

B.5 WET SCRUBBERS FOR GASEOUS CONTROL^{1,2,9,15}

B.5.1 Background

Wet scrubbers use a liquid to remove pollutants from an exhaust stream. In gaseous emission control applications, wet scrubbers remove pollutants by absorption. For this reason, wet scrubbers used for gaseous pollutant control often are referred to as absorbers. Absorption is very effective when controlling pollutant gases present in appreciable concentration, but also is feasible for gases at dilute concentrations when the gas is highly soluble in the absorbent. The driving force for absorption is related to the amount of soluble gas in the gas stream and the concentration of the solute gas in the liquid film in contact with the gas. Water is the most commonly used absorbent, but nonaqueous liquids of low vapor pressure (such as dimethylaniline or amines) may be used for gases with low water solubility, such as hydrocarbons or hydrogen sulfide (H₂S). Water used for absorption may frequently contain other chemicals to react with the gas being absorbed and reduce the concentration. When water is not used, absorbent separation and scrubbing liquid regeneration may be frequently required due to the cost of the scrubbing liquid.

Wet scrubbers rely on the creation of large surface areas of scrubbing liquid that allow intimate contact between the liquid and gas. The creation of large surface areas can be accomplished by passing the liquid over a variety of media (packing, meshing, grids, trays) or by creating a spray of droplets. There are several types of wet scrubber designs, including spray tower, tray-type, and packed-bed wet scrubbers; these are generally referred to as low-energy scrubbers.

Packed-bed scrubbers provide excellent gas-liquid contact and efficient mass transfer; they can generally be smaller in size than spray scrubbers and so are an effective option when space is limited. Plugging may occur in packed-bed scrubbers if there is a high PM loading, but the packing can be removed for cleaning. Some packed-bed scrubbers employ mobile spherical packing; the movement of the packing increases turbulence and helps keep the packing clean. Tray-type (or plate-type) scrubbers provide a film of liquid for the gas to pass through. Contact between gas and liquid is obtained by forcing the gas to pass upward through small orifices and bubbling through a liquid layer flowing across the plates. A number of plates are used in series to achieve the required absorption efficiency. Spray towers (countercurrent flow) may be used to control gaseous emissions when PM is also present.

Wet scrubbers should exhibit a relatively constant pressure differential, liquid flow, and gas flow. Common scrubber performance problems include: low gas flow rate; low liquid flow rate; condensation of aerosols in the system; poor liquid distribution; use of liquid with high pollutant concentration; use of high dissolved solids liquid (if PM is also present); nozzle erosion or pluggage (if PM is also present); bed pluggage (if PM is also present); tray/plate collapse; air leakage; pollutant re-entrainment; freezing/pluggage of lines; and scaling.

B.5.2 Indicators of Performance

Several parameters can be used as indicators of wet scrubber performance. The most appropriate indicators to monitor depend upon a number of factors, including type of pollutant (whether PM is also present), scrubber design, and exhaust gas characteristics. For the control of gaseous pollutants (VOC and acid gases), the key indicators of wet scrubber performance generally are the same as the critical performance indicators for PM emission control with a few exceptions. Pressure differential, liquid flow rate, scrubber liquid outlet concentration are the key indicators of performance. Other, less significant indicators of gaseous pollutant control efficiency for wet scrubbers are gas flow rate, neutralizing chemical feed rate, scrubber outlet gas temperature. Parameters to monitor as alternatives to scrubber liquid outlet concentration include scrubber liquid pH, scrubber liquid specific gravity, and scrubber makeup/blowdown rates. For systems that control thermal processes, scrubber outlet gas temperature may be monitored as a surrogate for scrubber liquid flow rate. For systems that are designed to control gaseous pollutants with low PM loadings, there is no advantage to monitoring the scrubbing liquid solids content. In such cases, significant changes in the solids content of the liquid would be expected to occur only over extended periods of time due to the low level of PM. Table B-5 lists these indicators and illustrates potential monitoring options for wet scrubbers for gaseous pollutants and acid gas control.

Pressure differential. Pressure differential is one of the most critical indicators of performance for most wet scrubber designs. Pressure differential remains fairly constant and reflects normal operation of the liquid flow and gas flow through the system. For packed-bed scrubbers, plugging of the bed can result in increased pressure differential; the increase in pressure differential would likely be observed as a gradual increase over time. In such cases, an increase in pressure differential can correspond to a decrease in performance.

Liquid flow rate. Gas flow rate is often a constant based on process conditions and is the major design consideration of the scrubber; the liquid-to-gas (L/G) ratio is determined and maintained by the scrubber liquid flow rate. Scrubber liquid flow rate is a key indicator of performance provided the liquid is being properly distributed, and the liquid-gas interface is maintained. Under these conditions, higher liquid flow rates are indicative of higher levels of control. However, for packed-bed scrubbers, there is a critical flow rate above which flooding occurs.

Scrubbing liquid distribution system pressure or pump motor current can be monitored as surrogates for liquid flow rate, but would be less reliable indicators of scrubber performance than would liquid flow rate. In addition, the scrubber liquid level in the scrubber liquid reservoir may be monitored as an indication of the liquid flow rate, however this would be a less reliable indicator because the actual flow through the scrubber is not monitored. Scrubber liquid outlet temperature is another surrogate parameter for liquid flow rate; this parameter may be used for thermal processes only and is less reliable than monitoring of the liquid flow rate.

Scrubber liquid outlet concentration. The scrubber liquid outlet concentration is a critical indicator of gaseous pollutant removal efficiency. Increases in the concentration of pollutant may result in lower removal efficiency of the pollutant because of increased vapor pressure of the component in the liquid and lowering of the absorption gradient. For wet scrubbers used to control acid gas emissions, monitoring scrubber liquid pH is an adequate surrogate for scrubber liquid outlet concentration.

Gas flow rate. Exhaust gas flow rate affects the L/G ratio, which is a key design parameter for wet scrubbers. Gas flow rate is generally a constant parameter and may be monitored to ensure that the flow is within design range. An increase in exhaust gas flow rate, without a corresponding increase in liquid flow rate, results in a decrease in the L/G ratio, which generally corresponds to a decrease in scrubber control efficiency. Fan motor current can be monitored as a surrogate for exhaust gas flow rate.

Scrubber outlet gas temperature. For wet scrubbers used to control thermal processes, the scrubber exhaust gas temperature is also an indicator of performance. Increases in the outlet or exhaust temperature of the gas stream are an indication of a change in operation. Either the process exhaust temperature has increased, the gas flow rate has increased, or the liquid flow rate has decreased.

Scrubber liquid pH. Scrubber liquid pH is an indicator of acid gas removal efficiency. A drop in pH can indicate that the acid gas inlet concentration is increasing or that less acid is being neutralized. If caustic or other acid neutralizing chemicals are used, a change in pH can indicate a problem with the chemical feed system. Low pH levels typically result in increased corrosion of liquid contact surfaces in the scrubber and the recirculating system piping, and high pH levels that result from excess chemical feed can cause scaling and encrustation of piping and other recirculation system components.

Neutralizing chemical feed rate. If a neutralizing chemical is used, the chemical feed rate is an indicator of wet scrubber operation. As explained below, changes in caustic feed rate that result in changes to pH can result in increased corrosion or scaling of piping and other surfaces in contact with the scrubbing liquid.

Scrubber liquid specific gravity. Scrubber liquid specific gravity is an indicator of pollutant gas removal efficiency. Changes in the specific gravity provide an indication that the pollutant concentration is increasing (or decreasing) in the scrubber liquid.

