Air Pollution Control Technology Fact Sheet

Name of Technology: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers

Type of Technology: Control Device - absorption and reaction using an alkaline reagent to produce a solid compound.

Applicable Pollutants: Sulfur dioxide (SO_2)

Achievable Emission Limits/Reductions: Scrubbers are capable of reduction efficiencies in the range of 50% to 98%. The highest removal efficiencies are achieved by wet scrubbers, greater than 90% and the lowest by dry scrubbers, typically less than 80%. Newer dry scrubber designs are capable of higher control efficiencies, on the order of 90%.

Applicable Source Type: Point

Typical Industrial Applications: Stationary coal- and oil-fired combustion units such as utility and industrial boilers, as well as other industrial combustion units such as municipal and medical waste incinerators, cement and lime kilns, metal smelters, petroleum refineries, glass furnaces, and H_2SO_4 manufacturing facilities. Approximately 85% of the FGD systems installed in the US are wet systems, 12% are spray dry and 3% are dry systems.

Emission Stream Characteristics:

a.   **Combustion Unit Size:** SO_2 scrubbers have been applied combustion units firing coal and oil ranging in size from 5 MW to over 1,500 MW (50 MMBtu/hr to 15,000 MMBut/hr). Dry and spray scrubbers are generally applied to units less than 3,000 MMBtu/hr (300 MW) (EPA, 2000).

b.   **Temperature:** For wet scrubbers, typical inlet gas temperatures are 150°C to 370°C (300°F to 700°F) (FETC, 1996). For spray dry systems, the temperature of the flue gas exiting the absorber must be 10°C to 15°C (20°F to 30°F) above the adiabatic saturation temperature. Optimal temperatures for SO_2 removal for dry sorbent injection systems range from 150°C to 180°C (300°F to 350°F). Optimal temperatures for SO_2 removal when applying dry sorbent injection systems vary between 150°C to 1000°C (300°F to 1830°F) depending on the sorbent properties (Joseph, 1998)

c.   **Pollutant Loading:** SO_2 scrubbers are limited to dilute SO_2 waste gas streams of approximately 2000 ppm.(Cooper, 2002).

d.   **Other Considerations:** The amount of chlorine in the flue gas affects the amount of water evaporated by the system due to the formation of salts. Chlorine content improves the SO_2 removal but also results in salt deposition on the absorber and downstream equipment (Schnelle, 2002).
An additional or upgraded induced draft (ID) fan may be required to compensate for flue gas pressure drop across the absorber.

Many wet systems reheat the flue gas downstream of the absorber to prevent corrosion caused by condensation inside the ducts and stack and reduce plume visibility.

Emission Stream Pretreatment Requirements: In spray dry and dry injection systems, the flue gas must be cooled to a temperature range of 10°C to 15°C (20°F to 30°F) above adiabatic saturation. This temperature range avoids wet solids deposition on downstream equipment and plugging of the baghouse. A heat recovery boiler, an evaporative cooler or a heat exchanger is typically used to cool the gas.

Cost Information:

Capital costs for SO_2 scrubbers have decreased by over 30% since the beginning of the 1990's. Current costs for SO_2 scrubbers applied to electric utilities are reported to be approximately $100/kW (Smith, 2001). Retrofit of scrubbers on existing units can increase the capital cost up to 30%. Retrofit costs vary significantly between sites and depend on space limitations, major modifications to existing equipment (e.g., ductwork and stack) and the operating condition of the units (e.g., temperature, flowrate).

O&M costs increase with increasing sulfur content since more reagent is required to treat the same volume of gas. Typical reagents such as lime and limestone are inexpensive; however, the use of proprietary reagents or reagent enhancers or additives that can significantly increase the O&M cost. Limestone is generally available for 10 to 20 $/ton and lime is available for 60 to 80 $/ton (Smith, 2001). Waste product disposal costs vary from $10/ton to $30/ton and byproduct saleable prices vary from 0 to 15 $/ton (Smith, 2001). The addition of a scrubbers causes a loss of energy available for generating steam due to evaporation of water and the energy required to drive the reaction. New scrubber designs result in an energy penalty of less than 1% of the total plant energy (Srivastava, 2001).

