Pollution control technologies applied to coal-fired power plant operation

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Burning of fossil fuels is the major source of energy in today's global economy with over one-third of the world's power generation derived from coal combustion. Although coal has been a reliable, abundant, and relatively inexpensive fuel source for most of the 20th century, its future in electric power generation is under increasing pressure as environmental regulations become more stringent worldwide. Current pollution control technologies for combustion exhaust gas generally treat the release of regulated pollutants: sulfur dioxide, nitrogen oxides and particulate matter as three separate problems instead of as parts of one problem. New and improved technologies have greatly reduced the emissions produced per ton of burning coal. The term "Clean Coal Combustion Technology" applies generically to a range of technologies designed to greatly reduce the emissions from coal-fired power plants. The wet methods of desulfurization at present are the widest applied technology in professional energetics. This method is economic and gives good final results but a future for clean technologies is the biomass. Power from biomass is a proven commercial option of the electricity generation in the World. An increasing number of power marketers are starting to offer environmentally friendly electricity, including biomass power, in response to the consumer demand and regulatory requirements.

Key words: *pollution control technologies, coal-fired power plant, FGD*

Introduction

The nation's first steam-electric power station was opened by the Edison Electric Light Company in New York City in 1882. Since that time, coal has become the most common fuel source used in generating steam to produce power. Coal fired power plants currently account for about 36 % of the electricity generated in the worldwide. Because coal is an abundant and inexpensive fuel, a considerable amount of new coal fired power plant capacity is planned worldwide in the next 15 to 20 years. A conventional coal fired plant consists of a coal handling system, boiler, turbine, generator, transformer, water handling, and an emission control system. Although fossil fuels are abundantly available, burning these fuels presents many environmental problems. Even the cleanest coal burning technology produces some emissions. Three major concerns arise from the fossil fuel combustion: the release of sulfur dioxide, the formation and release of nitrogen oxides, and the release of particulate matter (ash). Although not considered a pollutant due to its natural presence in the environment, carbon dioxide is a growing concern as it relates to the global warming. The first class of emission are **particulates**. Primarily, particulates are the ash and soot from the coal combustion. Studies report that very fine particles can lodge in human lungs, resulting in aggravated asthma and a decreased lung function. The fine particle release is associated most closely with the coal combustion because of the coal's ash content. **Sulfur compounds** (**SO_x**) are classified as a pollutant because they react with water vapor (in the flue gas and atmosphere) to form the sulfuric acid mist. Airborne sulfuric acid has been found in fog, smog, acid rain, and snow. Sulfuric acid has also been found in lakes, rivers, and soil. The acid is extremely corrosive and harmful to the environment. The combustion of coals containing sulfur results in pollutants occurring in the form of SO_2 (sulfur dioxide) and SO_3 (sulfur trioxide), together referred to as SOx (sulfur oxides). The level of SOx emitted depends directly on the sulfur content of the fuel. The level of SOx emissions is not dependent on the boiler size or the burner design. Typically, about 95 % of sulfur in the fuel will be emitted as SO_2, 1-5 % as SO_3. **Oxides of nitrogen (NO_x)** cause two significant problems in the environment. Nitrogen oxides with sulfur oxides, contribute to acid rain by forming nitric acid. More significantly, nitrogen oxides are a key in the creation of ground level ozone, contributing to smog and causing or aggravating human respiratory problems. Additionally, NO_x is a precursor to the ozone transport and, in some degree, to the fine particulate matter formation. NO_x compounds are formed from nitrogen in air used to burn the fuel and from nitrogen contained in the hydrocarbon fuel. For this reason, nitrogen oxides are produced at the combustion of almost all types of fuel. A potential problem of emerging significance in the combustion of coals is the formation and release of **carbon dioxide (CO_2)**, which may play a role in the reported warming of the atmosphere. This poses a problem different from those created by the release of SO_2, NO_x, and the particulate matter. Carbon dioxide is the preferred product of the combustion, with its formation resulting in much of the energy released in the burning process.