Makeup/blowdown rates. To keep the pollutant content of recirculating liquids from becoming excessive, additional liquid must be added to the system (makeup) and recirculating liquid must be bled from the system (blowdown). Therefore, the makeup rate and/or the blowdown rate of the recycled liquid are indicative of the pollutant content of the scrubber liquid, provided the scrubber inlet loading does not change significantly. Under the conditions of constant inlet loading, decreases in makeup or blowdown rates generally correspond to

increases in the pollutant content of the scrubbing liquid. This indicator is not commonly monitored, and scrubber liquid outlet concentration is a better indicator.

B.5.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for wet scrubbers:

- 5a: Monitoring scrubber liquid pH and liquid flow rate (for SO₂ control).
- 5b: Monitoring pressure differential (for fluorides control).
- 5c: Monitoring pressure differential, scrubber liquid flow rate, and make up liquid flow rate (for VOC control).

B.5.4 Bibliography

TABLE B-5. SUMMARY OF PERFORMANCE INDICATORS FOR WET SCRUBBERS FOR GASEOUS POLLUTANT AND ACID GAS CONTROL

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
		Illustration No.	5a											5b	5c		
		Example CAM Submittals	A20		A4b												A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	
Primary Indicators of Performance																	
Pressure differential	An adsorber will operate at a relatively constant pressure differential. Differential pressure shows whether there is normal gas flow and normal liquid flow. A significant increase in pressure differential indicates a resistance to flow caused by plugging within the packing, higher inlet gas flow, or higher liquid flow rate.							X	X	X		X	X	X			
Scrubber liquid flow rate	Decrease in liquid flow rate results in decrease in L/G; want to assure required L/G is maintained. Can use scrubber inlet liquid supply pressure or pump motor current as surrogates for liquid flow rate.	X	X	X		X	X	X	X	X				X		X	
Scrubber liquid outlet concentration	Increase in scrubber liquid concentration may indicate a decrease in the concentration gradient and removal efficiency, even with good gas-liquid contact. Can use scrubber liquid pH or specific gravity as surrogate for concentration.			X											X	X	
Other Performance Indicators																	
Gas flow rate	Increase in gas flow rate without increase in liquid flow rate results in lower L/G and potentially lower control efficiency. Can also measure fan current as surrogate for gas flow rate.		X			X										X	
Scrubber gas outlet temperature	Increase in outlet gas temperature can indicate inadequate liquid flow. For application with thermal processes only; surrogate parameter for scrubber liquid flow rate.																

CAM TECHNICAL GUIDANCE DOCUMENT
B.5 WET SCRUBBERS FOR VOC CONTROL

TABLE B-5. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
		Illustration No.	5a											5b	5c		
		Example CAM Submittals	A20		A4b												A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	
Scrubber liquid outlet temperature	Increase in outlet liquid temperature can indicate inadequate liquid flow. For application with thermal processes only; surrogate parameter for scrubber liquid flow rate.				X												
Scrubber liquid pH	For acid gas control applications. Decrease in pH results in a lower driving force, i.e., a decrease in ability to absorb. This is more important for some acid gases than others because of differing absorption coefficients, e.g., it is more important for SO ₂ control than HCl control. Can indicate likelihood of scaling or corrosion of piping and liquid contact surfaces.	X				X						X					
Neutralizing chemical feed rate	Changes in chemical feed rate can affect scrubber performance as well as pH, which can impact maintenance.									X							
Scrubber liquid specific gravity	Increase in specific gravity may indicate an increase in pollutant concentration, which may decrease removal efficiency.				X												
Scrubber liquid makeup and/or blowdown rate	Changes in makeup or blowdown rates can result in changes in pollutant concentration in recycled scrubber liquid, resulting in decreased removal efficiency.								X					X			
Scrubber liquid level	Changes in the liquid level in the reservoir may indicate insufficient liquid flow rate and insufficient makeup rate. Not as reliable a parameter as scrubber liquid flow rate.																

TABLE B-5. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
		Illustration No.	5a											5b	5c		
		Example CAM Submittals	A20		A4b												A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	
<p>Comments:</p> <ul style="list-style-type: none"> • Approach No. 1 also corresponds to 40 CFR 63, subparts U (Polymers and Resins I), JJJ (Polymers and Resins IV), and MMM (Pesticides). • Approach No. 2 corresponds to 40 CFR 63, subpart Y (Marine Vessels). • Approach No. 4 corresponds to 40 CFR 63, subparts G (HON), U (Polymers and Resins I), JJJ (Polymers and Resins IV), OOO (Polymers and Resins III) for HAP. • Approach No. 5 corresponds to 40 CFR 63, subpart G (HON) for halogenated HAPs from process vents or transfer operations, S (Pulp and Paper), and OOO (Polymers and Resins III). • Approach No. 6 corresponds to 40 CFR 63, subpart AA (Phosphoric Acid). • Approach No. 7 corresponds to 40 CFR 63, subpart CCC (Steel Pickling-HCl). • Approach No. 8 corresponds to 40 CFR 63, subpart NNN (Wool Fiberglass). • Approach No. 9 corresponds to 40 CFR 63, subpart W (Polymers and Resins II). • Approach No. 10 corresponds to 40 CFR 63, subpart MMM (Pesticies). • Approach No. 13 corresponds to 40 CFR 63, subpart O (Commercial Ethylene Oxide Sterilization). It should be scrubber liquid outlet concentration OR scrubber liquid level. Can move scrubber liquid level to another approach, but is bad ex. O (commercial Ed Ster) - scrubber liquid EO concentration, S (Pulp and Paper) -pH or oxid/red potential of liquid, liquid flow, gas flow. 																	

CAM ILLUSTRATION
No. 5a. WET SCRUBBER FOR SO₂ CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to gas scrubbers (general) [013], gas column absorber (packed or tray type) [050, 051]
- 1.2 Pollutants
 - Primary: Sulfur dioxide (SO₂)
 - Other: Acid gases
- 1.3 Process/Emissions Unit: Combustors

2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Scrubber liquid flow rate and scrubber liquid pH.
- 2.2 Rationale for Monitoring Approach
 - Scrubber liquid flow rate: Indicates adequate liquid flow through the scrubber.
 - Scrubber liquid pH: pH level is indicative of removal efficiency from exhaust stream.
- 2.3 Monitoring Location
 - Scrubber liquid flow rate: Measure at pump discharge or at scrubber liquid inlet.
 - Scrubber liquid pH: Measure at scrubber liquid effluent.
- 2.4 Analytical Devices Required
 - Scrubber liquid flow rate: Liquid flow meter or other device for liquid flow; see section 4.4 for information on specific types of instruments.
 - Scrubber liquid pH: pH meter.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
 - Reporting units:
 - Scrubber liquid flow rate: Gallons per minute (gal/min) or cubic feet per minute (ft³/min).
 - Scrubber liquid pH: pH units.
 - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
 - Baseline scrubber liquid flow rate and scrubber liquid pH concurrent with emissions test.
 - Historical plant records of scrubber liquid flow rate and scrubber liquid pH measurements.
- 2.7 Specific QA/QC Procedures
 - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.
- 2.8 References: 9, 14.

3. COMMENTS

- 3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 5b. WET SCRUBBER FOR FLUORIDES CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to gas scrubbers (general) [013], gas absorber column (packed or tray type) [050, 051]
- 1.2 Pollutants
Primary: Fluorides
Other:
- 1.3 Process/Emissions Unit: Primary aluminum processing units, phosphate fertilizer manufacturing

2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Pressure differential.
- 2.2 Rationale for Monitoring Approach: Increase in pressure differential indicates plugging or increased gas flow; decrease in pressure differential indicates decrease in gas or liquid flow or poor liquid distribution.
- 2.3 Monitoring Location: Measure across inlet and outlet ducts.
- 2.4 Analytical Devices Required: Differential pressure transducer, differential pressure gauge, manometers, or alternative methods/instrumentation; see section 4.3 for information on specific types of instruments.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
 - Reporting units: Inches of water column (in. w.c.).
 - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
 - Baseline pressure differential measurements concurrent with emissions test; or
 - Historical plant records of pressure differential measurements.
- 2.7 Specific QA/QC Procedures
 - Calibrate, maintain, and operate instrumentation taking into account manufacturer's specifications.
- 2.8 References:

3. COMMENTS

- 3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

- 3.2 For systems using once-through scrubber liquid, monitoring of pressure differential is sufficient. However, use of recycled water or scrubber liquid would require pH monitoring and caustic addition.

