

APPENDIX B  
CAM ILLUSTRATIONS

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## INTRODUCTION

The purpose of the illustrations presented in this appendix is to give examples of the types of monitoring (i.e., indicators or combinations of indicators) that may be used in conjunction with specific types of emission control methods to provide a reasonable assurance of compliance with emission limitations. Each illustration corresponds to a specific combination of pollutant, control method, and monitoring approach.

Each section within this appendix begins with a general description of the control device and the most common indicators of performance. Each section also includes a table showing different approaches that may be used to show compliance. The general description and the table of performance indicators are followed by the illustrations. The illustrations presented are not meant to be all-inclusive; monitoring approaches other than those addressed in these **nonprescriptive** illustrations may be acceptable for satisfying the requirements of Part 64. Facilities are encouraged to consider not only the monitoring approaches included in the CAM illustrations presented but other options that provide a reasonable assurance of compliance. For more details on the illustrations, please see chapter 3.0 of the Technical Guidance Document: Compliance Assurance Monitoring.

The CAM illustrations presented in this appendix are not meant to be examples of monitoring approach submittals; CAM submittals are addressed in Chapter 2 and Appendix A of the Technical Guidance Document. A CAM submittal provides all the monitoring information that is required [§ 64.4] to be submitted to the permitting authority for a PSEU.

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## B.1 FABRIC FILTERS<sup>1-6</sup>

### B.1.1 Background

Fabric filters, frequently referred to as baghouses, are typically used to control particulate matter (PM) emissions in exhaust gas streams. Certain gases may also be removed through interactions with the dust layer, or filter cake, that accumulates on the fabric filter bags. Fabric filters are normally used where a high control efficiency is required and where exhaust gas stream conditions are within the limitations of fabric filter operation. These limitations are high moisture, high temperatures, and exhaust gas constituents that attack the fabric or hinder the cleaning process (such as sticky particulate).

Three types of baghouses (pulse-jet, reverse-air, and shaker) are in common use, categorized by the method used for filter cleaning. Various fabric filter materials can be used in each type, depending on temperature, corrosiveness and moisture content of the gas stream, as well as dimensional stability and cost of the selected material. Important design parameters for baghouses are the air-to-cloth (A/C) ratio ( $\text{ft}^3$  per minute gas/ $\text{ft}^2$  fabric), which is somewhat dependent on particle size and grain loading, as well as operating temperatures and the cleaning mechanism. Minimum operating temperature is especially important where acid gases may be present in the gas stream; below this minimum temperature, acid gases can condense and corrode the fabric filter housing and other metal parts. Condensation within the fabric filter also can cause bag blinding (i.e., blockage of air flow through the bag). Cleaning mechanisms and maximum temperature may dictate the type of cloth that can be used.

Each type of baghouse presents different maintenance and monitoring challenges to operators, particularly in relation to cleaning mechanisms and bag materials. Cleaning at regular intervals is desirable in order to maintain a low pressure-drop across the baghouse and to save energy. Cleaning cycle frequency must be balanced against the increased PM removal efficiency that can be realized as the filter cake accumulates on the fabric.

1. Pulse-jet systems use a blast of high-pressure air (60 to 120 pounds per square inch [psi]) to clean or back-flush the bags. Pulse-jet cleaning can be accomplished with the baghouse on-line. Therefore, pulse-jet systems may only have one compartment. Equipment must be able to withstand the repeated stress of the pulses.

2. Reverse-air systems use a longer, gentler back-flush of low-pressure air (a few inches water column) to clean the bags. Cleaning air is provided to each compartment by a separate, smaller fan and duct system. Because the cleaning is at low pressure, each compartment must be effectively isolated from the gas stream during the cleaning cycle.

3. In shaker fabric filter systems, each compartment is off-line usually in succession for cleaning, which is accomplished by a mechanism that vigorously shakes the bags. Combination reverse air/shaker systems are also in use.

4. Sonic horns have been developed that augment reverse-air and shaker cleaning. Acoustic vibration in the range of 150 to 550 hertz (Hz) at 120 to 140 decibels (dB) helps dislodge particles during the regular cleaning cycle.

Common baghouse problems and malfunctions include: broken or worn bags; blinding of the filter material; failure of the cleaning system; leaks in the system or between filter bag and tube sheet; re-entrainment of dust; wetting of the bags; baghouse compartment corrosion; malfunction of dampers or material discharge equipment; and low fan speed.

### B.1.2 Indicators of Fabric Filter Performance

The best indicator of fabric filter performance is the outlet PM concentration. A bag leak detection system can be used to monitor for bag breakage and leakage. The most effective and representative monitoring approaches for fabric filters are a particulate matter continuous emissions monitoring system (PM CEMS) or a baghouse leak detection system. Other indicators of fabric filter performance include the outlet opacity, pressure differential, inlet temperature, temperature differential, exhaust gas flow rate, cleaning mechanism operation, and fan current. Below are descriptions of these indicators. Table B-1 lists these indicators and illustrates potential monitoring options for fabric filters.

Outlet PM concentration. Particulate matter CEMS can be used to monitor PM emissions concentrations continuously and with accuracy similar to gaseous CEMS (e.g., SO<sub>x</sub>, NO<sub>x</sub>). These instruments are a fairly recent development and have yet to be put into widespread use.

Bag leak detection signal. For most applications, the performance of fabric filters is most closely associated with the condition of the filter bags; bag tears and breaks can result in dramatic losses in control efficiency. Bag leak detection systems can provide continuous and immediate feedback and can be very sensitive to small changes in PM emissions increases indicating bag leaks. Several types of leak detection systems are available, including triboelectric monitors, light scattering monitors, beta gauges, and acoustic monitors.

Outlet opacity. As is the case for nearly all dry PM controls, opacity is an indicator of control device performance. An increase in opacity or visible emissions generally corresponds to a decrease in fabric filter performance. A continuous opacity monitor (COMS) may be used, or the visual determination of opacity (Method 9) or visible emissions (modified Method 22) may be made by plant personnel. Because of the high efficiencies achieved by fabric filters and the characteristics of particle size distributions depending on the facility type, opacity monitoring, whether with COMS or visible emissions (VE), is generally not as sensitive to small bag leaks as PM CEMS or bag leak detectors.

Pressure differential. The characteristic differential pressure is dependent on the baghouse design, including the type of cleaning mechanism and bag type. For a pulse jet type baghouse, when the fabric filter bags are newly installed, the filter cake builds up on the bags and the pressure differential increases steadily. Once the bags are in operation and the filter cake has built up on the bags, the pressure differential remains fairly constant. As pulses are applied

to clean the bags, the pressure differential will change slightly but overall remains constant. However, sudden changes in pressure differential can be a good indicator of several potential problems associated with the operation of a fabric filter. An increase in pressure differential may indicate blinding of the fabric. A change in pressure differential also can indicate the effectiveness of the cleaning mechanism.

For shaker type and reverse air type baghouses, the pressure differential of a compartment may demonstrate a cyclic increase and decrease, as a result of the cleaning cycle design. For example, the cleaning cycle may be set to activate when the pressure differential of a compartment reaches 5 in. w.c. Upon cleaning, the pressure differential drops to 3 in. w.c. and slowly rebuilds until the cleaning cycle is again activated. Changes in the pressure differential range and cycle can indicate a change in performance. Because of the large expected range of pressure drop throughout normal operation, pressure differential monitoring is insensitive to small leak formation and is useful only as a general guide best used in conjunction with other monitoring tools (e.g., periodic inspection).

Inspections and maintenance. Inspection and maintenance of a fabric filter are important components of long-term operation of the control device. Fabric filter inspections may include steps as simple as visually determining whether there are leaks from the fabric filter to more detailed inspections, including internal inspections of the device and inspection of the cleaning mechanism, hopper discharge mechanism, and the physical structure. Internal inspections may include looking over the bags for holes/tears or injection of a fluorescent dye and observation using a black light. Maintenance of the fabric filter would include regular replacement of filter bags. Periodic inspections can be an effective addition to a monitoring plan when used in conjunction with another continuous monitoring approach.

The following operational parameters provide important information about the operation of the fabric filters but are not generally suited as indicators of performance for compliance monitoring per Part 64, although they can be useful supplements to a monitoring approach.

Inlet temperature. Most fabric filters are designed to operate within a specified temperature range based on the type of bags employed. Excessive inlet temperatures can damage the bags. If acid gases are present in the exhaust stream, low inlet temperatures can result in the acid gases condensing and corroding the fabric filter housing and structural components. Condensation within the fabric filter also can result in bag blinding. Inlet temperature excursions outside the normal operating range may indicate that potential operational problems will occur with the fabric filter.

Temperature differential. An increase in the temperature differential across the fabric filter is an indication of possible infiltration of outside air. In normal operation of the fabric filter, the difference between the inlet and outlet gas temperature would be expected to remain fairly constant from day to day. Obviously, variables such as the ambient air temperature will affect the temperature differential. However, large changes in the temperature differential may indicate air infiltration that could cause condensation of water vapor and/or acid gases resulting in blinded bags and/or corrosion of the fabric filter components.

Exhaust gas flow rate. Increases in the exhaust gas flow rate can indicate infiltration of outside air. The addition of outside air will cause an increase in the temperature differential and cause blinding of the bags or corrosion of the fabric filter components, as discussed above.

Cleaning mechanism operation. The operation of the cleaning mechanism can indicate potential problems that can affect fabric filter performance. An increase in cleaning frequency can accelerate bag wear. Inadequate pulse-jet compressed air pressures can result in incomplete cleaning of bags. If cleaning frequency is too long, pressure differential can become excessive and energy costs increase. Excessive compressed air pressure can force dust through the fabric or can shorten bag life. Excessive dust buildup in the fabric filter hopper can result in re-entrainment of PM.

Fan current. Changes in fan current generally correspond to changes in exhaust gas flow rate. In negative-pressure fabric filters, a sudden decrease in fan current can indicate infiltration of outside air into the fabric filter.

### B.1.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for fabric filters:

- 1a: Daily observations of VE or opacity using RM 9 or modified RM 22; and periodic inspection and maintenance.
- 1b: Continuous instrumental monitoring of opacity using COMS or other analytical devices; and periodic inspection and maintenance.
- 1c: Monitoring pressure differential, opacity, and inlet temperature.
- 1d: Monitoring with a bag leak detection system.
- 1e: Monitoring PM concentration (PM CEMS).

TABLE B-1. SUMMARY OF PERFORMANCE INDICATORS AND EXAMPLE MONITORING APPROACHES FOR FABRIC FILTERS

Parameters	Performance indication	Approach No.										
		1	2	3	4	5	6	7	8	9	10	11
		Illustration No.		1c	1d			1e				
		Example CAM Submittals			A12	A10	A13	A19				
Comment		✓	✓		✓				✓	✓	✓	✓
<b>Primary Indicators of Performance</b>												
Outlet PM concentration	PM concentration is the most direct indicator of baghouse performance.							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				X		X	
Opacity	Increased opacity/VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.	X		X		X	X			X	X	X
<b>Other Performance Indicators</b>												
Inspection and maintenance	Visual determination of leaks; may include internal inspections, records of bag replacement. Should be paired with other parameters monitored for large units.	X					X	X	X		X	
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		X	X		X		X	
Inlet temperature	Indicator of potential for overheating of bags or condensation. Most applicable to fabric filters that control thermal process emissions; condensation can result in bag blinding, or increased corrosion of structural components; excessive temperatures can destroy bags or shorten bag life.			X						X		
Exhaust gas flow rate	Indicator of change in flow resistance; related to pressure differential. Increase in flow rate may result in changes in temperature differential, which may be an indication of infiltration of outside air.											X

TABLE B-1. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	
		Illustration No.	1a, 1b		1c	1d				1e				
		Example CAM Submittals				A12	A10	A13	A19					
		Comment	✓	✓		✓					✓	✓	✓	✓
Cleaning mechanism operation	Indicator that bags and hopper are cleaned/emptied properly and at prescribed intervals. Too frequent or too intense cleaning shortens bag life; too infrequent cleaning results in excessive pressure differential; improper or infrequent cleaning of hopper can result in PM re-entrainment.													
Fan current	Indirect indicator of gas flow rate. See comments for <i>Gas flow rate</i> above.							X						
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 includes use of opacity and VE; Illustration No. 1a includes VE/no VE by visual determination and Illustration 1b includes use of a COMS.</li> <li>• Approach No. 2 corresponds to 40 CFR 63, subpart GG (Aerospace Manufacturing and Rework). In this approach, the control device is a paint arrestor, which is not a typical fabric filter. The arrestor media (e.g., filter) is sensitive to pressure drop with increasing filtration (and corresponding pressure drop) as the filter becomes loaded over time. The paint arrestor is replaced on a standard maintenance schedule or when the pressure drop exceeds the predetermined limit.</li> <li>• Approach No. 4 also corresponds to 40 CFR 63, subparts MMM (Pesticides), DDD (Mineral Wool), and NNN (Wool Fiberglass).</li> <li>• Approach No. 8 corresponds to 40 CFR 63, subpart X (Secondary Lead Smelting) for controlling lead.</li> <li>• Approach No. 9 corresponds to 40 CFR 63, subpart LLL (Portland Cement).</li> <li>• Approach No. 10 corresponds to 40 CFR 63, subpart XXX (Ferrous Alloys Production; an existing source is required to monitor VE, pressure differential, and conduct I &amp; M, and a new source is required to monitor these parameters plus a bag leak detection system.).</li> <li>• Approach No. 11 corresponds to 40 CFR 63, subpart EE (Magnetic Tape).</li> </ul>														

CAM ILLUSTRATION  
No. 1a. FABRIC FILTER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]
- 1.2 Pollutants
  - Primary: Particulate matter (PM, PM-10)
  - Other: Toxic heavy metals
- 1.3 Process/Emissions units: Industrial process vents, fuel combustion units, and material handling processes

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Opacity of emissions or visible emissions (VE); and inspection and maintenance.
- 2.2 Rationale for Monitoring Approach
  - Opacity/VE: Changes in opacity and changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.
  - Inspection and maintenance: Maintain proper fabric filter operation.
- 2.3 Monitoring Location
  - Opacity/VE: Per RM 9 (opacity) or RM 22 (VE) requirements.
  - Inspection and maintenance: The fabric filter.
- 2.4 Analytical Devices Required
  - Opacity/VE: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).
  - Inspection and maintenance: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Opacity/VE: Daily or as weather permits.
    - Inspection and maintenance: Periodic (e.g., semiannual, annual).
  - Reporting units:
    - Opacity/VE: Percent opacity or visible/no visible emissions.
    - Inspection and maintenance: None.
  - Recording process:
    - Opacity/VE: Observers complete opacity or VE observation forms and log into binder or electronic data base as appropriate.
    - Inspection and maintenance: Operators log data manually.
- 2.6 Data Requirements
  - Baseline opacity or VE observations concurrent with emission test.
  - Historical plant records of opacity observations and fabric filter inspection and maintenance. (No data are needed if indicator is “any visible emissions.”)

- 2.7 Specific QA/QC Procedures: Initial training of observer per RM 9 or RM 22, semi-annual refresher training per RM 9, if applicable.

### 3. COMMENTS

- 3.1 Although RM 22 applies to fugitive sources, the visible/no visible emission observation techniques of RM 22 can be applied to ducted emissions. For situations where no visible emissions are the norm, a technique focused towards identifying a change in performance as indicated by any visible emission is a useful and effective technique. The use of the visible/no visible emissions technique reduces the need for onsite certified RM 9 observers.
- 3.2 For large pollutant specific emission units (post-control potential to emit equal to or greater than 100 percent of the amount required for a source to be classified as a major source), CAM requires the owner or operator to collect four or more data values equally spaced over each hour, unless the permitting authority approves a reduced frequency. Therefore, this monitoring approach may not be acceptable for large emission units unless used in conjunction with other appropriate parameter monitoring for which data are recorded at least four times each hour; e.g., baghouse pressure differential, air flow, temperature. (See Section 3.3.1.2.)



CAM ILLUSTRATION  
No. 1b. FABRIC FILTER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]
- 1.2 Pollutants
  - Primary: Particulate matter (PM, PM-10)
  - Other: Toxic heavy metals
- 1.3 Process/Emissions units: Industrial process vents, fuel combustion units, and material handling processes

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Opacity; and inspection and maintenance.
- 2.2 Rationale for Monitoring Approach
  - Opacity: An increase in opacity indicates process changes, changes in baghouse efficiency, or leaks.
  - Inspection and maintenance: Maintain proper fabric filter operation.
- 2.3 Monitoring Location
  - Opacity: Exhaust gas outlet.
  - Inspection and maintenance: The fabric filter.
- 2.4 Analytical Devices Required
  - Opacity: Opacity meter or COMS as appropriate for gas stream.
  - Inspection and maintenance: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Opacity: Once per shift if instruments read manually, or continuously recorded on strip chart or digital data acquisition system.
    - Inspection and maintenance: Periodic (e.g., semiannual, annual)
  - Reporting units:
    - Opacity: Percent opacity for COMS, or applicable units for other type monitors.
    - Inspection and maintenance: None.
  - Recording process:
    - Opacity: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
    - Inspection and maintenance: Operators log data manually.
- 2.6 Data Requirements
  - Baseline opacity measurements (e.g., opacity for COMS) concurrent with emission test.
  - Historical plant records of opacity measurements and fabric filter inspection and maintenance.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### 3. COMMENTS

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

CAM ILLUSTRATION  
No. 1c. FABRIC FILTER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Fabric filter (baghouse) [016]
- 1.2 Pollutants
  - Primary: Particulate matter (PM, PM-10)
  - Other: Toxic heavy metals
- 1.3 Process/Emissions units: Incinerators, furnaces, kilns, and other high temperature process units

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Pressure differential, opacity, and inlet temperature.
- 2.2 Rationale for Monitoring Approach
  - Pressure differential: Increase in pressure differential indicative of fabric blinding or decreased permeability; decrease in pressure differential indicative of change in operation.
  - Opacity or VE: An increase in opacity or changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.
  - Inlet temperature: Excessive temperature can lead to leaks, breakdown of filter material, and reduced lifetime of filter; temperatures below the dewpoint of the exhaust gas stream may also damage the filter bags.
- 2.3 Monitoring Location
  - Pressure differential: Across inlet and outlet of each compartment of control device.
  - Opacity or VE: Per RM 9 (opacity) or RM 22 (VE) requirements.
  - Inlet temperature: At fabric filter inlet duct.
- 2.4 Analytical Devices Required
  - Pressure differential: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate.
  - Opacity or VE: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).
  - Temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Once during each shift, or recorded continuously on strip chart or data acquisition system; for opacity or VE, daily or as weather permits.
  - Reporting units:
    - Pressure differential: Inches of water column (in. w.c.).
    - Opacity or VE: Percent opacity or visible/no visible emissions.
    - Temperature: Degrees Fahrenheit (°F) or Celcius (°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 pressure differential, opacity and inlet temperature measurements, and cleaning cycle concurrent with emission test.
- Historical plant records on pressure differential, opacity, and inlet temperature measurements.
- Temperature specifications for fabric filter material.

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

**3. COMMENTS**

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

CAM ILLUSTRATION  
No. 1d. FABRIC FILTER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]
- 1.2 Pollutants  
Primary: Particulate matter (PM, PM-10)  
Other: Toxic heavy metals
- 1.3 Process/Source Type: Industrial process vents, fuel combustion units, and material handling processes

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicator to be Monitored: Bag leak detection monitor signal.
- 2.2 Rationale for Monitoring Approach: Bag leak detectors that operate on principles such as triboelectricity, electrostatic induction, light scattering, or light transmission, produce a signal that is proportional to the particulate loading in the baghouse outlet gas stream. When bag leaks occur, the cleaning peak height or baseline signal level will increase. Alarm levels based on increases in normal cleaning peak heights or the normal baseline signal can be set to detect filter bag leaks.
- 2.3 Monitoring Locations: At the fabric filter outlet.
- 2.4 Analytical Devices Required: Bag leak detector and associated instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Amps, volts, or percent of scale.
  - Recording process: Recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Historical signal data showing baseline level and cleaning peak height during normal operation or signal data concurrent with emission testing.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

## 3. COMMENTS

None.

CAM ILLUSTRATION  
No. 1e. FABRIC FILTER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]
- 1.2 Pollutants  
Primary: Particulate matter (PM, PM-10)  
Other: Toxic heavy metals
- 1.3 Process/Emissions units: Industrial process vents, fuel combustion units, and material handling processes

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet PM concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of PM concentration.
- 2.3 Monitoring Location: At outlet stack of fabric filter.
- 2.4 Analytical Devices Required: PM CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: instrument response (e.g., milliamperes), or concentration (e.g., grains per dry standard cubic foot [gr/dscf], milligrams per dry standard cubic meter [mg/dscm]).
  - Recording process: Automatically recorded on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet PM concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: An initial correlation test to develop the relationship between PM concentration and instrument response is required. QA/QC should, as a minimum, include: periodic calibration and drift checks, routine maintenance, and inventory of spare parts. Calibrate, maintain, and operate the CEMS using procedures that take into account the manufacturer's specifications.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a PM continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented.
- 3.2 Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;

§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;  
subpart H and Appendix IX of 40 CFR 266; or  
comparable requirements established by the permitting authority.

For PM CEMS, this includes Performance Specification 11 of 40 CFR 60, Appendix B.

- 3.3 Indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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## B.2 ELECTROSTATIC PRECIPITATORS<sup>1,2,3,7,8,9,10,15,16</sup>

### B.2.1 Background

Electrostatic precipitators (ESPs) use electrical energy to remove PM from exhaust gas streams. As the exhaust stream enters an ESP, PM in the gas encounters negatively charged ions, which apply a charge to the particles. The charged particles then are attracted to collector plates carrying the opposite charge. As the particles accumulate, they periodically are removed from the collector plates and collected in a hopper. Electrostatic precipitators can be broadly classified as either dry ESPs or wet ESPs; the primary difference between these two classifications is the method by which the collector plates are cleaned. In dry ESPs, the plates are cleaned by applying a mechanical impulse or vibration to the plates, thereby knocking loose the collected PM. This cleaning method is referred to as rapping. In wet ESPs, collector plates are cleaned by rinsing with water. This section focuses on dry ESPs, which hereafter are referred to simply as ESPs. Wet ESPs are discussed further in section B.3 of this Appendix. Examples of ESP applications include: coal-fired boilers; cement kilns; solid waste incinerators; paper mill recovery boilers; catalytic crackers; metallurgical furnaces; sulfuric acid plants; and iron and steel sinter plants.

The primary components of an ESP are the shell or housing, discharge electrodes, collection electrodes, high voltage equipment, rapping system, and collection hoppers. The shell encloses and supports the electrical components of the unit. A discharge electrode is the component that creates ions that collide with the particles and applies the electrical charge to PM in the incoming gas stream. An ESP typically has a series of discharge electrodes. The two basic discharge electrode designs are the weighted-wire and rigid-frame electrode. Weighted-wire electrodes consist of wires suspended from a frame at the top of the unit with weights attached to the ends to keep the wires in place. In rigid-frame systems, both ends of the electrode wires are attached to a frame. The weighted-wire design typically has higher maintenance costs (due to wire breakage), but closer spacing is allowed between the collection and discharge electrodes. The collection electrodes, which typically are called plates, provide the collection surfaces for the particulates. Although collection plates come in a variety of shapes, most consist of closely spaced sheets of carbon steel. High voltage equipment includes a transformer, rectifier, and several meters. Collectively, this equipment is called a T-R set. The transformer steps up the input voltage from between 400 and 480 volts to between 20,000 and 70,000 volts. The rectifier converts the input current from alternating to direct current. Metering generally includes a primary voltmeter, which measures the input voltage; primary ammeter, which measures the current drawn across the transformer; secondary voltmeter, which measures the voltage applied to the discharge electrodes; secondary ammeter, which measures the current supplied to the discharge electrodes; and sparkmeter, which measures the spark rate across the electrodes. The rapping system, which removes collected PM from the collection plates, may be an external roof-mounted rapper or an internal rotating hammer rapper. Collection hoppers are bins located directly below the collection plates to temporarily store the collected PM until it can be disposed.

To maximize control efficiency, most ESPs are designed with several bus sections or fields, each of which is equipped with separate, independent power supplies, controllers, and meters. Each of these fields acts as a separate ESP. The power supplied to the initial fields generally is higher because PM concentrations are highest at the inlet. Having multiple fields allows the operator flexibility in operating the ESP and reduces the likelihood of electrical failure shutting down the entire ESP.

### B.2.2 Indicators of ESP Performance

The primary indicators of ESP performance are PM concentration, opacity, secondary corona power, secondary voltage (i.e., the voltage across the electrodes), and secondary current (i.e., the current to the electrodes). Other indicators of performance are the spark rate, primary current, primary voltage, inlet gas temperature, gas flow rate, rapper operation, and number of fields in operation. Each of these indicators is described below. Table B-2 lists these indicators and illustrates potential monitoring options for ESPs.

Outlet PM concentration. Particulate matter CEMS can be used to continuously monitor PM emission concentrations. These instruments are a fairly recent development and have yet to be put into widespread use.

Opacity. As is the case for all dry PM controls, opacity is an indicator of control device performance.

Secondary corona power. The secondary corona power is a measure of the energy consumed in the removal of PM from the gas stream. A decrease in power generally indicates a decrease in control efficiency. Secondary corona power is the product of the secondary voltage and the secondary current, and typically is monitored by measuring the secondary voltage and secondary current separately. Because each field is independent of the others, secondary voltage and current should be monitored in each field of the ESP.

Secondary current. Secondary current is a measure of the current supplied to the discharge electrodes and is a partial indicator of the energy or power consumed by the ESP. The secondary current is usually measured in conjunction with secondary voltage to calculate the power. A drop in current may indicate a loss of power. Current at too high a level indicates a short-circuit or sparking. Measuring the secondary current helps in identifying which fields are operating properly.

Secondary voltage. Secondary voltage is a measure of the voltage applied to the discharge electrodes and is a partial indicator of the energy or power consumed by the ESP. Increases in voltage result in increased corona, greater particle charging, and increased control efficiency up to a critical voltage, above which excessive spark occurs and control efficiency decreases. A decrease in voltage indicates lower particle charging. A decrease in voltage with a corresponding increase in current indicates a short circuit or sparking. Measuring the secondary voltage helps in identifying which fields are operating properly.

Fields in operation. As explained previously, most ESPs are designed with multiple fields, each of which is operated independently of the others. If any of the fields fail, the overall performance of the ESP will decrease; that reduction in performance will be a function of which specific fields fail and which are still in operation.

The following operational parameters provide important information about the operation of the ESP but are not generally suited as indicators of performance for compliance monitoring per Part 64, although they may be useful supplements to a monitoring approach.

Spark rate. Under normal operation, electrical current repeatedly surges from the discharge electrodes to the collector plates in the form of sparks. Sparks result in an instantaneous termination of the electrical field (i.e., a short circuit in the field). As the secondary voltage increases, particle charging and sparking increase. As a result, there is an optimal range of spark rates within which there is a high degree of particle charging without excessive sparking. Spark rates outside this range generally indicate a decrease in control efficiency.