Table 1a: Summary of Cost Information in $/MMBtu/hr (2001 Dollars) [a]

Scrubber Type	Unit Size (MMBtu/hr)	Capital Cost ($/MMBtu)	O&M Cost [b] ($/MMBtu)	Annual Cost ($/MMBtu)	Cost per Ton of Pollutant Removed ($/ton)
Wet	> 4,000	10,000 -25,000	200 - 800	25 - 40	200 - 500
	< 4,000	25,000 - 150,000	800 - 1,800	60 - 600	500 - 5,000
Spray Dry	> 2,000	4,000 - 15,000	600 - 1,000		150 - 300
	< 2,000	30,000 - 150,000	1,000 - 30,000	10,000 - 50,000	500 - 4,000

Table 1b: Summary of Cost Information in $/MW (2001 Dollars) [a]

Scrubber Type	Unit Size (MW)	Capital Cost ($/kW)	O&M Cost [b] ($/kW)	Annual Cost ($/kW)	Cost per Ton of Pollutant Removed ($/ton)
Wet	> 400	100 - 250	2 - 8	20 - 50	200 - 500
	< 400	250 - 1,500	8 - 20	50 - 200	500 - 5,000
Spray Dry	> 200	40 - 150	4 - 10	20 -50	150 - 300
	< 200	150 - 1,500	10 - 300	50 - 500	500 - 4,000

[a] (EIA, 2002; EPA, 2000; Srivastava, 2001)
[b] Assumes capacity factor > 80%

Theory of Operation:

The FDG or SO_2 scrubbing process typically uses a calcium or sodium based alkaline reagent. The reagent is injected in the flue gas in a spray tower or directly into the duct. The SO_2 is absorbed, neutralized and/or oxidized by the alkaline reagent into a solid compound, either calcium or sodium sulfate. The solid is removed from the waste gas stream using downstream equipment.

Scrubbers are classified as "once-through" or "regenerable", based on how the solids generated by the process are handled. Once-through systems either dispose of the spent sorbent as a waste or utilize it as a byproduct. Regenerable systems recycle the sorbent back into the system. At the present time, regenerable processes have higher costs than once-through processes; however, regenerable processes might be chosen if space or disposal options are limited and markets for byproducts (gypsum) are available (Cooper, 2002). In 1998, approximately 3% of FDG systems installed in the US were regenerable.

Both types of systems, once-through and regenerable, can be further categorized as wet, dry, or semi-dry. Each of these processes is described in the following sections.

Wet Systems

In a wet scrubber system, flue gas is ducted to a spray tower where an aqueous slurry of sorbent is injected into the flue gas. To provide good contact between the waste gas and sorbent, the nozzles and injection locations are designed to optimize the size and density of slurry droplets formed by the system. A portion of the water in the slurry is evaporated and the waste gas stream becomes saturated with water vapor. Sulfur dioxide dissolves into the slurry droplets where it reacts with the alkaline particulates. The slurry falls to the bottom of the absorber where it is collected. Treated flue gas passes through a mist eliminator before exiting the absorber which removes any entrained slurry droplets. The absorber effluent is sent to a reaction tank where the SO_2-alkali reaction is completed forming a neutral salt. In a regenerable system, the spent slurry is recycled back to the absorber. Once through systems dewater the spent slurry for disposal or use as a by-product.

Typical sorbent material is limestone, or lime. Limestone is very inexpensive but control efficiencies for limestone systems are limited to approximately 90%. Lime is easier to manage on-site and has control efficiencies up to 95% but is significantly more costly (Cooper 2002). Proprietary sorbents with reactivity-enhancing additives provide control efficiencies greater than 95% but are very costly. Electrical utilities store large volumes of limestone or lime on site and prepare the sorbent for injection, but this is generally not cost effective for smaller industrial applications.

The volume ratio of reagent slurry to waste gas is referred to as the liquid to gas ratio (L/G). The L/G ratio determines the amount of reagent available for reaction with SO_2. Higher L/G ratios result in higher control efficiencies. Higher L/G also increases oxidation of the SO_2, which results in a decrease of the formation of scale in the absorber. O&M costs are a direct function of reagent usage, so increasing the L/G increases annual costs. L/G ratios are approximately 1:1 for wet scrubbers and are expressed as gallons of slurry per 1000 ft^3 of flue gas (liters of slurry/1000Nm^3 of flue gas).

Oxidation of the slurry sorbent causes gypsum (calcium sulfate) scale to form in the absorber. Limestone forced oxidation (LSFO) is a newer process based on wet limestone scrubbing which reduces scale. In LSFO, air is added to the reaction tank which oxidizes the spent slurry to gypsum. The gypsum is removed from the reaction tank prior to the slurry being recycled to the absorber. The recycle slurry has a lower concentration of gypsum and scale formation in the absorber is significantly reduced. Gypsum can be commercially sold, eliminating the need for landfilling of the waste product (Srivastava, 2001). In addition to scale control, the larger size gypsum crystals formed in LSFO settle and dewater

more efficiently, reducing the size of the byproduct handling equipment (EPA, 2002). However, LSFO requires additional blowers which increase the capital and annual costs of the system.

