmental subject, is sulfur dioxides. They may include six different gaseous compounds, sulfur monoxide (SO), sulfur dioxide (SO_2), sulfur trioxide (SO_3), sulfur tetroxide (SO_4), sulfur sesquioxide (S_2O_3), and sulfur heptoxide (S_2O_7). Sulfur dioxide and sulfur trioxide are the two common forms and have been attracting the most interest in the study of air pollution.

Sulfur content in coal varies with the coal mine. A high-sulfur coal has a sulfur content above two percent by weight. The primary forms of sulfur in coal are pyritic sulfur (FeS_2) and organic sulfur (thiophene, mercaptan, etc.), with minor sulfates (see *Desulfurization of Coal*).

When coal is burned, most sulfur in coal, regardless of organic sulfur and pyritic sulfur, is oxidized to sulfur oxides, which are emitted from exhausted gas. Sulfur dioxide is the predominant form with over ninety percent of the total. The other is sulfur trioxide. Except for the controlled processes, less than ten percent of sulfur in coal may be fixed in coal ash due to the reaction of sulfur oxides with alkali components in coal. More sulfur may be retained in ash for some alkali-rich young coals.

The global emissions of sulfur oxides from human activities were around 90 Mt of sulfur per year in 1980. Coal combustion contributes to about sixty percent of this overall amount. Since 1980 global emissions have decreased because of the increased capability of desulfurization processes for coal-fired plants in most industrialized countries. Since 1990, some developing countries, which are large coal users, have gradually installed desulfurization processes in coal combustion. In the near future, the capability of desulfurization for coal combustion worldwide, would be increased and the

global emissions of sulfur oxides may tend to decline. At the present time, the annual amount of emissions from human activities is around 70–80 Mt of sulfur.

In coal gasification and carbonization, the sulfur is released mainly in the form of hydrogen sulfide (H₂S), with minor COS and CS₂ in the gas. Sulfur oxides are slightly formed under the reduced reaction atmosphere. Hydrogen sulfide is conventionally removed from the gas stream and recovered in the form of element sulfur or sulfuric acid as a byproduct. Resultant gases must be low enough in sulfur concentration to meet gas users' requirements.

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Biographical Sketches

Jie Wang earned his M.E. degree in chemical engineering, in 1988, from East China University of Science and Technology, where he then spent two years as an assistant professor and four years as a

lecturer. He obtained Ph.D. degree in applied chemistry from Tohoku University, Japan, in 1998. Since then he has served as an assistant professor in Gunma University, Japan. His research experiences mainly embraced coal desulfurization with microwave energy, coal demineralization with calcium hydroxide, and flash coal pyrolysis. His current research interests focus on the environmental problems related to the emissions of trace elements, and carbothermal reaction of minerals in coal, as well as supercritical water gasification of coal and biomass.

Takayuki Takarada graduated from Gunma University, Japan in March, 1974, with the degree of Bachelor of Chemical Engineering and obtained his M.S. degree in March 1976. He worked at Mitsubishi Kakoki Kaisha Ltd. for about five years. He moved to the Chemical Research Institute of Non-Aqueous Solutions, Tohoku University, Japan, in 1981. He received his Ph.D. in March, 1984 from Tohoku University for a thesis entitled “Study on the Catalytic Effect for Coal Gasification”; since 1987 he has taught there, as associate professor (1987–1994) and as a professor (1994–date). His research activities covered coal gasification, catalytic coal pyrolysis, coal combustion, desulfurization, fluidized bed technology, and diamond synthesis by CVD.