Primary current. Although secondary current is a better indicator of power consumption, the primary current is also an indicator of the power being consumed by the ESP. Low current levels indicate a potential problem with ESP operation.

Primary voltage. The primary voltage generally does not vary. However, this parameter can be used to identify a field that is not operating.

Inlet gas temperature. The control efficiency of an ESP depends partly on particle resistivity. Although particle resistivity is not typically monitored, resistivity decreases with increasing temperature. Therefore, changes in temperature can indicate changes in resistivity and the performance of the ESP. (Particles with low resistivity, i.e., less than  $1 \times 10^7$  ohm-centimeters [ $\Omega$ -cm] are difficult to collect because they lose their charge quickly and are not retained on the collection plates. Particles with high resistivity, i.e., greater than  $1 \times 10^{10}$   $\Omega$ -cm, are difficult to charge.) The inlet gas temperature may also be important to avoid condensation of components of the gas stream. The temperature must be maintained above the dew point.

Gas flow rate. The rate of gas flow through an ESP is an indicator of residence time. Control efficiency is a function of residence time; longer residence times allow for higher control efficiency (i.e., increased gas flow rate lowers the control efficiency and decreased gas flow increases the control efficiency).

Rapper operation. Rapper operation is an indication that collector plates are being cleaned at regular intervals and with the appropriate intensity. The process of rapping re-entrains a small amount of PM in the exhaust stream. Therefore, if rapping is too frequent or too intense, control efficiency is lower. On the other hand, if rapping is either too infrequent or of insufficient intensity to jar collected material loose, the dust layer on the collection plates becomes too thick and collection efficiency again decreases.

### B.2.3 Illustrations

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

- 2a: Monitoring secondary voltage, secondary current, and spark rate.
- 2b: Monitoring PM concentration (PM CEMS).

TABLE B-2. SUMMARY OF PERFORMANCE INDICATORS FOR ESPs

Parameter	Performance indication	Approach No.	1	2	3	4	5	6
		Illustration No.	2a					2b
		Example CAM Submittals				A25		
		Comment	✓		✓	✓	✓	✓
<b>Primary Indicators of Performance</b>								
Outlet PM concentration	PM concentration is the most direct indicator of ESP performance.							X
Opacity	Increased opacity or VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.			X		X		
Secondary corona power	Performance usually increases as power input increases; indicates work done by ESP to remove PM. Product of voltage and current; can help identify any fields that are not operating.	a	a	a	a	X		
Secondary current	Partial indicator of power consumption; too low indicates malfunction. Can help identify any fields that are not operating properly.	X	X	X	X			
Secondary voltage	Partial indicator of power consumption; too low indicates problem such as grounded electrodes. Can help identify any fields that are not operating properly.	X	X	X	X			
Fields operating	Performance decreases when individual fields fail. Effect depends on which section goes out; need to test to determine effects of outages.					X		
<b>Other Performance Indicators</b>								
Inlet gas temperature	Temperature affects resistivity of particulate. Temperature is also an important parameter when the exhaust stream includes condensable pollutants.		X					
Gas flow rate	Indication of residence time in ESP. Performance is a function of residence time; an increase in flow rate decreases control efficiency, and a decrease in flow rate increases efficiency.							X

TABLE B-2. (Continued)

Parameter	Performance indication	Approach No.	1	2	3	4	5	6
		Illustration No.	2a					2b
		Example CAM Submittals				A25		
		Comment	✓		✓	✓	✓	✓
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 is required by some State and Federal rules; spark rate may also be required by some rules.</li> <li>• Approach No. 3 corresponds to 40 CFR 63, Subpart LL (Primary Aluminum Production).</li> <li>• 40 CFR 61, subpart K, uses Approach No. 4 along with primary current as an additional parameter.</li> <li>• Approach No. 5 is an EPRI-type approach where opacity and power are the major indicators of performance. This is a tiered approach where opacity is monitored on a regular basis with a COMS; but when opacity reaches a particular level, the facility begins to monitor secondary power (i.e., secondary voltage and secondary current) for input to a model. The model calculates PM emissions based on secondary voltage and secondary current, among other parameters.</li> <li>• Approach No. 6 corresponds to 40 CFR 63, subpart LLL (Portland Cement); PM CEMS monitoring is deferred. [LLL also allows opacity via M9.]</li> </ul>								

<sup>a</sup> Monitoring both secondary current and voltage is essentially the same as monitoring secondary corona power. Monitoring of corona power is not appropriate for ESPs with a large number of fields.

CAM ILLUSTRATION  
No. 2a. ESP FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Electrostatic precipitator (ESP) [010, 011, 012]
- 1.2 Pollutants
  - Primary: Particulate matter (PM)
  - Other:
- 1.3 Process/Emissions units: Furnaces, combustors

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Secondary voltage and secondary current.
- 2.2 Rationale for Monitoring Approach
  - Secondary current and voltage: Operating with these parameters outside of normal (design) specifications indicates a change in PM collection efficiency.
- 2.3 Monitoring Location
  - Secondary current and Secondary voltage: Measure after each transformer/rectifier set prior to electrode.
- 2.4 Analytical Devices Required:
  - Secondary current and Secondary voltage: Ammeters, voltmeters, other methods or instrumentation as appropriate; see section 4.6 for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
  - Reporting units:
    - Secondary current and Secondary voltage: Amps and volts
  - Recording process: Operators log data manually, or automatically recorded on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline secondary current and secondary voltage measurements concurrent with emissions test.
  - Historical plant records of secondary current and secondary voltage measurements.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

## 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. 2b. ESP FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Electrostatic precipitator (ESP) [010, 011, 012]
- 1.2 Pollutants
  - Primary: Particulate matter (PM)
  - Other:
- 1.3 Process/Emissions units: Furnaces, combustors

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet PM concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of PM concentration.
- 2.3 Monitoring Location: At outlet stack of ESP.
- 2.4 Analytical Devices Required: PM CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: instrument response (e.g., milliamperes), or concentration (e.g., grains per dry standard cubic feet [gr/dscf], milligrams per dry standard cubic meter [mg/dscm]).
  - Recording process: Automatically recorded on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet PM concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: An initial correlation test to develop the relationship between PM concentration and instrument response is required. QA/QC should, as a minimum, include: periodic calibration and drift checks, routine maintenance, and inventory of spare parts. Calibrate, maintain, and operate the CEMS using procedures that take into account the manufacturer's specifications.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a PM continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented.
- 3.2 Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

- § 51.214 and Appendix P of 40 CFR 51;
- § 60.13 and Appendix B of 40 CFR 60;
- § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63;



40 CFR 75;  
subpart H and Appendix IX of 40 CFR 266; or  
comparable requirements established by the permitting authority.

For PM CEMS, this includes Performance Specification 11 of 40 CFR 60, Appendix B.

- 3.3 Indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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## B.3 WET ELECTROSTATIC PRECIPITATORS<sup>1,2,7,8,9,11,15,16</sup>

### B.3.1. Background

A wet electrostatic precipitator (WESP) typically is used to control PM emissions in exhaust gas streams containing sticky, condensible hydrocarbon pollutants, or where the potential for explosion is high. A WESP may be used to control a variety of emission points and pollutants, such as wood chip dryers; sulfuric acid mist; coke oven off-gas; blast furnaces; detarring operations; basic oxygen furnaces; cupolas; and aluminum potlines. In the wood products industry, WESPs often are used in combination with wet scrubbers or regenerative thermal oxidizers (RTOs) to control both PM and gaseous emissions. The general operating principles and components of ESPs and the specific features of dry ESPs are discussed in section B.2; this section focuses on the components and operation of WESPs that differ from those of dry ESPs.

The two primary differences between dry ESP and WESP design are the use of a prequench and the collector plate cleaning method. Unlike dry ESPs, WESP control systems typically incorporate a prequench (water spray) to cool and saturate the gases prior to entering the electrical fields. As PM accumulates on the collector plates of a WESP, the plates are cleaned by a continuous or intermittent film or spray of water. Major differences in the types of WESPs available include: the shape of the collector; orientation of the gas stream (vertical or horizontal); use of preconditioning water sprays; and whether the entire ESP is operated wet. Configurations include circular plate, concentric plate, tubular, and flat plate WESPs.

In circular-plate WESPs, the circular plates are irrigated continuously; this provides the electrical ground for attracting the particles and also removes them from the plates. Concentric-plate WESPs have an integral, tangential prescrubbing inlet chamber, followed by a vertical wetted-wall concentric ring ESP chamber. The discharge electrode system is made of expanded metal, with corona points on a mesh background.

Tube-type WESPs typically have vertical collecting pipes; electrodes are typically in the form of discs placed along the axis of each tube. The particles are charged by the high-intensity electric field, and, as they travel farther down the tube, they are forced to the tube walls by the electrostatic field. The tube walls remain wet because the fine mist entrained in the saturated gas is also collected on the tube surfaces and flows down along the tube walls. Flushing is performed periodically to clean the tube surfaces. The water is collected in a settling tank, and this water is used to quench the gaseous stream prior to its entering the WESP.

In rectangular plate WESPs (horizontal flow), water sprays precondition the incoming gas and provide some initial PM removal. Because the water sprays are located over the top of the electrostatic fields, collection plates are also continuously irrigated. The collected water and PM flow downward into a sloped trough. The last section of this type of WESP is sometimes operated dry to remove entrained water droplets from the gas stream.

The conditioning of the incoming gas stream and continual washing of the internal components with water eliminate re-entrainment problems common to dry ESPs. Efficiency is affected by particle size, gas flow rate, and gas temperature. Common problems with WESPs include: poor gas flow; high gas flow; poor water flow; low voltage; low current; and high dissolved solids in the flush or prequench water. Other common mechanical-type problems include: poor alignment of electrodes; bowed or distorted collecting plates; full or overflowing hoppers; plugged water sprays; corrosion of electrodes; and air inleakage.

### B.3.2 Indicators of WESP Performance

The primary indicators of WESP performance are opacity, secondary corona power, secondary voltage, and secondary current. Other indicators of WESP performance are the spark rate, primary current, primary voltage, inlet gas temperature, gas flow rate, inlet water flow rate, solids content of flush water (when recycled water is used), and field operation. section B-2 describes each of these indicators with the exception of the inlet water flow rate and the flush water solids content, which are described below. For some systems, mist may be entrained in the exhaust gas. In such cases, opacity measurements would be misleading. Table B-3 lists these indicators and illustrates potential monitoring options for WESPs.

Inlet water flow rate. Because WESPs use water to clean collector plates, the water flow rate is an indicator that the cleaning mechanism is operating properly. If flow rates decrease, sections of the WESP may not be as effective. As a result, PM collection rates would decrease as material built up on the collectors. In addition, low flow rates increase the likelihood of ineffective spraying and distribution of water, as well as nozzle plugging.

Flush water solids content. When recycled water is used, the solids content of the water increases with each recycling. If the solids content becomes excessive, the effectiveness of the cleaning mechanism is reduced. Increased solids content also can lead to plugging of spray nozzles. This parameter is useful when used in conjunction with other more direct monitoring approach.

### B.3.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for WESPs:

- 3a: Monitoring secondary current, secondary voltage, spark rate, and inlet water flow rate.
- 3b: Monitoring secondary current, secondary voltage, inlet water flow rate, and flush water solids content.

TABLE B-3. SUMMARY OF PERFORMANCE INDICATORS FOR WESPs

Parameter	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.	3a	3b			
		Example CAM Submittals				A9a	A9b
		Comment		✓	✓		
<b>Primary Indicators of Performance</b>							
Opacity	Increased opacity or VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions. If mist is entrained in exhaust gas or a condensed plume is present, opacity measurements may be misleading.				X		
Secondary corona power	Performance usually increases as power input increases; indicates work done by WESP to remove PM. Product of voltage and current; can help identify any fields that are not operating.	a	a				
Secondary current	Partial indicator of power consumption; too low indicates malfunction. Can help identify any fields that are not operating properly.	X	X				
Secondary voltage	Partial indicator of power consumption; too low indicates problem such as grounded electrodes. Can help identify any fields that are not operating properly.	X	X	X	X	X	X
<b>Other Performance Indicators</b>							
Inlet water flow rate	Indicates cleaning mechanism is working properly; if low, can indicate plugging. As an alternative to water flow, the water pressure can be monitored.	X	X	X			
Flush water solids content	High solids may cause plugging, reduce collection efficiency. Applies to systems that use recycled water.		X				
Inlet/outlet gas temperature	Indicates water sprays and prequench (if applicable) are working. Also, temperature affects resistivity of particulate.				X		X
Comments: <ul style="list-style-type: none"> <li>• Approach No. 2 also corresponds to 40 CFR 60, subpart PPP (Wool Fiberglass).</li> <li>• Approach No. 3 includes monitoring the voltage to indicate that the WESP is collecting particulate, VE as an indicator of PM emissions, water flow to indicate PM being removed, and outlet temperature to indicate sufficient water.</li> </ul>							

<sup>a</sup> Monitoring both secondary current and voltage is essentially the same as monitoring secondary corona power. Monitoring of corona power is not appropriate for WESPs with a large number of fields.

<sup>b</sup> No Part 63 rules refer to WESP.

CAM ILLUSTRATION  
No. 3a. WET ELECTROSTATIC PRECIPITATOR FOR PM

## 1. APPLICABILITY

- 1.1 Control Technology: Wet electrostatic precipitator (WESP) [010, 011, 012]
- 1.2 Pollutants
  - Primary: Particulate matter (PM)
  - Other:
- 1.3 Process/Emission units: Wood products dryers

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Secondary current, secondary voltage, and inlet water flow rate.
- 2.2 Rationale for Monitoring Approach
  - Secondary current: Current is generally constant and low; increase or drop in current indicates a malfunction. The current directly affects collection efficiency.
  - Secondary voltage: Voltage is maintained at high level; drop in voltage indicates a malfunction. When the voltage drops, less particulate is charged and collected. The voltage directly affects collection efficiency.
  - Inlet water flow rate: Indicates sufficient water flow for proper removal of particulate from the collection plates.

(Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 2.3 Monitoring Location
  - Secondary current and secondary voltage: Measure after each transformer/rectifier set.
  - Inlet water flow rate: Water line.
- 2.4 Analytical Devices
  - Secondary current: Ammeter.
  - Secondary voltage: Voltmeter.
  - Inlet water flow rate: Liquid flow meter or other device for liquid flow; see section 4 for more information on specific types of instruments.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or continuously by strip chart or data acquisition system.
  - Reporting units:
    - Current: Amps.
    - Voltage: Volts.
    - Inlet water flow rate: Gallons per minute (gpm) or cubic feet per minute (ft<sup>3</sup>/min)
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

- Baseline secondary current, secondary voltage, and inlet water flow rate measurements concurrent with emission test.
- Historical plant records on secondary current, secondary voltage, and inlet water flow rate measurements.

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

**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. 3b. WET ELECTROSTATIC PRECIPITATOR FOR PM

## 1. APPLICABILITY

- 1.1 Control Technology: Wet electrostatic precipitator (WESP) [010, 011, 012]  
 1.2 Pollutants  
     Primary: Particulate matter (PM)  
     Other:  
 1.3 Process/Emission units: Insulation manufacturing, dryers

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Secondary voltage and current, inlet water flow rate, and solids content of flush water.
- 2.2 Rationale for Monitoring Approach
- Secondary current: Current is generally constant and low; increase or drop in current indicates a malfunction. The current directly affects collection efficiency.
  - Secondary voltage: Low voltage or current indicates a problem in the WESP.
  - Inlet water flow rate: Indicates sufficient water flow for proper removal of particulate from the collection plates.
  - Flush water solids content: High solids content of recycled water reduces the efficiency of cleaning.
- (Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 2.3 Monitoring Location
- Secondary current and secondary voltage: Measure after each transformer/rectifier set.
  - Inlet water flow rate: Measure at inlet water inlet line or pump discharge.
  - Flush water solids content: Measure at inlet line or recycle water tank.
- 2.4 Analytical Devices:
- Secondary current: Ammeter.
  - Secondary voltage: Voltmeter.
  - Inlet water flow rate: Liquid flow meter or other device for liquid flow; see section 4 for more information on specific types of instruments.
  - Flush water solids content: Manual sampling of water.
- 2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or continuously on strip chart or data acquisition system; flush water solids, weekly.
  - Reporting units:
    - Current: Amps.
    - Voltage: Volts.
    - Inlet water flow rate: Gallons per minute (gpm) or cubic feet per minute (ft<sup>3</sup>/min).
    - Flush water solids content: Percent solids.



- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
- Baseline secondary current, secondary voltage, inlet water flow rate, and solids content measurements concurrent with emission test.
  - Historical plant records on secondary current, secondary voltage, inlet water flow rate, and solids content measurements.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### **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.)

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## **B.4 WET SCRUBBERS FOR PM CONTROL** <sup>1,2,8,9,10,12,15</sup>

### **B.4.1 Background**

Wet scrubbers use a liquid to remove pollutants from an exhaust stream. Applications include foundries, lime kilns, incinerators, boilers, wood products dryers, asphalt plants, and the chemical and pulp and paper industries. In particulate matter (PM) emission control applications, PM in the exhaust stream collide with the liquid droplets, are collected in the liquid, and are removed with the scrubbing liquid. The three main mechanisms by which wet scrubbers control PM emissions are: (1) impaction of the particle into the target droplet; (2) interception of the particle by the droplet; and (3) diffusion of the particle through the gas into the droplet. Collection efficiency tends to increase with particle size (for particles with diameters greater than 0.5  $\mu\text{m}$ ) and pressure differential across the scrubber. A wet scrubber's particle collection efficiency is directly related to the amount of energy expended in contacting the gas stream with the scrubber liquid. There are several types of wet scrubber designs, including venturi, spray towers, and mechanically aided wet scrubbers. High energy scrubbers include venturi, hydrosonic, collision, or free jet scrubber designs.

Venturi scrubbers are very common for PM control; compared to most scrubber designs, they create a larger pressure differential and higher turbulence, and therefore have a high energy consumption and a low penetration of small particles. However, they have co-current flow and are therefore not as effective as spray towers in controlling gaseous emissions. Mechanically aided wet scrubbers utilize a rotor or fan to shear the liquid into droplets. Again, there is low PM penetration but a high energy cost, and frequent buildup of PM and erosion of the blades. Spray towers (countercurrent flow) are frequently used to control gaseous emissions when PM is also present. Once the PM has been captured by the droplets, the water droplets are separated from the exhaust gas by gravity, centrifugal force, and baffles. Mesh pads and mist eliminators are used in the exhaust to capture any entrained droplets

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 high dissolved solids liquid; nozzle erosion or pluggage; air inleakage; particle re-entrainment; freezing/plugging of lines; and scaling.

### **B.4.2 Indicators of Wet Scrubber (for PM) 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 (PM or gaseous), scrubber design, and exhaust gas characteristics. For PM control, the primary indicators of wet scrubber performance are pressure differential and scrubber liquid flow rate. Other parameters that can indicate wet scrubber performance include gas flow rate, scrubber liquid solids content, scrubber outlet gas temperature, and scrubber liquid makeup or blowdown rates. For systems that recycle the scrubbing liquid, scrubbing liquid solids content and makeup or blowdown rate may be appropriate performance indicators. Scrubber outlet gas temperatures

may be appropriate parameters for thermal processes. Table B-4 lists these indicators and illustrates potential monitoring options for wet scrubbers for PM control. These indicators are described below.

Outlet PM concentration. Particulate matter PEMS can be used to continuously monitor PM emission concentrations. These instruments are a fairly recent development and have yet to be put into widespread use. There has been some discussion regarding the applicability of PM CEMS on scrubbers; however, there are models available for wet environments.

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. Pressure differential is particularly important for scrubber designs, such as venturi scrubbers, that operate with relatively high pressure differentials. The control efficiency of a venturi scrubber is a function of the total energy consumption within the scrubber, and total energy consumption is largely a function of the pressure differential across the scrubber.

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 or atomized, and the liquid-gas interface is maintained. Under these conditions, higher liquid flow rates are indicative of higher levels of control.

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 solids content. When the scrubber liquid is recycled, the solids content of the liquid is indicative of the likelihood of re-entrainment of PM from the scrubber liquid, of nozzle plugging, and of solids buildup elsewhere in the recirculation system. Although less reliable as an indicator of performance, the scrubber liquid conductivity can be monitored as a surrogate for monitoring the scrubber liquid solids content when the scrubber water is recycled. This parameter may be an important parameter to monitor in conjunction with other parameters.

Makeup/blowdown rates. To keep the solids 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 solids content of the scrubber liquid, provided the scrubber inlet PM loading does not change significantly. Under the conditions of constant inlet loading, decreases in makeup or blowdown rates generally correspond to increases

in the solids content of the scrubbing liquid. This indicator is not commonly monitored, and scrubber liquid solids content is a better indicator.

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 inlet gas temperature/Process exhaust temperature. For wet scrubbers that are used to control thermal processes, the inlet gas temperature (or process exhaust temperature) also is an important indicator of performance. Increases in scrubber inlet temperatures may indicate that the scrubber liquid flow rate should be increased to ensure that the process exhaust stream is being quenched properly and/or the scrubber liquid flow is adequate. Too high a temperature and too low a liquid flow rate can indicate a decrease in performance. Scrubber liquid temperature can be monitored as a surrogate for inlet gas temperature (or process exhaust gas temperature), but would not be as reliable an indicator of performance as would monitoring scrubber inlet gas temperature directly.

#### B.4.3 Illustrations

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

- 4a: Monitoring pressure differential across scrubber.
- 4b: Monitoring pressure differential across scrubber and scrubber liquid flow rate.
- 4c: Monitoring pressure differential across scrubber, scrubber liquid flow rate, and scrubber liquid solids content.
- 4d: Monitoring PM concentration (PM CEMS).

TABLE B-4. SUMMARY OF PERFORMANCE INDICATORS FOR WET SCRUBBERS FOR PM CONTROL

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	
		Illustration No.	4a	4b							4c	4d	
		Example CAM Submittal	A17		A2					A8	A14		
		Comment	✓	✓		✓	✓	✓					
<b>Primary Indicators of Performance</b>													
Outlet PM concentration	PM concentration is the most direct indicator of scrubber performance.											X	
Pressure differential ( $\Delta P$ )	A wet scrubber will operate at a relatively constant pressure differential. Shows whether there is normal gas flow and normal liquid flow. Poor gas-liquid distribution can decrease efficiency without affecting pressure differential; plugging can result in higher pressure differential without corresponding increase in control.	X	X		X		X		X	X			
Scrubber liquid flow rate	Low liquid flow causes a decrease in pressure differential and lower collection efficiency; want to maximize L/G ratio. Can use scrubber inlet liquid supply pressure or pump motor current as surrogates for liquid flow rate.		X	X		X					X		
<b>Other Performance Indicators</b>													
Scrubber liquid solids content	High solids can cause plugging and reduced particle capture. Applicable if scrubber liquid is recycled or if water quality is an issue; can monitor conductivity or specific gravity as surrogates of solids content.										X		
Gas flow rate	Increase in gas flow rate without increase in liquid flow rate results in lower L/G ratio and lower control efficiency. Can also measure fan current or inlet velocity pressure as surrogate for gas flow rate.			X		X							
Scrubber outlet gas temperature	Increase in outlet gas temperature can indicate inadequate liquid flow.			X					X	X			
Scrubber inlet gas temperature	High inlet gas temperature indicates that there has been a change in operation; scrubber liquid must be increased to handle the gas stream. Applies only to scrubbers that control thermal processes; scrubber liquid temperature can be used as a surrogate for inlet gas temperature.									X			

TABLE B-4. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	
		Illustration No.	4a	4b							4c	4d	
		Example CAM Submittal	A17		A2					A8	A14		
		Comment	✓	✓		✓	✓	✓					
Inlet velocity pressure	Inlet pressure provides an indication of the inlet gas flow rate.							X					
Scrubber liquid supply pressure	Pressure provides indicator of liquid flow rate (see above). Because it typically is easier to measure than measuring liquid flow rate, pressure often is used as a surrogate for flow rate.				X								
Inspections	Check or visible emissions inspection.					X			X				
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 also corresponds to 40 CFR 63, subpart XXX (Ferroalloys Production) for a venturi scrubber.</li> <li>• Approach No. 2 is required by several NSPS and 40 CFR 63, subparts X (Secondary Lead Smelting) and AA (Phosphoric Acid).</li> <li>• Approach No. 4 is required by several NSPS.</li> <li>• Approach No. 5 corresponds to 40 CFR 63, subpart LL (Primary Aluminum) for wet scrubbers.</li> <li>• Approach No. 6 corresponds to 40 CFR 63, subpart N (Chromium Electroplating) for combination packed bed and composite mesh-pad systems for chromium acid droplets; the pressure differential and inlet velocity pressure are monitored for the packed bed, and the pressure differential is monitored for the composite mesh pad.</li> </ul>													

CAM ILLUSTRATION  
No. 4a. WET SCRUBBER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to spray towers [052], venturi scrubbers [053], impingement scrubbers [055], and wet cyclonic separator [085]
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other:
- 1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Differential pressure.
- 2.2 Rationale for Monitoring Approach: Decrease in pressure differential indicates decrease in gas or liquid flow or poor liquid distribution; increase in pressure differential indicates clogging or increased gas flow.
- 2.3 Monitoring Location: 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 automatically recorded 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 using procedures that take into account manufacturer's specifications.

## 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. 4b. WET SCRUBBER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003], spray tower [052], venturi scrubber [053], impingement scrubber [055], or wet cyclonic separator [085]
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other: Fluorides
- 1.3 Process/Emissions Unit: Combustors, furnaces, dryers, calciners, kilns, material handling systems

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Pressure differential and scrubber liquid flow rate.
- 2.2 Rationale for Monitoring Approach
  - Pressure differential: Decrease in pressure differential indicates decrease in gas or liquid flow or poor liquid distribution; increase in pressure differential indicates clogging or increased gas flow.
  - Scrubber liquid flow rate: Monitoring scrubber liquid flow will indicate adequate liquid flow through the scrubber.
- 2.3 Monitoring Location
  - Pressure differential: Measure across inlet and outlet ducts.
  - Scrubber liquid flow rate: Measure at scrubber liquid inlet.
- 2.4 Analytical Devices Required
  - Pressure differential: Differential pressure transducer, differential pressure gauge, manometers, or alternative methods/instrumentation for pressure.
  - Scrubber liquid flow rate: Liquid flow meter or other device for liquid flow; see section 4 for more 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:
    - Pressure differential: Inches water column (in. wc).
    - Scrubber liquid flow rate: Gallons per minute (gpm) or cubic feet per minute (ft<sup>3</sup>/min).
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline pressure differential and scrubber liquid flow rate measurements concurrent with emissions test.
  - Historical plant records of pressure differential and scrubber liquid flow rate measurements.