B.13 DRY INJECTION FABRIC FILTERS^{25,26,27}

B.13.1 Background

Dry injection fabric filters (DIFFs) are control devices that reduce acid gas emissions. Dry injection fabric filters consist of a sorbent injection system and a reaction chamber followed by a fabric filter. (Note: Dry injection for acid gas control may also be used in conjunction with other PM control devices—for example, an electrostatic precipitator—but is most frequently used in conjunction with a fabric filter.) To remove SO₂, HCl, and HF, dry sorbent is injected into a reaction chamber on the emission stream duct where the sorbent reacts with the acid gas in the emission stream to form salts that are subsequently removed by the fabric filter. The sorbent may include hydrated lime or sodium bicarbonate. The use of a reaction chamber promotes intimate contact and increased residence time for the acid gas and sorbent particles to react. The emission stream is then vented to a fabric filter to remove the resulting PM. Additional removal of acid gas is achieved when unreacted acid contacts the sorbent-coated bags as it flows through the fabric filter. The acid gas reduction efficiency is affected by dry sorbent injection rate, emission stream gas temperature, the residence time or reaction time between the sorbent and gas stream, the degree of turbulence, and the other parameters discussed for fabric filters in section B.1. Lower emission stream gas temperatures increase the sorbent reactivity and increase the removal of acid gas. In some applications, the emission stream may need to be cooled prior to the DIFF to avoid damage to the fabric filter and to promote reactivity. The emission gas stream can be cooled by a heat exchanger, humidification, or addition of lower temperature cooling air. The desired molar ratio of dry sorbent (calcium) to acid gas is dependent on the equipment configuration, i.e., whether there is a reaction chamber.

B.13.2 Indicators of DIFF Performance

The primary indicators for DIFF performance are outlet acid gas concentration, dry sorbent feed rate, fabric filter inlet gas temperature, and the primary indicators that are discussed in section B.1 for fabric filters. Other parameters that can indicate DIFF performance include DIFF inlet gas temperature (process exhaust temperature), exhaust gas flow rate, sorbent carrier flow rate, sorbent nozzle pressure differential, sorbent specifications, and other indicators that are discussed in section B.1 for fabric filters. Table B.13a lists these indicators and illustrates potential monitoring options for DIFF. See Table B.1 for potential monitoring options for fabric filters.

Outlet acid gas concentration. The most direct single indicator of DIFF performance in removing acid gas from the emission gas stream is the acid gas concentration at the outlet of the unit.

Sorbent feed rate. The dry sorbent feed rate is a key indicator of performance provided the sorbent is properly distributed and has good contact with the emission gas stream. The feed rate is determined based on stoichiometry with the amount of acid gas in the emission gas stream. In general, higher sorbent feed rates are indicative of higher levels of control up to a

critical point, above which the sorbent feed rate may overload the fabric filter and contribute to PM emissions.

Fabric filter inlet temperature. Most fabric filters are designed to operate within a specified temperature range based on the type of bags used. High inlet temperatures can damage the bags. However, cooling to too low a temperature may result in moisture condensation that will cause caking or blinding of the fabric filter bags or acid gas condensation that may corrode the fabric filter housing and other metal components.

Sorbent carrier gas flow rate. A minimum carrier gas flow rate will ensure that the flow and dispersion of the injected sorbent is maintained. With low carrier gas flow to the DIFF, the sorbent flow rate will decrease, causing the acid gas emissions to increase, i.e., less control of acid gas emissions.

Sorbent/carrier gas nozzle pressure differential. Nozzle pressure is a surrogate for the carrier gas flow rate. Higher pressure differentials indicate that more sorbent is being carried to the DIFF and also indicates that good dispersion of the sorbent is being achieved.

Sorbent specifications. Changes in the sorbent may affect the control efficiency of the unit. A facility should identify the sorbent brand and type or identify the adsorption properties of the sorbent.

DIFF inlet gas temperature (process exhaust temperature). For thermal processes, increases in the DIFF inlet temperature may indicate that additional cooling of the gas stream is necessary. Increases in temperature reduce the reactivity of the sorbent with the acid gas and may cause acid gas emissions to increase.

Exhaust gas flow rate. Gas flow rate affects the residence time of the gas stream in the reactor, the duct, and the fabric filter. Increases in the gas flow rate decrease the residence time, which may decrease the control efficiency. The longer the residence time, the more time the acid in the gas stream is in contact with the sorbent.

Indicators for fabric filters. See section B.1.

B.13.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for Dry Injection Fabric Filters:

- 13a: Monitoring sorbent feed rate, fabric filter inlet temperature, opacity, and fabric filter pressure differential.
- 13b: Monitoring sorbent feed rate, fabric filter inlet temperature, and bag leak detector.

B.13.4 Bibliography

TABLE B-13. SUMMARY OF PERFORMANCE INDICATORS FOR DIFFs

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.		13a		13b	
		Example CAM Submittals					
		Comment			✓		
Primary Indicators of Performance							
Outlet acid concentration	Direct measure of outlet acid concentration.		X				
Sorbent feed rate	Low feed rate may indicate insufficient alkali to react with acid gases. High feed rates above an optimum level may cause bag blinding.			X		X	X
Fabric filter inlet temperature	High temperatures can destroy the bags or shorten bag life; high temperatures indicate a need for additional cooling. Applies only to DIFF that control thermal process emissions. Too low a temperature can cause condensation that can result in bag blinding or increased corrosion of structural components.			X		X	
Bag leak detector signal	Indicator of bag degradation or rupture. Signal is proportional to particulate loading in exhaust; in some cases, signal can be affected by changes in velocity, particle size/type, and humidity.					X	
Opacity/VE	Increased opacity/VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.			X			X
Other Performance Indicators							
Sorbent/carrier gas nozzle pressure differential	High pressure differential indicates that more sorbent is being delivered to the unit and that good dispersion is being achieved. May be used as a surrogate for carrier gas flow rate.				X		
Sorbent specifications	Changes in the type or brand of sorbent may affect the acid reduction efficiency.				X		
Sorbent carrier gas flow rate	Ensures that flow and dispersion of the solvent is maintained. Lower carrier gas may indicate lower sorbent feed rate and decreased acid removal.						X

TABLE B-13. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.		13a		13b	
		Example CAM Submittals					
		Comment			✓		
DIFF inlet temperature (process exhaust temperature)	Lower gas stream temperatures provide an increase in sorbent reactivity and an increase in acid gas removal. Increases in inlet temperature may indicate that additional cooling is necessary. Applies only to DIFF that control thermal process emissions.				X		
Fabric filter pressure differential	Indicator of blinding or malfunction of cleaning cycle. Sudden increase in pressure differential can indicate bag blinding; also can indicate if cleaning mechanism is operating properly.			X	X		
Exhaust gas flow rate	Indication of residence time in control device.				X		
Comments: <ul style="list-style-type: none"> • Approach No. 3 corresponds to 40 CFR 63, subpart EEE (Hazardous Waste Combustors) • Approach No. 5: 40 CFR 63, subpart LL (Primary Aluminum Production). Note: Other monitoring options for fabric filters are discussed in section B.1 for Fabric Filters.							

