

OTHER TEST METHOD 27 - April 15, 2009

DETERMINATION OF PM₁₀ AND PM_{2.5} EMISSIONS FROM

STATIONARY SOURCES (Constant Sampling Rate Procedure)

1.0 Scope and Applicability

1.1 Scope. The U.S. Environmental Protection Agency (U.S. EPA or "we") developed this method to describe the procedures that the stack tester ("you") must follow to measure particulate matter emissions equal to or less than a nominal aerodynamic diameter of 10 micrometer (PM₁₀) and 2.5 micrometer (PM_{2.5}). If the gas filtration temperature exceeds 30°C (85°F), this method includes procedures to measure only filterable particulate matter (material that does not pass through a filter or a cyclone/filter combination). If the gas filtration temperature exceeds 30°C (85°F), and you must measure total primary (direct) particulate matter emissions to the atmosphere, both the filterable and condensable (material that condenses after passing through a filter) components, then you must combine the procedures in this method with the procedures in Method 202 or Other Test Method 28 (OTM 28) for measuring condensable particulate matter. However, if the gas filtration temperature never exceeds 30°C (85°F), then use of Method 202 or OTM 28 is not required to measure total primary particulate matter.

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1.2 Applicability. You can use this method to measure filterable particulate matter from stationary sources only. Filterable particulate matter is collected in-stack with this method (i.e., the method measures materials that are solid or liquid at stack conditions).

1.3 Responsibility. You are responsible for obtaining the equipment and supplies you will need to use this method. You must also develop your own procedures for following this method and any additional procedures to ensure accurate sampling and analytical measurements.

1.4 Results. To obtain results, you must have a thorough knowledge of the following test methods that are found in Appendices A-1 through A-3 of 40 CFR Part 60.

- (a) Method 1 - Sample and Velocity Traverses for Stationary Sources.
- (b) Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube).
- (c) Method 3 - Gas Analysis for the Determination of Dry Molecular Weight.
- (d) Method 4 - Determination of Moisture Content in Stack Gases.
- (e) Method 5 - Determination of Particulate Matter Emissions from Stationary Sources.

1.5 Additional Methods. We do not anticipate that you will need additional test methods to measure ambient contributions of particulate matter to source emissions

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because ambient contributions are insignificant for most of the sources that are expected to be measured using this test method. However, when an adjustment for the ambient air particulate matter is needed, use the ambient air reference methods to quantify the ambient air contribution. If the source gas filtration temperature never exceeds 30°C (85°F) and condensable particulate is not measured by Method 202, then the correction for ambient particulate matter must be adjusted for condensable material that vaporizes at the process temperature.

1.6 Limitations. You cannot use this method to measure emissions following a wet scrubber because this method is not applicable for in-stack gases containing water droplets. To measure PM₁₀ and PM_{2.5} in emissions where water droplets are known to exist, we recommend that you use Method 5. This method may not be suitable for sources with stack gas temperatures exceeding 260°C (500°F). You may need to take extraordinary measures—including the use of specialty metals (e.g., Inconel) to achieve reliable particulate mass since the threads of the cyclones may gall or seize, thus preventing the recovery of the collected particulate matter and rendering the cyclone unusable for subsequent use.

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1.7 Conditions. You can use this method to obtain both particle sizing and total filterable particulate if the isokinetics are within 90-110 percent, the number of sampling points is the same as Method 5 or 17, and the in-stack filter temperature is within the acceptable range. The acceptable range for the in-stack filter temperature is generally defined as the typical range of temperature for emission gases. The acceptable range varies depending on the source and control technology. To satisfy Method 5 criteria, you may need to remove the in-stack filter and use an out-of-stack filter and recover the PM in the probe between the PM_{2.5} particle sizer and the filter. In addition, to satisfy Method 5 and Method 17 criteria, you may need to sample from more than 12 traverse points. Be aware that this method determines in-stack PM₁₀ and PM_{2.5} filterable emissions by sampling from a recommended maximum of 12 sample points, at a constant flow rate through the train (the constant flow is necessary to maintain the size cuts of the cyclones), and with a filter that is at the stack temperature. In contrast, Method 5 or Method 17 trains are operated isokinetically with varying flow rates through the train. Method 5 and Method 17 require sampling from as many as 24 sample points. Method 5 uses an out-of-stack filter that is maintained at a constant temperature

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of 120°C (248°F). Further, to use this method in place of Method 5 or Method 17, you must extend the sampling time so that you collect the minimum mass necessary for weighing on each portion of this sampling train. Also, if you are using this method as an alternative to a required performance test, then you must receive approval from the appropriate authorities prior to conducting the test.