2.7 Specific QA/QC Procedures

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

**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. 4c. WET SCRUBBER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003], spray tower [052], venturi scrubber [053], impingement scrubber [055], or wet cyclonic separator [085]
- 1.2 Pollutants
  - Primary: Particulate matter (PM)
  - Other: Fluorides
- 1.3 Process/Emissions Unit: Combustors, furnaces, dryers, calciners, kilns, material handling systems

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Pressure differential, scrubber liquid flow rate, and scrubber liquid solids content.
- 2.2 Rationale for Monitoring Approach
  - Pressure differential: Decrease in pressure differential indicates decrease in gas or liquid flow or poor liquid distribution; increase in pressure differential indicates clogging or increased gas flow.
  - Scrubber liquid flow rate: Monitoring scrubber liquid flow will indicate adequate liquid flow through the scrubber.
  - Scrubber liquid solids content: High solids content increases likelihood of re-entrainment.
- 2.3 Monitoring Location
  - Pressure differential: Measure across inlet and outlet ducts.
  - Scrubber liquid flow rate: Measure at scrubber liquid inlet.
  - Scrubber liquid solids content: Measure at inlet water line or recycle liquid tank.
- 2.4 Analytical Devices Required
  - Pressure differential: Differential pressure transducer, differential pressure gauge, manometers, or alternative methods/instrumentation for pressure; see section 4 for more information.
  - Scrubber liquid flow rate: Liquid flow meter or other device for liquid flow; see section 4 for more information.
  - Scrubber liquid solids content: Manual sampling of liquid.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system; scrubber liquid solids content, weekly.
  - Reporting units:
    - Pressure differential: Inches water column (in. wc).
    - Scrubber liquid flow rate: Gallons per minute (gpm) or cubic feet per minute (ft<sup>3</sup>/min).
    - Scrubber liquid solids content: Percent solids.

- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
- Baseline pressure differential, scrubber liquid flow rate, scrubber liquid solids content measurements concurrent with emissions test.
  - Historical plant records of pressure differential, scrubber liquid flow rate, scrubber liquid solids content measurements.
- 2.7 Specific QA/QC Procedures
- Calibrate, maintain, and operate instruments using procedures that take into account manufacturer's recommendations.

### **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. 4d. WET SCRUBBER FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to spray towers [052], venturi scrubbers [053], impingement scrubbers [055], and wet cyclonic separator [085]
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other:
- 1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet PM concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of PM concentration.
- 2.3 Monitoring Location: At outlet stack for wet scrubber.
- 2.4 Analytical Devices Required: PM CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: instrument response (e.g., milliamperes), or concentration (e.g., grains per dry standard cubic feet [gr/dscf], milligrams per dry standard cubic meter [mg/dscm]).
  - Recording process: Automatically recorded on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet PM concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: An initial correlation test to develop the relationship between PM concentration and instrument response is required. QA/QC should, as a minimum, include: periodic calibration and drift checks, routine maintenance, and inventory of spare parts. Calibrate, maintain, and operate the CEMS using procedures that take into account the manufacturer's specifications.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a PM continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented.
- 3.2 Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;

§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;  
subpart H and Appendix IX of 40 CFR 266; or  
comparable requirements established by the permitting authority.

For PM CEMS, this includes Performance Specification 11 of 40 CFR 60, Appendix B.

- 3.3 Indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

## B.5 WET SCRUBBERS FOR GASEOUS CONTROL<sup>1,2,9,10,12</sup>

### 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 (H<sub>2</sub>S). 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.

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 undesirable 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.

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 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.

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.

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.

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.

Neutralizing chemical feed rate. If a neutralizing chemical is used, the chemical feed rate is an indicator of wet scrubber operation. The feed rate is related to the pH of the scrubber liquid. 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 SO<sub>2</sub> 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).

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	
		Illustration No.	5a					5b						5c		
		Example CAM Submittals	A20		A4b											A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	
<b>Primary Indicators of Performance</b>																
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		
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 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 <sub>2</sub> control than HCl control. Can indicate likelihood of scaling or corrosion of piping and liquid contact surfaces.	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	

TABLE B-5. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
		Illustration No.	5a					5b						5c		
		Example CAM Submittals	A20		A4b											A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	
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			
<b>Other Performance Indicators</b>																
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.															
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 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											

TABLE B-5. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
		Illustration No.	5a					5b						5c		
		Example CAM Submittals	A20		A4b											A4a
		Comment	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	
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.															
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 also corresponds to 40 CFR 63, subparts U (Polymers and Resins I), JJJ (Polymers and Resins IV), and MMM (Pesticides).</li> <li>• Approach No. 2 corresponds to 40 CFR 63, subpart Y (Marine Vessels).</li> <li>• 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.</li> <li>• 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).</li> <li>• Approach No. 6 corresponds to 40 CFR 63, subpart AA (Phosphoric Acid).</li> <li>• Approach No. 7 corresponds to 40 CFR 63, subpart CCC (Steel Pickling–HCl).</li> <li>• Approach No. 8 corresponds to 40 CFR 63, subpart NNN (Wool Fiberglass).</li> <li>• Approach No. 9 corresponds to 40 CFR 63, subpart W (Polymers and Resins II).</li> <li>• Approach No. 10 corresponds to 40 CFR 63, subpart MMM (Pesticides).</li> <li>• Approach No. 12 corresponds to 40 CFR 63, subpart O (Commercial Ethylene Oxide Sterilization).</li> </ul>																

CAM ILLUSTRATION  
No. 5a. WET SCRUBBER FOR SO<sub>2</sub> 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 (SO<sub>2</sub>)
  - 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 (ft<sup>3</sup>/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.

### 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: Scrubber liquid flow rate and pressure differential.
- 2.2 Rationale for Monitoring Approach
  - Scrubber liquid flow rate: Adequate liquid flow ensures good gas/liquid contact.
  - Pressure differential: 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
  - Scrubber liquid flow rate: Measure at pump discharge or scrubber liquid inlet.
  - Pressure differential: Measure across inlet and outlet ducts.
- 2.4 Analytical Devices Required
  - Scrubber liquid flow rate: Liquid flow meter, pump discharge pressure gauge, or other device for liquid flow; see Section 4 of CAM document for information on specific types of instruments.
  - Pressure differential: 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:
    - Scrubber liquid flow rate: Hourly, or recorded continuously on strip chart or data acquisition system.
    - Pressure differential: Hourly, or recorded continuously on strip chart or data acquisition system.
  - Reporting units:
    - Scrubber liquid flow rate: Gallons per minute (gpm).
    - 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.
- 2.6 Data Requirements
  - Baseline scrubber liquid flow rate and pressure differential measurements concurrent with emissions test; or



- Historical plant records of scrubber liquid flow rate and pressure differential measurements.
- 2.7 Specific QA/QC Procedures
- Calibrate, maintain, and operate instrumentation taking into account manufacturer's specifications.

### 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.

CAM ILLUSTRATION  
No. 5c. WET SCRUBBER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Packed bed scrubber [050]
- 1.2 Pollutants
  - Primary: Volatile organic compounds (VOCs)
  - Other: Sulfur dioxide (SO<sub>2</sub>), acid gases
- 1.3 Process/Emissions Unit: Polymer manufacturing, distillation units, air oxidation units, miscellaneous reactors

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Pressure differential, scrubber liquid flow rate, and makeup liquid flow rate.
- 2.2 Rationale for Monitoring Approach
  - Pressure differential: Indicative of adequate system performance.
  - Scrubber liquid flow rate: Adequate liquid flow insures good gas/liquid contact and maintenance of proper pressure differential.
  - Makeup liquid flow rate: If makeup flow rate is maintained, VOC concentration is likely being maintained at a consistent level to maintain scrubber control efficiency.
- 2.3 Monitoring Location
  - Pressure differential: Measure across inlet and outlet ducts.
  - Scrubber liquid flow rate: Measure at pump discharge or scrubber liquid inlet.
  - Makeup liquid flow rate: Measure at inlet to reservoir or scrubber inlet.
- 2.4 Analytical Devices Required
  - Pressure differential: Differential pressure gauges, manometers, or alternative methods/instrumentation for pressure differential.
  - Scrubber liquid flow rate: liquid flow meter, pump discharge pressure gauge, or other device for liquid flow; see section 4 for information on specific types of instruments.
  - Makeup liquid flow rate: liquid flow meter, pump discharge pressure gauge, or other device for liquid flow; see section 4 for information on specific types of instruments.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously strip chart or data acquisition system.
  - Reporting units:
    - Pressure differential: Inches water column (in. wc).
    - Scrubber liquid flow rate: Gallon per minute (gpm).
    - Makeup liquid flow rate: Gallon per minute (gpm).
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

- Baseline pressure differential, scrubber liquid flow rate, and makeup liquid flow rate measurements concurrent with emissions test.
- Historical plant records of pressure differential, scrubber liquid flow rate, and makeup liquid flow rate measurements.

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

**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.)

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## B.6 THERMAL OXIDIZERS<sup>1,2,3,4,13,14</sup>

### B.6.1 Background

Thermal oxidizers or thermal incinerators are combustion systems that control VOC, CO, and volatile HAP emissions by combusting them to carbon dioxide (CO<sub>2</sub>) and water. The design of an incineration system is dependent on the pollutant concentration in the waste gas stream, type of pollutant, presence of other gases, level of oxygen, stability of processes vented to the system, and degree of control required. Important design factors include temperature (a temperature high enough to ignite the organic constituents in the waste gas stream), residence time (sufficient time for the combustion reaction to occur), and turbulence or mixing of combustion air with the waste gas. Time, temperature, degree of mixing, and sufficient oxygen concentration govern the completeness of the combustion reaction. Of these, only temperature and oxygen concentration can be significantly controlled after construction. Residence time and mixing are fixed by oxidizer design, and flow rate can be controlled only over a limited range.

The rate at which VOC compounds, volatile HAP, and CO are oxidized is greatly affected by temperature; the higher the temperature, the faster the oxidation reaction proceeds. Because inlet gas concentrations are well below the lower explosive limit (LEL) to prevent pre-ignition explosions in ducting the stream from the process to the oxidizer, the gas must be heated with auxiliary fuel above the autoignition temperature. Thermal destruction of most organics occurs at combustion temperatures between 800°F and 2000°F. Residence time is equal to the oxidizer chamber volume divided by the total actual flow rate of flue gases (waste gas flow, added air, and products of combustion). A residence time of 0.2 to 2.0 seconds, a length-to-diameter ratio of 2 to 3 for the chamber dimensions, and an average gas velocity of 10 to 50 feet per second are common. Thorough mixing is necessary to ensure that all waste and fuel come in contact with oxygen. Because complete mixing generally is not achieved, excess air/oxygen is added (above stoichiometric or theoretical amount) to ensure complete combustion.

Normal operation of a thermal oxidizer should include a fixed outlet temperature or an outlet temperature above a minimum level. A variety of operating parameters that may be used to indicate good operation include: inlet and outlet VOC concentration, outlet combustion temperature, auxiliary fuel input, fuel pressure (magnehelic gauge), fan current (ammeter), outlet CO concentration, and outlet O<sub>2</sub> concentration.

### B.6.2 Indicators of Thermal Oxidizer Performance

For VOC control, the primary indicators of thermal oxidizer performance are the outlet VOC concentration and outlet or combustion chamber temperature. Other indicators of thermal oxidizer performance include outlet CO concentration, exhaust gas flow rate, fan current, outlet CO<sub>2</sub> concentration, outlet O<sub>2</sub> concentration, and auxiliary fuel line pressure. For CO control, the indicators of performance are the same as for VOC control, with the exception of outlet VOC and CO<sub>2</sub> concentrations, which would not be monitored for a CO emission limit. Each of these indicators is described below. Table B-6A lists these indicators and illustrates potential

monitoring options for thermal oxidizers for VOC control, and Table B-6B lists the indicators and monitoring options for CO control by thermal oxidation.

Outlet VOC concentration. The most direct single indicator of the performance of a thermal oxidizer is the VOC concentration at the outlet of the unit.

Outlet combustion temperature. The outlet temperature of the combustion chamber provides a good indication of thermal oxidizer performance. As temperature increases, control efficiency also increases.

Outlet CO concentration. When VOC is the primary pollutant to be controlled, the CO concentration at the outlet of a thermal oxidizer provides an indication of combustion efficiency. The presence of CO indicates incomplete combustion. An increase in CO levels indicates a decrease in combustion efficiency. When CO is the primary pollutant, outlet CO concentration is a direct indicator of performance.

Exhaust gas flow rate. Thermal oxidizer control efficiency is primarily a function of combustion chamber temperature and residence time, and residence time is a function of exhaust gas flow rate. Consequently, as flow rate increases, residence time decreases and control efficiency may also decrease. For processes with fairly constant flow rates or tested at maximum flow, exhaust gas flow rate is not as good an indicator of performance as is outlet combustion temperature because temperature has a much greater effect on control efficiency than small variations in flow rates.

Fan current. Changes in fan current generally correspond to changes in exhaust gas flow rate. Consequently, fan current can be a surrogate for exhaust gas flow rate. An increase in fan current would signify an increase in flow rate and a decrease in residence time.

Outlet O<sub>2</sub> or CO<sub>2</sub> concentration. Outlet O<sub>2</sub> or CO<sub>2</sub> concentration by itself does not provide an indication of thermal oxidizer performance. However, monitoring the O<sub>2</sub> or CO<sub>2</sub> level provides an indication of the excess air rate and may be used to normalize the measured VOC concentration to a standard O<sub>2</sub> or CO<sub>2</sub> level. For emission limits that specify VOC concentrations corrected to a specified percent O<sub>2</sub>, monitoring both the VOC and O<sub>2</sub> concentrations would be required to determine compliance.

Inspections. Inspections of the oxidizer can ensure proper operation of the device. These inspections may include frequent visual checks of the flame and burner while in operation and annual inspections of the burner assemblies, blowers, fans, dampers, refractory lining, oxidizer shell, fuel lines, and ductwork.

### B.6.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for thermal oxidizers:

For CO Control:

- 6a: Monitoring combustion temperature and annual burner inspection.
- 6b: Monitoring CO concentration.

For VOC Control:

- 6c: Monitoring combustion temperature and annual burner inspection.
- 6d: Monitoring combustion temperature, annual burner inspection, and exhaust gas flow rate.
- 6e: Monitoring combustion temperature and CO concentration.
- 6f: Monitoring VOC concentration (CEMS).

TABLE B-6A. SUMMARY OF PERFORMANCE INDICATORS FOR THERMAL OXIDIZERS FOR VOC CONTROL

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.	6c	6d	6e		6f
		Example CAM Submittals	A1a		A1b		
		Comment	✓	✓		✓	✓
<b>Primary Indicators of Performance</b>							
Outlet VOC concentration	Direct measure of outlet concentration. Most direct single indicator of oxidizer performance; for limits that are corrected to an O <sub>2</sub> content, must be combined with O <sub>2</sub> monitoring to determine compliance.						X
Outlet combustion temperature	Control efficiency is largely a function of temperature. Control efficiency increases with increasing outlet combustion temperature.	X	X	X	X		
<b>Other Performance Indicators</b>							
Outlet CO concentration	Indicator of combustion efficiency. Presence of CO indicates incomplete combustion.			X			
Exhaust gas flow rate	Determines residence time within oxidizer. Increase in flow rate generally indicates a decrease in residence time, which may affect control efficiency.		X				
Inspections	Visual check of burner and flame can indicate if burner is operating properly. Annual inspection of the burner and oxidizer can ensure proper operation.	X	X				
Comments: <ul style="list-style-type: none"> <li>• Approach No. 1 is required by 40 CFR 63, subpart NNN (Wool Fiberglass).</li> <li>• Approach No. 4 is specified by several NSPS and NESHAP, including 40 CFR 63, subparts G (HON), O (Commercial Ethylene Oxide Sterilization), R (Gasoline Distribution), U (Polymers and Resins I), Y (Marine Vessel), CC (Petroleum Refiners), DD (Offsite Waste and Recovery), EE (Magnetic Tape), GG (Aerospace), HH (Oil and Natural Gas), JJ (Wood Furniture), KK (Printing and Publishing), JJJ (Polymers and Resins IV), MMM (Pesticides), and OOO (Polymers and Resins III).</li> <li>• Approach No. 5 is specified as an alternative monitoring approach by 40 CFR 63, subparts G (HON), S (Pulp and Paper), Y (Marine Vessel), DD (Offsite Waste and Recovery), EE (Magnetic Tape), HH (Oil and Natural Gas), and MMM (Pesticides).</li> </ul>							



TABLE B-6B. SUMMARY OF PERFORMANCE INDICATORS FOR THERMAL OXIDIZERS FOR CO CONTROL

Parameters	Performance indication	Approach No.	1	2
		Illustration No.	6a	6b
		Example CAM Submittals		
		Comment		
<b>Primary Indicators of Performance</b>				
Outlet CO concentration	Direct measure of outlet concentration. Most direct single indicator of oxidizer performance for CO.			X
Outlet combustion temperature	Control efficiency is largely a function of temperature. Control efficiency increases with increasing combustion chamber temperature.	X		
<b>Other Performance Indicators</b>				
Exhaust gas flow rate	Determines residence time within oxidizer. Increase in flow rate generally indicates a decrease in residence time, which may affect control efficiency.			
Inspections	Visual check of burner and flame can indicate if burner is operating properly. Annual inspection of the burner and oxidizer can ensure long-term proper operation.	X		
Comments: None.				

CAM ILLUSTRATION  
No. 6a. THERMAL OXIDIZER FOR CO CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling CO emissions by combustion
- 1.2 Pollutants  
Primary: Carbon monoxide (CO)  
Other: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions units: Fluid catalytic cracking unit (FCCU) catalyst regenerators; petroleum refining

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Combustion chamber temperature and annual burner inspection.
- 2.2 Rationale for Monitoring Approach
  - Combustion chamber temperature: Low temperature indicates potential for insufficient destruction of CO.
  - Annual burner inspection: Maintain proper burner operation and efficiency.
- 2.3 Monitoring Location
  - Combustion chamber temperature: Outlet of combustion chamber.
  - Annual burner inspection: At the burner.
- 2.4 Analytical Devices Required
  - Combustion chamber temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream; see section 4.2 (Temperature) for additional information on devices.
  - Annual burner inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Combustion chamber temperature: Hourly, or recorded continuously on strip chart or data acquisition system.
    - Annual burner inspection: Annually.
  - Reporting units:
    - Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Annual burner inspection: None
  - Recording process:
    - Combustion chamber temperature: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
    - Annual burner inspection: Operators log data manually
- 2.6 Data Requirements
  - Baseline combustion chamber temperature measurements concurrent with emission test.

- Historical plant records on combustion chamber temperature measurements and burner inspection.
  - Manufacturer's data and recommended operating ranges.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate thermocouples using procedures that take into account manufacturer's specifications.

### 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. 6b. THERMAL OXIDIZER FOR CO CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling CO emissions by combustion
- 1.2 Pollutants  
Primary: Carbon monoxide (CO)  
Other: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions units: Fluid catalytic cracking unit (FCCU) catalyst regenerators; petroleum refining

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet CO concentration.
- 2.2 Rationale for Monitoring Approach: Provides direct indicator of CO emissions.
- 2.3 Monitoring Location: Combustion chamber outlet.
- 2.4 Analytical Devices Required: Nondispersive infrared (NDIR) analyzer or other methods or instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, if read manually; continuously, if CEMS.
  - Reporting units: Parts per million by volume (ppm<sub>v</sub>), dry basis.
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet CO concentration measurements concurrent with emissions test.
  - Historical plant records outlet CO concentration measurements.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications.

## 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 Concentration measurements: Outlet CO concentration in terms of ppm can be used as an indicator of control device performance even if the emission standard is a mass emissions standard (i.e., lb/hr); additional information (e.g., flow) to calculate/report emission in units of the standard is not required for CAM; however, such a measurement may be a monitoring requirement of the applicable requirement.

CAM ILLUSTRATION  
No. 6c. THERMAL OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling VOC emissions by combustion
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCOMI units

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Combustion chamber temperature and annual burner inspection.
- 2.2 Rationale for Monitoring Approach
  - Combustion chamber temperature: Proper temperature range is related to good performance.
  - Annual burner inspection: Maintain proper burner operation and efficiency.
- 2.3 Monitoring Location
  - Combustion chamber temperature: Outlet of combustion chamber.
  - Annual burner inspection: At the burner.
- 2.4 Analytical Devices Required
  - Combustion chamber temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream; see section 4.2 (Temperature) for additional information on devices.
  - Annual burner inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Combustion chamber temperature: Hourly, or recorded continuously on strip chart or data acquisition system.
    - Annual burner inspection: Annually.
  - Reporting units:
    - Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Annual burner inspection: None.
  - Recording process:
    - Combustion chamber temperature: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
    - Annual burner inspection: Operators log data manually.

2.6 Data Requirements

- Baseline combustion chamber temperature measurements concurrent with emissions test.
- Historical plant records on combustion chamber temperature measurements and burner inspection.

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

**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. 6d. THERMAL OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], for controlling VOC emissions by combustion
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Combustion chamber temperature, annual burner inspection, and exhaust gas flow rate.
- 2.2 Rationale for Monitoring Approach
  - Combustion chamber temperature: Proper temperature range can be related to good performance.
  - Exhaust gas flow rate: Maintaining proper flow through the entire control system is important for maintaining capture efficiency.
  - Annual burner inspection: Maintain proper burner operation and efficiency.
- 2.3 Monitoring Location
  - Combustion chamber temperature: Outlet of combustion chamber.
  - Exhaust gas flow rate: Oxidizer outlet or fan instrumentation.
- 2.4 Analytical Devices Required
  - Combustion chamber temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream.
  - Exhaust gas flow rate: Differential pressure flow device, fan motor ammeter, or other type of device that measures gas velocity or flow rate.
- 2.5 Data Acquisition and Measurement System Operation:
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or digital data acquisition system.
  - Reporting units:
    - Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Exhaust gas flow rate: Cubic feet per minute (ft<sup>3</sup>/min); amps if fan motor current.
  - Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.
- 2.6 Data Requirements
  - Baseline combustion chamber temperature measurements, exhaust gas flow rate measurements, and outlet VOC concentration or destruction efficiency measurements concurrent with emission test; or
  - Historical plant records on combustion chamber temperature and exhaust gas flow rates.

2.7 Specific QA/QC Procedures

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

**3. COMMENTS**

- 3.1 Data Collection Frequency: For large emission units, collection of four or more data points each hour is required. (See Section 3.3.1.2.)



CAM ILLUSTRATION  
No. 6e. THERMAL OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling VOC emissions by combustion
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: High molecular weight organic compounds
- 1.3 Process/Emissions Unit: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCOMI units

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Combustion chamber temperature and outlet CO concentration.
- 2.2 Rationale for Monitoring Approach
  - Combustion chamber temperature: Proper temperature range is related to good performance.
  - Outlet CO concentration: CO is a product of incomplete combustion and is an indicator of combustion efficiency.
- 2.3 Monitoring Location
  - Combustion chamber temperature: Outlet of combustion chamber.
  - Outlet CO concentration: Outlet to oxidizer.
- 2.4 Analytical Devices Required
  - Combustion chamber temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream; see section 4.2 (Temperature) for additional information on devices.
  - Outlet CO concentration: Nondispersive infrared (NDIR) analyzer calibrated to manufacturer's specifications, or other methods or instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly if read manually, or continuously recorded on strip chart or data acquisition system.
  - Reporting units:
    - Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Outlet CO concentration: parts per million by volume (ppmv), dry basis.
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

- Baseline combustion chamber temperature measurements and outlet CO concentration measurements concurrent with emission test.
- Historical plant records on combustion chamber temperature and outlet CO concentrations.

2.7 Specific QA/QC Procedures

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

**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. 6f. THERMAL OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Thermal oxidizer [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling VOC emissions by combustion
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing, chemical manufacturing

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet THC concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of VOC concentration.
- 2.3 Monitoring Location: At outlet stack of thermal oxidizer.
- 2.4 Analytical Devices Required: THC analyzer.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet THC concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;  
§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;

subpart H and Appendix IX of 40 CFR 266; or comparable requirements established by the permitting authority. For example, this would include performance specifications 8 and 9 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

## **B.7 CATALYTIC OXIDIZERS**<sup>1,2,3,4,13,14</sup>

### **B.7.1 Background**

Catalytic oxidizers are oxidation systems (similar to thermal oxidizers) that control VOC and volatile HAP emissions. Catalytic oxidizers use a catalyst to promote the oxidation of VOCs to CO<sub>2</sub> and water (i.e., increase the kinetic rate).

The design of the oxidation system is dependent on the pollutant concentration in the waste gas stream, type of pollutant, presence of other gases, level of oxygen, stability of processes vented to the system, and degree of control required. Important design factors include temperature (an operating temperature high enough to oxidize the waste gas on the catalyst), residence time (sufficient residence time in the catalyst bed for the oxidation reaction to occur), turbulence or mixing of combustion air with the waste gas, VOC concentration and species, catalyst characteristics, and the presence of masking agents in the waste gas that can reduce the effectiveness of the catalyst bed. Time, temperature, degree of mixing, and sufficient O<sub>2</sub> govern the completeness of the combustion reaction. Of these, only the temperature and the oxygen can be significantly controlled after construction. Residence time and mixing are fixed by incinerator design, and flow rate can be controlled only over a limited range.

The rate at which VOC compounds and volatile HAP are oxidized is greatly affected by temperature; the higher the temperature, the faster the oxidation reaction proceeds. The operating temperature needed to achieve a particular VOC control efficiency depends on the species of pollutants, concentration, and the catalyst type. Each pollutant has a temperature which must be reached to initiate the catalytic oxidation reaction. The initiation temperature is also dependent on the type of catalyst. The use of the catalyst allows the combustion reaction to occur at a lower temperature than the autoignition temperature. Catalytic oxidizers generally operate between 650°F and 1000°F.

The catalyst support and bed geometry influence the size and shape of the catalyst bed and affect the pressure differential across the bed. The catalyst typically lasts 2 to 5 years. Thermal aging over the lifetime of the catalyst and the presence of PM and catalyst poisons in the inlet gas streams reduce the catalyst's ability to promote the oxidation reaction by masking and coating the catalyst, thereby preventing contact between VOC and the catalyst surface.

Thorough mixing is necessary to ensure that all waste and fuel come in contact with oxygen. Because complete mixing generally is not achieved, excess air/oxygen is added (above stoichiometric or theoretical amount) to ensure complete combustion. For catalytic oxidizers, good mixing of the waste gas and oxygen promotes uniform oxidation in the catalyst bed and avoids localized heating of bed sections.