CAM ILLUSTRATION
No. 13a. DIFF FOR ACID GAS CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Dry injection fabric filter (DIFF)
- 1.2 Pollutants
Primary: Sulfur dioxide (SO₂), hydrogen chloride (HCl), hydrogen fluoride (HF)
Other:
- 1.3 Process/Emissions units: Combustors, kilns

2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Sorbent feed rate, opacity, fabric filter inlet temperature, and fabric filter pressure differential.
- 2.2 Rationale for Monitoring Approach
 - Sorbent feed rate: Amount of sorbent injected is based stoichiometrically on acid gas concentration; want to maximize sorbent feed rate without generating excess sorbent particulate that will overload the fabric filter.
 - Opacity or VE: An increase in opacity or changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.
 - Fabric filter inlet temperature: High temperature can damage filter bags; low temperature can cause condensation of moisture that will cause caking on the filter bags or of acid gases that will damage the unit.
 - Fabric filter pressure differential: Decrease in pressure differential indicates change in operation; increase in pressure differential indicates filter bag blinding.
- 2.3 Monitoring Location
 - Sorbent feed rate: Measure at sorbent injection point or sorbent weigh tank.
 - Opacity or VE: Per RM 9 (opacity) or RM 22 (VE) requirements.
 - Fabric filter inlet temperature: Measure at the fabric filter inlet duct.
 - Fabric filter pressure differential: Measure across inlet and outlet of each compartment of fabric filter.
- 2.4 Analytical Devices Required
 - Sorbent feed rate: Use of a scale or other weight monitor.
 - Opacity or VE: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).
 - Fabric filter inlet temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
 - Fabric filter pressure differential: Pressure transducers, differential pressure gauges, manometers, and other methods or alternative instrumentation, as appropriate; see section 4.3 for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement: Hourly, or continuously on strip chart or data acquisition system; for opacity or VE, daily or as weather permits.

- Reporting units:
 - Sorbent feed rate: Pounds per hour (lb/hr).
 - Opacity or VE: Percent opacity or visible/no visible emissions.
 - Fabric filter inlet temperature: Degrees Celsius or Fahrenheit (°C or °F).
 - Fabric filter pressure differential: Inches of water column (in. w.c.).
 - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system; observers complete opacity or VE observation forms and log into binder or electronic database as appropriate.
- 2.6 Data Requirements
- Baseline sorbent feed rate, opacity or VE, fabric filter inlet temperature, and fabric filter pressure differential measurements concurrent with emissions test.
 - Historical plant records of sorbent feed rate, opacity observations, fabric filter inlet temperature, and fabric filter pressure differential measurements. (No data are needed if indicator is “any visible emissions.”)
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer’s specifications; initial training of observer per RM 9 or RM 22, semi-annual refresher training per RM 9, if applicable.
- 2.8 References: _____

3. COMMENTS

- 3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 13b. DIFF FOR ACID GAS CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Dry injection fabric filter (DIFF)
- 1.2 Pollutants
Primary: Sulfur dioxide (SO₂), hydrogen chloride (HCl), hydrogen fluoride (HF)
Other:
- 1.3 Process/Emissions units: Combustors, kilns

2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Sorbent feed rate, fabric filter inlet temperature, and PM concentration using a bag leak detector.
- 2.2 Rationale for Monitoring Approach
 - Sorbent feed rate: Amount of sorbent injected is based stoichiometrically on acid gas concentration; want to maximize sorbent feed rate without generating excess sorbent particulate that will overload the fabric filter.
 - Fabric filter inlet temperature: High temperature can damage filter bags; low temperature can cause condensation of moisture that will cause caking on the filter bags or of acid gases that will damage the unit.
 - PM concentration: A bag leak detector generates a signal that is proportional to the PM loading. It provides an indication of bag degradation or rupture. Operates on principles such as triboelectricity, electrostatic induction, light scattering, or light transmission.
- 2.3 Monitoring Location
 - Sorbent feed rate: Measure at sorbent injection point or sorbent weigh tank.
 - Fabric filter inlet temperature: Measure at the fabric filter inlet duct.
 - PM concentration: Measure at outlet of fabric filter.
- 2.4 Analytical Devices Required
 - Sorbent feed rate: Use of a scale or other weight monitor.
 - Fabric filter inlet temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
 - PM concentration: Bag leak detector and associated instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement: Hourly, or continuously on strip chart or data acquisition system.
 - Reporting units:
 - Sorbent feed rate: Pounds per hour (lb/hr).
 - Fabric filter inlet temperature: Degrees Celsius or Fahrenheit (°C or °F).
 - PM concentration: Amps, volts, or percent of scale.
 - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

- Baseline sorbent feed rate, fabric filter inlet temperature, and bag leak detector measurements concurrent with emissions test.
- Historical plant records of sorbent feed rate, fabric filter inlet temperature, and bag leak detector measurements.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: _

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.14 SPRAY DRYER^{25,26,27}

B.14.1 Background

Spray dryers are control devices that reduce acid gas emissions. A spray dryer system consists of a slurry atomizer, reaction chamber, and a PM collection unit. The slurry is made of alkali sorbent (typically lime) and water. This slurry is injected into the flue gas in the reaction chamber to remove SO₂, HCl, and HF. The lime slurry rate is determined stoichiometrically by the acid gas content. The PM collection unit is usually a fabric filter. The atomized slurry droplets cool the emission gas stream and the hydrated lime reacts with acid gas to form calcium salts. Lower emission stream gas temperatures increase the sorbent reactivity and increase the removal of acid gas; however the temperature must be high enough to ensure the slurry and reaction products are dry before collection in the fabric filter. The residence time in the reaction chamber ranges from 5 to 15 seconds. Smaller droplet size increases the surface area for reaction between the lime and acid gas. The acid gas reduction efficiency is affected by the slurry feed rate, the residence time or reaction time between the sorbent and gas stream, emission stream gas temperature, slurry reactor outlet temperature (fabric filter inlet temperature), slurry droplet size, and the other parameters discussed for fabric filters in section B.1.

B.14.2 Indicators of Spray Dryer Performance

The primary indicators for spray dryer performance include the outlet acid gas concentration, alkali feed rate to the slurry mixing tank, water feed rate to the slurry mixing tank, slurry feed rate, slurry droplet size, fabric filter inlet temperature, and the primary indicators that are discussed in section B.1 for fabric filters. Other parameters that can indicate spray dryer performance include spray dryer inlet gas temperature (process exhaust temperature), exhaust gas flow rate, and the other indicators for fabric filters that are discussed in section B.1. Table B-14 lists these indicators and illustrates potential monitoring options for spray dryers.

Outlet acid gas concentration. The most direct single indicator of spray dryer performance is the acid gas concentration at the outlet of the unit.

Alkali feed rate to slurry mix tank. The alkali feed rate is a key indicator of spray dryer performance. The alkali is dissolved in water for slurry injection to the spray dryer; the slurry feed rate is determined by stoichiometry of alkali to the acid gas content in the emission stream. The alkali feed rate must be at a sufficient level to generate the desired alkali concentration in the slurry.

Water feed rate to slurry mix tank. Water feed rate is a key indicator of spray dryer performance. Water is used to dissolve the alkali for slurry injection to the spray dryer; the slurry feed rate is determined by stoichiometry of alkali to the acid gas content in the emission stream. The water feed rate must be at a sufficient level to generate the desired alkali concentration in the slurry and to generate appropriate cooling of the gas stream.

