

CLEAN COAL TECHNOLOGIES

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Summary

Coal traditionally has consisted of dust and grime, degraded hillsides, mining catastrophes, and chimneys emitting black smoke. It is accused to be a major contributor to environmental issues at local, regional and global level, such as urban air pollution, acid rain and climate change. It is virtually impossible to predict the degree of serious and, hence, the costs of the environmental problems attributed wholly or partly to coal use. It is possible, however, to examine what can be done to improve the environmental performance of coal in the 21st century, both through better combustion and emissions control in the near term and through a shift toward more efficient and environmentally

benign coal processing to produce energy and liquid or gaseous fuels from coal. The principal questions are technical and economic: In what ways and at what cost can this complex substance be transformed into useful energy (and possibly useful materials) while reducing its environmental impact to an acceptable level over the long term? The solutions, which are being developed today or proposed for tomorrow, fall under the generic name of “clean coal technologies”.

Clean coal technologies are intended to reduce the policy conflict between continuing coal use and protecting environmental quality by improving the effectiveness of control technologies and reduce their costs. Clean coal technologies include a family of precombustion, combustion, postcombustion, and conversion technologies designed to provide the coal user (usually an industry or electric power utility) with added technical capabilities and flexibility and better environmental controls at a lower cost.

Clean coal technologies generally are classified by the stage of energy production at which they are applied. In precombustion technologies, sulfur and other impurities are removed from the fuel before it is burned. Combustion technologies employ techniques to prevent pollutant emissions in the boiler while the coal burns. With postcombustion technologies, fuel gas released from a boiler is treated to reduce its content of pollutants. Finally, in conversion, the coal, rather than being burned, is transformed into a gas or liquid that can be cleaned and used as a fuel.

1. Precombustion Technologies

Precombustion clean coal technologies mainly refer to coal cleaning or beneficiation before combustion. The purpose is to remove impurities and improve coal's heat content, which affects generating efficiency.

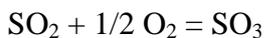
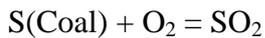
Most physical cleaning processes crush and wash the raw coal before removing the impurities. The impurities are separated out by density differences or variations in their physical characteristics. Almost all the conventional separation processes use water-based methods, which require subsequent water removal. Coarse sizes are invariably separated by gravity-based methods, which become increasingly inefficient for smaller particles. Methods based on surface property difference are then used. Conventional methods are not readily applicable to ultra-fines. The efficiency of conventional coal cleaning techniques in removing sulfur is variable. Only inorganic sulfur can be removed by conventional methods and the degree of removal is influenced greatly by mineral type and coal particle size; the larger the particle, the lower the potential for sulfur removal. Statically, physical cleaning can remove from coal 30 to 50 percent of the pyretic sulfur (which is not organically bound into the coal), or 10 to 30 percent of the total sulfur content. Advanced physical cleaning methods include flotation, agglomeration and flocculation and dry cleaning. Works carried out to date indicates that these techniques could yield 80-90% removal of inorganic sulfur.

To remove sulfur that is organically bound in coal requires chemical or biological coal cleaning. Report results suggest that it is possible to remove up to 90% of either pyretic or organic sulfur from coal using oxidation agent at high temperature and pressure, and micro-organisms (the use of bacteria to eat the sulfur in coal). These processes are still in

development.

2. Combustion Processes

SO₂ formation: All coals contain sulfur. Some of this sulfur, known as organic sulfur, is intimately associated with the coal matrix. The rest of the sulfur, in the form of pyrites or sulfates, is associated with the mineral matter. High-sulfur bituminous coals contain up to about 4% sulfur, whereas low-sulfur Western coals may have sulfur content below 1%. Upon combustion, most of the sulfur is converted to SO₂, with a small amount being further oxidized to sulfur trioxide (SO₃).



Because, in the absence of a catalyst, the formation of SO₃ is slow, over 98% of the combusted sulfur is in the form of SO₂.

NO_x formation: Most of the NO_x formed during the combustion process is the result of two oxidation mechanisms: (1) reaction of nitrogen in the combustion air with excess oxygen, referred to as thermal NO_x; and (2) reaction of nitrogen that is chemically bound in the coal, referred to as fuel NO_x. Thermal NO_x generally represents about 25% of the total and fuel NO_x about 75%. In addition, minor amounts of NO_x are formed through complex interaction of molecular nitrogen with hydrocarbons in an early phase of the flame front; this is referred to as prompt NO_x. The quantity of NO_x formed depends primarily on the "three t's:" temperature, time, and turbulence. In other words, flame temperature and the residence time of the fuel/air mixture, along with the nitrogen content of the coal and the quantity of excess air used for combustion, determine NO_x levels in the flue gas. Combustion modifications delay the mixing of fuel and air, thereby reducing temperature and initial turbulence, which minimizes NO_x formation.

Several techniques are in use to remove sulfur dioxide or limit NO_x emissions during coal combustion while maintaining or improving thermal efficiency.