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Current Pollution Control Technologies

Current pollution control technologies for the combustion exhaust gas generally treat the release of regulated pollutants: sulfur dioxide, nitrogen oxides and particulate matter, as three separate problems, rather than as parts of one problem. After coal is mined it generally goes through a process known as preparation or coal cleaning. This is done for two main reasons. The first is to remove impurities in order to boost the heat content of the coal and to improve the power plant capacity. The removal of impurities also will reduce the maintenance costs at the power plant and extend the plant life. The second reason for the coal preparation is to reduce potential air pollutants, especially sulfur dioxide. The extent to which SO_2 emissions can be reduced varies depending upon the amount of sulfur in the coal and the form of its occurrence. Sulfur in coal occurs in two forms: 1) organic sulfur that is chemically bonded with carbon; and, 2) inorganic sulfur (pyritic sulfur). Physical coal cleaning works to remove only inorganic sulfur. Physical coal cleaning techniques take advantage of the differences in specific gravity of the coal and its impurities. These coal cleaning systems have been shown to remove up to 90 % of the pyritic sulfur in coal, although in some coals this amount can be as low as 20 %.However, pyritic sulfur generally accounts for only about one half of the total sulfur found in coal. For this reason, the physical coal cleaning is rarely thought of as a stand-alone SO_2 emission control strategy. SO_2 is formed through the combustion of sulfur contained in coal. Most sulfur dioxide control technologies involve the addition of a calcium or sodium based sorbent to the system. Under the proper conditions, these materials react with SO_2 to form calcium sulfite ($CaSO_3$), which is oxidized to calcium sulfate ($CaSO_4$). Principally technologies applied to coal-fired power plants, are referred to as the Flue Gas Desulfurization ((FGD). The FGD processes can be categorized as:

- wet processes,
- dry or semidry processes.

In the wet FGD, SO_2 is removed from the flue gas by a reaction with the sorbent in an aqueous solution or slurry. A relatively high degree of SO_2 removal is usually achieved, with a high level of sorbent utilization. The major reactions occurring in the wet FGD processes are shown by the following equations:

- absorption

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad SO_3 + H_2O \rightarrow H_2SO_4$$

- neutralization

$$CaCO_3 + H_2SO_3 \rightarrow CaSO_3 + CO_2 + H_2O$$
$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

- oxidation and crystalization

$$CaCO_3 + ½\ O2 \rightarrow CaSO_4 + 2\ H_2O \rightarrow CaSO_4 * 2\ H_2O$$

The dry and semidry FGD processes involve injecting a solid dry sorbent, usually limestone, or a semidry sorbent (slurry), usually lime, into the economizer or flue gas duct to react directly with SO_2 in the flue gas. The two most common calcium based sorbents are limestone or slaked lime. Typical sodium based sorbents are: sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3). The solid products are collected in the dry form along with the fly ash from the boiler. In this process, an option is the production of sulfuric acid (SO_3 reacts with water to form sulfuric acid). The wet processes are the most efficient, but the less efficient dry process is the most economical. The most common of FGD is the lime/limestone scrubbing process, used in about 90 % of the utility power plants that have SO_2 removal systems.

Oxides of nitrogen, NOx, are produced in all combustion processes occurring in air. They are formed initially as nitric oxide, NO. The nitric oxide gradually combines with oxygen to form nitrogen dioxide, NO_2. Unfortunately, coals burned in power plants contain high quantities of nitrogen. Most of the NO_x formed during the combustion processes is the result of two oxidation mechanisms:

- reaction of nitrogen in the combustion air with the excess oxygen – thermal NO_x,
- oxidation of nitrogen that is chemically bound in the coal – fuel NOx.

For most coal-fired boilers, thermal NOx typically represents about 25 % of the total NO_x formed. The quantity of thermal NO_x depends primarily on the combustion: temperature, time and turbulence. NO_x control technologies are categorized in two broad categories:

- pre-combustion techniques,
- post-combustion techniques.

