EPA-452/F-03-032

Air Pollution Control Technology
Fact Sheet

Name of Technology: Selective Catalytic Reduction (SCR)

Type of Technology: Control Device - Chemical reduction via a reducing agent and a catalyst.

Applicable Pollutants: Nitrogen Oxides (NOx)

Achievable Emission Limits/Reductions: SCR is capable of NOx reduction efficiencies in the range of 70% to 90% (ICAC, 2000). Higher reductions are possible but generally are not cost-effective.

Applicable Source Type: Point

Typical Industrial Applications: Stationary fossil fuel combustion units such as electrical utility boilers, industrial boilers, process heaters, gas turbines, and reciprocating internal combustion engines. In addition, SCR has been applied to nitric acid plants. (ICAC, 1997)

Emission Stream Characteristics:

a. **Combustion Unit Size:** In the United States, SCR has been applied to coal- and natural gas-fired electrical utility boilers ranging in size from 250 to 8,000 MMBtu/hr (25 to 800 MW) (EPA, 2002). SCR can be cost effective for large industrial boilers and process heaters operating at high to moderate capacity factors (>100 MMBtu/hr or >10MW for coal-fired and >50 MMBtu/hr or >5MW for gas-fired boilers). SCR is a widely used technology for large gas turbines.

b. **Temperature:** The NOx reduction reaction is effective only within a given temperature range. The optimum temperature range depends on the type of catalyst used and the flue gas composition. Optimum temperatures vary from 480°F to 800°F (250°C to 427°C) (ICAC, 1997). Typical SCR systems tolerate temperature fluctuations of ± 200°F (± 90°C) (EPA, 2002).

c. **Pollutant Loading:** SCR can achieve high reduction efficiencies (>70%) on NOx concentrations as low as 20 parts per million (ppm). Higher NOx levels result in increased performance; however, above 150 ppm, the reaction rate does not increase significantly (Environex, 2000). High levels of sulfur and particulate matter (PM) in the waste gas stream will increase the cost of SCR.

d. **Other Considerations:** Ammonia slip refers to emissions of unreacted ammonia that result from incomplete reaction of the NOx and the reagent. Ammonia slip may cause: 1) formation of ammonium sulfates, which can plug or corrode downstream components, and 2) ammonia absorption into fly ash, which may affect disposal or reuse of the ash. In the U.S., permitted ammonia slip levels are typically 2 to 10 ppm. Ammonia slip at this levels do not result in plume formation or human health hazards. Process optimization after installation can lower slip levels.

   Waste gas streams with high levels of PM may require a sootblower. Sootblowers are installed in the SCR reactor to reduce deposition of particulate onto the catalyst. It also reduces fouling of downstream equipment by ammonium sulfates.

The pressure of the waste gas decreases significantly as it flows across the catalyst. Application of SCR generally requires installation a new or upgraded induced draft fan to recover pressure.

Emission Stream Pretreatment Requirements: The flue gas may require heating to raise the temperature to the optimum range for the reduction reaction. Sulfur and PM may be removed from the waste gas stream to reduce catalyst deactivation and fouling of downstream equipment.

Cost Information:

Capital costs are significantly higher than other types of NOx controls due to the large volume of catalyst that is required. The cost of catalyst is approximately 10,000 $\$/m^3$ (283 $\$/ft^3$). A 350 MMBtu/hr natural gas-fired boiler operating at 85% capacity requires approximately 17 m^3 (600 ft^3). For the same sized coal-fired boiler, the required catalyst is on the order of 42 m^3 (1,500 ft^3). (NESCAUM 2000).

SCR is a proprietary technology and designs on large combustion units are site specific. Retrofit of SCR on an existing unit can increase costs by over 30% (EPA, 2002). The increase in cost is primarily due to ductwork modification, the cost of structural steel, and reactor construction. Significant demolition and relocation of equipment may be required to provide space for the reactor.

The O&M costs of using SCR are driven by the reagent usage, catalyst replacement, and increased electrical power usage. SCR applications on large units (>100 MMBtu/hr) generally require 20,000 to 100,000 gallons of reagent per week (EPA, 2002). The catalyst operating life is on the order of 25,000 hours for coal-fired units and 40,000 hours for oil- and gas-fired units (EPA, 2002). A catalyst management plan can be developed so that only a fraction of the total catalyst inventory, rather than the entire volume, is replaced at any one time. This distributes the catalyst replacement and disposal costs more evenly over the lifetime of the system. O&M costs are greatly impacted by the capacity factor of the unit and annual versus seasonal control of NO_X.

O&M cost and the cost per ton of pollutant removed is greatly impacted by the capacity factor and whether SCR is utilized seasonally or year round.