2.1. LIFAC Sorbent Injection Desulfurization

2.1.1. Process Description

The abbreviation LIFAC refers to the process, which involves Limestone Injected into the Furnace with Activation of untreated Calcium oxide. LIFAC technology is designed to remove sulfur dioxide (SO₂) produced in a coal-fired utility boiler, using a limestone sorbent at a calcium/sulfur molar ratio of 2.0-2.5. A unique feature of this technology is humidification of the flue gas in a separate activation reactor, which increases SO₂ removal. An electrostatic precipitator downstream from the point of injection captures the reaction products, along with the fly ash entrained in the flue gas. Pulverized limestone is pneumatically blown into the upper part of the boiler near the superheater where it absorbs some of the SO₂ in the boiler flue gas. The limestone is calcined into calcium oxide and is available for capture of additional SO₂ downstream in the activation, or

humidification, reactor. In the vertical chamber, water sprays initiate a series of chemical reactions leading to SO₂ capture. After leaving the chamber, the sorbent is easily separated from the flue gas along with the fly ash in the electrostatic precipitator (ESP). The sorbent material from the reactor and electrostatic precipitator are recirculated back through the reactor for increased efficiency. The waste is dry, making it easier to handle than the wet scrubber sludge produced by conventional wet limestone scrubber systems.

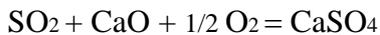
The technology enables power plants with space limitations to use high-sulfur coals by providing an injection process that removes 75-85% of the SO₂ from flue gas and produces a dry solid waste product suitable for disposal in a landfill.

2.1.2. SO₂ Removal

Finely pulverized limestone (CaCO₃) is injected into the furnace at a point where temperatures range from 1,800 to 2,000°F, which results in decomposition to lime (CaO), which is more reactive:



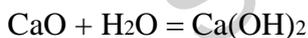
About 25 percent of the SO₂ in the flue gas reacts with the lime to form calcium sulfite (CaSO₃) and calcium sulfate (CaSO₄):



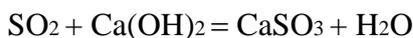
As a result the SO₂ oxidizing, the flue gas also contains a small amount of sulfur trioxide (SO₃), essentially all of which reacts with lime, yielding additional CaSO₄:



The flue gas, containing the remaining 75 percent of the SO₂ plus unreacted lime, exits the boiler and passes through the furnace air preheater, after which the mixture enters the LIFAC activation reactor. This reactor is an elongated vertical duct equipped with spray nozzles at the top. A water spray humidifies the gas, converting the lime to hydrated lime, Ca(OH)₂:



Further SO₂ removal occurs through reaction with hydrated lime, yielding additional CaSO₃:



The flue gas leaving the activation reactor enters the existing ESP, where the spent sorbent and fly ash are removed. A portion of the solids is recycled to the activation reactor and the remainder is sent to a landfill for disposal. Figure 1 is schematic flow of the LIFAC process.

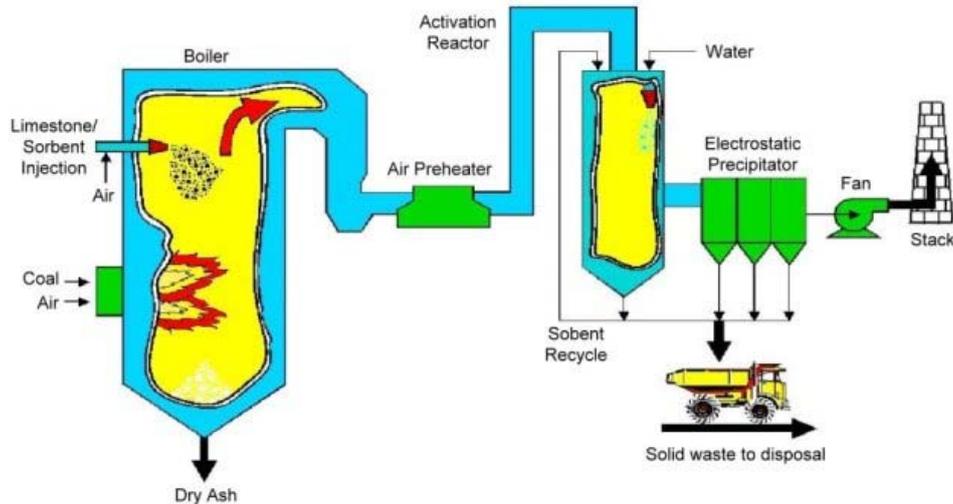


Figure 1: Schematic flow of the LIFAC process

2.1.3. Environmental and Economic Performances

The SO removal efficiency can reach at least 70% for coal with sulfur ranging from low to middle, depending on the calcium/sulfur molar ratio. Other emissions, including particulates in the stack gas and solids in the water effluent are below well into local requirements as specified. The ash by-product does not require additional treatment before being disposed of in a landfill. The main advantage of LIFAC is its low capital cost, which makes it a retrofit option for moderate sulfur removal where regulations permit. But the levelized cost is relatively higher than traditional flue gas desulfurization.

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Biographical Sketch

Mr. Bingjiang Liu is an assistant professor, Institute of Environmental Sciences and Engineering, Tsinghua University, Beijing, China, also senior research associate at Harvard University Center for the Environment. He received B.Sc (1990) and Ph.D. degrees (1998) in Environmental Engineering respectively from Xi'an Architecture University and Tsinghua University. His current interests include air pollution control of coal combustion, policy analysis on controlling acid rain and sulfur dioxide pollution, life cycle assessment, energy planning and health damage estimation from air pollution.