Normal operation of a catalytic oxidizer is characterized by a fixed inlet gas temperature and a higher bed outlet temperature. A thermocouple, or other temperature monitoring device, is placed at the inlet to the catalyst bed to measure the temperature of the preheated waste gas stream. A thermocouple at the outlet to the catalyst bed can be connected to a controller that

maintains the desired catalyst bed temperature by altering the rate of auxiliary fuel consumption in the oxidizer's burner. A variety of operating parameters that may be used to indicate good operation include: outlet VOC concentration, inlet temperature (prior to catalyst bed), outlet temperature (after catalyst bed), pressure differential across oxidizer sections (preheat, catalyst bed, heat exchanger), auxiliary fuel input, and outlet CO concentration. Periodic tests of samples of the catalyst also may be used to confirm performance of the catalyst.

### B.7.2 Indicators of Catalytic Oxidizer Performance

The primary indicators of catalytic oxidizer performance are the outlet VOC or volatile HAP concentration, catalyst bed inlet temperature, and catalyst activity. Other indicators of catalytic oxidizer performance include outlet CO concentration, temperature rise across the catalyst bed, exhaust gas flow rate, catalyst bed outlet temperature, fan current, outlet O<sub>2</sub> or CO<sub>2</sub> concentration, and pressure differential across the catalyst bed. Each of these indicators is described below. Table B-7 lists these indicators and illustrates potential monitoring options for catalytic oxidizers that are used for VOC or volatile HAP control.

Outlet VOC concentration. The most direct single indicator of the performance of a catalytic oxidizer is the VOC or volatile HAP concentration at the outlet of the unit.

Catalyst bed inlet temperature. The temperature at the inlet to the catalyst bed is a key catalytic oxidizer operating parameter. The inlet gas stream must be heated to the minimum temperature at which catalytic oxidation will occur on the bed. Above this minimum temperature, as temperature increases, control efficiency also increases.

Catalyst activity. When the catalyst becomes contaminated or masked, the control efficiency of the unit decreases. Catalyst deactivation will result in increased VOC emissions. The catalyst should be tested periodically to determine its activity.

Outlet CO concentration. The CO concentration at the outlet of a catalytic oxidizer provides an indication of combustion efficiency. The presence of CO indicates incomplete combustion. An increase in CO levels indicates a decrease in combustion efficiency.

Temperature rise across catalyst bed. The temperature rise across the catalyst bed provides an indication of the degree of combustion that is occurring in the unit. The greater the level of combustion, the greater the rise in temperature. Because the temperature rise is dependent on the degree of combustion occurring across the catalyst, the temperature rise is dependent upon the inlet VOC loading to the catalyst. In other words, if the VOC loading to the oxidizer is reduced, the temperature rise across the catalyst will decrease. Consequently, a decrease in temperature rise across the catalyst is not necessarily an indication of reduced performance, but may simply be an indication of reduced VOC loading to the oxidizer.

Exhaust gas flow rate. Catalytic oxidizer control efficiency is primarily a function of catalyst bed inlet temperature and space velocity (similar to residence time), and space velocity is a function of exhaust gas flow rate. Consequently, as flow rate increases, space velocity

increases and control efficiency may decrease. For processes with fairly constant flow rates, exhaust gas flow rate is not as good an indicator of performance as is bed inlet temperature because temperature has a much greater effect on control efficiency than small variations in flow rates.

Outlet O<sub>2</sub> or CO<sub>2</sub> concentration. Outlet O<sub>2</sub> or CO<sub>2</sub> concentration by itself does not provide an indication of thermal oxidizer performance. However, monitoring the O<sub>2</sub> or CO<sub>2</sub> level provides an indication of the excess air rate and may be used to normalize the measured VOC concentration to a standard O<sub>2</sub> or CO<sub>2</sub> level. For emission limits that specify VOC concentrations corrected to a specified percent O<sub>2</sub>, monitoring both the VOC and O<sub>2</sub> concentrations would be required to determine compliance.

Catalyst bed outlet temperature. For a particular type of catalyst, there is a maximum operating temperature, above which the catalyst begins to sinter. Monitoring the bed outlet temperature can ensure that the temperature within the bed does not exceed its working limit. In addition, the bed outlet temperature is an indicator that minimum oxidation temperatures are occurring in the unit.

The following operational parameters provide important information about the operation of the catalytic oxidizer but are not generally suited as indicators of performance for compliance monitoring per Part 64, although they may be useful supplements to a monitoring approach.

Fan current. Changes in fan current generally correspond to changes in exhaust gas flow rate. Consequently, fan current can be a surrogate for exhaust gas flow rate. An increase in fan current would signify an increase in flow rate and space velocity.

Pressure differential across catalyst bed. For inlet gas streams that contain significant levels of PM, bed fouling or plugging can be a problem. An increase in pressure differential across the bed is an indicator that plugging is occurring. Pressure differential across the catalyst bed should be maintained within an optimal pressure differential range for the system. Changes in pressure differential are likely to be gradual over time.

### B.7.3 Illustrations

The following illustration presents examples of compliance assurance monitoring for catalytic oxidizers:

- 7a: Monitoring catalyst bed inlet temperature and catalyst bed outlet temperature.
- 7b: Monitoring VOC concentration (CEMS).
- 7c: Monitoring catalyst bed inlet temperature and catalyst activity check.
- 7d: Monitoring catalyst bed inlet temperature, catalyst bed outlet temperature, and outlet CO concentration.

TABLE B-7. SUMMARY OF PERFORMANCE INDICATORS FOR CATALYTIC OXIDIZERS FOR VOC CONTROL

Parameters	Performance indication	Approach No.										
		1	2	3	4	5	6	7	8			
		Illustration No.		7a		7b				7c		7d
		Example CAM Submittals										
		Comment										
		✓	✓	✓	✓	✓	✓					
<b>Primary Indicators of Performance</b>												
Outlet VOC concentration	Direct measure of outlet concentration. Most direct single indicator of oxidizer performance.			X								
Catalyst bed inlet temperature	Indicator that bed inlet is of sufficient temperature to initiate oxidation. Above the minimum oxidation temperature, control efficiency increases with increasing bed inlet temperature.	X	X		X	X	X	X	X	X		
Catalyst bed activity	Indicates contamination, masking, or deactivation of the catalyst; the control efficiency of the unit decreases as catalyst activity decreases.								X			
<b>Other Performance Indicators</b>												
Outlet CO concentration	Indicator of combustion efficiency. Presence of CO indicates incomplete combustion.										X	
Temperature rise across bed	Indicates level of combustion occurring in unit. The greater the degree of combustion, the greater the temperature rise. NOTE: Degree of combustion and resulting temperature rise is dependent upon VOC loading to control device. As VOC loading decreases, temperature rise also will decrease, even when combustion efficiency is being maintained. Therefore, may not be an appropriate indicator for situations where VOC loading to oxidizer varies greatly.				X			X				
Exhaust gas flow rate	Determines space velocity within catalyst bed. Increase in flow rate generally indicates an increase in space velocity and may result in a decrease in control level.		X									
Catalyst bed outlet temperature	Indicates level of combustion occurring in unit. Indicator used to assure temperature does not exceed design limits of bed. If bed outlet temperature exceeds working limit, the catalyst bed can be destroyed.	X	X								X	



TABLE B-7. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5	6	7	8	
		Illustration No.	7a		7b				7c	7d	
		Example CAM Submittals									
		Comment	✓	✓	✓	✓	✓	✓			
Pressure differential across 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				
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 is specified by several NSPS and by 40 CFR 63, subparts U (Polymers and Resins I), DD (Offsite Waste and Recovery), JJ (Wood Furniture), HH (Oil and Natural Gas), and OOO (Polymers and Resins III).</li> <li>• Approach No. 3 is specified as an alternative monitoring approach by 40 CFR 63, subpart G (HON), DD (Offsite Waste and Recovery), HH (Oil and Natural Gas), MMM (Pesticides) and OOO (Polymers and Resins III).</li> <li>• Approach No. 4 is required by 40 CFR 63, subpart G (HON), CC (Petroleum Refiners), EE (Magnetic Tape), GG (Aerospace), JJJ (Polymers and Resins IV), and MMM (Pesticides).</li> <li>• Approach No. 5 corresponds to 40 CFR 63, subpart JJ (Wood Furniture) for fluidized catalyst bed.</li> </ul>											

CAM ILLUSTRATION  
No. 7a. CATALYTIC OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Catalytic incinerator [019]; also applicable to catalytic afterburners with or without heat exchangers [019, 020]
- 1.2 Pollutants
  - Primary: Volatile organic compounds (VOCs)
  - Other: High molecular weight organic compounds
- 1.3 Process/Emissions Unit: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCOMI units

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Catalyst bed inlet and outlet temperatures.
- 2.2 Rationale for Monitoring Approach
  - Catalyst bed inlet temperature: Indicates whether the gas flowing into catalyst bed is of sufficient temperature to initiate oxidation.
  - Catalyst bed outlet temperature: Indication that combustion is occurring on the catalyst bed, allows for calculation of temperature differential across bed, and that temperature does not exceed design limits of the catalyst.
- 2.3 Monitoring Location
  - Catalyst bed inlet temperature: Preheat chamber outlet or catalyst bed inlet.
  - Catalyst bed outlet temperature: Catalyst bed outlet.
- 2.4 Analytical Devices Required: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly if manually read, or recorded continuously on strip chart or data acquisition system; continuously if CEMS.
  - Reporting units: Degrees Fahrenheit or Celsius (°F, °C).
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline catalyst bed inlet and outlet temperatures concurrent with emission test; or
  - Historical plant records on catalyst bed inlet and outlet temperature measurements.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

## 3. COMMENTS

- 3.1 Data Collection Frequency: For large emission units, collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION  
No. 7b. CATALYTIC OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Catalytic incinerator [019]; also applicable to catalytic afterburners with or without heat exchangers [019, 020]
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: High molecular weight organic compounds
- 1.3 Process/Emissions Unit: Coating, spraying, printing, chemical manufacturing, polymer manufacturing.

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Outlet THC concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of VOC concentration.
- 2.3 Monitoring Location: At outlet stack of catalytic oxidizer.
- 2.4 Analytical Devices Required: THC analyzer.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet THC concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;  
§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;

subpart H and Appendix IX of 40 CFR 266; or comparable requirements established by the permitting authority. For example, this would include performance specifications 8 and 9 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

CAM ILLUSTRATION  
No. 7c. CATALYTIC OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Catalytic incinerator [019]; also applicable to catalytic afterburners with or without heat exchangers [019, 020]
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: High molecular weight organic compounds
- 1.3 Process/Emissions Unit: Printing and publishing

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Catalyst bed inlet temperature and catalyst activity.
- 2.2 Rationale for Monitoring Approach
  - Catalyst bed inlet temperature: Indicates whether the gas flowing into catalyst bed is of sufficient temperature to initiate oxidation.
  - Catalyst activity: Determines conversion efficiency of catalyst; indicates that catalyst is not poisoned or masked beyond operational range.
- 2.3 Monitoring Location
  - Catalyst bed inlet temperature: Preheat chamber outlet or catalyst bed inlet.
  - Catalyst activity: Sample of catalyst.
- 2.4 Analytical Devices Required
  - Temperature: Thermocouples, RTDs, or alternative methods/ instrumentation as appropriate for specific gas stream.
  - Catalyst activity: Qualified laboratory (e.g., catalyst manufacturer) for determining activity of catalyst sample.
- 2.5 Data Acquisition and Measurement System Operation
  - Temperature:
    - Frequency of measurement: Hourly or recorded continuously on strip chart or data acquisition system.
    - Reporting units: Degrees Fahrenheit or Celsius (°F, °C).
    - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
  - Catalyst activity: Annual analyses of catalyst sample.
- 2.6 Data Requirements
  - Temperature:
    - Baseline catalyst bed inlet and outlet temperatures concurrent with emission test; or
    - Historical plant records on catalyst bed inlet and outlet temperature measurements.
  - Catalyst activity: Laboratory results of conversion efficiency.
- 2.7 Specific QA/QC Procedures

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

### 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 This illustration is applicable for catalytic systems controlling process streams that exhibit a highly variable range of VOC concentration, thereby making the use of temperature differential as a routine monitoring parameter impractical.

CAM ILLUSTRATION  
No. 7d. CATALYTIC OXIDIZER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Catalytic incinerator [019]; also applicable to catalytic afterburners with or without heat exchangers [019, 020]
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)  
Other: High molecular weight organic compounds
- 1.3 Process/Emissions Unit: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCOMI units

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Catalyst bed inlet and outlet temperatures and outlet CO concentration.
- 2.2 Rationale for Monitoring Approach
  - Catalyst bed inlet temperature: Indicates whether the gas flowing into catalyst bed is of sufficient temperature to initiate oxidation.
  - Catalyst bed outlet temperature: Indication that combustion is occurring on the catalyst bed, allows for calculation of temperature differential across bed, and that temperature does not exceed design limits of the catalyst.
  - Outlet CO concentration: CO is a product of incomplete combustion and is an indicator of combustion efficiency.
- 2.3 Monitoring Location
  - Catalyst bed inlet temperature: Preheat chamber outlet or catalyst bed inlet.
  - Catalyst bed outlet temperature: Catalyst bed outlet.
  - Outlet CO concentration: Outlet to oxidizer.
- 2.4 Analytical Devices Required
  - Catalyst bed inlet temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream.
  - Catalyst bed outlet temperature: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream.
  - Outlet CO concentration: Nondispersive infrared (NDIR) analyzer calibrated to manufacturer's specifications, or other methods or instrumentation.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement
    - Catalyst bed inlet temperature: Hourly, or recorded continuously on strip chart or data acquisition system.
    - Catalyst bed outlet temperature: Hourly, or recorded continuously on strip chart or data acquisition system.
    - Outlet CO concentration: Continuously.

- Reporting units
    - Catalyst bed inlet temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Catalyst bed outlet temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Outlet CO concentration: Parts per million by volume (ppmv), dry basis.
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
- Baseline catalyst bed inlet and outlet temperatures and outlet CO concentration concurrent with emission test; or
  - Historical plant records on catalyst bed inlet and outlet temperature and outlet CO concentration measurements.
- 2.7 Specific QA/QC Procedures
- Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### 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.8 FLARES [Reserved]**

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## B.9 CONDENSERS<sup>1,2,17</sup>

### B.9.1 Background

Condensers are used to convert condensible components of a gas stream to the liquid phase, usually by reducing the temperature of the gas stream. Condenser efficiencies vary from 50 to 95 percent, and are dependent on the type of gas stream entering the condenser and on the condenser's operating parameters (e.g., coolant temperature). Gas stream properties such as the number of pollutants, chemical and physical properties of those pollutants, moisture content, particulate matter content, flow rate, and temperature all affect how well the condenser operates. Condensers can be classified as either contact condensers or surface condensers. In contact condensers, the exhaust gas comes into direct contact with the coolant. Contact condenser designs are similar to spray towers. In surface condensers, the coolant typically is circulated through a series of tubes around which the exhaust gas flows. No secondary pollutants are generated from the operation of surface condensers because the coolant flows through a closed system.

Condensation occurs when the partial pressure of the condensible pollutant in the waste gas stream is equal to its vapor pressure as a pure substance at the outlet gas temperature of the condenser. The waste gas stream is cooled by transfer of its heat to a refrigerant or coolant; the waste gas becomes saturated with one or more of its pollutants at the dew point or saturation temperature, and as the gas continues to cool, the pollutants condense. The temperature at which the gases condense can be predicted from vapor pressure data for the pollutant and its mole fraction in the waste gas stream. The temperature required to achieve a given removal efficiency or outlet concentration depends on the inlet conditions of the waste gas stream.

The coolant used in a condenser depends upon the saturation temperature needed to condense the pollutants of interest in the gas stream. Chilled water can be used for condensation temperatures above approximately 40° to 45°F, brines above 10° to 15°F, and chlorofluorocarbons for condensation temperatures below -29°F. Temperatures as low as -80°F may be necessary to condense some streams. When such low temperatures must be achieved to reach the dew point for a particular pollutant, other components of the waste gas stream, such as water, can solidify and foul the heat transfer surfaces. In these instances a two-stage condensation system can be designed; the first stage removes moisture while the second stage is cooled to the lower temperature desired.

A condenser is designed for a maximum pressure and temperature. Normal operation of a condenser should include an outlet gas maximum temperature setpoint and a fixed inlet and outlet coolant/refrigerant temperature. The outlet gas temperature is a critical indicator of the efficiency of a condenser. Normal operation may also include a constant pressure differential across nozzles, tubes, etc. System pressures are important operating parameters that can indicate proper waste gas stream flow and coolant flow. The coolant flow rate should be checked on a regular basis to ensure that it is within design criteria. Several operating parameters may be used to indicate good operation of the condenser, including: outlet pollutant concentration of the most volatile pollutant, inlet temperature of the waste gas stream, outlet temperature of the waste gas

stream, temperature of the condensate pool, inlet temperature of the coolant, and outlet temperature of the coolant.

There are several common problems or malfunctions associated with condenser operation. Excessive flow rates may increase erosion of the device and may cause entrainment of liquids and PM in the waste gas stream. Fouling or plugging may occur on the shell, tubes, pipes, valves, and monitors; symptoms of fouling or plugging may include an increase or decrease in pressure, a performance decrease, hot or cold spots, and short-circuiting of flow patterns. Routine maintenance is an important component of proper condenser operation.

### B.9.2 Indicators of Condenser Performance

The primary indicators of the performance of condensers are the condenser outlet VOC concentration and condenser outlet gas temperature. Other parameters that indicate condenser performance include coolant inlet temperature, coolant outlet temperature, exhaust gas flow rate, pressure differential across condenser, coolant flow rate, pressure differential across coolant recirculation system, and condensate collection rate. Each of these indicators is described below. Table B-9 lists these indicators and illustrates potential monitoring options for condensers.

Outlet VOC concentration. The most direct indicator of condenser performance in removing specific organic compounds from the exhaust stream is the concentration of those compounds at the condenser outlet; however, measuring concentrations of specific compounds may be impractical. For most applications, the most practical and direct indicator of condenser performance is the outlet VOC concentration.

Outlet gas temperature. The temperature of the gas exiting the condenser is a key indicator of condenser performance. The temperature necessary to achieve a specific outlet concentration of a compound can be determined based upon engineering principles. Increases in outlet temperature can indicate a problem with the condenser, such as plugging, or an increase in process gas temperature as it enters the condenser. In either case, removal rates are likely to decrease as condenser outlet temperature increases.

Condensate collection rate. The rate at which condensate is collected from the condenser provides a direct measure of the rate of organics removal from the process exhaust gas stream. This parameter is a useful indicator of condenser performance only if the process gas stream characteristics (flow rate, temperature, concentrations of organic constituents) do not vary significantly, or if process input data (i.e., usage) are being used in conjunction with the condensate removal data to conduct a material balance and calculate control efficiency or emission rate.

Coolant inlet temperature. The temperature of the coolant as it enters the condenser provides a good indication the condenser is operating as designed. If the incoming process gas stream flow rate and temperature do not vary significantly, coolant inlet temperature can be a reliable indicator of condenser performance. However, if the process gas stream characteristics vary, coolant inlet temperature is not a good indicator of condenser performance. Generally,

increases in coolant temperature are likely to result in decreased organic removal from the process exhaust stream.

Coolant outlet temperature. Coolant outlet temperature, together with the coolant inlet temperature and coolant flow rate, affect the degree of heat transfer from the inlet gas stream to the coolant. The heat transfer rate provides a good indicator of condenser performance. However, by itself, this parameter would be a less reliable indicator of condenser performance than other parameters (outlet VOC concentration, condenser outlet gas temperature). The coolant outlet temperature should be monitored in conjunction with other coolant parameters; coolant outlet temperature must be compared to the coolant inlet temperature and flow rate to determine heat transfer and the rate of organic compound removal.

Exhaust gas flow rate. Exhaust gas flow rate determines the gas residence time within the condenser. Higher flow rates result in shorter residence times and less cooling of the inlet process gas stream; higher gas flow rates affect the heat transfer equation. Consequently, the level of organic removal (or the efficiency) would likely decrease with increasing exhaust gas flow rate.

Coolant flow rate. The coolant flow rate affects the rate of heat transfer from the incoming process exhaust gas to the coolant. Decreases in coolant flow rate are likely to result in decreases in organic removal rates. This parameter is of limited use as an indicator of condenser performance unless coolant temperatures also are measured.

Pressure differential across coolant refrigeration system. Increases in the pressure differential through the refrigeration system are an indication of plugging of the tubes and can result in a decrease in coolant flow rate. Decreases in coolant flow rate would adversely affect condenser performance.

Pressure differential across condenser. An increase in pressure differential (resistance to flow) across the condenser is an indication of fouling, plugging, or obstruction of the flow paths around the condenser tubes; as a result, condenser effectiveness would diminish. Fouling would decrease the heat transfer rate from exhaust gas stream to coolant. Pressure differential across the condenser should be maintained within design range. Changes in pressure differential are likely to be gradual over time.

Periodic inspection. An annual inspection of the internal surfaces of the condenser should be performed to check for fouling or corrosion of condenser surfaces.

### B.9.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for condensers:

9a: Monitoring outlet gas temperature.

- 9b: Monitoring inlet coolant temperature, outlet coolant temperature, coolant flow rate, and condensate collection rate.
- 9c: Monitoring VOC concentration (CEMS).

TABLE B-9. SUMMARY OF PERFORMANCE INDICATORS FOR CONDENSERS

Parameters	Performance indication	Approach No.	1	2	3	4
		Illustration No.	9a	9b		9c
		Example CAM Submittals	A3			
		Comment	✓		✓	✓
<b>Primary Indicators of Performance</b>						
Outlet VOC concentration	Direct measure of outlet concentration. Most direct indicator of condenser performance; can be monitored continuously or periodically.					X
Outlet gas temperature	Indicates if gas is being cooled to/below dew point of target compounds; indicator of level of condensation. Too high indicates condensation to the level expected will not occur; increase in outlet temperature may indicate plugging or fouling problems.	X		X		
<b>Other Performance Indicators</b>						
Condensate collection rate	Organic compound removal rate. Useful indicator of condenser performance only if process gas stream characteristics do not vary, or if used in conjunction with material balance.		X			
Coolant inlet temperature	Indicates that condenser is meeting inlet design parameters. Good indicator of performance if inlet gas temperature and flow rate do not vary; increase in coolant inlet temperature indicates organic compound removal rate will be lower.		X			
Coolant outlet temperature	If coolant inlet and outlet temperature and flow rate are measured, indicates level of heat transfer from inlet gas stream. By itself, would be less reliable indicator of performance than other parameters; decrease would indicate decrease in organic compound removal rate (i.e., heat transfer to the coolant is not occurring).		X	X		
Coolant flow rate	Affects heat transfer rate. Decrease indicates decrease in condenser performance; parameter is of limited use without coolant temperature data.		X			

TABLE B-9. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4
		Illustration No.	9a	9b		9c
		Example CAM Submittals	A3			
		Comment	✓		✓	✓
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach No. 1 corresponds to 40 CFR 60, subparts DDD (Polymer Manufacturing), III (SOCMI Air Oxidation), NNN (SOCMI Distillation), SSS (Magnetic Tape), VVV (Polymeric Coating), RRR (SOCMI Reactor); and 40 CFR 63, subparts G (HON), M (Perchloroethylene Dry Cleaning), R (Gasoline Distribution), U (Polymers and Resins I), W (Polymers and Resins II), Y (Marine Tank Vessel Loading), DD (Offsite Waste and Recovery), EE (Magnetic Tape), HH (Oil and Natural Gas), JJJ (Polymer and Resins IV), MMM (Pesticides), and OOO (Polymers and Resins III); 40 CFR 63, subpart M (Perchloroethylene Dry Cleaning) requires both inlet and outlet gas temperatures for condensers on washer units.</li> <li>• Approach No. 3 corresponds to 40 CFR 61, subpart FF (Benzene Waste).</li> <li>• Approach No. 4 corresponds to 40 CFR 60, subparts DDD (Polymer Industry), III (SOCMI Air Oxidation), NNN (SOCMI Distillation), and RRR (SOCMI Reactor); 40 CFR 61, subpart FF (Benzene Waste); and 40 CFR 63, subparts G (HON), R (Gasoline Distribution), U (Polymers and Resins I), Y (Marine Tank Vessel Loading), DD (Offsite Waste and Recovery), HH (Oil and Natural Gas), MMM (Pesticides), OOO (Polymers and Resins III); 40 CFR 63, Subpart EE (Magnetic Tape) requires both inlet and outlet VOHAP concentration.</li> </ul>						



CAM ILLUSTRATION  
No. 9a. CONDENSER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Condenser [072, 073, 074]
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions Unit: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Outlet gas temperature.
- 2.2 Rationale for Monitoring Approach: Condenser outlet gas temperature affects removal efficiency; an increase in outlet gas temperature indicates decreased removal efficiency.
- 2.3 Monitoring Location: Outlet vent of condenser.
- 2.4 Analytical Devices Required: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
  - Reporting units: Degrees Fahrenheit or Celsius (°F, °C).
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet gas temperature measurements concurrent with emissions test;
  - Calculations indicating outlet gas temperature necessary to achieve compliance; or
  - Historical plant records on outlet gas temperature measurements.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

## 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. 9b. CONDENSER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Condenser [072, 073, 074]
- 1.2 Pollutants: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions units: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Inlet and outlet coolant temperatures, coolant flow rate, and condensate collection rate.
- 2.2 Rationale for Monitoring Approach
  - Inlet coolant temperature: Affects removal efficiency; an increase in the coolant temperature decreases removal efficiency; demonstrates that coolant is at design temperature.
  - Outlet coolant temperature: Gives an indication of removal efficiency; a decrease in the outlet coolant temperature decreases removal efficiency.
  - Coolant flow rate: Affects the heat transfer rate.
  - Condensate collection rate: Demonstrates that VOC component is being removed by the condenser; a decrease in collection rate indicates a decrease in removal efficiency.
- 2.3 Monitoring Location
  - Inlet coolant temperature: Front end heads.
  - Outlet coolant temperature: Rear end heads.
  - Coolant flow rate: Front end heads.
  - Condensate collection rate: Condensate pool.
- 2.4 Analytical Devices Required
  - Inlet coolant temperature: Thermocouples, RTDs , or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
  - Outlet coolant temperature: Thermocouples, RTDs , or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
  - Coolant flow rate: Liquid flow meter or other flow device; see section 4 for more information on specific types of instruments.
  - Condensate collection rate: If measured by weight, use of a scale or other weight monitor; if measured by volume, use of a flow meter, tank level indicator, or visually observing changes in the level of the condensate pool tank.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.

- Reporting units:
    - Inlet coolant temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Outlet coolant temperature: Degrees Fahrenheit or Celsius (°F, °C).
    - Coolant flow rate: Gallons per minute (gpm) or pounds per hour (lb/hr).
    - Condensate collection rate: Weight or volume units (pounds, kilograms, liters, gallons, etc.).
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
- Baseline coolant temperature measurements, coolant flow rate, and condensate collection measurements concurrent with emission test;
  - Calculations indicating outlet gas temperature necessary to achieve compliance, baseline outlet gas temperature measurements concurrent with coolant temperature measurements, coolant flow rate, and condensate collection rate; or
  - Historical plant records on coolant temperature, coolant flow rate, and condensate collection rate measurements.
- 2.7 Specific QA/QC Procedures
- Annual process review to determine process or materials changes that could affect the initial determination of condensation parameters.
  - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### 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 Use of these control device parameters are appropriate for process systems where the process vent gas stream characteristics (flow rate, temperature, VOC concentration) are consistent over time.