2.0 Summary of Method

2.1 Summary. To measure PM_{10} and $PM_{2.5}$, extract a sample of gas at a predetermined constant flow rate through an in-stack sizing device. The sizing device separates particles with nominal aerodynamic diameters of 10 microns and 2.5 microns. To minimize variations in the isokinetic sampling conditions, you must establish well-defined limits. Once a sample is obtained, remove uncombined water from the particulate, then use gravimetric analysis to determine the particulate mass for each size fraction. This method changes Method 201A of Appendix M to 40 CFR part 51 filterable particulate procedures with the addition of a $PM_{2.5}$ cyclone from a conventional five-stage cascade cyclone train. The addition of a $PM_{2.5}$ cyclone between the PM_{10} cyclone and the stack temperature filter in the sampling train supplements the measurement of PM_{10} with the measurement of fine particulate matter. Without the

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addition of the PM_{2.5} cyclone, the filterable particulate portion of the sampling train may be used to measure total and PM₁₀ emissions. Likewise, with the exclusion of the PM₁₀ cyclone, the filterable particulate portion of the sampling train may be used to measure total and PM_{2.5} emissions. Figure 1 of Section 17 presents the schematic of the sampling train configured with these changes.

3.0 Definitions

[Reserved]

4.0 Interferences

You cannot use this method to measure emissions following a wet scrubber because this method is not applicable for in-stack gases containing water droplets. Stacks with entrained moisture droplets may have water droplets larger than the cut sizes for the cyclones. These water droplets normally contain particles and dissolved solids that become PM₁₀ and PM_{2.5} following evaporation of the water.

5.0 Safety

Disclaimer: You may have to use hazardous materials, operations, and equipment while using this method. We do not provide information on appropriate safety and health practices. You are responsible for determining the applicability of regulatory limitations and establishing

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appropriate safety and health practices. Handle materials and equipment properly.

6.0 Equipment and Supplies

Figure 2 of Section 17 shows details of the combined cyclone heads used in this method. The sampling train is the same as Method 17 of Appendix A-6 to Part 60 with the exception of the PM₁₀ and PM_{2.5} sizing devices. The following sections describe the sampling train's primary design features in detail.

6.1 Filterable Particulate Sampling Train Components.

6.1.1 Nozzle. You must use stainless steel (316 or equivalent) or Teflon[®]-coated stainless steel nozzles with a sharp tapered leading edge. We recommend one of the 12 nozzles listed in Figure 3 of Section 17 because they meet design specifications when PM₁₀ cyclones are used as part of the sampling train. We also recommend that you have a large number of nozzles in small diameter increments available to increase the likelihood of using a single nozzle for the entire traverse. We recommend one of the nozzles listed in Figure 4A or 4B of Section 17 because they meet design specifications when PM_{2.5} cyclones are used without PM₁₀ cyclones as part of the sampling train.

6.1.2 PM₁₀ and PM_{2.5} Sizing Device. Use a stainless steel (316 or equivalent) PM₁₀ and PM_{2.5} sizing devices. The

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sizing devices must be cyclones that meet the design specifications shown in Figures 3, 4, 5, and 6 of Section 17. Use a caliper to verify the dimensions of the PM₁₀ and PM_{2.5} sizing devices to within ± 0.02 cm of the design specifications. Example suppliers of PM₁₀ and PM_{2.5} sizing devices include the following:

