B.1 FABRIC FILTERS[1-6]

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 (ft^3 per minute gas/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 are expected to 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 cycles must be balanced, however, 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 must also be taken off-line 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. In the absence of a PM continuous emissions monitoring system (CEMS) or a baghouse leak detection system, the primary indicator of fabric filter performance is the outlet opacity. Other indicators of fabric filter performance include pressure differential, inlet temperature, temperature differential, exhaust gas flow rate, cleaning mechanism operation, and fan current. Each of these indicators is described below. Table B-1 lists these indicators and illustrates potential monitoring options for fabric filters.

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.

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 immediate feedback on bag failure. 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.

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.

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.

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 flourescent dye and observation using a black light. Maintenance of the fabric filter would include regular replacement of filter bags.

B.1.3 Illustrations

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

- 1a: Daily observations of visible emissions (VE) or opacity using RM 9 or modified RM 22.
- 1b: Continuous instrumental monitoring of opacity using COMS or other analytical device.
- 1c: Monitoring pressure differential, opacity, and inlet temperature.
- 1d: Monitoring with a bag leak detection system.

B.1.4 Bibliography

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

		Approach No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
		Illustration No.	**1a, 1b**		**1c**	**1d**							
		Example CAM Submittals				**A12**	**A10**	**A13**	**A19**				
Parameters	**Performance indication**	**Comment**	✔	✔		✔				✔	✔	✔	✔
Primary Indicators of Performance													
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
Other Performance Indicators													
Pressure differential	Indicator of blinding or malfunction of cleaning cycle. Sudden increase in pressure differential can indicate bag blinding; also can indicate if cleaning mechanism is operating properly.			X	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)

		Approach No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
		Illustration No.	**1a, 1b**		**1c**	**1d**							
		Example CAM Submittals				**A12**	**A10**	**A13**	**A19**				
Parameters	**Performance indication**	**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 *Gas flow rate* above.							X					
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	

Comments:

- 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.
- Approach No. 2 corresponds to 40 CFR 63, subpart GG (Aerospace Manufacturing and Rework).
- Approach No. 4 also corresponds to 40 CFR 63, subparts MMM (Pesticides), DDD (Mineral Wool), and NNN (Wool Fiberglass).
- Approach No. 8 corresponds to 40 CFR 63, subpart X (Secondary Lead Smelting) for controlling lead.
- Approach No. 9 corresponds to 40 CFR 63, subpart LLL (Portland Cement).
- Approach No. 10 corresponds to 40 CFR 63, subpart XXX (Ferroalloys Production; an existing source is required to monitor VE, pressure differential, and conduct I & M, and a new source is required to monitor these parameters plus a bag leak defection system.).
- Approach No. 11 corresponds to 40 CFR 63, subpart EE (Magnetic Tape).

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).
2.2 Rationale for Monitoring Approach: Changes in opacity and changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.
2.3 Monitoring Location: Per RM 9 (opacity) or RM 22 (VE) requirements.
2.4 Analytical Devices Required: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Daily or as weather permits.
- Reporting units: Percent opacity or visible/no visible emissions.
- Recording process: Observers complete opacity or VE observation forms and log into binder or electronic data base as appropriate.

2.6 Data Requirements
- Baseline opacity or VE observations concurrent with emission test.
- Historical plant records of opacity observations. (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.
2.8 References: 1, 2, 3, 4, 5, 23.

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.
2.2 Rationale for Monitoring Approach: An increase in opacity indicates process changes, changes in baghouse efficiency, or leaks.
2.3 Monitoring Location: Exhaust gas outlet.
2.4 Analytical Devices Required: Opacity meter or COMS as appropriate for gas stream.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once per shift if instruments read manually, or continuously recorded on strip chart or digital data acquisition system.
- Reporting units: Percent opacity for COMS, or applicable units for other type monitors.
- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements
- Baseline opacity measurements (e.g., opacity for COMS) concurrent with emission test.
- Historical plant records of opacity measurements.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.
2.8 References: 1, 2, 3, 4, 5, 23.

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.

2.8 References: 1, 2, 3, 4, 5, 23.

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.
2.9 References: 1, 5, 6.

3. COMMENTS

None.

B.2 ELECTROSTATIC PRECIPITATORS[1,2,7,8,9,22,23]

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.

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 1×10^7 ohm-centimeters [Ʊ-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 1×10^{10} Ʊ-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.

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.

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.