CAM ILLUSTRATION  
No. 9c. CONDENSER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Condenser [072, 073, 074]
- 1.2 Pollutants  
Primary: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions Unit: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Outlet THC concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of VOC concentration.
- 2.3 Monitoring Location: Outlet vent of the condenser.
- 2.4 Analytical Devices Required: THC analyzer.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet THC concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

- § 51.214 and Appendix P of 40 CFR 51;
- § 60.13 and Appendix B of 40 CFR 60;
- § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63;
- 40 CFR 75;
- subpart H and Appendix IX of 40 CFR 266; or
- comparable requirements established by the permitting authority.

For example, this would include performance specifications 8 and 9 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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## **B.10 ELECTRIFIED FILTER BED**<sup>11,24,25</sup>

### **B.10.1 Background**

Electrified filter beds (EFBs) are used to control particulate matter (PM), including fine dust and smoke particles from flue gas streams. Example applications include wood waste-fired boilers and wood products dryers. In an EFB, fine dust particles are charged in a corona formed by the ionizer, and are then deposited on an electrically polarized bed of pea gravel. The pea gravel is either periodically replaced, or is continuously removed from the filter bed, cleaned in a pneumatic conveyor, and returned to the filter bed; the dust removed from the gravel is sent to a fabric filter.

A typical EFB system can be divided into three sections: the ionizer (corona charger), the filter bed, and the gravel cleaning and recirculation system. As the gas stream passes through the ionizer system, dust particles are electrostatically charged. An ion flux is created in the gas stream by high voltage electrodes; the ions attach to the particles, giving them an electrical charge. The filter bed is formed by pea gravel held between two annular inner and outer louver sets. The louvers are electrically grounded. A cylindrical, metal sheet is suspended between the two louver sets and is held at a high direct current positive voltage. The voltage polarizes the gravel, inducing regions of positive and negative charge. As the gas flows through the filter bed, the negatively charged dust particles are attracted to the positively charged regions on the gravel and are transferred to the surface of the gravel. Cleaned gas collects in the outlet plenum and exits the system.

In some systems, to maintain a constant gas flow and pressure differential across the system, gravel is slowly and continuously removed from the filter bed. The purpose of the gravel cleaning and recirculation system is to clean the gravel and elevate it to the top of the filter bed for reuse. The gravel travels from the bottom of the filter bed, through an infeed pipe, and into the lift line. Agitation in the lift line, along with the loss of gravel charge, dislodges dust from the gravel. The lift line discharges into the disengagement chamber, which decreases the lift air velocity. The cleaned gravel falls into the gravel reserve hopper, and the dust is conveyed with the lift air to a fabric filter. Other systems require manual removal of spent gravel and addition of new gravel on a weekly basis.

A common problem with EFBs is buildup of a glaze on the ionizer or gravel. The combination of dust, condensed hydrocarbons, and condensed moisture in the gas stream forms a hard, powder-like material which settles on the ionizer and gravel. This glaze buildup interferes with the corona charging of the ionizer and the charging of the filter bed. Manufacturers recommend continuous blowdown with air to prevent buildup, and once buildup occurs, it can be removed with low-pressure sandblasting. The EFB has a relatively narrow temperature operating range. The temperature must be low enough to allow condensible hydrocarbons to form into liquid aerosol form for removal in the filter bed, and high enough to ensure that water condensation does not occur. Moisture condensation in the bed can result in an electrical short in the gravel bed, in addition to contributing to the hydrocarbon glaze described above. Manufacturers recommend that EFBs operate at 30°F above the dew point temperature. The

inlet gas stream may be heated in a preheater prior to the EFB to maintain the appropriate temperature.

### B.10.2 Indicators of EFB Performance

Outlet PM concentration and opacity can be monitored for an EFB. The primary operating parameters that are indicators of performance for EFBs are the ionizer voltage, ionizer current, filter bed voltage, filter bed current, filter bed temperature, and the inlet gas temperature. Other parameters that indicate EFB performance include pressure differential and gas flow rate. Each of these indicators is described below. Table B-10 lists these indicators and illustrates potential monitoring options for EFBs.

Outlet PM concentration. Particulate matter CEMS can be used to continuously monitor PM emission concentrations. These instruments are a fairly recent development and have yet to be placed into widespread use.

Opacity. As is the case for nearly all dry PM controls, opacity is an indicator of control device performance. An increase in opacity or visible emissions generally corresponds to a decrease in EFB performance. A continuous opacity monitor may be used, or the visual determination of opacity (Method 9) or visible emissions (modified Method 22) may be made by plant personnel. Condensibles in the outlet gas stream may be an issue if the inlet gas temperature is too high. One manufacturer indicates that inlet gas temperatures above 200°F result in opacity due to vaporization of condensibles that normally are collected on the bed with lower inlet temperatures.

Ionizer current and voltage. Both the voltage and the current are important monitoring parameters for the ionizer. The ionizer is held at high voltage to create the corona. The voltage is increased to a voltage value that corresponds to initiation of the corona; the current is zero until this corona voltage is reached. The voltage then is increased to a maximum voltage above which sparking or short-circuiting occurs, and the current continues to increase as well. In general, higher voltage indicates increased control efficiency, up to this critical sparking voltage. Because the current is zero until the corona voltage is reached and continues to increase along with voltage from this point, it is also an indicator of the amount of corona available for electrical charging of the PM. The current also gives an indication of the PM control efficiency of the EFB; higher current indicates increased control efficiency. The ionizer may become coated with PM and condensed hydrocarbon (hydrocarbon glazing); the ionizer may need frequent low-pressure sand-blasting to remove the coating or continuous air blowdown to prevent coating buildup. A decrease in ionizer current could indicate fouling or buildup of PM and condensed hydrocarbons on the ionizer or that the cleaning system may have malfunctioned. When the ionizer current increases suddenly with low or zero ionizer voltage, a short circuit or coated surfaces are likely.

If only one parameter for the ionizer is measured, the ionizer current should be monitored as it provides an indication of both current and voltage. One manufacturer recommends ionizer



current at 2 to 4 milliamps (mA) for normal operation, with a minimum ionizer current of 1 mA; this manufacturer recommends ionizer voltage of 30 to 40 kilovolts (kV) for normal operation.

Filter bed current and voltage. Both current and voltage are important monitoring parameters for the filter bed. The filter bed voltage is an indicator of the PM control efficiency of the EFB; the voltage indicates the intensity of the electric field in the bed. A decrease in filter bed voltage could indicate an electrical short or a buildup of PM or condensed hydrocarbons on the gravel. The filter bed current is generally low and constant. If the bed current increases suddenly with no corresponding increase in bed voltage or a bed voltage at zero, there is a short in the filter bed (likely caused by moisture condensation and the flue gas temperature approaching the dew point of the gas stream). If only one parameter for the filter bed is to be monitored, it should be the filter bed voltage. One manufacturer recommends that the bed voltage be maintained at 5 to 10 kV and the bed current at 0.5 amps (A).

Filter bed temperature. Electrified filter beds are designed with a narrow operating range for temperature; the filter bed temperature must be maintained above the dew point of the gas stream to avoid water condensation but also maintained at a low enough temperature to allow the hydrocarbons to form into liquid aerosol. The temperature of the filter bed provides a good indication that condensation is not occurring; water condensation may cause an electrical short in the filter bed. Maintaining the filter bed temperature above the dew point also provides a good indication that hydrocarbon glaze is not occurring on the ionizer.

Inlet gas temperature. Electrified filter beds are designed with a narrow operating range for temperature; the temperature of the inlet gas stream must be maintained above the dew point of the stream to avoid moisture condensation and low enough to allow formation of liquid aerosols. To maintain this temperature, the inlet gas stream may be heated in a preheater. A decrease in the inlet gas temperature may cause condensation in the filter bed or hydrocarbon glaze in the ionizer.

Pressure differential. To maintain constant pressure differential across the filter bed, PM-coated gravel must be removed from the filter bed on a regular basis. An increase in pressure differential over the EFB may indicate excessive buildup of PM in the filter bed and indicate a need for an increased gravel removal rate, more frequent removal, or a need to replace the gravel bed. An increase in pressure differential indicates decreased gas flow rate through the filter bed. One EFB manufacturer indicates that a pressure differential of 3 to 5 in. H<sub>2</sub>O gauge is appropriate for normal operation. This manufacturer also indicated that an increase in pressure differential of 10 percent each week can be expected.

Gas flow rate. The gas flow rate through an EFB is an indicator of residence time, and control efficiency is a function of residence time. An increase in the gas flow rate lowers the residence time in the filter bed and lowers the control efficiency.

### B.10.3 Illustrations

The following illustrations present an example of compliance assurance monitoring for an EFB:

- 10a: Monitoring ionizer voltage, ionizer current, filter bed voltage, filter bed current, pressure differential, filter bed temperature, and inlet gas temperature.
- 10b: Monitoring ionizer current, filter bed voltage, and filter bed inlet and outlet temperatures.
- 10c: Monitoring PM concentration (PM CEMS)

TABLE B-10. SUMMARY OF PERFORMANCE INDICATORS FOR EFBs

Parameters	Performance indication	Approach No.	1	2	3	4
		Illustration No.	10a	10b		10c
		Example CAM Submittals			A.11	
		Comment				
<b>Primary Indicators of Performance</b>						
Outlet PM concentration	PM concentration is the most direct indicator of EFB performance.					X
Opacity	Increased opacity/VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.					
Ionizer current	Partial indicator of power consumption of the corona. Want highest current/voltage without sparking or short-circuit. Decreased current can indicate fouling on the ionizer. Increased current with low or zero voltage indicates short-circuit.	X	X	X		
Ionizer voltage	Partial indicator of power consumption of the corona. Want highest current/voltage without sparking or short-circuit. Increased voltage corresponds with increased control efficiency up to a maximum voltage above which sparking occurs. Decreased voltage indicates decreased control efficiency due to lower corona. Best if monitored in conjunction with ionizer current.	X				
Filter bed voltage	Partial indicator of power consumption of the bed. Decreased voltage can indicate fouling of the bed.	X	X	X		
Filter bed current	Partial indicator of power consumption of the bed. Increased current with low or zero voltage indicates short-circuit. Best if monitored in conjunction with filter bed voltage.	X				
Filter bed temperature	Indicator of potential for condensation in the filter bed. Condensation can result in gravel coating and decreased control efficiency and can also cause an electrical short in the filter bed.	X	X			
Inlet gas temperature	Indicator of potential for condensation in the ionizer or filter bed. Condensation can result in ionizer coating or gravel coating, an electrical short in the filter bed, and decreased control efficiency.	X			X	
Comments: <ul style="list-style-type: none"> <li>Opacity also may be used in conjunction with any of these approaches.</li> </ul>						

CAM ILLUSTRATION  
No. 10a. ELECTRIFIED FILTER BED FOR PM

## 1. APPLICABILITY

- 1.1 Control Technology: Electrified filter bed (EFB) [079]
- 1.2 Pollutants
  - Primary: Particulate matter (PM)
  - Other:
- 1.3 Process/Emission units: Kilns, coolers, wood products dryers

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Ionizer current, ionizer voltage, filter bed voltage, filter bed current, filter bed temperature, and inlet gas temperature.
- 2.2 Rationale for Monitoring Approach
  - Ionizer current: The current on the ionizer provides an indicator of the voltage. A decrease in current could indicate a malfunction, such as a buildup of PM or condensed hydrocarbons on the ionizer.
  - Ionizer voltage: The voltage indicates that a corona is formed and is generating ions for charging particles.
  - Filter bed voltage: The voltage on the gravel must be maintained so charged PM is attracted to the gravel. A decrease in voltage could indicate a malfunction, such as a short or a buildup of PM or condensed hydrocarbons on the gravel.
  - Filter bed current: A sudden increase in bed current with no corresponding increase in bed voltage or a bed voltage at zero indicates a short in the filter bed.
  - Filter bed temperature: An EFB is designed to operate within a relatively narrow temperature operating range. The temperature inside the unit should remain above the dew point of the gas stream being treated because condensation within the system could result in an electrical short in the gravel bed.
  - Inlet gas temperature: An EFB is designed to operate within a relatively narrow temperature operating range. The temperature inside the unit should remain above the dew point of the gas stream being treated because condensation within the system could result in an electrical short in the gravel bed.

(Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 2.3 Monitoring Location
  - Ionizer current: Measure current to ionizer electrode (after transformer-rectifier).
  - Ionizer voltage: Measure voltage of ionizer electrode (after transformer-rectifier).
  - Filter bed voltage: Measure voltage of filter bed electrode (after transformer-rectifier).
  - Filter bed current: Measure current to filter bed electrode (after transformer-rectifier).
  - Filter bed temperature: Measure at the outlet of the filter bed.
  - Inlet gas temperature: Measure at the inlet duct to the EFB.

#### 2.4 Analytical Devices Required

- Ionizer current: Ammeter.
- Ionizer voltage: Voltmeter.
- Filter bed voltage: Voltmeter.
- Filter bed current: Ammeter.
- Filter bed temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
- Inlet gas temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.

#### 2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
- Reporting units:
  - Ionizer current: Milliamps.
  - Ionizer voltage: Kilovolts.
  - Filter bed voltage: Kilovolts.
  - Filter bed current: Amps.
  - Filter bed temperature: Degrees Fahrenheit or Celsius as appropriate.
  - Inlet gas temperature: Degrees Fahrenheit or Celsius as appropriate.
- Recording process: Operators log data manually, or automatically recorded on strip chart or data acquisition system.

#### 2.6 Data Requirements

- Baseline ionizer voltage, ionizer current, filter bed voltage, filter bed current, inlet gas temperature, and filter bed temperature measurements concurrent with emissions test.
- Historical plant records of ionizer voltage, ionizer current, filter bed voltage, filter bed current, inlet gas temperature, and filter bed temperature measurements.

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

### 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. 10b. ELECTRIFIED FILTER BED FOR PM

## 1. APPLICABILITY

- 1.1 Control Technology: Electrified filter bed (EFB) [079]
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other:
- 1.3 Process/Emission units: Kilns, coolers, wood products dryers

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Ionizer current, filter bed voltage, and filter bed temperature.
- 2.2 Rationale for Monitoring Approach
  - Ionizer current: The current on the ionizer provides an indicator of the voltage. A decrease in current could indicate a malfunction, such as a buildup of PM or condensed hydrocarbons on the ionizer.
  - Filter bed voltage: The voltage on the gravel must be maintained so charged PM are attracted to the gravel. A decrease in voltage could indicate a malfunction, such as a short or a buildup of PM or condensed hydrocarbons on the gravel.
  - Filter bed temperature: An EFB is designed to operate within a relatively narrow temperature operating range. The temperature inside the unit should remain above the dew point of the gas stream being treated because condensation within the system could result in an electrical short in the gravel bed.  
(Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 2.3 Monitoring Location
  - Ionizer current: Measure current to ionizer electrode (after transformer-rectifier).
  - Filter bed voltage: Measure voltage of filter bed electrode (after transformer-rectifier).
  - Filter bed temperature: Measure at the outlet of the filter bed.
- 2.4 Analytical Devices Required
  - Ionizer current: Ammeter.
  - Filter bed voltage: Voltmeter.
  - Filter bed temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
  - Reporting units:
    - Ionizer current: Milliamps.
    - Filter bed voltage: Kilovolts.
    - Filter bed temperature: Degrees Fahrenheit or Celsius as appropriate.

- Recording process: Operators log data manually, or automatically recorded on strip chart or data acquisition system.
- 2.6 Data Requirements
- Baseline ionizer current, filter bed voltage, and filter bed temperature measurements concurrent with emissions test.
  - Historical plant records of ionizer current, filter bed voltage, and filter bed temperature measurements.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### 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. 10c. ELECTRIFIED FILTER BED FOR PM

## 1. APPLICABILITY

- 1.1 Control Technology: Electrified filter bed (EFB) [079]
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other:
- 1.3 Process/Emission units: Kilns, coolers, wood products dryers

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators to be Monitored: Outlet PM concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of PM concentration.
- 2.3 Monitoring Location: At outlet stack of EFB.
- 2.4 Analytical Devices Required: PM CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: instrument response (e.g., milliamperes), or concentration (e.g., grains per dry standard cubic feet [gr/dscf], milligrams per dry standard cubic meter [mg/dscm]).
  - Recording process: Automatically recorded on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet PM concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: An initial correlation test to develop the relationship between PM concentration and instrument response is required. QA/QC should, as a minimum, include: periodic calibration and drift checks, routine maintenance, and inventory of spare parts. Calibrate, maintain, and operate the CEMS using procedures that take into account the manufacturer's specifications.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a PM continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented.
- 3.2 Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;



§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;  
subpart H and Appendix IX of 40 CFR 266; or  
comparable requirements established by the permitting authority.

For PM CEMS, this includes Performance Specification 11 of 40 CFR 60, Appendix B.

- 3.3 Indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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## **B.11 CARBON ADSORBERS<sup>1,2,27</sup>**

### **B.11.1 Background**

Carbon adsorbers control VOC emissions in exhaust gas streams. Adsorbers are used for both air pollution control and solvent or product recovery. There are three basic types of adsorption systems, which can be categorized by the manner in which the adsorbent bed is maintained or handled during the adsorption and regeneration cycles. These three types of systems are: (1) fixed or stationary bed, (2) moving bed or rotary concentrator, and (3) fluidized bed. The stationary bed design is the most common. Units typically have two identical beds, one adsorbing while the other is desorbing, but may also consist of multiple identical beds depending on the volumetric flow and concentration of the stream to be controlled. In a typical stationary bed system, the vapor is collected from various point sources, transported through a particulate filter and into one of two carbon adsorption beds. As the carbon adsorber operates, three zones form within the bed: the saturated zone, mass transfer zone, and fresh zone. In the saturated zone, which is located at the entrance to the bed, the carbon has already adsorbed its working capacity of VOC; no additional mass transfer can occur in this zone. The mass transfer zone is where VOC is removed from the gas stream. The carbon in this zone is at various degrees of saturation, but is still capable of adsorbing VOC. The fresh zone is the region of the bed that has not encountered VOC-laden air since the last regeneration. This zone has a full working capacity available for adsorption of additional VOC.

As the carbon bed operates, the mass transfer zone moves through the bed in the direction of flow toward the bed outlet. Breakthrough occurs when the mass transfer zone first reaches the bed outlet. At this point, a sharp increase in the outlet VOC concentration occurs. The available adsorption time (the time before breakthrough occurs) depends on the amount of carbon in the bed, the working capacity of the bed, and the VOC concentration and mass flow rate of the gas stream. Once the breakthrough point is reached, the carbon bed must be regenerated. When this occurs, the flow of VOC-laden air is redirected to the second bed, while the first bed undergoes a regeneration cycle.

Most carbon adsorption beds are regenerated using steam. Regeneration removes the adsorbed VOC vapor from the carbon and restores the carbon's ability to adsorb VOC for the next cycle. The steam desorbs the VOC from the carbon bed and carries the VOC through a condenser, then through a decanter and/or distillation column for separation of the VOC from the steam condensate. An ambient air stream is often passed through the bed to dry the bed and reduce the bed temperature following the steam desorption. The regenerated carbon bed is then ready to be put back online before the second bed reaches breakthrough.

Carbon bed systems may also be regenerated by vacuum. Regeneration is accomplished with a combination of high vacuum and purge air stripping.

A moving bed or rotary concentrator adsorber consists of a rotating cylindrical shell within which is a second cylindrical shell containing the carbon bed. The carbon bed is partitioned into several pie-shaped sections that are parallel to the axis of the shell. The VOC-

laden gas enters the unit, flows through a section of the bed, then exits the unit. As the unit operates, one section of the bed is online, while the section that has just come offline undergoes regeneration. During each rotation of the unit, each bed section undergoes an adsorption cycle and a regeneration cycle. Regeneration of a rotary concentrator unit is often conducted with hot gas rather than steam or vacuum. Two advantages of rotary adsorbers are lower pressure differentials and shorter bed lengths. The main disadvantage of rotary bed adsorbers is that, unlike stationary bed units, rotary bed units contain moving parts and seals that contact moving parts.

In a fluidized bed adsorber, the VOC-laden gas flows up through the carbon at high velocity. The granular carbon, which is fluidized by the upward flowing gas, migrates to the bottom of the bed, where it continuously exits the bed and is transported to a separate regeneration chamber, then fed back into the top of the bed. The countercurrent movement of the incoming gas and carbon increases the effectiveness of the carbon. The main disadvantage to a fluidized bed adsorber is that some carbon is suspended in the outlet gas stream and is lost.

Adequate auxiliary equipment is needed to collect, transport, and filter vapor-laden air streams to a carbon adsorber. The ducts and piping must be sized properly for the air flows required to optimize adsorber efficiency. A fan forces the gas stream into and out of the unit; designing and sizing this equipment is critical. The placement of a particulate matter (PM) filter varies, depending on the adsorber configuration and the inlet gas stream characteristics. Placed before the inlet air stream (in stationary or rotary bed units), the PM filter will reduce possible contamination of the adsorbent and fouling of the bed. In a fluidized-bed adsorber, the PM filter is placed at the outlet to reduce emissions of suspended carbon. Additional auxiliary equipment is also required for recovery of the contaminant from the regeneration cycle. Generally, a condenser and separator installed in series are used to recover VOC from the regeneration stream in traditional fixed bed units with stream regeneration. For rotary concentrators or moving bed units, other devices such as thermal oxidizers or catalytic oxidizers may be used to handle the regeneration stream.

Inlet gas stream characteristics are important to the design and operation of adsorption systems. Characteristics that may be important include: specific compounds present in the gas stream and their concentration, flow rate, temperature, and relative humidity.

Bed fouling and channeling gradually reduce the carbon's adsorption capacity. Carbon particles erode with time, the capillaries become plugged with contaminants, and the carbon may become masked. This erosion and contamination results in the carbon granules losing their ability to adsorb and retain VOC molecules; consequently, control efficiency decreases over time. A routine maintenance program should provide for scheduled inspections of all equipment components as well as all necessary monitoring of operating parameters to ensure continued proper operation of the control equipment. Four major categories of system components that require routine maintenance include: air handling, adsorbing, regeneration, and recovery. Routine maintenance also may include yearly sampling and testing of the carbon to evaluate its working capacity.

### B.11.2 Indicators of Carbon Adsorber Performance

The primary indicators of the performance of carbon adsorbers are the adsorber outlet VOC concentration, regeneration cycle timing, total regeneration stream (steam or nitrogen) flow or the vacuum achieved during regeneration, and carbon bed activity sampling. Other indicators of adsorber performance include bed operating temperature, inlet gas temperature, gas flow rate, inlet VOC concentration, pressure differential, inlet gas moisture content, and leak check monitoring. Each of these indicators is described in the following paragraphs. Table B-11 lists these indicators and illustrates potential monitoring options for carbon adsorbers.

Outlet VOC concentration. The most direct indicator of performance of a carbon adsorber in removing VOC from the exhaust stream is the VOC concentration at the bed outlet.

Regeneration cycle timing or Bed replacement interval. The timing of the regeneration cycle is critical to the continued performance of a carbon adsorber. Specifically, the frequency and length of regeneration cycles are key operating parameters that affect the adsorption capacity of the bed. If regeneration cycles do not occur before or immediately after breakthrough, periods of high VOC emissions are likely. In addition, the length of regeneration cycles must be adequate to allow complete or near complete desorption of the bed. Otherwise, breakthrough will occur sooner once the bed is back online.

If the carbon bed is not regenerated onsite (e.g., if a carbon drum is used and sent back to the manufacturer for regeneration), the replacement interval is an important parameter. The amount of time the unit is online and adsorbing VOC will indicate when it is time to replace the unit, based on the rated capacity of the unit and a mass balance calculation.

Total regeneration stream flow. This parameter is important for carbon beds regenerated using steam or nitrogen. The total regeneration stream flow, which is a measure of the total mass of the regenerating fluid (e.g., steam, nitrogen) used over the course of a complete regeneration cycle, determines the extent to which the bed is desorbed during regeneration. If the total regeneration stream flow decreases, the bed may not be fully regenerated when it is put back online (depending on the VOC loading during the adsorption cycle), and the bed may reach breakthrough sooner than expected.

Vacuum profile during regeneration cycle. The vacuum profile during regeneration is an important variable in the performance of the unit. Sufficient vacuum must be achieved at a long enough interval to assure desorption of VOC from the carbon bed. If the carbon bed is saturated, the time to achieve certain vacuum levels will be longer. This parameter is important only for carbon beds that employ vacuum regeneration.

Carbon bed activity sampling. When the carbon in the bed becomes contaminated or masked or erodes over time, the carbon loses its adsorptive ability and the control efficiency of the unit decreases. The carbon should be tested periodically to determine its activity.

Bed operating temperature and Bed regeneration temperature. The adsorptive capacity of the bed decreases with increasing bed temperature. Therefore, bed operating temperature can provide an indication of the need to adjust the regeneration cycle frequency. The bed temperature also can indicate problems in the unit (e.g., VOC combustion in the bed). For steam regeneration, measuring the maximum temperature achieved during the regeneration cycle can indicate that a temperature sufficient to regenerate the bed was reached (e.g., a temperature at or above the boiling point of the least volatile component). Similarly, measuring the minimum temperature achieved before the regenerated bed is placed back into adsorption service indicates that the bed has cooled sufficiently to operate within the prescribed range of bed operating temperature.

Inlet gas temperature. The bed operating temperature is a better indicator of adsorber performance than inlet gas temperature because inlet temperature measurements do not account for chemical reactions occurring within the bed that generate additional heat. However, if monitoring bed temperature is impractical, monitoring the inlet gas temperature is an option.

Gas flow rate. An increase in gas flow rate results in a decrease in the time period before the carbon bed reaches breakthrough. By monitoring the gas flow rate, regeneration cycle timing can be adjusted as needed. The pressure in the carbon adsorber inlet duct can be used as an indicator of flow and can be used to trigger bypass if excess pressure builds up in the inlet line.

Inlet VOC concentration. The inlet VOC concentration can be monitored to ensure that the adsorption system is operating within design limits. If inlet VOC concentrations increase, it may be necessary to change the timing of the regeneration cycles. If an applicable rule requires the control device to achieve a certain control efficiency, monitoring the inlet and outlet VOC concentration provides the most accurate measurement of compliance.

Pressure differential. An increase in pressure differential across the adsorber is an indication of bed fouling or plugging. A decrease in pressure differential across the bed may indicate channeling (the vapor is not flowing through all areas of the bed).

Inlet gas moisture content. At moderate to low inlet VOC concentrations (less than 1,000 ppm), moisture competes with adsorbate (VOC) for adsorption sites on the carbon. As a result, the adsorptive capacity of the bed is reduced and adjustments should be made to the regeneration cycle timing.