Slurry feed rate. Slurry feed rate is a key indicator of performance provided the slurry is maintained at a constant concentration, the slurry is properly distributed and atomized, and the liquid-gas interface is maintained. The alkali feed rate is determined by stoichiometry with the acid gas content; the alkali is dissolved in water for injection to the spray dryer. The slurry concentration and feed rate must be maintained to assure sufficient alkali to react with acid gas and to assure sufficient water for cooling the gas stream. In general, higher slurry feed rates are indicative of higher levels of control up to a critical point, above which the slurry feed rate results in excess alkali sorbent injection that may overload the particulate control device (e.g., fabric filter) and contribute to increased particulate matter emissions. Also, a slurry feed rate that is too high may result in the addition of sufficient water to cool the emission stream below the dew point temperature, causing condensation and operational problems with the system (e.g., blinding of the fabric filter bags).

Fabric filter inlet temperature. Most fabric filters are designed to operate within a specified temperature range based on the type of bags used. High inlet temperatures can damage the bags. However, cooling to too low a temperature may result in moisture condensation that will cause caking or blinding of the fabric filter bags or acid gas condensation that may corrode the fabric filter housing and other metal components.

Spray dryer inlet gas temperature (process exhaust temperature). For thermal processes, increases in the spray dryer inlet gas temperature may indicate that additional cooling of the gas stream is necessary, i.e., additional slurry injection. Increases in temperature reduce the reactivity of the sorbent with the acid gas and may cause an increase in acid gas emissions. This temperature must be maintained within an optimal range to promote the reaction and to ensure that a dry gas stream enters the fabric filter.

Slurry droplet size. The slurry is sprayed into the reaction chamber through the slurry atomizer. Smaller particles increase the surface area of the slurry and promote reaction with acid gas. The pressure differential across the slurry atomizer feed is a surrogate indicator for both the droplet size and the slurry feed rate. This pressure should be maintained within design limits to ensure the slurry is properly atomized.

Indicators for fabric filters. See section B.1.

B.14.3 Illustrations

14a: Monitoring alkali feed rate to slurry mix tank, water feed rate to slurry mix tank, fabric filter inlet temperature, opacity, and fabric filter pressure differential.

B.14.4 Bibliography

TABLE B-14. SUMMARY OF PERFORMANCE INDICATORS FOR SPRAY DRYING

Parameters	Performance indication	Approach No.	1
		Illustration No.	14a
		Example CAM Submittals	
		Comment	
Primary Indicators of Performance			
Outlet acid gas concentration	Direct measure of outlet acid gas concentration. Most direct single indicator of spray dryer performance.		
Alkali feed rate to slurry mix tank	Indicates whether sufficient alkali to react with acid gas is being added to the system. Increases in alkali feed rate may cause overloading of the fabric filter. Decreases in alkali feed rate may cause a reduction in performance.		X
Water feed rate to slurry mix tank	Indicates that water to provide the correct alkali concentration is being added. Also indicates whether sufficient cooling water is being added. Increases in water feed rate may cause a slurry with dilute concentration and overcool the gas stream. Decreases in water rate may result in an increase in the reaction chamber temperature, causing a decrease in sorbent reactivity or temperatures exceeding the design of the fabric filter system.		X
Slurry feed rate	Low feed rate may indicate insufficient alkali to react with acid gases and insufficient water injection to cool the gas stream to the fabric filter design temperature. Increases in feed rate may cause excess PM and overloading of the PM control system or excess moisture and cooling of the emission gas stream to below the dew point temperature.		
Fabric filter inlet temperature	Indicator of potential for overheating of bags or condensation. High temperatures can destroy the bags or shorten bag life; high temperatures indicate a need for additional cooling water (in the slurry) injection. Too low a temperature can cause condensation, which can result in bag blinding or increased corrosion of structural components.		X
Opacity	Increased opacity/VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.		X
Other Performance Indicators			
Pressure differential	Indicator of blinding or malfunction of cleaning cycle. Sudden increase in pressure differential can indicate bag blinding; also can indicate if cleaning mechanism is operating properly.		X
Comments: None.			

CAM ILLUSTRATION
No. 14a. SPRAY DRYER FOR ACID GAS CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Spray drying [067]
- 1.2 Pollutants
Primary: Sulfur oxides (SO_x), hydrogen chloride (HCl), hydrogen fluoride (HF)
Other:
- 1.3 Process/Emissions units: Combustors, kilns, furnaces, boilers

2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Alkali feed rate to slurry mixing tank, water feed rate to slurry mixing tank, fabric filter inlet temperature, opacity, and fabric filter pressure differential.
- 2.2 Rationale for Monitoring Approach
 - Alkali feed rate to slurry mixing tank: Removal of acid gas components is dependent on sufficient alkali feed to the system.
 - Water feed rate to slurry mixing tank: Removal of acid gas components and cooling of the emission stream depend on sufficient water feed to the system.
 - Fabric filter inlet temperature: Excessive temperature can lead to leaks, breakdown of filter material, and reduced life of filter; temperatures below the dewpoint of the exhaust gas stream may cause condensation that damages the filter bags.
 - Opacity or VE: An increase in opacity or changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.
 - Fabric filter pressure differential: Indicates proper operation of the fabric filter; decrease in pressure differential indicates bag failure; increase in pressure differential indicates fabric blinding.
- 2.3 Monitoring Location
 - Alkali feed rate to slurry mixing tank: At alkali feed line on the slurry mix tank.
 - Water feed rate to slurry mixing tank: At water injection line on the slurry mix tank.
 - Fabric filter inlet temperature: At fabric filter inlet duct.
 - Opacity or VE: Per RM 9 (opacity) or RM 22 (VE) requirements.
 - Fabric filter pressure differential: Across inlet and outlet of each compartment.
- 2.4 Analytical Devices Required
 - Alkali feed rate to slurry mixing tank: If measured by weight, use of a scale, weigh tank, load cells, or other weight monitor; if measured by volume, use of in-line flow meters; see section 4.4 (Flow) for additional information on devices.
 - Water feed rate to slurry mixing tank: In-line flow meters; see section 4.4 (Flow) for additional information on devices.
 - Fabric filter inlet temperature: Thermocouple, TRD, or other temperature sensing device; see section 4.2 (Temperature) for additional information on devices.

- Opacity or VE: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).
 - Fabric filter pressure differential: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate; see section 4.3 (Pressure) for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or monitored continuously on strip chart or data acquisition system; for opacity or VE, daily or as weather permits.
 - Reporting units:
 - Alkali feed rate to slurry mixing tank: Weight in pounds per hour (lb/hr), or other unit of mass.
 - Water feed rate to slurry mixing tank: Volume in gallons per hour (gal/hr) or other units.
 - Fabric filter inlet temperature: Degrees Celsius or Fahrenheit (C or F).
 - Opacity or VE: Percent opacity or visible/no visible emissions.
 - Fabric filter pressure differential: Inches of water column (in. w.c.).
 - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system; observers complete opacity or VE observation forms and log into binder or electronic database as appropriate.
- 2.6 Data Requirements
- Stoichiometric calculations.
 - Baseline alkali feed rate to slurry mixing tank, water feed rate to slurry mixing tank, fabric filter inlet temperature, opacity or VE, and fabric filter pressure differential measurements concurrent with emissions test.
 - Historical plant records on alkali feed rate, water feed rate, fabric filter inlet temperature, opacity observation, and fabric filter pressure differential measurements. (No data are needed if indicator is “any visible emissions.”)
- 2.7 Specific QA/QC Procedures: Calibration, maintenance, and operation using procedures that take into account manufacturer’s specifications.
- 2.8 References: 9, 14.

3. COMMENTS

- 3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)
- 3.2 In lieu of opacity and pressure differential for the fabric filter, see section B.1 for other monitoring approaches, such as bag leak detector, that provide a higher level of confidence than opacity for fabric filter.