- (a) Environmental Supply Company, Inc.
2142 Geer Street
Durham, North Carolina 27704
(919) 956-9688 (phone)
(919) 682-0333 (fax)
- (b) Apex Instruments
P.O. Box 727
125 Quantum Street
Holly Springs, North Carolina 27540
(919) 557-7300 (phone)
(919) 557-7110 (fax)
- (c) Andersen Instruments Inc.
500 Technology Court
Smyrna, Georgia 30082
(770) 319-9999 (phone)
(770) 319-0336 (fax)

You may use alternative particle sizing devices if they meet the requirements in Development and Laboratory Evaluation of a Five-Stage Cyclone System, EPA-600/7-78-008 (incorporated by reference) and are approved by the Administrator. The Director of the Federal Register approves this incorporation by reference in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. You may obtain a copy

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from National Technical Information Service, <http://www.ntis.gov> or (800) 553-6847. You may inspect a copy at the Office of Federal Register, 800 North Capitol Street, NW., Suite 700, Washington, DC.

6.1.3 Filter Holder. Use a filter holder that is either stainless steel (316 or equivalent) or Teflon[®]-coated stainless steel. A heated glass filter holder may be substituted for the steel filter holder when filtration is performed out-of-stack. Commercial size filter holders are available depending upon project requirements, including commercial filter holders to support 25-, 47-, and 63-mm diameter filters. Commercial size filter holders contain a Teflon[®] O-ring, a stainless steel screen that supports the filter, and a final Teflon[®] O-ring. Screw the assembly together and attach to the outlet of cyclone IV.

6.1.4 Pitot Tube. You must use a pitot tube made of heat resistant tubing. Attach the pitot tube to the probe with stainless steel fittings. Follow the specifications for the pitot tube and its orientation to the inlet nozzle given in Section 6.1.1.3 of Method 5.

6.1.5 Probe Liner. The probe extension must be glass-lined or Teflon[®]. Follow the specifications in Section 6.1.1.2 of Method 5.

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6.1.6 Differential Pressure Gauge, Condensers, Metering Systems, Barometer, and Gas Density Determination Equipment. Follow the requirements in Sections 6.1.1.4 through 6.1.3 of Method 5, as applicable.

6.2 Sample Recovery Equipment.

6.2.1 Filterable Particulate Recovery. Use the following equipment to quantitatively determine the amount of filterable particulate matter recovered from the sampling train. Follow the requirements specified in Sections 6.2.1 through 6.2.8 of Method 5, respectively.

- (a) Filter holder brushes
- (b) Wash bottles
- (c) Glass sample storage containers
- (d) Petri dishes
- (e) Graduated cylinders and balance
- (f) Plastic storage containers
- (g) Funnel
- (h) Rubber policeman

7.0 Reagents, Standards, and Sampling Media

7.1 Sample Collection. To collect a sample, you will need a filter and silica gel. You must also have water and crushed ice. Additional information on these items is in the following paragraphs.

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7.1.1 Filter. Use a glass fiber, quartz, or Teflon[®] filter that does not have an organic binder. The filter must also have an efficiency of at least 99.95 percent (<0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. Conduct the filter efficiency test in accordance with ASTM Method D2986-95a—Standard Method for Evaluation of Air, Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test (incorporated by reference). The Director of the Federal Register approves this incorporation by reference in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. You may obtain a copy from American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, Post Office Box C700, West Conshohocken, PA 19428-2959. You may inspect a copy at the Office of Federal Register, 800 North Capitol Street, NW., Suite 700, Washington, DC. Alternatively, you may use test data from the supplier's quality control program. If the source you are sampling has sulfur dioxide (SO₂) or sulfite (SO₃) emissions, you must use a filter that will not react with SO₂ or SO₃. Depending on your application and project data quality objectives (DQOs), filters are commercially available in 25-, 47-, 83-, and 110-mm sizes.

7.1.2 Silica Gel. Use an indicating-type silica gel of 6 to 16 mesh. We must approve other types of desiccants

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(equivalent or better) before you use them. Allow the silica gel to dry for 2 hours at 175°C (350°F) if it is being reused. You do not have to dry new silica gel.