Leak check. Vapor leaks in the vapor collection or recovery system mean VOC emissions are not being controlled. Periodic checks while the unit is online ensure that there are no leaks and all captured VOC emissions are routed to the carbon adsorber. A leak is defined as greater than or equal to 10,000 ppmv, as methane.

### B.11.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for carbon adsorbers:

- 11a: Regeneration cycle frequency, total regeneration stream flow, maximum bed temperature during regeneration cycle, minimum bed temperature at end of cooling cycle, and carbon bed activity.
- 11b: Monitoring bed replacement interval.
- 11c: Monitoring VOC concentration (CEMS).

TABLE B-11. SUMMARY OF PERFORMANCE INDICATORS FOR CARBON ADSORBERS

Parameter	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	
		Illustration No.		11a		11b					11c	
		Example CAM Submittals	A18						A5	A24		
		Comment		✓		✓	✓	✓		✓		
<b>Primary Indicators of Performance</b>												
Outlet VOC concentration	Direct measure of outlet concentration. Most direct indicator of adsorber performance; can be monitored continuously or periodically.	X						X		X		
Regeneration cycle timing	Key factor in determining adsorptive capacity of bed. If regeneration cycles are too infrequent, VOC emissions may be excessive; if regeneration times are too short, the adsorption capacity of the bed is reduced.		X								X	
Bed replacement interval	For non-regenerative units, frequency of carbon replacement is important.				X							
Total regeneration stream flow	Indicates extent to which bed is desorbed (regenerated). Decreases in regeneration stream flow result in a shorter time period to reach breakthrough.		X	X								
Vacuum profile during regeneration cycle	Indicates extent to which bed is desorbed (regenerated). If the maximum vacuum is not achieved during the regeneration cycle, the bed may not be fully regenerated and may reach breakthrough more quickly during the next adsorption cycle.								X		X	
Carbon bed activity sampling	Indicates contamination or masking of the carbon and its adsorptive ability; the control efficiency of the unit decreases as carbon activity decreases.		X						X			



TABLE B-11. (Continued)

Parameter	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	
		Illustration No.		11a		11b					11c	
		Example CAM Submittals	A18						A5	A24		
		Comment		✓		✓	✓	✓			✓	
<b>Other Performance Indicators</b>												
Bed operating temperature	Affects adsorptive capacity of bed. Indicates problems such as fire in the bed. Adsorptive capacity decreases with increasing temperature.											
Bed regeneration temperatures	Measuring maximum temperature during regeneration cycle assures temperature required for regeneration was reached; measuring minimum temperature to which bed is cooled after regeneration before adsorption cycle begins assures bed is at proper operating temperature; applies to steam regeneration only.		X	X			X					
Inlet gas temperature	Indirect indicator of bed operating temperature. See comments for <i>Bed operating temperature</i> . Not as useful as bed operating temperature but can be used as an alternative.						X					
Inlet VOC concentration	Indicator that system is operating within design limits. Increases in VOC concentrations may require adjustments to regeneration cycle timing.							X				
Leak check of unit	Identifies vapor leaks in the system and reduces VOC emissions from leaks; a leak is defined as greater than or equal to 10,000 ppmv, as methane.	X								X		

TABLE B-11. (Continued)

Parameter	Performance indication	Approach No.	1	2	3	4	5	6	7	8	9	
		Illustration No.		11a		11b					11c	
		Example CAM Submittals	A18						A5	A24		
		Comment		✓		✓	✓	✓		✓		
<p>Comments:</p> <ul style="list-style-type: none"> <li>• Approach 2 corresponds to 40 CFR 63, subpart MMM (Pesticides)</li> <li>• Approach 3 corresponds to 40 CFR 60, subparts III (SOCMI Air Oxidation), NNN (SOCMI Distillation), and RRR (SOCMI Reactor); 40 CFR 63, subparts G (HON), U (Polymers and Resins I), Y (Marine Tank Vessel Loading), DD (Offsite Waste and Recovery), HH (Oil and Natural Gas), JJ (Wood Furniture), KK (Printing and Publishing), JJJ (Polymer and Resins IV), and OOO (Polymers and Resins III).</li> <li>• Approach 4 corresponds to 40 CFR 60, subpart FF; 40 CFR 63, subparts G (HON), DD (Offsite Waste and Recovery), EE (Magnetic Tape), GG (Aerospace), HH (Oil and Natural Gas), and MMM (Pesticides).</li> <li>• Approach 5 corresponds to 40 CFR 61, subpart E (Mercury).</li> <li>• Approach 6 corresponds to 40 CFR 63, subparts EE (Magnetic Tape) and GG (Aerospace).</li> <li>• Approach 8 corresponds to 40 CFR 60, subparts BBB (Rubber Tire), DDD (Polymer Industry), III (SOCMI Air Oxidation), NNN (SOCMI Distillation), QQQ (Petroleum Refinery Wastewater), RRR (SOCMI Reactor), SSS (Magnetic Tape), and VVV (Polymeric Coating); 40 CFR 61, subparts L (Benzene from Coke By-product), BB (Benzene Transfer), FF (Benzene Waste); 40 CFR 63, subparts G (HON), M (Perchloroethylene Dry Cleaning), R (Gasoline Distribution), T (Halogenated Solvents), U (Polymers and Resins I), W (Polymers and Resins II), Y (Marine Tank Vessel Loading), DD (Offsite Waste and Recovery), EE (Magnetic Tape), GG (Aerospace), HH (Oil and Natural Gas), JJ (Wood Furniture), KK (Printing and Publishing), III (Flexible Polyurethane Foam), MMM (Pesticides), and OOO (Polymers and Resins III).</li> <li>• Approach 9 corresponds to 40 CFR 63, subpart Y (Marine Vessels).</li> </ul>												

CAM ILLUSTRATION  
No. 11a. CARBON ADSORBER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Carbon adsorption system [048]
- 1.2 Pollutants
  - Primary: Volatile organic compounds (VOCs)
  - Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, bed temperature to which bed is cooled after regeneration, and carbon activity.
- 2.2 Rationale for Monitoring Approach
  - Regeneration cycle timing: The timing of the regeneration cycle is critical to the continued performance of the carbon adsorber. The minimum regeneration frequency (i.e., operating time since last regeneration) is established and monitored.
  - Total regeneration stream flow: The total regeneration stream flow determines the extent to which the bed is desorbed during regeneration. If the total regeneration stream flow decreases, the bed may not be fully regenerated when it is put back online.
  - Bed regeneration temperature: Measuring the temperature achieved during the regeneration cycle indicates that a temperature sufficient to regenerate the bed was reached.
  - Bed temperature after regeneration: The adsorptive capacity of the carbon bed decreases with increasing bed temperature. Monitoring the bed temperature after regeneration assures the proper operating temperature is achieved before returning the bed to the absorption cycle.
  - Carbon activity: Periodic checks of the bed for poisoning assure that bed activity still meets specifications.

(Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 2.3 Monitoring Location
  - Regeneration cycle timing: Each bed.
  - Total regeneration stream flow: Carbon bed inlet during each regeneration cycle.
  - Bed regeneration temperature: Each carbon bed.
  - Bed temperature after regeneration: Each carbon bed.
  - Carbon activity: Sample of bed material.

#### 2.4 Analytical Devices Required

- Regeneration cycle timing: Clock.
- Total regeneration stream flow: Mass flow meter.
- Bed regeneration temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
- Bed temperature after regeneration: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
- Carbon activity: Analytical laboratory to evaluate per manufacturer's instructions.

#### 2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement:
  - Regeneration cycle timing: Each cycle.
  - Total regeneration stream flow: Hourly, or continuously during each regeneration cycle on strip chart or data acquisition system.
  - Bed regeneration temperature: Hourly, or continuously during each regeneration cycle on strip chart or data acquisition system.
  - Bed temperature after regeneration: Hourly, or continuously during cooling cycle, on strip chart or data acquisition system.
  - Carbon activity: Annually.
- Reporting units:
  - Regeneration cycle timing: Minutes or hours.
  - Total regeneration stream flow: Pounds or other unit of mass.
  - Bed regeneration temperature: Degrees Fahrenheit or degrees Celsius.
  - Bed temperature after regeneration: Degrees Fahrenheit or degrees Celsius.
  - Carbon activity: Activity level per manufacturer's specifications.
- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

#### 2.6 Data Requirements

- Baseline regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, and bed temperature after regeneration measurements concurrent with emission test data, and manufacturer's (supplier's) specifications for carbon activity.
- Historical plant records on regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, bed temperature after regeneration measurements, and carbon activity levels.

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

### 3. COMMENTS

None.

CAM ILLUSTRATION  
No. 11b. CARBON ADSORBER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Non-regenerative carbon adsorption system [048]
- 1.2 Pollutants
  - Primary: Volatile organic compounds (VOCs)
  - Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Bed replacement interval.
- 2.2 Rationale for Monitoring Approach
  - Bed replacement interval: The carbon replacement interval ensures that periods of high VOC emissions do not occur. The replacement interval can be determined based on design and engineering calculations (e.g., mass balance).
- 2.3 Monitoring Location
  - Bed replacement interval: Each carbon bed.
- 2.4 Analytical Devices Required
  - Bed replacement interval: Timers or alternative methods/instrumentation that conform to performance specifications acceptable to the Administrator.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Bed replacement interval: Each cycle.
  - Reporting units:
    - Bed replacement interval: Hours, days, months, or other unit of time, as appropriate.
  - Recording process:
    - Bed replacement interval: Operators log replacement interval data manually.
- 2.6 Data Requirements
  - Design and mass balance calculations on which the replacement interval is based; or
  - Historical plant records on bed replacement interval with periodic VOC measurements establishing that interval is adequate.
- 2.7 Specific QA/QC Procedures: NA.

## 3. COMMENTS

- 3.1 The time interval may be based upon design calculations under worst case conditions. Alternatively, the VOC concentration level in the exhaust vent stream from the adsorption system may be periodically monitored (e.g., daily or at an interval no greater

than 20 percent of the time required to consume the total carbon working capacity under worst case conditions) to assure breakthrough has not occurred.

CAM ILLUSTRATION  
No. 11c. CARBON ADSORBER FOR VOC CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Carbon adsorption system [048]
- 1.2 Pollutants
  - Primary: Volatile organic compounds (VOCs)
  - Other: Higher molecular weight organic compounds
- 1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet THC concentration.
- 2.2 Rationale for Monitoring Approach: Direct measurement of VOC concentration.
- 2.3 Monitoring Location: At outlet stack of carbon adsorber.
- 2.4 Analytical Devices Required: THC analyzer.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically recorded on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet THC concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

- § 51.214 and Appendix P of 40 CFR 51;
- § 60.13 and Appendix B of 40 CFR 60;
- § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63;
- 40 CFR 75;

subpart H and Appendix IX of 40 CFR 266; or comparable requirements established by the permitting authority. For example, this would include performance specifications 8 and 9 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).



## **B.12 CYCLONES**<sup>1,2,9,15</sup>

### **B.12.1 Background**

A cyclone is a mechanically aided collector that uses inertia to separate PM from the gas stream as it spirals through the cyclone. The collection efficiency of a cyclone improves as the number of revolutions made by the gas and the gas velocity increase. Ultimately, however, the overall performance depends on the particle size distribution of the incoming gas stream. Cyclones are generally used for collection of medium-sized and coarse particles.

Cyclone designs can be classified according to the manner by which the gas stream enters and exits the cyclone as: tangential inlet, axial dust outlet; tangential inlet, peripheral dust outlet; axial inlet, axial dust outlet; and axial inlet, peripheral dust outlet. In general, a vortex is created in the cylinder by injecting gas tangentially or using a spin vane. In the cyclone, the gas makes one or more revolutions, spiraling toward the bottom or end of the cyclone. Because of inertia, the particles resist the direction change as the gas turns, and they migrate toward the cylinder walls. Near the bottom of the cylinder, the gas changes direction and turns back toward the outlet duct, flowing through the center of the spiral; the particles are discharged downward or tangentially and are collected in a hopper.

Cyclones have a relatively simple construction and generally have no moving parts. Simple cyclones consist of an inlet cylindrical section, conical section, outlet gas duct, outlet dust tube, and collection hopper; a cyclone uses an induced draft fan to move the gas stream through the device. They are sized to provide the maximum inlet velocity possible for high separation without excessive turbulence. Multiclones (or multicyclones) consist of multiple small-diameter tubes in parallel, each of which acts like a small cyclone. This configuration combines the high efficiency of a small diameter with the ability to treat large gas volumes. Multiclone collection efficiency can be further improved by slip-streaming, in which a small portion of the gas is drawn through the collection hopper to create suction on the dust outlet tube and reduce dust re-entrainment into the multiclone tubes. Multiclones are sized to include the minimum number of tubes needed to treat the required gas volume without exceeding the maximum flow per tube.

Common operational problems experienced with cyclones and multiclones include erosion of cyclone components that come into contact with high velocity particles; plugging of the dust outlet or the gas inlet vanes; corrosion from contact with acid gases in the inlet gas stream; and air inleakage that affects the inlet velocity and control efficiency of the cyclone.

### **B.12.2 Indicators of Cyclone Performance**

The primary indicators of the performance of cyclones are the outlet opacity and inlet velocity. Other indicators of cyclone performance are the pressure differential across the cyclone and inlet gas temperature. Each of these indicators is described below. Table B-12 lists these indicators and illustrates potential monitoring options for cyclones.

Opacity. As is the case for all dry PM controls, opacity is an indicator of control device performance. An increase in opacity or visible emissions generally corresponds to a decrease in cyclone performance.

Inlet velocity or Inlet gas flow rate. Among other factors, cyclone control efficiency is a function of inlet velocity. As velocity increases, the inertial forces acting on particles in the gas stream increase, as does the likelihood that particles will impact the cyclone wall and be transported to the collection hopper. However, as velocity increases, turbulence forms in the gas stream and disrupts gas flow. Beyond a critical velocity, control efficiency decreases with increasing velocity. Below this critical velocity, decreases in velocity result in reductions in control efficiency.

Pressure differential. Because pressure differential across a cyclone is primarily a function of velocity, it can be used as a surrogate for velocity measurements. Therefore, up to the pressure differential that corresponds to the critical velocity, control efficiency increases with increasing pressure differential.

Inlet temperature. As temperature increases, gas density decreases, which can result in a decrease in collection efficiency. A change in gas temperature and density affects the inlet velocity. Monitoring inlet temperature applies to control of thermal processes only. However, the other parameters listed above are more reliable indicators of cyclone performance.

Periodic inspections. Periodic inspections of the cyclone for corrosion/erosion and damage resulting in air in-leakage should be conducted in conjunction with other monitoring.

### B.12.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for cyclones:

- 12a: Monitoring cyclone inlet gas velocity (inlet gas flow rate).
- 12b: Monitoring pressure differential across cyclone.

TABLE B-12. SUMMARY OF PERFORMANCE INDICATORS AND MONITORING OPTIONS FOR CYCLONES

Parameters	Performance indication	Approach No.	1	2	3
		Illustration No.	12a	12b	
		Example CAM Submittals			
		Comment			
<b>Primary Indicators of Performance</b>					
Opacity/visible emissions	Increased opacity or VE denotes performance degradation. COMS, opacity observations, or visible/no visible emissions.				X
Inlet gas velocity or Inlet gas flow rate	Collection efficiency varies with inlet velocity. Efficiency increases with increasing velocity up to a critical velocity, beyond which turbulence disrupts flow patterns and control efficiency begins to decrease.	X			
Pressure differential	Indicator of gas velocity through cyclone. Increase in pressure differential generally indicates an increase in control efficiency, up to a critical pressure differential.		X		
Periodic inspections	Identifies damage from erosion, corrosion, or leaks that reduce performance of cyclone.	X			
Comments: None.					

CAM ILLUSTRATION  
No. 12a. CYCLONE FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Cyclone [075]; also applicable to multiclones with or without fly ash reinjection [076, 077], centrifugal collectors [007, 008, 009], and other types of mechanical collectors and dry inertial separators
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other: Heavy metals
- 1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Inlet gas velocity (Inlet gas flow rate) and periodic inspections.
- 2.2 Rationale for Monitoring Approach:
  - Inlet gas velocity: Control efficiency increases with increased velocity; if inlet velocity exceeds a specific value, turbulence becomes excessive and control efficiency begins to decrease.
  - Periodic inspections: Identify damage resulting from erosion, corrosion, or leaks that results in a reduction in performance.
- 2.3 Monitoring Location:
  - Inlet gas velocity: Inlet gas duct.
  - Periodic inspection: Cyclone.
- 2.4 Analytical Devices Required:
  - Inlet gas velocity: Differential pressure flow meter, anemometer, or other type of device that measures gas velocity or gas flow rate; see section 4.3 for information on specific types of instruments.
  - Periodic inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Inlet gas velocity: Once per shift, or recorded continuously on strip chart or data acquisition system.
    - Periodic inspections: Quarterly, semiannually, or annually.
  - Reporting units:
    - Inlet gas velocity: Feet per minute (ft/min).
    - Periodic inspections: Not applicable.
  - Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.
- 2.6 Data Requirements
  - Baseline inlet gas velocity measurements concurrent with emission test.
  - Historical plant records of inlet gas velocity measurements and periodic inspections.
  - Manufacturer's design specifications and efficiency curve/equation for inlet gas velocity or pressure differential.

2.7 Specific QA/QC Procedures

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

**3. COMMENTS**

- 3.1 Because this illustration applies to a PM source, visible emissions or opacity monitoring is also an appropriate performance indicator.
- 3.2 Data Collection Frequency: For large emission units, a measurement frequency of once per shift or 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. 12b. CYCLONE FOR PM CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Cyclone [075]; also applicable to multiclones with or without fly ash reinjection [076, 077], centrifugal collectors [007, 008, 009], and other types of mechanical collectors and dry inertial separators
- 1.2 Pollutants  
Primary: Particulate matter (PM)  
Other: Heavy metals
- 1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Pressure differential.
- 2.2 Rationale for Monitoring Approach: Control efficiency increases with increasing pressure differential; however, if the pressure differential exceeds a specific value, turbulence becomes excessive and control efficiency decreases. (Pressure differential is a function of inlet gas velocity, and changes in velocity result in changes in pressure differential across device.)
- 2.3 Monitoring Location: Gas 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: Once per shift, 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
  - Manufacturer's design specifications and efficiency curve/equation for inlet velocity and pressure differential.
  - Baseline pressure differential measurements concurrent with emission test.
  - Historical plant records of pressure differential measurements.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

### 3. COMMENTS

- 3.1 Because this illustration applies to a PM source, visible emissions or opacity monitoring is also an appropriate performance indicator.
- 3.2 Data Collection Frequency: For large emission units, a measurement frequency of once per shift would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

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## B.13 DRY INJECTION FABRIC FILTERS<sup>18,19,20</sup>

### 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 SO<sub>2</sub>, 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 PM concentration (PM CEMS)
- 13b: Monitoring sorbent feed rate, fabric filter inlet temperature, opacity, and fabric filter pressure differential.
- 13c: Monitoring sorbent feed rate, fabric filter inlet temperature, and bag leak detector.

TABLE B-13. SUMMARY OF PERFORMANCE INDICATORS FOR DIFFs

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.	13a	13b		13c	
		Example CAM Submittals					
		Comment			✓		
<b>Primary Indicators of Performance</b>							
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
<b>Other Performance Indicators</b>							
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 sorbent is maintained. Lower carrier gas may indicate lower sorbent feed rate and decreased acid removal.						X
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		

TABLE B-13. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.	13a	13b		13c	
		Example CAM Submittals					
		Comment			✓		
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: • Approach No. 3 corresponds to 40 CFR 63, subpart EEE (Hazardous Waste Combustors) • Approach No. 5 corresponds to 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: Hydrogen chloride (HCl)
  - Other:
- 1.3 Process/Emissions units: Combustors, kilns

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Parameters to be Monitored: Outlet HCl concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of HCl concentration.
- 2.3 Monitoring Location: At outlet stack of fabric filter.
- 2.4 Analytical Devices Required: HCl CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet HCl measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

- § 51.214 and Appendix P of 40 CFR 51;
- § 60.13 and Appendix B of 40 CFR 60;
- § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63;
- 40 CFR 75;
- subpart H and Appendix IX of 40 CFR 266; or
- comparable requirements established by the permitting authority.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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 (SO<sub>2</sub>), 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.

### 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. 13c. DIFF FOR ACID GAS CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Dry injection fabric filter (DIFF)
- 1.2 Pollutants  
Primary: Sulfur dioxide (SO<sub>2</sub>), 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.

**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<sup>10,18,19,20</sup>

### 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 SO<sub>2</sub>, 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.

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).

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.

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 outlet acid gas concentration (CEMS).

14b: 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.

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

Parameters	Performance indication	Approach No.	1	2
		Illustration No.	14a	14b
		Example CAM Submittals		
		Comment		
<b>Primary Indicators of Performance</b>				
Outlet acid gas concentration	Direct measure of outlet acid gas concentration. Most direct single indicator of spray dryer performance.		X	
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
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
<b>Other Performance Indicators</b>				
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<sub>x</sub>), 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: Outlet SO<sub>2</sub> concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of SO<sub>2</sub> concentration.
- 2.3 Monitoring Location: At outlet stack of spray dryer.
- 2.4 Analytical Devices Required: SO<sub>2</sub> CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv), pounds per dry standard cubic feet (lb/dscf), or pounds per million British thermal unit (lb/million Btu).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet SO<sub>2</sub> concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;

§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;

subpart H and Appendix IX of 40 CFR 266; or comparable requirements established by the permitting authority. For example, this would include performance specification 2 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

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

## 1. APPLICABILITY

- 1.1 Control Technology: Spray drying [067]
- 1.2 Pollutants  
Primary: Sulfur oxides (SO<sub>x</sub>), 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.
- (Separate, independent indicator ranges typically would be established for each of the parameters; an excursion would occur if any one of the indicator ranges was exceeded.)
- 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.

### 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.

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## B.15 SELECTIVE CATALYTIC REDUCTION<sup>21,22,23</sup>

### B.15.1 Background

Selective catalytic reduction (SCR) is an add-on NO<sub>x</sub> control technology for process gas streams with significant oxygen (O<sub>2</sub>) content. An SCR consists of a catalyst surface, reactor housing and support, ammonia (NH<sub>3</sub>) system (storage tank, vaporizer, injection grid, dilution air system, and control system), CEMS, and control system. The control efficiency achieved for NO<sub>x</sub> ranges from approximately 70 to 90 percent depending on the application. In SCR, NH<sub>3</sub> is injected into the inlet gas stream upstream of the catalyst bed; in the catalyst bed, the NH<sub>3</sub> reacts with NO<sub>x</sub> in the presence of O<sub>2</sub> to form nitrogen (N<sub>2</sub>) and water (H<sub>2</sub>O). The NO<sub>x</sub> reduction efficiency is controlled by the ratio of NH<sub>3</sub> injected to the amount of NO<sub>x</sub> in the gas stream (NH<sub>3</sub>/NO<sub>x</sub>), the catalyst material and condition, the space velocity, and the catalyst bed operating temperature. Increasing the NH<sub>3</sub>/NO<sub>x</sub> ratio increases the level of NO<sub>x</sub> emission reduction but may also result in higher NH<sub>3</sub> slip levels. (Ammonia slip occurs when too much NH<sub>3</sub> is injected and the unreacted portion is emitted in the outlet stream from the SCR.) In general, the outlet concentration of NH<sub>3</sub> from the SCR should be held to less than 5 ppmv. Side reactions may produce ammonium sulfate and ammonium bisulfate byproducts when SO<sub>3</sub> is also present; SO<sub>2</sub> in the process gas stream oxidizes to SO<sub>3</sub> 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<sub>x</sub> emission levels from the process, and various exhaust temperature and NO<sub>x</sub> swings may pose problems for the SCR unit. The complexity of the NH<sub>3</sub> 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 NH<sub>3</sub> slip increases. Above the range, NH<sub>3</sub> may be oxidized to form NO<sub>x</sub>, 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 NH<sub>3</sub> 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<sub>x</sub> reduction rates.

### B.15.2 Indicators of SCR Performance

The primary indicators of SCR performance are outlet NO<sub>x</sub> concentration, NH<sub>3</sub>/NO<sub>x</sub> ratio, catalyst bed inlet temperature, and the catalyst activity. Other parameters that can indicate SCR performance include the outlet NH<sub>3</sub> 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<sub>x</sub> concentration. The most direct single indicator of the performance of a SCR is the NO<sub>x</sub> concentration at the outlet of the unit.

NH<sub>3</sub>/NO<sub>x</sub> ratio (NH<sub>3</sub> injection rate). The NH<sub>3</sub> injection rate should increase or decrease with changes in inlet NO<sub>x</sub> levels due to varying process load. With increasing NH<sub>3</sub>/NO<sub>x</sub> ratio, the NO<sub>x</sub> level and the NH<sub>3</sub> slip remain fairly constant and the SCR reduces NO<sub>x</sub> emissions; however, above a certain value or ratio, the NH<sub>3</sub> slip begins to increase. Limiting the amount of NH<sub>3</sub> slip is important to limit NH<sub>3</sub> emissions from the SCR and to suppress reactions of the additional NH<sub>3</sub> with SO<sub>2</sub> and SO<sub>3</sub>, 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<sub>x</sub> on the catalyst. Too high of an inlet temperature (i.e., of the process gas stream) may cause NO<sub>x</sub> generation in the SCR rather than NO<sub>x</sub> reductions.

Catalyst activity. Catalyst deactivation will result in increases in NO<sub>x</sub> emissions and NH<sub>3</sub> emissions (ammonia slip). Catalyst activity should be checked periodically and/or the catalyst or portion of the catalyst should be replaced periodically.

Outlet NH<sub>3</sub> concentration. NH<sub>3</sub> in the outlet stream is an indicator that too much NH<sub>3</sub> is being injected or that reduction of NO<sub>x</sub> 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<sub>x</sub> generation at high temperatures. In general, lower operating temperatures mean lower NO<sub>x</sub> emissions, to a minimum temperature below which NO<sub>x</sub> reduction does not occur. Increases in the operating temperature of the SCR may cause an increase in NO<sub>x</sub> generation rather than NO<sub>x</sub> 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: Monitoring outlet NO<sub>x</sub> concentration (CEMS).

15b. Catalyst bed temperature, outlet NH<sub>3</sub> concentration, and catalyst activity.