B.15 SELECTIVE CATALYTIC REDUCTION^{28,29,30}

B.15.1 Background

Selective catalytic reduction (SCR) is an add-on NO_x control technology for process gas streams with significant oxygen (O₂) content. An SCR consists of a catalyst surface, reactor housing and support, ammonia (NH₃) system (storage tank, vaporizer, injection grid, dilution air system, and control system), CEMS, and control system. The control efficiency achieved for NO_x ranges from approximately 70 to 90 percent depending on the application. In SCR, NH₃ is injected into the inlet gas stream upstream of the catalyst bed; in the catalyst bed, the NH₃ reacts with NO_x in the presence of O₂ to form nitrogen (N₂) and water (H₂O). The NO_x reduction efficiency is controlled by the ratio of NH₃ injected to the amount of NO_x in the gas stream (NH₃/NO_x), the catalyst material and condition, the space velocity, and the catalyst bed operating temperature. Increasing the NH₃/NO_x ratio increases the level of NO_x emission reduction but may also result in higher NH₃ slip levels. (Ammonia slip occurs when too much NH₃ is injected and the unreacted portion is emitted in the outlet stream from the SCR.) In general, the outlet concentration of NH₃ from the SCR should be held to less than 5 ppmv. Side reactions may produce ammonium sulfate and ammonium bisulfate byproducts when SO₃ is also present; SO₂ in the process gas stream oxidizes to SO₃ in some catalysts. These byproducts may cause plugging and corrosion of downstream equipment. The load applied to the process unit (e.g., gas turbine or some stationary internal combustion engines) affects both the exhaust temperature and the NO_x emission levels from the process, and various exhaust temperature and NO_x swings may pose problems for the SCR unit. The complexity of the NH₃ injection control system increases with fluctuations in load.

The catalyst is arranged in a series of two to four beds or layers. Catalysts may include base-metal oxides, precious metals, or zeolite. Optimum operating temperatures for SCR units using a base-metal oxides catalyst range from 600° to 750°F, depending on catalyst type; operating temperatures for platinum catalysts are lower than this range. Zeolite catalysts require an operating temperature of 600° to 900°F, and as high as 1100°F. Typically, the optimum performance of each SCR catalyst lies within a narrow temperature range of ±50°F. Below this range, catalyst activity is reduced and NH₃ slip increases. Above the range, NH₃ may be oxidized to form NO_x, which is counter to the control device purpose.

As catalyst activity declines, additional catalyst should be installed; as deactivation continues, the catalyst can be replaced one layer at a time. Sufficient catalyst volume must be provided to allow for inevitable catalyst deactivation. Catalyst deactivation may average up to 20 percent over a two-year period depending on the application. The use of fuels other than natural gas may mask or poison the catalyst. If diesel or other fuels are used, a bed guard upstream of the catalyst bed should be used to collect heavy hydrocarbons that would deposit on or mask the catalyst. Zeolite catalyst is recommended for diesel fuel processes to minimize masking and poisoning and to limit NH₃ byproduct side reactions. Soot blowing, vacuuming, or superheated steam application may be conducted periodically to remove particulate or masking from the catalyst.

Space velocity (gas flow rate divided by the catalyst bed volume) is an indicator of residence time in the catalyst bed. Lower space velocities give higher residence times and higher NO_x reduction rates.

B.15.2 Indicators of SCR Performance

The primary indicators of SCR performance are outlet NO_x concentration, NH₃/NO_x ratio, catalyst bed inlet temperature, and the catalyst activity. Other parameters that can indicate SCR performance include the outlet NH₃ concentration, catalyst bed outlet temperature, inlet gas flow rate, sulfur content of the fuel combusted, and the pressure differential across the catalyst bed. Table B-15 lists these indicators and illustrates potential monitoring options for SCR.

Outlet NO_x concentration. The most direct single indicator of the performance of a SCR is the NO_x concentration at the outlet of the unit.

NH₃/NO_x ratio (NH₃ injection rate). The NH₃ injection rate should increase or decrease with changes in inlet NO_x levels due to varying process load. With increasing NH₃/NO_x ratio, the NO_x level and the NH₃ slip remain fairly constant and the SCR reduces NO_x emissions; however, above a certain value or ratio, the NH₃ slip begins to increase. Limiting the amount of NH₃ slip is important to limit NH₃ emissions from the SCR and to suppress reactions of the additional NH₃ with SO₂ and SO₃, if present, to form ammonia salt byproducts.

Catalyst bed inlet temperature. The temperature at the inlet to the catalyst bed provides a good indication of catalytic reduction performance because it indicates that the gas stream is at sufficient temperature to initiate reduction of NO_x on the catalyst. Too high of an inlet temperature (i.e., of the process gas stream) may cause NO_x generation in the SCR rather than NO_x reductions.

Catalyst activity. Catalyst deactivation will result in increases in NO_x emissions and NH₃ emissions (ammonia slip). Catalyst activity should be checked periodically and/or the catalyst or portion of the catalyst should be replaced periodically.

Outlet NH₃ concentration. NH₃ in the outlet stream is an indicator that too much NH₃ is being injected or that reduction of NO_x is not occurring on the catalyst.

Catalyst bed outlet temperature. The bed outlet temperature provides an indication that reduction is occurring on the bed. Maintaining the operating temperature in the catalyst bed is crucial in avoiding NO_x generation at high temperatures. In general, lower operating temperatures mean lower NO_x emissions, to a minimum temperature below which NO_x reduction does not occur. Increases in the operating temperature of the SCR may cause an increase in NO_x generation rather than NO_x reductions. Also, there is a maximum temperature above which the catalyst begins to sinter; monitoring the bed outlet temperature will ensure that the temperature within the bed does not exceed its working limit.

Inlet gas flow rate (Space velocity). Control efficiency is a function of the space velocity (similar to residence time), and space velocity is a function of the gas flow rate. As flow rate increases, the space velocity increases and control efficiency declines. Decreases in flow rate typically mean an increase in control efficiency.

Sulfur content of fuel. Processes that use sulfur-containing fuels should include a limit on the sulfur content. Higher sulfur content may result in increased formation of ammonia salt byproducts.

Pressure differential across catalyst bed. An increase in pressure differential over time may provide an indication that particulate matter (PM) is accumulating on the catalyst bed. Periodic blowing, vacuuming, or steaming of the bed is necessary to remove accumulated PM.

B.15.3 Illustrations

The following illustration presents an example of compliance assurance monitoring for SCR:

15a: Catalyst bed temperature, outlet NH₃ concentration, and catalyst activity.

B.15.4 Bibliography

TABLE B-15. SUMMARY OF PERFORMANCE INDICATORS FOR SCR_s

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.		15a			
		Example CAM Submittals					
		Comment					
Primary Indicators of Performance							
Outlet NO _x concentration	Direct measure of outlet concentration. Best single indicator of SCR performance.		X				
NH ₃ /NO _x ratio (NH ₃ injection rate)	Amount of NH ₃ injection should be stoichiometrically based on NO _x concentration in the inlet stream. Want to maximize the ratio without increasing NH ₃ slip.				X	X	X
Catalyst bed inlet temperature	Indicator that bed inlet is of sufficient temperature to initiate reduction. Also an indicator that bed inlet temperature is not too high for catalyst longevity. High temperatures encourage generation of NO _x rather than a reduction in NO _x .				X	X	X
Catalyst activity	Periodic check of catalyst activity gives an indication of catalyst fouling or masking. Must periodically clean and/or replace catalyst to ensure reduction is occurring.			X	X		
Other Performance Indicators							
Outlet NH ₃ concentration	Indicator that NH ₃ injection rate is too high. Must adjust to reduce NH ₃ slip.			X			
Catalyst bed outlet temperature	Indicator of the level of reduction that is occurring in the catalyst bed and that temperature does not exceed design limits of catalyst. Too high a temperature may encourage generation of NO _x rather than a reduction in NO _x .			X	X	X	X
Pressure differential across catalyst bed	Indicator of bed fouling or plugging. Increase in pressure differential indicates that bed is becoming fouled or plugged. Changes in pressure differential are likely to be gradual.						X
Comments: None.							