7.1.3 Crushed ice. Obtain from the best readily available source.

7.2 Sample Recovery and Analysis Reagents. You will need acetone and anhydrous sodium sulfate for the sample analysis. Unless otherwise indicated, all reagents must conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society. If such specifications are not available, then use the best available grade. Additional information on each of these items is in the following paragraphs.

7.2.1 Acetone. Use acetone that is stored in a glass bottle. Do not use acetone from a metal container because it normally produces a high residue blank. You must use acetone with blank values <1 ppm, by weight residue. Analyze acetone blanks prior to field use to confirm low blank values. In no case shall a blank value of greater than 1E-06 of the weight of acetone used in sample recovery be subtracted from the sample weight (i.e., the maximum blank correction is 0.079 mg per 100 mL of acetone used to recover samples).

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7.2.2 Particulate Sample Desiccant. Use indicating-type anhydrous sodium sulfate to desiccate samples prior to weighing.

8.0 Sample collection, Preservation, Storage, and Transport

8.1 Qualifications. This is a complex test method. To obtain reliable results, you must be trained and experienced with in-stack filtration systems (such as cyclones, impactors, and thimbles) and their operations.

8.2 Preparations. Follow the pretest preparation instructions in Section 8.1 of Method 5.

8.3 Site Setup. You must complete the following to properly set up for this test:

- (a) Determine the sampling site location and traverse points.
- (b) Calculate probe/cyclone blockage.
- (c) Verify the absence of cyclonic flow.
- (d) Complete a preliminary velocity profile, and select a nozzle.

8.3.1 Sampling Site Location and Traverse Point Determination. Follow the standard procedures in Method 1 to select the appropriate sampling site. Then do all of the following:

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(a) Sampling site. Choose a location that maximizes the distance from upstream and downstream flow disturbances.

(b) Traverse points. The recommended maximum number of total traverse points at any location is 12 as shown in Figure 7 of Section 17. Prevent the disturbance and capture of any solids accumulated on the inner wall surfaces by maintaining a 1-inch distance from the stack wall ($\frac{1}{2}$ inch for sampling locations less than 24 inches in diameter).

(c) Round or rectangular duct or stack. If a duct or stack is round with two ports located 90 degrees apart, use six sampling points on each diameter. Use a 3x4 sampling point layout for rectangular ducts or stacks. Consult with the Administrator to receive approval for other layouts before you use them.

(d) Sampling ports. To accommodate the in-stack cyclones for this method, you may need larger diameter sampling ports than those used by Method 5 or Method 17 for total filterable particulate sampling. When you must use nozzles smaller than 0.16 inch in diameter, the sampling port diameter must be 6 inches. Do not use the conventional 4-inch diameter port because the combined dimension of the PM₁₀ cyclone and the nozzle extending from

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the cyclone exceeds the internal diameter of the port.

[**Note:** If the port nipple is short, you may be able to "hook" the sampling head through a smaller port into the duct or stack.]

8.3.2 Probe/Cyclone Blockage Calculations. Follow the procedures in the next two sections, as appropriate.

8.3.2.1 *Ducts with diameters greater than 24 inches.*

Minimize the blockage effects of the combination of the in-stack nozzle/cyclones and filter assembly for ducts with diameters greater than 24 inches by keeping the cross-sectional area of the assembly at 3 percent or less of the cross-sectional area of the duct.

8.3.2.2 *Ducts with diameters between 18 and 24 inches.* Ducts with diameters between 18 and 24 inches have blockage effects ranging from 3 to 6 percent, as illustrated in Figure 8 of Section 17. Therefore, when you conduct tests on these small ducts, you must adjust the observed velocity pressures for the estimated blockage factor whenever the combined sampling apparatus blocks more than 3 percent of the stack or duct (see Sections 8.7.2.2 and 8.7.2.3 on the probe blockage factor and the final adjusted velocity pressure, respectively).

8.3.3 Cyclonic Flow. Do not use the combined cyclone sampling head at sampling locations subject to cyclonic

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flow. Also, you must follow procedures in Method 1 to determine the presence or absence of cyclonic flow and then perform the following calculations.

(a) As per Section 11.4 of Method 1, find and record the angle that has a null velocity pressure for each traverse point using a S-type pitot tube.