Wet limestone scrubbing has high capital and operating cost due to the handling of liquid reagent and waste. Nonetheless, it is the preferred process for coal-fired electric utility power plants burning coal due to the low cost of limestone and SO_2 control efficiencies from 90% up to 98% (Schnelle, 2002).

Semi-Dry Systems

Semi-dry systems, or spray dryers, inject an aqueous sorbent slurry similar to a wet system, however, the slurry has a higher sorbent concentration. As the hot flue gas mixes with the slurry solution, water from the slurry is evaporated. The water that remains on the solid sorbent enhances the reaction with SO_2. The process forms a dry waste product which is collected with a standard particulate matter (PM) collection device such as a baghouse or ESP. The waste product can be disposed, sold as a byproduct or recycled to the slurry.

Various calcium and sodium based reagents can be utilized as sorbent. Spray dry scrubbers typically inject lime since it is more reactive than limestone and less expensive than sodium based reagents. The reagent slurry is injected through rotary atomizers or dual-fluid nozzles to create a finer droplet spray than wet scrubber systems (Srivastava, 2000).

The performance of a lime spray dry scrubber is more sensitive to operating conditions. A "close approach" to adiabatic saturation temperature is required to maximize the removal of SO_2. However, excess moisture causes the wet solids to deposit on the absorber and downstream equipment. The optimum temperature is 10°C to 15°C (20°F to 50°F) below saturation temperature (Srivastava, 2000). Lower L/G ratios, approximately 1:3, must be utilized do to the limitation on flue gas moisture (Schnelle, 2002). Flue gas with high SO_2 concentrations or temperatures reduce the performance of the scrubber (Schnelle, 2002).

SO_2 control efficiencies for spray dry scrubbers are slightly lower than wet systems, between 80% and 90% due to its lower reactivity and L/G ratios. Application of a single spray dry absorber is limited to combustion units less than 200 MW (2,000 MMBtu/hr) (IEA, 2001). Larger combustion units require multiple absorber systems. The capital and operating cost for spray dry scrubbers are lower than for wet scrubbing because equipment for handling wet waste products is not required. In addition, carbon steel can be used to manufacture the absorber since the flue gas is less humid. Typically applications include electric utility units burning low- to medium- sulfur coal, industrial boilers, and municipal waste incinerators that require 80% SO_2 control efficiency (Schnelle, 2002).

Dry systems

Dry sorbent injection systems, pneumatically inject powdered sorbent directly into the furnace, the economizer, or downstream ductwork. The dry waste product is removed using particulate control equipment such as a baghouse or electrostatic precipitator (ESP). The flue gas is generally cooled prior to the entering the PM control device. Water can be injected upstream of the absorber to enhance SO_2 removal (Srivastava, 2001).

Furnace injection requires flue gas temperatures between 950°C to 1000°C (1740°F to 1830°F) in order to decompose the sorbent into porous solids with high surface area (Srivastava 2001). Injection into the economizer requires temperatures of 500°C to 570°C (930°F to 1060°F) (Srivastava 2001). Duct injection requires the dispersion of a fine sorbent spray into the flue gas downstream of the air preheater. The injection must occur at flue gas temperatures between 150°C to 180°C (300°F to 350°F) (Joseph, 1998).

Dry sorbent systems typically use calcium and sodium based alkaline reagents. A number of proprietary reagents are also available. A typical injection system uses several injection lances protruding from the furnace or duct walls. Injection of water downstream of the sorbent injection increases SO_2 removal by the sorbent.

An even distribution of sorbent across the reactor and adequate residence time at the proper temperature are critical for high SO_2 removal rates (Srivastava 2001). Flue gas must be kept 10°C to 15°C (20°F to 50°F) below saturation temperature to minimize deposits on the absorber and downstream equipment.

Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems install easily and use less space, therefore, they are good candidates retrofit applications. SO_2 removal efficiencies are significantly lower than wet systems, between 50% and 60% for calcium based sorbents. Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiencies (Srivastava 2001). Dry sorbent injection is viewed as an emerging SO_2 control technology for medium to small industrial boiler applications. Newer applications of dry sorbent injection on small coal-fired industrial boilers have achieved greater than 90% SO_2 control efficiencies.

Advantages:

- High SO_2 removal efficiencies, from 50% up to 98%.
- Products of reaction may be reusable
- Difficulty of retrofit is moderate to low
- Inexpensive and readily available reagents

Disadvantages:

- High capital and O&M costs
- Scaling and deposit of wet solids on absorber and downstream equipment
- Wet systems generate a wet waste product and may result in a visible plume
- Cannot be used for waste gas SO_2 concentrations greater than 2,000 ppm
- Disposal of waste products significantly increases O&M costs

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