CAM ILLUSTRATION

No. 15a. SELECTIVE CATALYTIC REDUCTION FOR NO_x CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Selective catalytic reduction [065]
- 1.2 Pollutants
 - Primary: Nitrogen oxides (NO_x)
 - Other: Nitric acid (HNO₃), ammonia (NH₃)
- 1.3 Process/Emission units: Gas turbines, internal combustion engines (ICE), process heaters, nitric acid production units, and boilers

2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Catalyst bed temperature, outlet NH₃ concentration in flue gas (NH₃ slip causes ammonia salt fouling of the catalyst), and catalyst activity.
- 2.2 Rationale for Monitoring Approach
 - Catalyst bed temperature: Indication that the reaction is occurring in the catalyst bed; too high a bed temperature may generate NO_x rather than reduce NO_x.
 - Outlet NH₃ concentration: Indication of NO_x reduction or indication that NH₃ feed is too high; fouling of the catalyst is caused by ammonia salt byproducts, the formation of which can be avoided by limiting ammonia slip and limiting fuel sulfur content.
 - Catalyst activity: Indication of the catalyst's ability to promote the reaction between NO_x and NH₃.
- 2.3 Monitoring Location
 - Catalyst bed temperature: Outlet to the catalyst bed.
 - Outlet NH₃ concentration: NH₃ monitored at outlet duct of catalyst bed.
 - Catalyst activity: Removal of a small portion of catalyst for testing.
- 2.4 Analytical Devices Required: Thermocouples or other temperature instrumentation, NH₃ CEMS (other methods and instruments may be unit-specific).
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement:
 - Catalyst bed temperature: Measure continuously.
 - Outlet NH₃ concentration: Measure continuously.
 - Catalyst activity: Measure periodically.
 - Reporting units:
 - Catalyst bed temperature: Degrees Celsius or Fahrenheit (C or F).
 - Outlet NH₃ concentration: Parts per million by volume (ppm_v) NH₃.
 - Catalyst activity: Percent active compared with new catalyst (or other as appropriate).
 - Recording process:
 - Catalyst bed temperature: recorded automatically on strip chart or data acquisition system.

- Outlet NH₃ concentration: recorded automatically on strip chart or data acquisition system.
- Catalyst activity: manually recorded in SCR maintenance log.

2.6 Data Requirements

- Baseline catalyst bed temperature, outlet NH₃ concentration, and catalyst activity measurements concurrent with emission test.
- Historical plant records of catalyst bed temperature, outlet NH₃ concentrations, and catalyst activity measurements.

2.7 Specific QA/QC Procedures

- Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's recommendations.

2.8 References: _____

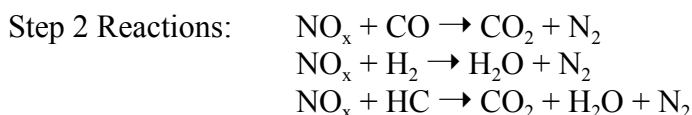
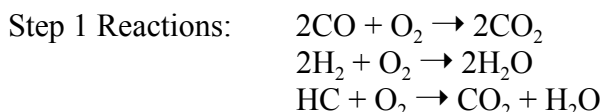
3. COMMENTS

None.

B.16 NONSELECTIVE CATALYTIC REDUCTION^{28,29,30}

B.16.1 Background

Nonselective catalytic reduction (NSCR) is an add-on NO_x control technology for exhaust streams with low O₂ content. Nonselective catalytic reduction uses a catalyst reaction to simultaneously reduce NO_x, CO, and hydrocarbon (HC) to water, carbon dioxide, and nitrogen. The catalyst is usually a noble metal. The conversion occurs in two sequential steps, as shown in the following equations:



The step 1 reactions remove excess O₂ from the exhaust gas because CO and HC will more readily react with O₂ than with NO_x. The O₂ content of the stream must be kept below approximately 0.5 percent to ensure NO_x reduction.

One type of NSCR system injects a reducing agent into the exhaust gas stream prior to the catalyst reactor to reduce the NO_x. Another type of NSCR system has an afterburner and two catalytic reactors (one reduction catalyst and one oxidation catalyst). In this system, natural gas is injected into the afterburner to combust unburned HC (at a minimum temperature of 1700°F). The gas stream is cooled prior to entering the first catalytic reactor where CO and NO_x are reduced. A second heat exchanger cools the gas stream (to reduce any NO_x reformation) before the second catalytic reactor where remaining CO is converted to CO₂.

The control efficiency achieved for NO_x ranges from 80 to 90 percent. The NO_x reduction efficiency is controlled by similar factors as for SCR, including the catalyst material and condition, the space velocity, and the catalyst bed operating temperature. Other factors include the air-to-fuel (A/F) ratio, the exhaust gas temperature, and the presence of masking or poisoning agents. The discussions in section B.15 for SCR relating to catalyst issues and space velocity also apply to NSCR. The operating temperatures for NSCR system range from approximately 700° to 1500°F, depending on the catalyst. For NO_x reductions of 90 percent, the temperature must be between 800° to 1200°F. One source indicates that the O₂ concentration for NSCR must be less than 4 percent, and another source indicates that the O₂ concentration must be at or below approximately 0.5 percent.

B.16.2 Indicators of NSCR Performance

The key indicators for NSCR are the same performance indicators for SCR with a few exceptions (minus the NH_3/NO_x ratio, outlet NH_3 concentration, and sulfur content of the fuel). Outlet NO_x concentration, catalyst bed inlet temperature, catalyst activity, pressure differential across the catalyst bed, catalyst bed outlet temperature, inlet gas flow rate, and outlet O_2 concentration were discussed above. Table B-16 lists these indicators and illustrates potential monitoring approaches for NSCR.

B.16.3 Illustrations

The following illustration presents an example of compliance assurance monitoring for NSCR:

- 16a: Monitoring catalyst bed inlet temperature, catalyst bed outlet temperature, and catalyst activity.

B.16.4 Bibliography

TABLE B-16. SUMMARY OF PERFORMANCE INDICATORS FOR NSCRs

Parameters	Performance indication	Approach No.	1	2	3
		Illustration No.		16a	
		Example CAM Submittals			
		Comment			
Primary Indicators of Performance					
Outlet NO _x concentration	Direct measure of outlet concentration. Most direct single indicator of NSCR performance.		X		
Catalyst bed inlet temperature	Indicator that bed inlet is of sufficient temperature to initiate reduction. Also an indicator that bed inlet temperature is not too high for catalyst longevity.			X	X
Catalyst activity	Periodic check of catalyst activity gives an indication of catalyst fouling or masking. Must periodically clean and/or replace catalyst to ensure reduction is occurring.			X	
Other Performance Indicators					
Catalyst bed outlet temperature	Indicator of level of reduction occurring in the catalyst bed and that temperature does not exceed design limits of catalyst. Higher temperatures improve reduction of CO and VOC but encourage generation of NO _x .			X	X
Pressure differential across catalyst bed	Indicator of bed fouling or plugging. Increase in pressure differential indicates that bed is becoming fouled or plugged. Changes in pressure differential are likely to be gradual.				X
Outlet O ₂ concentration	Indicator of dilution rate. Generally monitored in combination with NO _x , VOC, or CO concentration to allow for correcting concentration to a specified percent O ₂ .		X		
Comments: None.					