(b) Average the absolute values of the angles that have a null velocity pressure. Do not use the sampling location if the average absolute value exceeds 20°.

[**Note:** You can minimize the effects of cyclonic flow conditions by moving the sampling location, placing gas flow straighteners upstream of the sampling location or applying a modified sampling approach as described in EPA Guideline Document 008. You may need to obtain an alternate method approval prior to using a modified sampling approach.]

8.3.4 Preliminary Velocity Profile. Conduct a preliminary velocity traverse by following Method 2 velocity traverse procedures. The purpose of the preliminary velocity profile is to determine all of the following:

(a) The gas sampling rate for the combined probe/cyclone sampling head in order to meet the required particle size cut.

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(b) The appropriate nozzle to maintain the required gas sampling rate for the velocity pressure range and isokinetic range. If the isokinetic range cannot be met (e.g., batch processes, extreme process flow or temperature variation), void the sample or use methods subject to the approval of the Administrator to correct the data.

(c) The necessary sampling duration to obtain sufficient particulate catch weights.

8.3.4.1 *Preliminary traverse.* You must use an S-type pitot tube with a conventional thermocouple to conduct the traverse. Conduct the preliminary traverse as close as possible to the anticipated testing time on sources that are subject to hour-by-hour gas flow rate variations of approximately ± 20 percent and/or gas temperature variations of approximately $\pm 10^{\circ}\text{C}$ ($\pm 50^{\circ}\text{F}$). [**Note:** You should be aware that these variations can cause errors in the cyclone cut diameters and the isokinetic sampling velocities.]

8.3.4.2 *Velocity pressure range.* Insert the S-type pitot tube at each traverse point, and record the range of velocity pressures measured on data form in Method 2. You will use this later to select the appropriate nozzle.

8.3.4.3 *Initial gas stream viscosity and molecular weight.* Determine the average gas temperature, average gas oxygen content, average carbon dioxide content, and

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estimated moisture content. You will use this information to calculate the initial gas stream viscosity (Equation 3) and molecular weight (Equations 1 and 2). [**Note:** You must follow the instructions outlined in Method 4 to estimate the moisture content. You may use a wet bulb-dry bulb measurement or hand-held hygrometer measurement to estimate the moisture content of sources with gas temperatures less than 71°C (160°F).]

8.3.4.4 *Particulate matter concentration in the gas stream.* Determine the particulate matter concentration for the PM_{2.5} and the PM_{2.5} to PM₁₀ components of the gas stream through qualitative measurements or estimates. Having an idea of the particulate concentration in the gas stream is not essential but will help you determine the appropriate sampling time to acquire sufficient particulate matter weight for better accuracy at the source emission level. The collectable particulate matter weight requirements depend primarily on the types of filter media and weighing capabilities that are available and needed to characterize the emissions. Estimate the collectable particulate matter concentrations in the >10 micrometer, ≤10 and >2.5 micrometers, and ≤2.5 micrometer size ranges. Typical particulate matter concentrations are listed in Table 1 of Section 17. Additionally, relevant sections of AP-42 may

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contain particle size distributions for processes characterized in those sections and Appendix B2 of AP-42 contains generalized particle size distributions for nine industrial process categories (e.g., stationary internal combustion engines firing gasoline or diesel fuel, calcining of aggregate or unprocessed ores). The generalized particle size distributions can be used if source-specific particle size distributions are unavailable. Appendix B2 also contains typical collection efficiencies of various particulate control devices and example calculations showing how to estimate uncontrolled total particulate emissions, uncontrolled size-specific emissions, and controlled size-specific particulate emissions.

8.4 Pre-test Calculations. You must perform pre-test calculations to help select the appropriate gas sampling rate through cyclone I (PM_{10}) and cyclone IV ($PM_{2.5}$). Choosing the appropriate sampling rate will allow you to maintain the appropriate particle cut diameters based upon preliminary gas stream measurements, as specified in Table 2 of Section 17.