B.2.4 Bibliography

TABLE B-2. SUMMARY OF PERFORMANCE INDICATORS FOR ESPs

		Approach No.	**1**	**2**	**3**	**4**	**5**
		Illustration No.	**2a**				
		Example CAM Submittals				A?	
Parameter	**Performance indication**	**Comment**	✔		✔	✔	✔
Primary Indicators of Performance							
PM concentration							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	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		
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		
Other Performance Indicators							
Inlet gas temperature	Temperature affects resistivity of particulate. Temperature is also an important parameter when the exhaust stream includes condensible 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
Fields operating	Performance decreases when individual fields fail. Effect depends on which section goes out; need to test to determine effects of outages.					X	

TABLE B-2. (Continued)

Parameter	**Performance indication**						
		Approach No.	**1**	**2**	**3**	**4**	**5**
		Illustration No.	**2a**				
		Example CAM Submittals				A?	
		Comment	✔		✔	✔	✔

Comments:

- Approach No. 1 is required by some State and Federal rules; spark rate may also be required by some rules.
- Approach No. 3 corresponds to 40 CFR 63, Subpart LL (Primary Aluminum Production).
- 40 CFR 61, subpart K, uses Approach No. 4 along with primary current as an additional parameter.
- Approach No. 5 is an EPRI/UARG-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.
- Approach No. 6 corresponds to 40 CFR 63, subpart LLL (Portland Cement); PM CEMS monitoring is deferred. ***[LLL also allows opacity via mg.] Where does it say "Gas flow rate/"***

[a] 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.
2.8 References: 1, 3, 7, 8, 9, 10, 11, 12.

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.3 WET ELECTROSTATIC PRECIPITATORS[1,2,7,8,22,23]

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.

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.

B.3.4 Bibliography

TABLE B-3. SUMMARY OF PERFORMANCE INDICATORS FOR WESPs

Parameter	Performance indication		1	2	3	4	5	6
		Approach No.	**1**	**2**	**3**	**4**	**5**	**6**
		Illustration No.	**3a**	**3b**				
		Example CAM Submittals					**A9a**	**A9b**
Parameter	**Performance indication**	**Comment**		✔	✔	✔		
Primary Indicators of Performance								
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		a		
Secondary current	Partial indicator of power consumption; too low indicates malfunction. Can help identify any fields that are not operating properly.		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	X	X
Other Performance Indicators								
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	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:
- Approach No. 2 also corresponds to 40 CFR 60, subpart PPP (Wool Fiberglass).
- 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.

[a] 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.

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.

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^3/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.

2.8 References: 7, 8, 9, 13.

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:
- 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.

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^3/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.

2.8 References: 7, 8, 9, 11, 13.

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.4 WET SCRUBBERS FOR PM CONTROL[1,2,8,9,15,22]

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 μm) 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.

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.

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.

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.

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.

B.4.4 Bibliography

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

		Approach No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
		Illustration No.	**4a**	**4b**							**4c**
		Example CAM Submittal	**A17**		**A2**				**A8**	**A14**	
Parameters	**Performance indication**	**Comment**	✔	✔		✔	✔	✔			
Primary Indicators of Performance											
Pressure differential (ΔP)	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
Other Performance Indicators											
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 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
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	
Inlet velocity pressure	Inlet pressure provides an indication of the inlet gas flow rate.							X			

TABLE B-4. (Continued)

		Approach No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
		Illustration No.	**4a**	**4b**							**4c**
		Example CAM Submittal	**A17**		**A2**				**A8**	**A14**	
Parameters	**Performance indication**	**Comment**	✔	✔		✔	✔	✔			
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	Filter check or visible emissions inspection.						X		X		

Comments:
- Approach No. 1 also corresponds to 40 CFR 63, subpart XXX (Ferroalloys Production) for a venturi scrubber.
- Approach No. 2 is required by several NSPS and 40 CFR 63, subparts X (Secondary Lead Smelting) and AA (Phosphoric Acid).
- Approach No. 4 is required by several NSPS.
- Approach No. 5 corresponds to 40 CFR 63, subpart LL (Primary Aluminum) for wet scrubbers.
- 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 packet bed, and the pressure differential is monitored for the composite mesh pad.

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.

2.8 References: 8, 9, 14.

3. COMMENTS

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

CAM ILLUSTRATION
No. 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^3/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.

2.8 References: 8, 9, 14.

3. COMMENTS

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

CAM ILLUSTRATION
No. 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^3/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.

2.8 References: 8, 9, 14.

3. COMMENTS

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

B.10 ELECTRIFIED FILTER BED[13, 31, 32]

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

The primary 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. Outlet PM concentration and opacity may also be monitored for an EFB. Each of these indicators is described below. Table B-10 lists these indicators and illustrates potential monitoring options for EFBs.

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_2O 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.

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.

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.

B.10.4 Bibliography

TABLE B-10. SUMMARY OF PERFORMANCE INDICATORS FOR EFBs

		Approach No.	**1**	**2**	**3**
		Illustration No.	**10a**	**10b**	
		Example CAM Submittals			**A.11**
Parameters	**Performance indication**	**Comment**			
Primary Indicators of Performance					
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: • Opacity also may be used in conjunction with any of these approaches.					