Table 1a: Summary of Cost Information in $/MMBtu/hr (1999 Dollars) [a, b]

Unit Type	Capital Cost ($/MMBtu)	O&M Cost [d] ($/MMBtu)	Annual Cost [d] ($/MMBtu)	Cost per Ton of Pollutant Removed ($/ton)
Industrial Coal Boiler	10,000 - 15,000	300	1,600	2,000 - 5,000
Industrial Oil, Gas, Wood [c]	4,000 - 6,000	450	700	1,000 - 3,000
Large Gas Turbine	5,000 - 7,500	3,500	8,500	3,000 - 6,000
Small Gas Turbine	17,000 - 35,000	1,500	3,000	2,000 - 10,000

Table 1b: Summary of Cost Information in $/MW (1999 Dollars) [a, b]

Unit Type	Capital Cost ($/MW)	O&M Cost [d] ($/MW)	Annual Cost [d] ($/MW)	Cost per Ton of Pollutant Removed ($/ton)
Industrial Coal Boiler	1,000 - 1,500	30	160	2,000 - 5,000
Industrial Oil, Gas, Wood [c]	400 - 600	45	70	1,000 - 3,000
Large Gas Turbine	500 - 750	350	850	3,000 - 6,000
Small Gas Turbine	1,700- 3,500	150	300	2,000 - 10,000

[a] (ICAC, 1997; NESCAUM, 2000; EPA, 2002)
[b] Assumes 85% capacity factor and annual control of NOx
[c] SCR installed on wood fired boiler assumes a hot side electrostatic precipitator for PM removal
[d] Coal and oil O&M and annual costs are based on 350MMBtu boiler, and gas turbine O&M and annual costs are based on 75 MW and 5 MW turbine

Theory of Operation:

The SCR process chemically reduces the NOx molecule into molecular nitrogen and water vapor. A nitrogen based reagent such as ammonia or urea is injected into the ductwork, downstream of the combustion unit. The waste gas mixes with the reagent and enters a reactor module containing catalyst. The hot flue gas and reagent diffuse through the catalyst. The reagent reacts selectively with the NOx within a specific temperature range and in the presence of the catalyst and oxygen.

Temperature, the amount of reducing agent, injection grid design and catalyst activity are the main factors that determine the actual removal efficiency. The use of a catalyst results in two primary advantages of the SCR process over the SNCR: higher NOx control efficiency and reactions within a lower and broader temperature range. The benefits are accompanied by a significant increase in capital and operating costs. The catalyst is composed of active metals or ceramics with a highly porous structure. Catalysts configurations are generally ceramic honeycomb and pleated metal plate (monolith) designs. The catalyst composition, type, and physical properties affect performance, reliability, catalyst quantity required, and cost. The SCR system supplier and catalyst supplier generally guarantee the catalyst life and performance. Newer catalyst designs increase catalyst activity, surface area per unit volume, and the temperature range for the reduction reaction.

Catalyst activity is a measure of the NOx reduction reaction rate. Catalyst activity is a function of many variables including catalyst composition and structure, diffusion rates, mass transfer rates, gas temperature, and gas composition. Catalyst deactivation is caused by:

- poisoning of active sites by flue gas constituents,
- thermal sintering of active sites due to high temperatures within reactor,
- blinding/plugging/fouling of active sites by ammonia-sulfur salts and particulate matter, and
- erosion due to high gas velocities.

As the catalyst activity decreases, NOx removal decreases and ammonia slip increases. When the ammonia slip reaches the maximum design or permitted level, new catalyst must be installed. There are several different locations downstream of the combustion unit where SCR systems can be installed. Most coal-fired applications locate the reactor downstream of the economizer and upstream of the air heater and particulate control devices (hot-side). The flue gas in this location is usually within the optimum temperature window for NOx reduction reactions using metal oxide catalysts. SCR may be applied after PM and sulfur removal equipment (cold-side), however, reheating of the flue gas may be required, which significantly increases the operational costs.

SCR is very cost-effective for natural gas fired units. Less catalyst is required since the waste gas stream has lower levels of NOx, sulfur, and PM. Combined-cycle natural gas turbines frequently use SCR technology for NOx reduction. A typical combined-cycle SCR design places the reactor chamber after the superheater within a cavity of the heat recovery steam generator system (HRSG). The flue gas temperature in this area is within the operating range for base metal-type catalysts.

SCR can be used separately or in combination with other NOx combustion control technologies such as low NOx burners (LNB) and natural gas reburn (NGR). SCR can be designed to provide NOx reductions year-round or only during ozone season.

Advantages:

- Higher NOx reductions than low-NOx burners and Selective Non-Catalytic Reduction (SNCR)
- Applicable to sources with low NOx concentrations
- Reactions occur within a lower and broader temperature range than SNCR.
- Does not require modifications to the combustion unit

Disadvantages:

- Significantly higher capital and operating costs than low-NOx burners and SNCR
- Retrofit of SCR on industrial boilers is difficult and costly
- Large volume of reagent and catalyst required.
- May require downstream equipment cleaning.
- Results in ammonia in the waste gas stream which may impact plume visibility, and resale or disposal of ash.

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