The pre-combustion modifications provide the NO_x control by reducing the temperature of combustion. The most effective pre-combustion control techniques are:

- low NO_x burners – lower maximum flame temperature, control of the mixing,
- overfire air – OFA nozzles, air is injected above the normal combustion zone,

- reburning – part of the boiler heat input is added in a separate reburning zone,
- flue gas recirculation – FGR – part of the flue gas is mixed with the combustion air,
- operational & construction modifications – changing the boiler operational parameters.

The post-combustion NO_x control is primarily accomplished by reacting ammonia with nitrogen oxides, forming nitrogen and water vapor. Two basic variations exist, using thermal energy or a catalyst:

- selective non-catalytic reduction – SNCR – typically ammonia/urea is injected into the boiler above the combustion zone – efficiency ~50 %,
- selective catalytic reduction – SCR – a catalyst vessel is installed downstream of the boiler, catalysts can be made inactive by ash, efficiency ~85 %,
- hybrid process – SNCR and SCR can be used in conjunction with each other.

Controlling particulate emissions are the easiest of the power plant pollutants to control. The particulate matter is usually classified by the particle size and source. In the power plant boiler, the particulate mater from coal ash is called fly ash. There are five basic methods for reducing particulate emissions:

- mechanical collectors,
- wet collectors,
- granular bed filters,
- electrostatic precipitators,
- fabric filters.

Only fabric filters and electrostatic precipitators are feasible systems for the power plant boilers applications. Other methods are used primarily for industrial boilers and small utility boiler applications.

Industry tests

A project was prepared to conduct industry tests hosted by the power plant A. There are boilers with FGD wet processes. The purpose of the performance tests was to determine the operating factors of the boilers and emission efficiencies. Controlled experiments on the operating boiler were used to provide an information about the system efficiency. The fuel burned during this project were bituminous coals from Silesia mines. Average analyses of the fuels used to fire in the boiler are shown in the tab. 1.

Tab. 1. Pulverized coal analysis.

Ash [%]	**Moisture** [%]	**Sulfur** [%]	**LHV** [MJ/kg]
20 - 22	8 - 10	0.89 – 0.98	20 - 21

The method of desulfurization is presently the widest applied technology in the professional energetics. Limestone was used as a sorbent. Gypsum was the final product of the process of removing the harmful components of flue gases. The process flow diagram is illustrated in fig. 1.

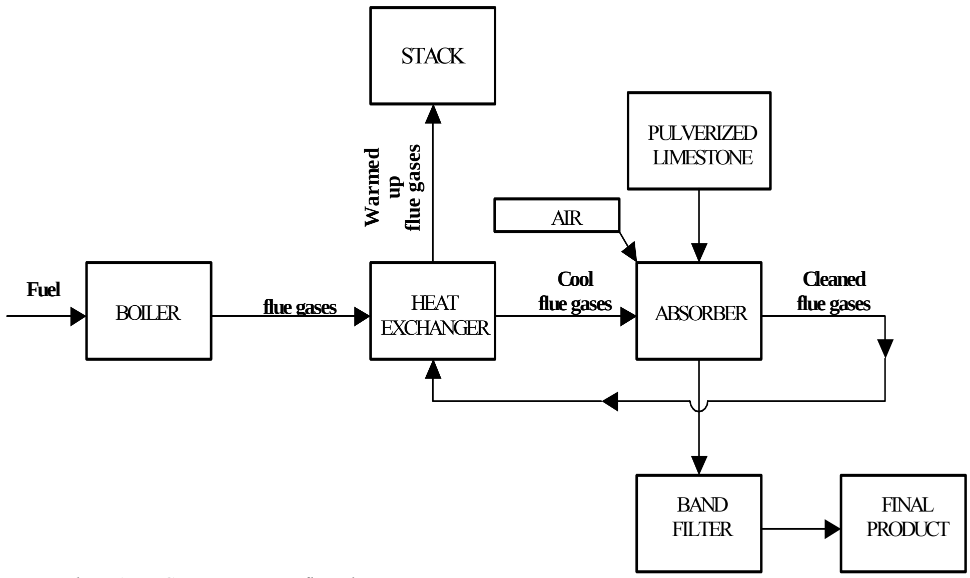

Fig. 1. Power plant A – FGD wet process flow diagram.