TABLE B-15. SUMMARY OF PERFORMANCE INDICATORS FOR SCR<sub>s</sub>

Parameters	Performance indication	Approach No.	1	2	3	4	5
		Illustration No.	15a	15b			
		Example CAM Submittals					
		Comment					
<b>Primary Indicators of Performance</b>							
Outlet NO <sub>x</sub> concentration	Direct measure of outlet concentration. Best single indicator of SCR performance.		X				
NH <sub>3</sub> /NO <sub>x</sub> ratio (NH <sub>3</sub> injection rate)	Amount of NH <sub>3</sub> injection should be stoichiometrically based on NO <sub>x</sub> concentration in the inlet stream. Want to maximize the ratio without increasing NH <sub>3</sub> 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 <sub>x</sub> rather than a reduction in NO <sub>x</sub> .				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		
<b>Other Performance Indicators</b>							
Outlet NH <sub>3</sub> concentration	Indicator that NH <sub>3</sub> injection rate is too high. Must adjust to reduce NH <sub>3</sub> 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 <sub>x</sub> rather than a reduction in NO <sub>x</sub> .			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<sub>x</sub> CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Selective catalytic reduction [065]
- 1.2 Pollutants  
Primary: Nitrogen oxides (NO<sub>x</sub>)  
Other: Nitric acid (HNO<sub>3</sub>), ammonia (NH<sub>3</sub>)
- 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: Outlet NO<sub>x</sub> concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of NO<sub>x</sub> concentration.
- 2.3 Monitoring Location: At outlet of catalyst bed.
- 2.4 Analytical Devices Required: NO<sub>x</sub> CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet NO<sub>x</sub> concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's recommendations. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

§ 51.214 and Appendix P of 40 CFR 51;  
§ 60.13 and Appendix B of 40 CFR 60;  
§ 63.8 and applicable performance specifications of the applicable subpart of  
40 CFR 63;  
40 CFR 75;  
subpart H and Appendix IX of 40 CFR 266; or  
comparable requirements established by the permitting authority.

For example, this would include performance specification 2 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).



CAM ILLUSTRATION  
No. 15b. SELECTIVE CATALYTIC REDUCTION FOR NO<sub>x</sub> CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Selective catalytic reduction [065]
- 1.2 Pollutants  
Primary: Nitrogen oxides (NO<sub>x</sub>)  
Other: Nitric acid (HNO<sub>3</sub>), ammonia (NH<sub>3</sub>)
- 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 NH<sub>3</sub> concentration in flue gas (NH<sub>3</sub> 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<sub>x</sub> rather than reduce NO<sub>x</sub>.
  - Outlet NH<sub>3</sub> concentration: Indication of NO<sub>x</sub> reduction or indication that NH<sub>3</sub> 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<sub>x</sub> and NH<sub>3</sub>.
- 2.3 Monitoring Location
- Catalyst bed temperature: Outlet to the catalyst bed.
  - Outlet NH<sub>3</sub> concentration: NH<sub>3</sub> 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, NH<sub>3</sub> 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 NH<sub>3</sub> concentration: Measure continuously.
    - Catalyst activity: Measure periodically.
  - Reporting units:
    - Catalyst bed temperature: Degrees Celsius or Fahrenheit (C or F).
    - Outlet NH<sub>3</sub> concentration: Parts per million by volume (ppm<sub>v</sub>) NH<sub>3</sub>.
    - 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 NH<sub>3</sub> 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 NH<sub>3</sub> concentration, and catalyst activity measurements concurrent with emission test.
- Historical plant records of catalyst bed temperature, outlet NH<sub>3</sub> 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.

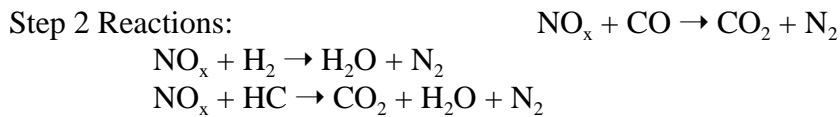
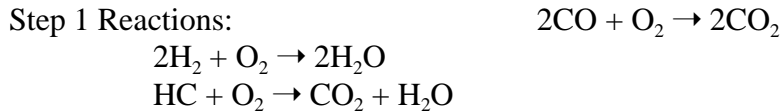
### 3. COMMENTS

None.

## B.16 NONSELECTIVE CATALYTIC REDUCTION<sup>21,22,23</sup>

### B.16.1 Background

Nonselective catalytic reduction (NSCR) is an add-on NO<sub>x</sub> control technology for exhaust streams with low O<sub>2</sub> content. Nonselective catalytic reduction uses a catalyst reaction to simultaneously reduce NO<sub>x</sub>, 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 O<sub>2</sub> from the exhaust gas because CO and HC will more readily react with O<sub>2</sub> than with NO<sub>x</sub>. The O<sub>2</sub> content of the stream must be kept below approximately 0.5 percent to ensure NO<sub>x</sub> reduction.

One type of NSCR system injects a reducing agent into the exhaust gas stream prior to the catalyst reactor to reduce the NO<sub>x</sub>. 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<sub>x</sub> are reduced. A second heat exchanger cools the gas stream (to reduce any NO<sub>x</sub> reformation) before the second catalytic reactor where remaining CO is converted to CO<sub>2</sub>.

The control efficiency achieved for NO<sub>x</sub> ranges from 80 to 90 percent. The NO<sub>x</sub> 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<sub>x</sub> reductions of 90 percent, the temperature must be between 800° to 1200°F. One source indicates that the O<sub>2</sub> concentration for NSCR must be less than 4 percent, and another source indicates that the O<sub>2</sub> 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<sub>3</sub>/NO<sub>x</sub> ratio, outlet NH<sub>3</sub> concentration, and sulfur content of the fuel).

Outlet NO<sub>x</sub> concentration, catalyst bed inlet temperature, catalyst activity, pressure differential across the catalyst bed, catalyst bed outlet temperature, inlet gas flow rate, and outlet O<sub>2</sub> 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 outlet NO<sub>x</sub> concentration (CEMS).
- 16b: Monitoring catalyst bed inlet temperature, catalyst bed outlet temperature, and catalyst activity.

TABLE B-16. SUMMARY OF PERFORMANCE INDICATORS FOR NSCRs

Parameters	Performance indication	Approach No.	1	2	3
		Illustration No.	16a	16b	
		Example CAM Submittals			
		Comment			
<b>Primary Indicators of Performance</b>					
Outlet NO <sub>x</sub> 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	
<b>Other Performance Indicators</b>					
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 <sub>x</sub> .			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 <sub>2</sub> concentration	Indicator of dilution rate. Generally monitored in combination with NO <sub>x</sub> , VOC, or CO concentration to allow for correcting concentration to a specified percent O <sub>2</sub> .		X		
Comments: None.					

CAM ILLUSTRATION  
No. 16a. NONSELECTIVE CATALYTIC REDUCTION FOR NO<sub>x</sub> CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Nonselective catalytic reduction [065]
- 1.2 Pollutants
  - Primary: Nitrogen oxides (NO<sub>x</sub>)
  - Other: Nitric acid (HNO<sub>3</sub>), ammonia (NH<sub>3</sub>)
- 1.3 Process/Emission units: Internal combustion engines (ICE)

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Outlet NO<sub>x</sub> concentration.
- 2.2 Rationale for Monitoring Approach: Direct measure of NO<sub>x</sub> concentration.
- 2.3 Monitoring Location: At outlet of catalyst bed.
- 2.4 Analytical Devices Required: NO<sub>x</sub> CEMS.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement: Continuous.
  - Reporting units: Parts per million by volume (ppmv).
  - Recording process: Automatically on data acquisition system.
- 2.6 Data Requirements
  - Baseline outlet NO<sub>x</sub> concentration measurements concurrent with emissions test.
- 2.7 Specific QA/QC Procedures
  - Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's recommendations. QA/QC should, as a minimum, include: initial calibration, periodic calibration and drift checks, routine maintenance, and inventory of spare parts.

## 3. COMMENTS

- 3.1 This illustration presents a general monitoring approach for using a continuous emissions analyzer as an indicator of performance; the indicator range must be selected and QA/QC procedures appropriate for the application must be implemented. Note that § 64.3(d)(2) of the CAM rule indicates that CEMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria for CAM and further justification for their use are not required:

- § 51.214 and Appendix P of 40 CFR 51;
- § 60.13 and Appendix B of 40 CFR 60;
- § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63;
- 40 CFR 75;
- subpart H and Appendix IX of 40 CFR 266; or
- comparable requirements established by the permitting authority.

For example, this would include performance specification 2 of 40 CFR 60, Appendix A.

- 3.2 Furthermore, indicator ranges need not be specified for CEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emissions occurs. The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3(d)(2) is presumptively acceptable CAM. (See sections 2.2 and 3.4).

CAM ILLUSTRATION  
No. 16b. NONSELECTIVE CATALYTIC REDUCTION FOR NO<sub>x</sub> CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Nonselective catalytic reduction [065]
- 1.2 Pollutants
  - Primary: Nitrogen oxides (NO<sub>x</sub>)
  - Other: Nitric acid (HNO<sub>3</sub>), ammonia (NH<sub>3</sub>)
- 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<sub>x</sub> rather than reduce NO<sub>x</sub>.
  - Catalyst bed outlet temperature: Indication that the reaction is occurring in the catalyst bed; too high a bed temperature may generate NO<sub>x</sub> rather than reduce NO<sub>x</sub>.
  - Catalyst activity: Indication of the catalyst's ability to promote the reduction of NO<sub>x</sub>.
- 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.

**3. COMMENTS**

None.

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## **B.17 WATER OR STEAM INJECTION**<sup>21,22,23</sup>

### **B.17.1 Background**

Water or steam injection provides control of NO<sub>x</sub> in the combustion zone. The formation of NO<sub>x</sub> results from one of three mechanisms: thermal NO<sub>x</sub>, fuel NO<sub>x</sub>, and prompt NO<sub>x</sub>. Because thermal NO<sub>x</sub> formation increases exponentially with temperature, small reductions in temperature will result in significant reductions of NO<sub>x</sub>. Water or steam injection into the flame area provides a heat sink that lowers the flame temperature and reduces thermal NO<sub>x</sub> formation. Water injection provides greater NO<sub>x</sub> reduction than steam injection. Injection rates are defined by water-to-fuel ratios (WFR). Water or steam injection only control thermal NO<sub>x</sub> formation due to the lower flame temperature; injection may actually increase the rate of fuel NO<sub>x</sub> 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<sub>x</sub> by 70 to 80 percent (depending on initial NO<sub>x</sub> levels). The reduction efficiency of NO<sub>x</sub> 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<sub>x</sub> emissions. Fuel types such as natural gas and distillate oils have low-nitrogen contents and provide lower NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> concentration, WFR, and fuel-bound N<sub>2</sub> content.

Outlet NO<sub>x</sub> concentration. The most direct single indicator of the performance of water or steam injection is the NO<sub>x</sub> 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<sub>x</sub>. Increases in the injection rate reduce formation of NO<sub>x</sub> up to a critical rate beyond which the water or steam interfere with combustion in the turbine.

Fuel-bound N<sub>2</sub> concentration. The fuel-bound N<sub>2</sub> content is a factor in the amount of NO<sub>x</sub> formed from the combustion of fuel. Increases in the N<sub>2</sub> content will result in increases in the outlet NO<sub>x</sub> concentration. This information is used in conjunction with other monitoring.

### B.17.3 Illustrations

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

17a: Monitoring water-to-fuel ratio.

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

Parameters	Performance indication	Approach No.	1	2
		Illustration No.		17a
		Example CAM Submittals		
		Comment		
<b>Primary Indicators of Performance</b>				
Outlet NO <sub>x</sub> 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 <sub>x</sub> formation. Increase in the water rate results in a decrease in NO <sub>x</sub> emissions up to a critical rate, after which the combustion flame may be doused.			X
<b>Other Performance Indicators</b>				
Fuel-bound N <sub>2</sub> content	Affects the fuel NO <sub>x</sub> formation. Increase in N <sub>2</sub> content of the fuel or increase in the amount of fuel used will increase NO <sub>x</sub> emissions.			
Comments: None.				

CAM ILLUSTRATION  
No. 17a. WATER INJECTION FOR NO<sub>x</sub> CONTROL

## 1. APPLICABILITY

- 1.1 Control Technology: Water injection [028]
- 1.2 Pollutants  
Primary: Nitrogen oxides (NO<sub>x</sub>); (NO, NO<sub>2</sub>, NO<sub>3</sub>)
- 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<sub>x</sub> 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.

## 3. COMMENTS

None.

**B.18 EXHAUST GAS RECIRCULATION [Reserved]**

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**B.19 CAPTURE SYSTEMS**<sup>26,27</sup>**B.19.1 Background**

Capture efficiency is defined as the percentage of emissions captured and vented to a control device. Various capture systems may be used to capture emissions and direct them to a control device. These systems include enclosures and local exhaust ventilation measures.

There are basically two types of enclosures: (1) total enclosures, referred to as permanent total enclosures (PTEs), and (2) nontotal, or partial, enclosures. A PTE is an enclosure that completely surrounds a source such that all volatile organic compound (VOC) emissions are contained and directed to a control device. The EPA has established a set of criteria that must be met for an enclosure to qualify as a PTE; these criteria are contained in Reference Method 204--Criteria For And Verification of a Permanent or Temporary Total Enclosure (40 CFR 51, Appendix M). If the criteria set forth in this method are met, the capture efficiency may be assumed to be 100 percent and need not be measured. An enclosure that does not meet the minimum criteria for a PTE is not a total enclosure; it is a partial enclosure (PE) and capture efficiency is determined by measurement. Table B-19 summarizes the PTE criteria.

**TABLE B-19. PERMANENT TOTAL ENCLOSURE DESIGN CRITERIA**

1. Any natural draft opening (NDO) shall be at least four equivalent opening diameters from each VOC emitting point.
2. The total area of all NDOs shall not exceed 5 percent of the surface area of the enclosure's four walls, floor, and ceiling.
3. The average face velocity (FV) of air through all NDOs shall be at least 3,600 m/hr (200 ft/min). The direction of flow through all NDOs shall be into the enclosure.
4. All access doors and windows whose areas are not included in the calculation in item No. 2 shall be closed during routine operation of the process.
5. All VOC emissions must be captured and contained for discharge through a control device.

The second type of control measure used to capture emissions and vent them to a control device is the application of local exhaust ventilation. Local exhaust ventilation systems typically consist of a hood, or hoods, that capture the contaminant at the point of generation and a duct system and exhaust fan that moves the VOC-laden air to the control device.

For both types of capture systems discussed (enclosures and local exhaust ventilation systems), maintaining the integrity of the capture device (i.e., enclosure, hood) and the airflow (ventilation) through the system are the critical operating/maintenance parameters with respect to maintaining capture system performance. The indicators of performance for capture systems relate to these two parameters and, for purposes of this discussion, monitoring approaches can be divided into two subcategories:

1. Indicators of capture by the enclosure or hood (e.g., enclosure differential pressure, NDO velocity, hood face velocity); and
2. Indicators of system air flow (e.g., fan rpm, duct pressure differential) measured downstream of the capture device combined with a system integrity inspection.

The first monitoring approach is applicable to all types of capture systems. The second approach is applicable to simpler capture systems including either (a) a simply configured PTE or partial enclosure or (b) a simple exhaust ventilation system, such as a system consisting of a single hood (as opposed to multiple hoods), noncomplicated ductwork (e.g., without recirculation and multiple dampers), and a fan.

The first approach, measuring indicators of performance at the capture device, provides more reliable data related to capture efficiency than measuring air flow downstream of the capture device. For this reason, the second approach may provide a lower level of confidence than the first approach, which uses a more direct indicator of performance; the level of confidence will depend upon system design and frequency of inspection. While not essential to provide an acceptable level of confidence for the first monitoring approach, periodic inspection of the enclosure or hood and the exhaust system may be added to further increase the level of confidence. On the other hand, periodic inspections are necessary for the second monitoring approach to provide an acceptable level of confidence. The frequency and rigor of the inspection is a factor that affects the level of confidence; continuous data are not provided for this parameter. As with other CAM monitoring, the specific situation needs to be considered during selection of a monitoring approach and the factors discussed in Chapter 3 of the CAM technical guidance document should be considered (e.g., potential to emit, margin of safety, and cost).

In many cases, for both enclosures and other exhaust ventilation systems, single parameter monitoring may not be sufficient to ensure that capture efficiency is maintained. A combination of several parameters may be necessary to provide reasonable assurance of compliance with the capture efficiency requirements.

Common problems and malfunctions with capture systems include (1) an out-of-balance ventilation system due to the excessive opening and closing of doors and windows in an enclosure, (2) degradation in fan performance, (3) changes in PTE configuration due to process changes such as introducing a new VOC source within the enclosure (e.g., coating vessels or cleanup solvent drums that can be moved during the facility's day-to-day operations), and not maintaining the acceptable distance between VOC sources and NDOs; and (4) problems with the ductwork such as particulate matter accumulation in duct work, holes in the duct work, damaged hoods or enclosures, and disconnected pick up points.

## B.19.2 Indicators of Capture System Performance

B.19.2.1 Enclosures. For enclosures, the primary indicators of performance include:

1. Differential pressure across the enclosure;

2. Average FV through all NDOs (measured using total volumetric air flow divided by NDO surface area) and periodic inspection of NDOs; and
3. Face velocity (FV) through all NDOs or through selected representative NDOs (measurement of face velocity at each NDO).

For PTEs, FV through all NDOs and pressure differential across the enclosure are essentially equivalent measurements, and either can be used to demonstrate performance of the PTE. Note that Reference Method 204 [paragraph 8.3] indicates that a pressure differential of 0.013 mm Hg (0.0007 in. H<sub>2</sub>O) corresponds to an average FV of 3,600 m/hr (200 ft/min). In some situations, the measurement of one parameter may be simpler than that of the other.

As stated earlier, periodic inspections of the enclosure can be used in conjunction with continuous or periodic measurement of the indicators identified above to further increase the level of confidence. The items incorporated into the inspection will vary depending on whether the enclosure is a PTE or a PE. For PTEs, the inspection should include all items required to demonstrate that the PTE criteria as established in EPA Reference Method 204 (summarized in Table 14-1) are maintained although the frequency of inspection for individual items might vary. For PEs, the inspection should require demonstration that the configuration of the enclosure remains identical to the configuration during the most recent test conducted to measure capture efficiency and is in good physical condition. Inspections for both types of enclosures also should demonstrate that the capture exhaust system is maintained in good working condition (ductwork is clear with no holes, damper operation is correct, fan is in good condition).

As discussed earlier, another indicator of performance for simply configured enclosures is measurement of the capture system air flow (or indicators of air flow, such as fan amperage, fan rpm, or static pressure) downstream of the enclosure. This monitoring approach must be combined with periodic inspections to provide an acceptable level of confidence for the approach. The type of inspection conducted will vary depending on whether the enclosure is a PTE or a PE. Also, inspections under this monitoring approach may need to be more frequent to provide a higher level of confidence.

**B.19.2.3 Exhaust Ventilation Systems.** For exhaust ventilation systems, the primary indicators of performance include:

1. Face velocity at the hood;
2. Exhaust flow rate in the duct near the hood; and
3. Hood static pressure.

Periodic inspections of the capture system (hood and exhaust system) could be used in conjunction with either continuous or periodic measurement of the indicators identified above to further increase the level of confidence.

Another indicator of performance for simple exhaust ventilation systems is measurement of the capture system air flow (or indicators of air flow such as fan amperage, fan rpm, or static pressure) downstream of the capture device (hood) combined with periodic capture system inspections. The frequency of inspections under this approach must be sufficient to provide an acceptable level of confidence.

### B.19.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for capture systems:

- 19a: PTE capture system for VOC: Pressure differential across the enclosure and periodic inspection of PTE capture system.
- 19b: PTE capture system for VOC: Average FV through all NDOs (net exhaust flow divided by NDO surface area) and periodic inspection of PTE capture system (including quarterly inspection of NDOs).
- 19c: PTE capture system for VOC: Average FV through selected NDOs (direct measure of FV) and periodic inspection of PTE capture system.
- 19d: PE capture system for VOC: Pressure differential across the enclosure and periodic inspection of capture system.
- 19e: Local exhaust ventilation system for capture of VOC: FV at the hood and periodic inspection of capture system.
- 19f: Local exhaust ventilation system for capture of VOC: Fan parameters and periodic inspection of capture system.

CAM ILLUSTRATION  
No. 19a. PTE CAPTURE SYSTEM FOR VOC

## 1. APPLICABILITY

- 1.1 Capture Method: Permanent total enclosure (100 percent capture)
- 1.2 Pollutants: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions Units: Coating operations, printing operations

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Pressure differential across the enclosure and semi-annual inspection of PTE capture system.
- 2.2 Rationale for Monitoring Approach: Changes in pressure differential indicate changes in capture system performance. Semi-annual inspection and necessary maintenance will be used to ensure PTE criteria are maintained and exhaust system is in good working condition.
- 2.3 Monitoring Location (see Figure 1 for monitoring locations)
  - Pressure differential: Pressure measured at points inside and outside the enclosure.
  - Inspection: At all portions of PTE and exhaust system.
- 2.4 Analytical Devices Required
  - Pressure differential: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate.
  - Inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Pressure differential: Recorded continuously at 1-minute intervals using data acquisition system.
    - Inspections: Conducted semi-annually.
  - Reporting units:
    - Pressure differential: Inches of water column (in. w.c.).
    - Inspection: Checklist used to verify PTE configuration and maintenance status and exhaust system conditions.
  - Recording process:
    - Pressure differential: Recorded automatically on data acquisition system.
    - Inspection: Results manually logged.
- 2.6 Supporting Data Requirements
  - Pressure differential measurements taken during PTE verification test (not required if relying on minimum “equivalent” pressure differential of 0.013 mmHg [0.0007 in. w.c.]).
  - Diagram of PTE and exhaust system at time of initial PTE verification.

## 3. COMMENTS

None.

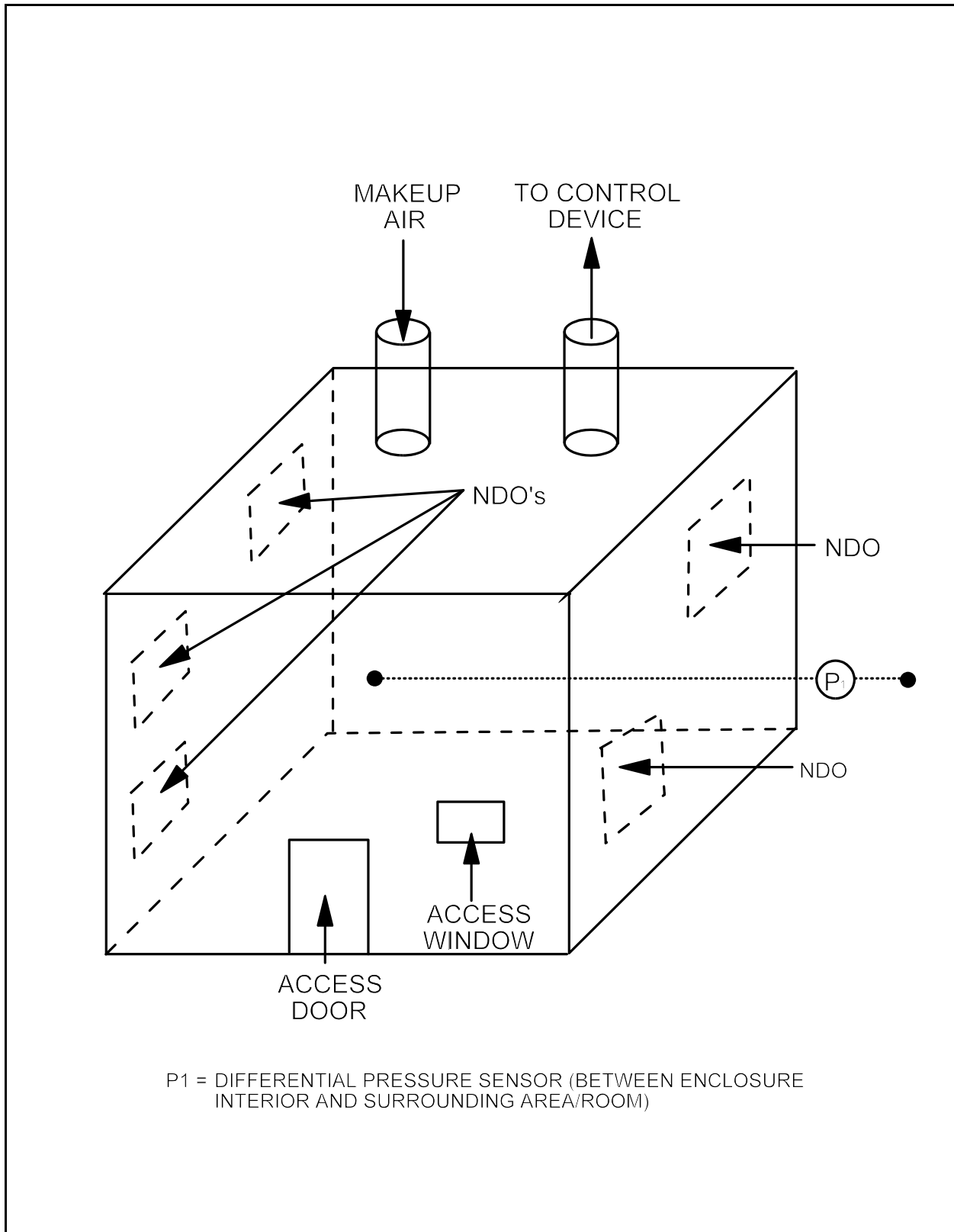


Figure B-19A. PTE: Monitoring location for differential pressure across enclosure (Illustration 19a).

CAM ILLUSTRATION  
No. 19b. PTE CAPTURE SYSTEM FOR VOC

## 1. APPLICABILITY

- 1.1 Capture Method: Permanent total enclosure (100 percent capture)
- 1.2 Pollutants: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions Units: Coating operations, printing operations

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Average FV through all NDOs determined by measuring exhaust gas flow rate to control device and flow rate of forced makeup air, if any. Quarterly inspection of NDOs, and semi-annual inspection of PTE.
- 2.2 Rationale for Monitoring Approach: Changes in FV indicate changes in capture system performance. Quarterly NDO inspections ensure NDOs are maintained as during initial PTE verification. Semi-annual inspection and necessary maintenance will be used to ensure PTE criteria are maintained and exhaust system is in good working condition.
- 2.3 Monitoring Location (see Figure 2 for monitoring locations)
  - Average FV: Exhaust gas duct to control device; forced makeup air duct. Net exhaust flow (total exhaust minus forced makeup air, if any) is divided by the total NDO area to determine the average FV.
  - Inspections: All portions of PTE and exhaust system.
- 2.4 Analytical Devices Required
  - FV: Flow monitors.
  - Inspections: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - FV: Recorded continuously at 1-minute intervals on data acquisition system.
    - Inspections: Conducted quarterly on NDOs and semi-annually on PTE capture system.
  - Reporting units:
    - FV: Feet per minute (ft/min).
    - Inspections: Checklist used to verify NDO and PTE configuration and maintenance status, and exhaust system conditions.
  - Recording process:
    - FV: Recorded automatically on data acquisition system.
    - Inspections: Results manually logged.
- 2.6 Supporting Data Requirements
  - Diagram of PTE and exhaust system at time of initial PTE verification.