CAM ILLUSTRATION

No. 16a. NONSELECTIVE CATALYTIC REDUCTION FOR NO_x CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Nonselective catalytic reduction [065]
- 1.2 Pollutants
 - Primary: Nitrogen oxides (NO_x)
 - Other: Nitric acid (HNO₃), ammonia (NH₃)
- 1.3 Process/Emission units: Internal combustion engines (ICE)

2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Catalyst bed inlet temperature, catalyst bed outlet temperature, and catalyst activity.
- 2.2 Rationale for Monitoring Approach
 - Catalyst bed inlet temperature: Indication that the gas stream is at sufficiency temperature to initiate reduction on the catalyst bed; too high a bed temperature may generate NO_x rather than reduce NO_x.
 - Catalyst bed outlet temperature: Indication that the reaction is occurring in the catalyst bed; too high a bed temperature may generate NO_x rather than reduce NO_x.
 - Catalyst activity: Indication of the catalyst's ability to promote the reduction of NO_x.
- 2.3 Monitoring Location
 - Catalyst bed inlet temperature: Inlet to the catalyst bed.
 - Catalyst bed outlet temperature: Outlet to the catalyst bed.
 - Catalyst activity: Removal of a small portion of catalyst for testing.
- 2.4 Analytical Devices Required: Thermocouples or other temperature instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement:
 - Catalyst bed inlet temperature: Measure continuously.
 - Catalyst bed outlet temperature: Measure continuously.
 - Catalyst activity: Measure periodically.
 - Reporting units:
 - Catalyst bed inlet temperature: Degrees Celsius or Fahrenheit (C or F).
 - Catalyst bed outlet temperature: Degrees Celsius or Fahrenheit (C or F).
 - Catalyst activity: Percent active compared with new catalyst (or other as appropriate).
 - Recording process:
 - Catalyst bed inlet temperature: Recorded automatically on strip chart or data acquisition system.
 - Catalyst bed outlet temperature: Recorded automatically on strip chart or data acquisition system.
 - Catalyst activity: Manually recorded in NSCR maintenance log.

2.6 Data Requirements

- Baseline catalyst bed inlet temperature, catalyst bed outlet temperature, and catalyst activity measurements concurrent with emission test.
- Historical plant records of catalyst bed inlet temperature, catalyst bed outlet temperature, and catalyst activity measurements.

2.7 Specific QA/QC Procedures

- Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's recommendations.

2.8 References: _____

3. COMMENTS

None.

B.17 WATER OR STEAM INJECTION^{28,29,30}

B.17.1 Background

Water or steam injection provides control of NO_x in the combustion zone. The formation of NO_x results from one of three mechanisms: thermal NO_x, fuel NO_x, and prompt NO_x. Because thermal NO_x formation increases exponentially with temperature, small reductions in temperature will result in significant reductions of NO_x. Water or steam injection into the flame area provides a heat sink that lowers the flame temperature and reduces thermal NO_x formation. Water injection provides greater NO_x reduction than steam injection. Injection rates are defined by water-to-fuel ratios (WFR). Water or steam injection only control thermal NO_x formation due to the lower flame temperature; injection may actually increase the rate of fuel NO_x formation. The most important factors in the injection system performance are the WFR, the combustor geometry, injection nozzle design, and the fuel-bound nitrogen (FBN) content. Water injection corresponds to an approximate 60 to 70 percent reduction from uncontrolled levels for small turbines and approximately 70 to 80 percent reduction for utility and large turbines. For natural gas, typical WFR range from 0.33 to 2.48 on a weight basis. For oil fuel, typical WFR range from 0.46 to 2.28. A WFR of 1.0 (weight basis) on a natural gas-fired turbine will reduce NO_x by 70 to 80 percent (depending on initial NO_x levels). The reduction efficiency of NO_x increases as the WFR increases, up to an optimum level, beyond which water injection interferes with combustion. Combustor geometry and injection nozzle design affect the performance. The water must be atomized to give a homogeneous spray of water droplets to avoid localized hot spots in the combustor that may produce increased NO_x emissions. Fuel types such as natural gas and distillate oils have low-nitrogen contents and provide lower NO_x emissions levels when water injection is used. The FBN contents of coal-derived liquid fuel, shale oil, and residual oils result in higher fuel NO_x formation.

In some applications, CO emissions increase as the WFR increases; steam injection does not cause as much increase in CO emissions as water injection. Increasing WFR also results in an increase in HC emissions but to a lesser extent than for CO emissions.

A combustor using water or steam injection has increased maintenance requirements due to erosion and wear. The interval of time between inspections should be decreased due to injection use. Water and steam injection is not applicable to internal combustion engines but the technology has been applied to many turbines. High purity water is used to minimize wear on turbine components (nozzles, combustor cans, turbine blades). The water quality, amount of water injected, combustor can design and materials, and load cycle are factors affecting the failure rate of turbine units.

B.17.2 Indicators of Water/Steam Injection Performance

The key indicators for water or steam injection are outlet NO_x concentration, WFR, and fuel-bound N₂ content.

Outlet NO_x concentration. The most direct single indicator of the performance of water or steam injection is the NO_x concentration at the outlet of the unit.

Water-to-fuel ratio. The water or steam injection rate to the burner reduces the combustion temperature and reduces the formation of thermal NO_x. Increases in the injection rate reduce formation of NO_x up to a critical rate beyond which the water or steam interfere with combustion in the turbine.

Fuel-bound N₂ concentration. The fuel-bound N₂ content is a factor in the amount of NO_x formed from the combustion of fuel. Increases in the N₂ content will result in increases in the outlet NO_x concentration.

B.17.3 Illustrations

The following illustration presents an example of compliance assurance monitoring for Water Injection:

17a: Monitoring water-to-fuel ratio.

B.17.4 Bibliography

TABLE B-17. SUMMARY OF PERFORMANCE INDICATORS FOR WATER INJECTION

Parameters	Performance indication	Approach No.	1	2
		Illustration No.		17a
		Example CAM Submittals		
		Comment		
Primary Indicators of Performance				
Outlet NO _x concentration	Direct measure of outlet concentration. Most direct indicator of water or steam injection performance.		X	
Water-to-fuel ratio	Affects the combustion temperature and lowers thermal NO _x formation. Increase in the water rate results in a decrease in NO _x emissions up to a critical rate, after which the combustion flame may be doused.			X
Other Performance Indicators				
Fuel-bound N ₂ content	Affects the fuel NO _x formation. Increase in N ₂ content of the fuel or increase in the amount of fuel used will increase NO _x emissions.			
Comments: None.				

CAM ILLUSTRATION
No. 17a. WATER INJECTION FOR NO_x CONTROL

1. APPLICABILITY

- 1.1 Control Technology: Water injection [028]
- 1.2 Pollutants
Primary: Nitrogen oxides (NO_x); (NO, NO₂, NO₃)
- 1.3 Process/Emissions Units: Stationary gas turbines

2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Water-to-fuel ratio.
- 2.2 Rationale for Monitoring Approach: Water injection reduces the combustion temperature and reduces thermal NO_x formation.
- 2.3 Monitoring Location
 - Water injection rate: Inlet water feed line.
 - Fuel use: Inlet fuel line.
- 2.4 Analytical Devices Required
 - Water injection rate: Liquid flow meter or other device for liquid flow.
 - Fuel use: Natural gas flow meter or other device for gas flow.
- 2.5 Data Acquisition and Measurement System Operation
 - Frequency of measurement: Continuously on strip chart or data acquisition system.
 - Reporting units: Pound of water per pound of fuel combusted.
 - Recording process: Recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
 - Baseline water injection rate and fuel flow rate measurements and WFR calculations concurrent with emission test.
 - Historical plant records of fuel feed rate and water injection rate measurements and WFR calculations.
- 2.7 Specific QA/QC Procedures
 - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.
- 2.8 References: _____

3. COMMENTS

None.