Industry measurements

For the investigations, a stationary measuring equipment installed on boilers was used. This equipment collaborate with the continuous computer monitoring system. The analyses continuous as well as the quantity of flue gases were executed. The measurements were executed before and for the installation of desulfurization of flue gases. The quantities on this basis were appointed the SO_2 in different periods of work of the line desulfurization. SO_2 measuring tests were divided in two basic groups depending on the concentration in flue gases. The same was with the content of sulfur concentration in burnt coal. Series consisted of several measurements. The efficiences of desulfurization was calculated on the basis of measurements. The example values are introduced in fig. 2.

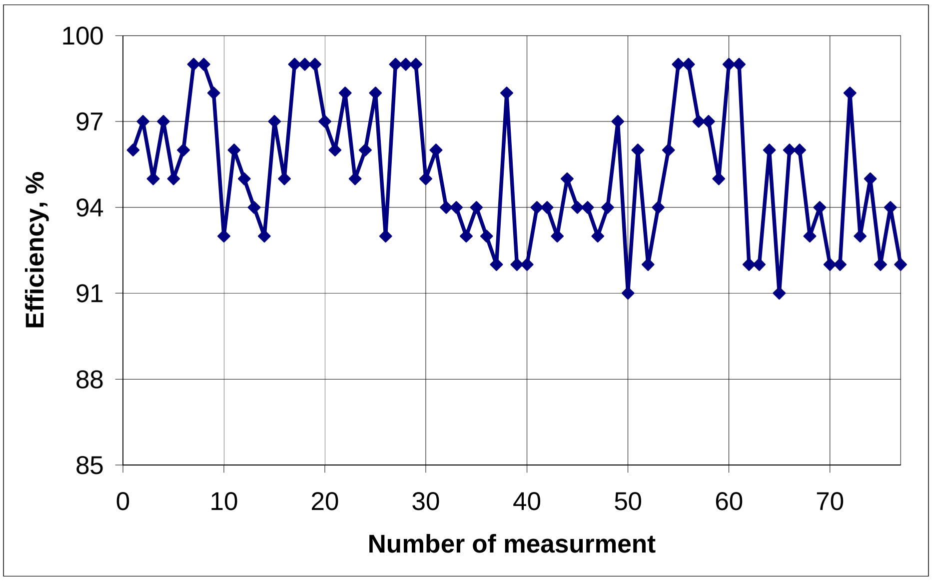

Fig. 2. FGD wet process efficiency (concentration SO_2 < 2400 mg/m^3_n).

In the tab. 2 were introduced the example results of the measurements of SO_2 flowing by the installation of desulfurization. The relative values of results of the measurement were introduced in tab. 2, accepting the maximum values for the studied period as 100 %.

Tab. 2. Relative values of inlet / outlet quantity of SO_2 flow by the desulfurization installation.

Time	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Inlet quantity SO_2 %	100	77	82	82	68	86	95	86	83	93	88	75
Outlet quantity SO_2 %	17	17	17	18	100	10	25	25	25	25	50	25

Results

The FGD wet system achieved the average sulfur reduction in the range of 92 %. The sulfur reduction varied with operating conditions in the range 59 – 96 % with the maximum 96.6 %. In the tab. 3 were introduced the average value of the reduction of SO_2 for the desulfurization line.

Tab. 3. Average SO_2 reduction for the desulfurization line.

Time	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Average SO_2 reduction %	96	96	97	96	60	97	94	94	94	94	88	92

The experimental runs showed that FGD wet system in the power plant A operates with a nearly quaranteed efficiency. The produced gypsum is of a good quality and it fulfils the requirement of building trade. Gypsum as a final by-product is used to manufacture wallboards and such technology eliminates the need to dispose the solid waste.

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