## 3. COMMENTS

None.

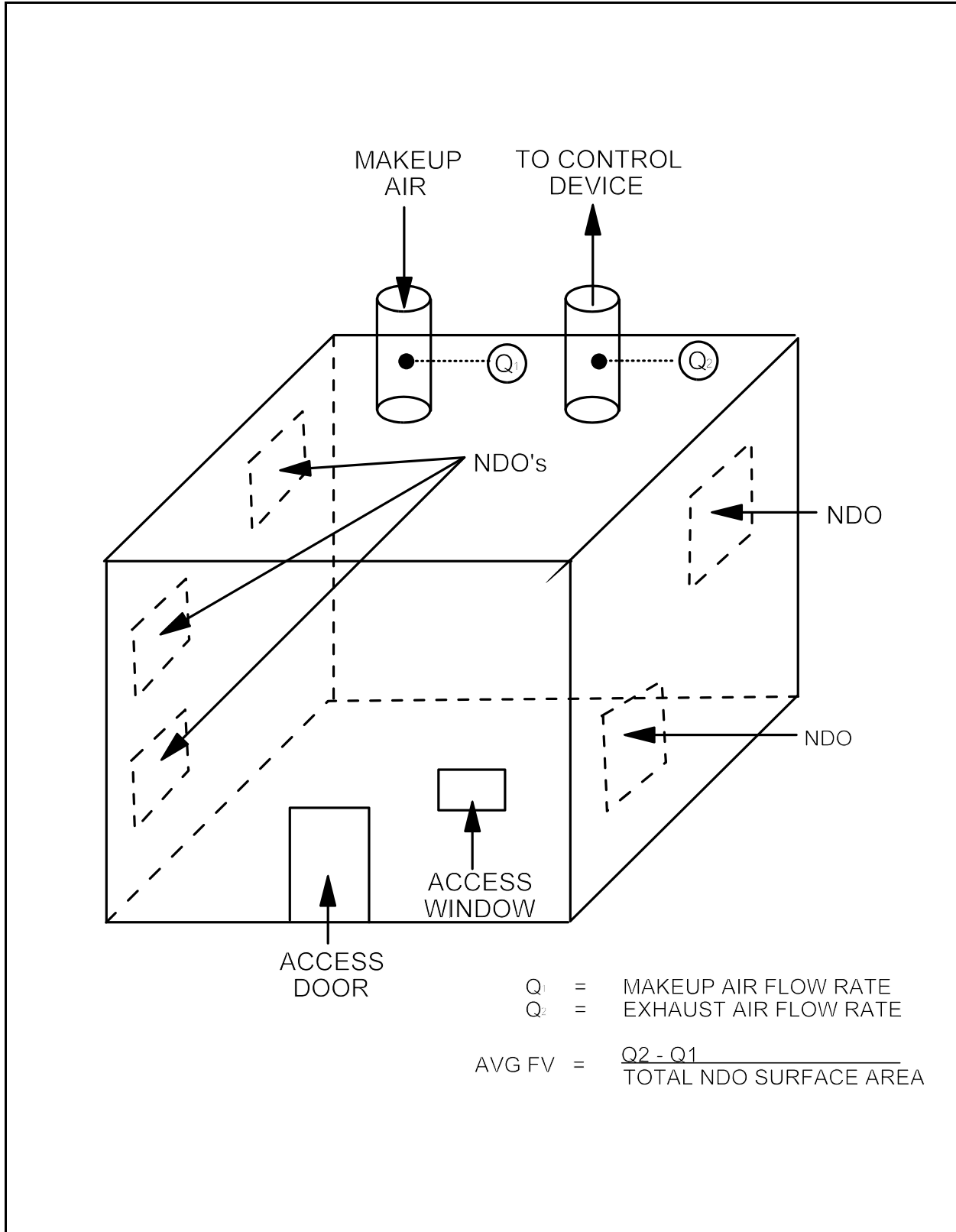


Figure B-19B. PTE: Monitoring location for average face velocity through all NDOs (Illustration 19b).



CAM ILLUSTRATION  
No. 19c. PTE CAPTURE SYSTEM FOR VOC

## 1. APPLICABILITY

- 1.1 Capture Method: Permanent total enclosure (100 percent capture)
- 1.2 Pollutants: Volatile organic compounds (VOCs)
- 1.3 Process/Emissions Units: Coating operations, printing operations

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: FV at selected NDOs and semi-annual inspection of PTE capture system.
- 2.2 Rationale for Monitoring Approach: Changes in FV at NDOs indicate changes in capture system performance. Semi-annual inspection and necessary maintenance will be used to ensure PTE criteria are maintained and exhaust system is in good working condition.
- 2.3 Monitoring Location (see Figure 3 for monitoring locations)
  - FV: Direct measurement at selected NDOs.
  - Inspection: At all portions of PTE and exhaust system.
- 2.4 Analytical Devices Required
  - FV: Flow velocity monitors.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - FV: Recorded continuously at 1-minute intervals on data acquisition system.
    - Inspections: Conducted semi-annually.
  - Reporting units:
    - FV: Feet per minute (ft/min).
    - Inspection: Checklist used to verify PTE configuration and maintenance status and exhaust system conditions.
  - Recording process:
    - FV: Recorded automatically on data acquisition system.
    - Inspections: Results manually logged.
- 2.6 Supporting Data Requirements
  - Diagram of PTE and exhaust system at time of initial PTE verification.

## 3. COMMENTS

None.

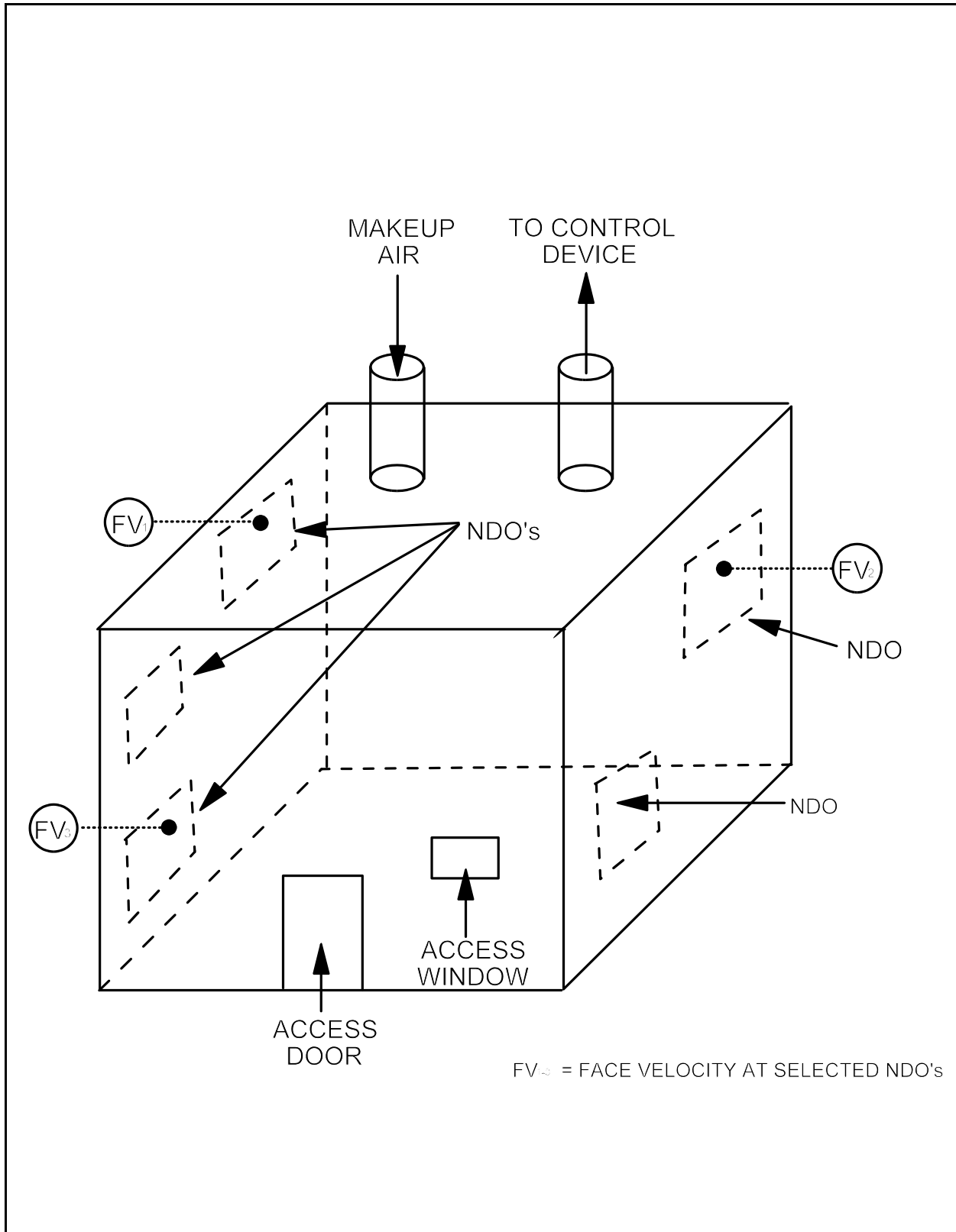


Figure B-19C. PTE: Monitoring location for face velocity at selected NDOs (Illustration 19c).

CAM ILLUSTRATION  
No. 19d. PARTIAL ENCLOSURE CAPTURE SYSTEM FOR VOC

## 1. APPLICABILITY

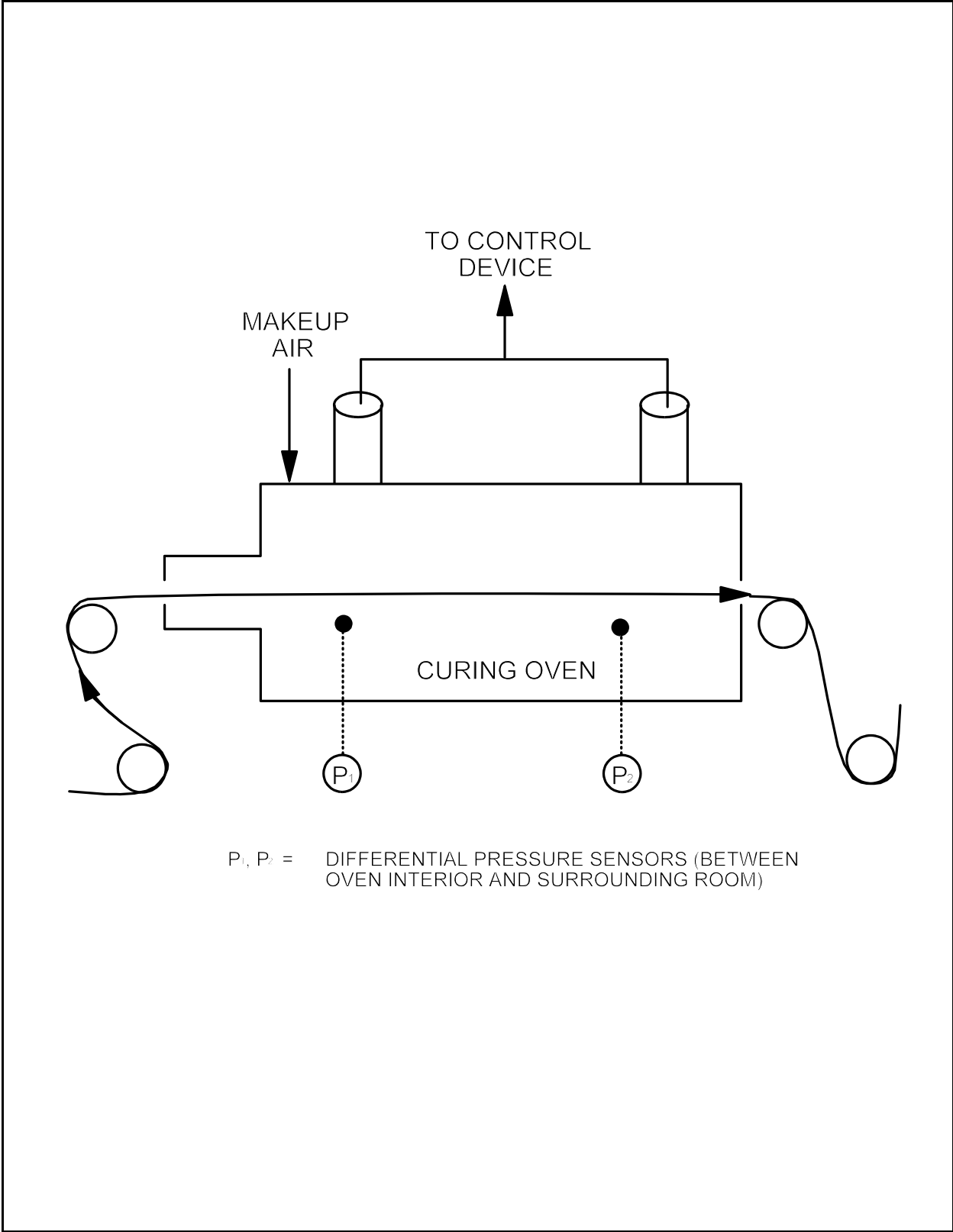
- 1.1 Capture Method: Partial enclosure (less than 100 percent capture)
- 1.4 Pollutants: Volatile organic compounds (VOCs)
- 1.5 Process/Emissions Units: Coating operations, printing operations

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored: Pressure differential across the enclosure and semi-annual inspection of capture system.
- 2.2 Rationale for Monitoring Approach: Changes in pressure differential indicate changes in capture system performance. Semi-annual inspections and necessary maintenance will be used to maintain capture system integrity.
- 2.3 Monitoring Location (see Figure 4 for monitoring locations)
  - Pressure differential: Pressure measured at points inside and outside the enclosure (e.g., curing oven).
  - Inspection: At all portions of capture system.
- 2.4 Analytical Devices Required
  - Pressure differential: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate.
  - Inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Pressure differential: Recorded continuously at 1-minute intervals on data acquisition system.
    - Inspection: Conducted semi-annually.
  - Reporting units:
    - Pressure differential: Inches of water column (in. w.c.).
    - Inspection: Checklist used to verify condition of capture system.
  - Recording process:
    - Pressure differential: Recorded automatically on data acquisition system.
    - Inspection: Results manually logged.
- 2.6 Supporting Data Requirements
  - Pressure differential measurements taken during test to measure capture efficiency, or design information if capture efficiency test not required by applicable regulation.
  - Diagram of enclosure and exhaust system at time of test to measure capture efficiency.

## 3. COMMENTS

None.



P<sub>1</sub>, P<sub>2</sub> = DIFFERENTIAL PRESSURE SENSORS (BETWEEN OVEN INTERIOR AND SURROUNDING ROOM)

Figure B-19D. Partial enclosure: Example monitoring locations for pressure differential across enclosure (Illustration 19d).

## CAM ILLUSTRATION

## No. 19e. LOCAL EXHAUST VENTILATION SYSTEM FOR CAPTURE OF VOC

**1. APPLICABILITY**

- 1.3 Capture Method: Local exhaust ventilation system
- 1.4 Pollutants: Volatile organic compounds (VOCs)
- 1.5 Process/Emissions Units: Coating operations

**2. MONITORING APPROACH DESCRIPTION**

- 2.1 Indicators Monitored: Velocity at the hood and semi-annual inspection of capture system.
- 2.2 Rationale for Monitoring Approach: A change in velocity at the hood indicates changes in capture system performance. Semi-annual inspections and necessary maintenance will be used to maintain the capture system in good working condition.
- 2.3 Monitoring Location (see Figure 5 for monitoring locations)
  - Velocity: At hood or in duct near hood.
  - Inspection: At all portions of capture system.
- 2.4 Analytical Devices Required
  - Velocity: Velocity meter.
  - Inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Velocity: Recorded continuously at 1-minute intervals on data acquisition system.
    - Inspection: Conducted semi-annually.
  - Reporting units:
    - Velocity: Feet per minute (ft/min).
    - Inspection: Checklist used to verify condition of capture system.
  - Recording process:
    - Velocity: Recorded automatically on data acquisition system.
    - Inspection: Results manually logged.
- 2.6 Supporting Data Requirements
  - Velocity measurements taken during test to measure capture efficiency or design velocity information if capture efficiency test not required by applicable regulation.

**3. COMMENTS**

None.

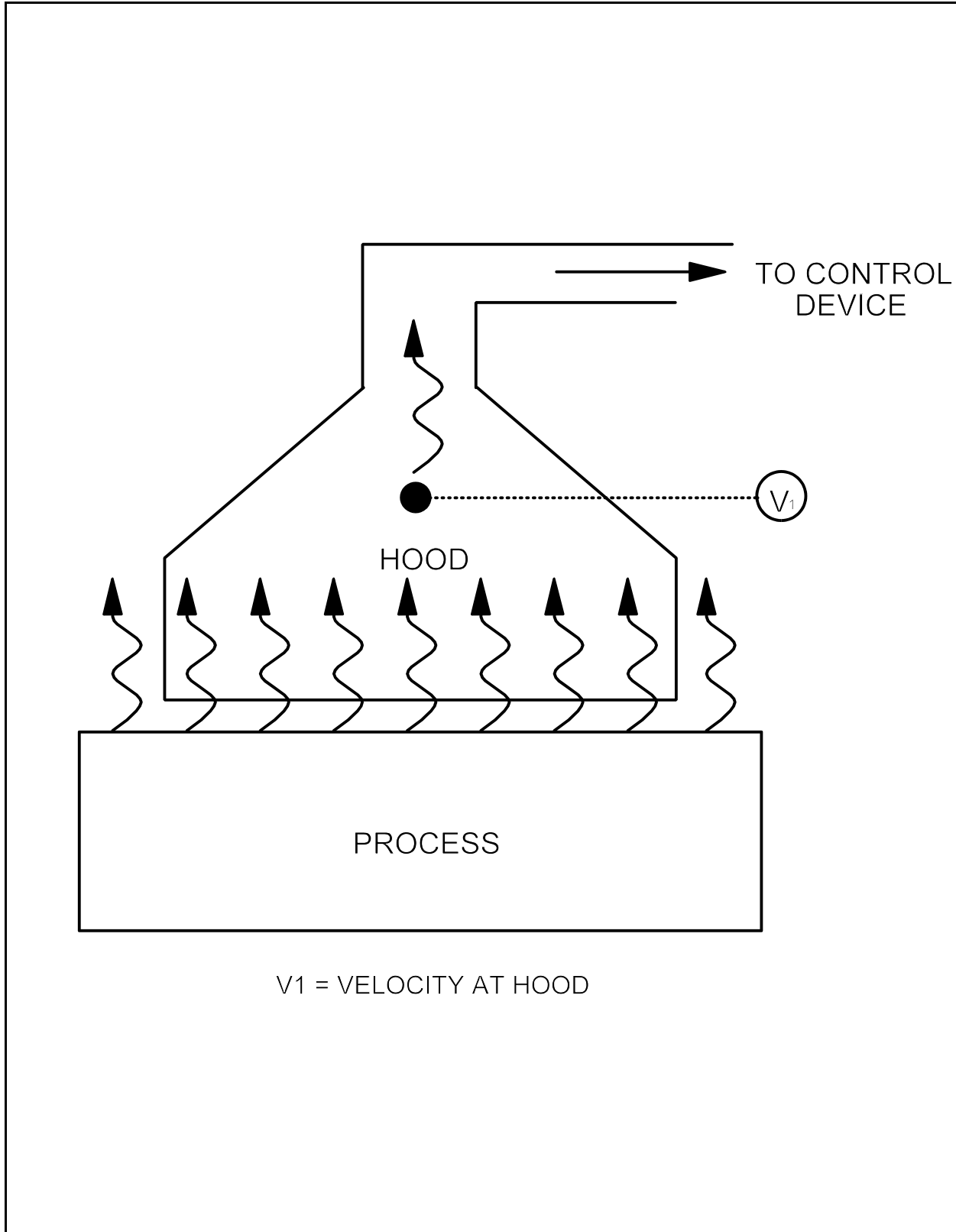


Figure B-19E. Local exhaust ventilation system: Monitoring location for velocity at the hood (Illustration 19e).

CAM ILLUSTRATION  
No. 19f. LOCAL EXHAUST VENTILATION SYSTEM FOR CAPTURE OF VOC  
OR FUGITIVE PM

## 1. APPLICABILITY

- 1.1 Capture Method: Local exhaust ventilation system
- 1.2 Pollutants: Volatile organic compounds (VOCs), fugitive particulate matter (PM)
- 1.3 Process/Emissions Units: Coating operations, material handling

## 2. MONITORING APPROACH DESCRIPTION

- 2.1 Indicators Monitored
  - Ventilation system fan parameters such as speed, current, static pressure, damper position, or a combination these parameters depending upon fan type and system design; and
  - Inspection of capture hood and duct integrity.
- 2.2 Rationale for Monitoring Approach: A change in ventilation flow through the system will impact capture system efficiency; a decrease in flow will decrease the capture efficiency. Also, for any given ventilation rate through the system, the integrity of the capture hood and ducting must be maintained in order to maintain the capture efficiency. Fan performance is monitored as an indicator that a minimum ventilation rate is maintained. Periodic inspection is used to monitor the capture system condition and indicate the need for corrective action (maintenance).
- 2.3 Monitoring Location (see Figure 6 for monitoring locations)
  - Fan operation: Fan housing and ductwork.
  - Inspection: All portions of capture system.
- 2.4 Analytical Devices Required
  - Fan parameters: (Will depend on parameters monitored)
    - Fan speed: revolutions per minute (rpm) meter.
    - Fan current: Ammeter.
    - Fan static pressure: Differential pressure gauge.
    - Damper position: Position indicator.
  - Inspection: None.
- 2.5 Data Acquisition and Measurement System Operation
  - Frequency of measurement:
    - Fan parameters: Once per day or once per shift, or continuously at 15-minute intervals on data acquisition system; less frequent measurements (e.g., once per shift or day) may be considered for smaller systems.
    - Inspection: Daily.
  - Reporting units:
    - Fan parameters: Speed (rpm), current (amperage), pressure (inches of water).
    - Inspection: Checklist used to verify condition of capture system.

- Recording process:
  - Fan parameters: Operators log data manually (for smaller systems), or recorded automatically on strip chart or data acquisition system.
  - Inspection: Operators log results manually.

#### 2.6 Supporting Data Requirements

- Fan parameters measured during initial demonstration test of capture system (e.g., initial capture system efficiency test, face velocity measurements) or parameters established by design (e.g, flow needed to achieve minimum hood face velocity); and
- Fan curve from manufacturer or vendor.

### 3. COMMENTS

This approach relies on the basic concept that a minimum capture system performance level will be achieved when the system ventilation rate is maintained at a minimum level and the capture system integrity is maintained. Consequently, this approach is most applicable to systems which are rather simple in design, e.g., a system consisting of a single hood or enclosure connected to a fan with a limited amount of ductwork and dampers. As the complexity of the capture system increases (e.g, a single fan ventilating multiple hoods or enclosures with a complicated dampering system and recycle air), the level of confidence of this approach decreases. For more complex capture systems, an approach that incorporates a performance indicator involving a more direct measure at the point of capture is recommended.



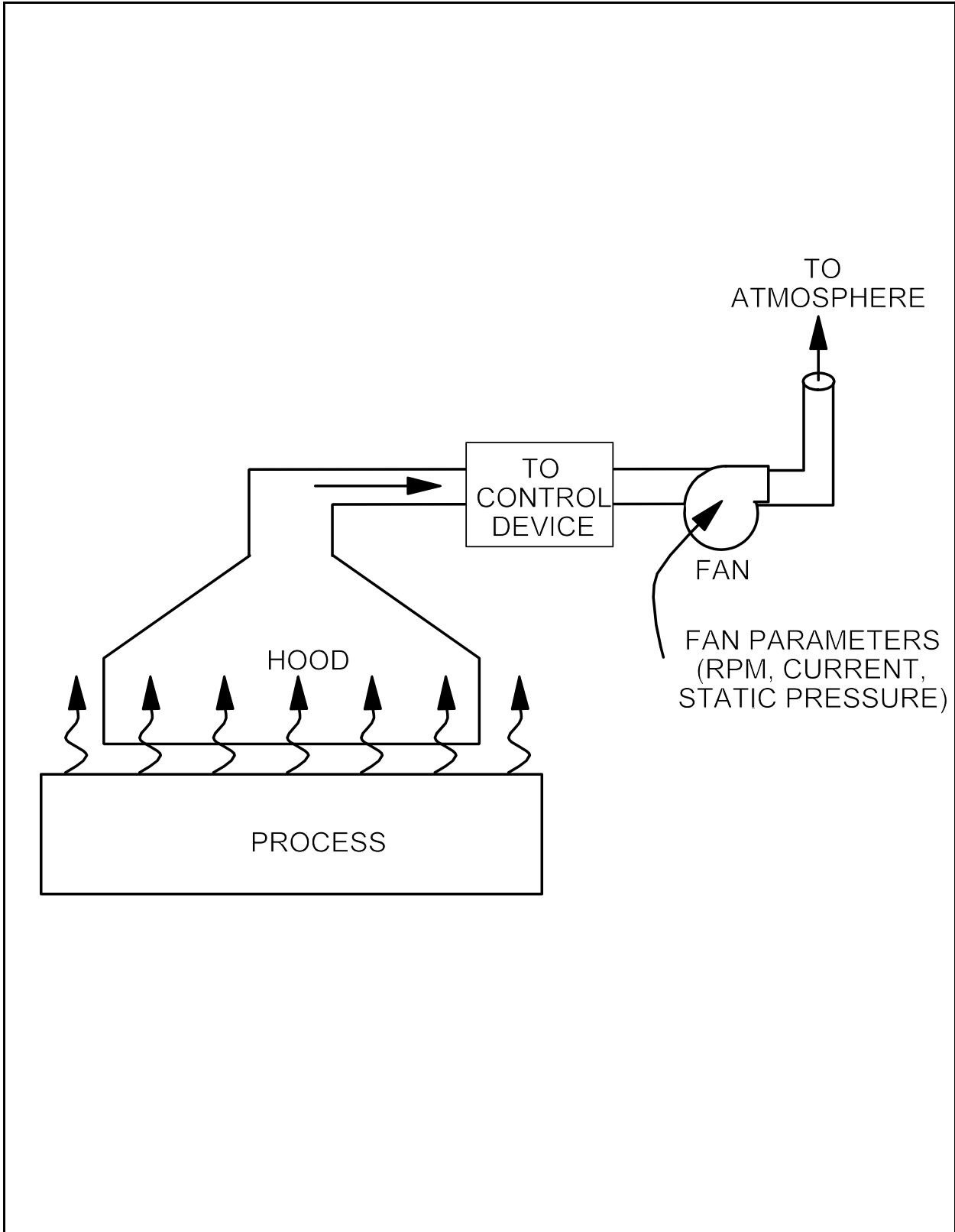


Figure B-19F. Local exhaust ventilation system: Monitoring locations for fan parameter (Illustration 19f).

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