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.

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.

2.8 References: 13, 31, 32.

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.

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.

2.8 References: 13, 31, 32.

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.12 CYCLONES[1,2,9,22]

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.

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.

B.12.4 Bibliography

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

		Approach No.	**1**	**2**	**3**
		Illustration No.	**12a**	**12b**	
		Example CAM Submittals			
Parameters	**Performance indication**	**Comment**			
Primary Indicators of Performance					
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	
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).
2.2 Rationale for Monitoring Approach: Control efficiency increases with increased velocity; if inlet velocity exceeds a specific value, turbulence becomes excessive and control efficiency begins to decrease.
2.3 Monitoring Location: Inlet gas duct.
2.4 Analytical Devices Required: 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.
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: Feet per minute (ft/min).
- 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.
- 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.

2.8 References: 1, 2, 22.

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.

2.8 References: 1, 2, 22.

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.)

B.19 CAPTURE SYSTEMS[33]

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 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. Face velocity (FV) through all NDOs or through selected representative NDOs (measurement of face velocity at each NDO);

2. Differential pressure across the enclosure; and

3. Average FV through all NDOs (measured using total volumetric air flow divided by NDO surface area) and daily inspection of NDOs.

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_2O) 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.

B.19.4 Bibliography

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.

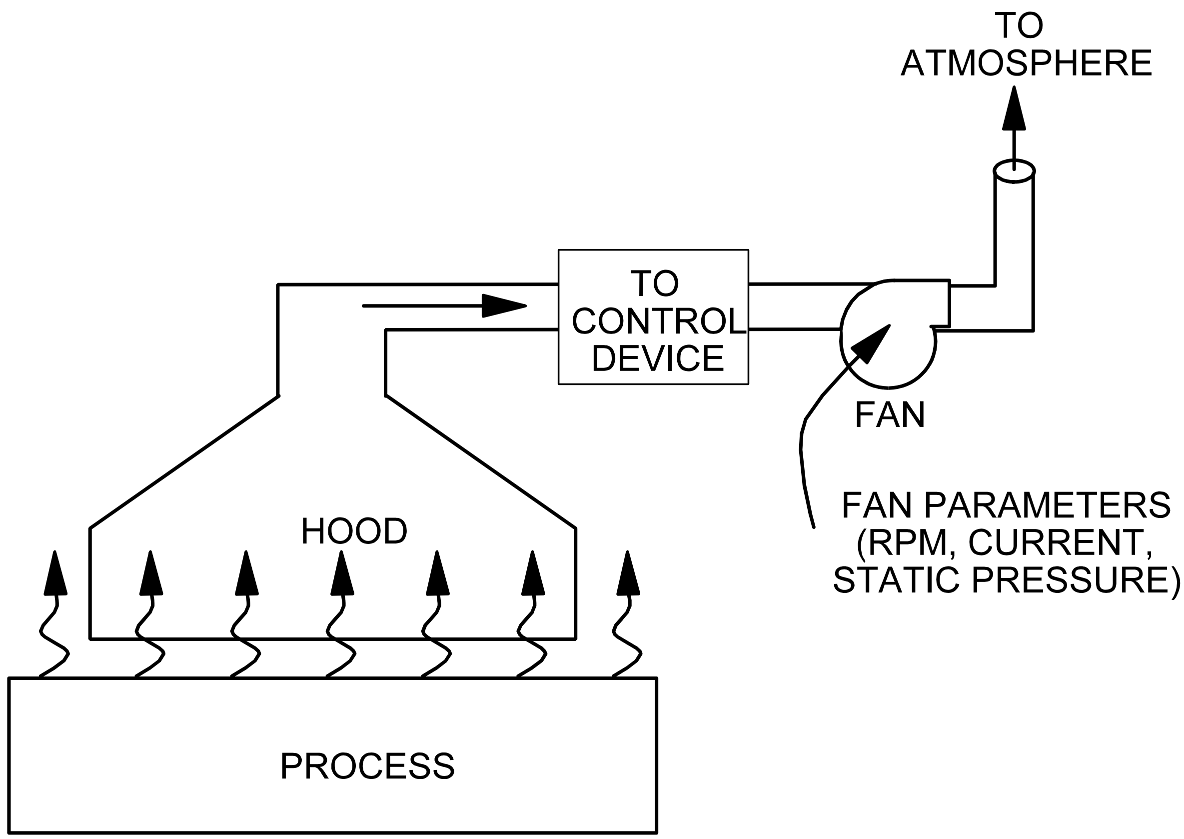

Figure B-19F. Local exhaust ventilation system: Monitoring locations for fan parameter (Illustration 19f).