8.4.1 Gas Sampling Rate. The gas sampling rate is defined by the performance curves for both cyclones, as illustrated in Figure 9 of Section 17. You must use the

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calculations in Section 8.5 to achieve the appropriate cut size specification for each cyclone. The optimum gas sampling rate is the overlap zone defined as the range below the cyclone IV 2.25 micrometer curve down to the cyclone I 11.0 micrometer curve (area between the two dark, solid lines in Figure 9 of Section 17).

8.4.2 Choosing the Appropriate Sampling Rate. You must select a gas sampling rate in the middle of the overlap zone (discussed in Section 8.4.1), as illustrated in Figure 9 of Section 17 to maximize the acceptable tolerance for slight variations in flow characteristics at the sampling location. The overlap zone is also a weak function of the gas composition. [**Note:** The acceptable range is limited, especially for gas streams with temperatures less than approximately 100°F. At lower temperatures, it may be necessary to perform the PM₁₀ and PM_{2.5} separately in order to meet the necessary particle size criteria shown in Table 2 of Section 17.0.]

8.5 Test Calculations. You must perform all of the calculations in Table 3 of Section 17 and the calculations described in Sections 8.5.1 through 8.5.5.

8.5.1 The Assumed Reynolds Number. Verify the assumed Reynolds number (N_{re}) by substituting the sampling rate (Q_s) calculated in Equation 7 into Equation 8. Then

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use Table 5 of Section 17 to determine if the N_{re} used in Equation 5 was correct.

8.5.2 Final Sampling Rate. Recalculate the final sampling rate (Q_s) if the assumed Reynolds number used in your initial calculation is not correct. Use Equation 7 to recalculate the optimum sampling rate (Q_s).

8.5.3 Meter Box ΔH . Use Equation 9 to calculate the meter box ΔH after you calculate the optimum sampling rate and confirm the Reynolds number. [**Note:** The stack gas temperature may vary during the test, which could affect the sampling rate. If the stack gas temperature varies, you must make slight adjustments in the meter box ΔH to maintain the correct constant cut diameters. Therefore, use Equation 9 to recalculate the ΔH values for 50°F above and below the stack temperature measured during the preliminary traverse (see Section 8.3.4.1), and document this information in Table 4 of Section 17.]

8.5.4 Choosing a Sampling Nozzle. Select one or more nozzle sizes to provide for near isokinetic sampling rate (that is, 80 percent to 120 percent). This will also minimize an isokinetic sampling error for the particles at each point. First calculate the mean stack gas velocity, v_s , using Equation 11. See Section 8.7.2 for information on correcting for blockage and use of different pitot tube

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coefficients. Then use Equation 12 to calculate the diameter of a nozzle that provides for isokinetic sampling at the mean stack gas velocity at flow Q_s . From the available nozzles just smaller and just larger of this diameter, D , select the most promising nozzle. Perform the following steps for the selected nozzle.

8.5.4.1 *Minimum/maximum nozzle/stack velocity ratio.*

Use Equation 14 to calculate the minimum nozzle/stack velocity ratio, R_{\min} . Use Equation 15 to calculate the maximum nozzle/stack velocity ratio, R_{\max} .

8.5.4.2 *Minimum gas velocity.* Use Equation 16 to calculate the minimum gas velocity (v_{\min}) if R_{\min} is an imaginary number (negative value under the square root function) or if R_{\min} is less than 0.5. Use Equation 17 to calculate v_{\min} if R_{\min} is greater than or equal to 0.5.

8.5.4.3 *Maximum stack velocity.* Use Equation 18 to calculate the maximum stack velocity (v_{\max}) if R_{\max} is less than 1.5. Use Equation 19 to calculate the stack velocity if R_{\max} is greater than or equal to 1.5.

8.5.4.4 *Conversion of gas velocities to velocity pressure.* Use Equation 20 to convert v_{\min} to minimum velocity pressure, Δp_{\min} . Use Equation 21 to convert v_{\max} to maximum velocity pressure, Δp_{\max} .

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8.5.4.5 Compare minimum and maximum velocity

pressures with the observed velocity pressures at all traverse points during the preliminary test (see Section 8.3.4.2).

8.5.5 Optimum sampling nozzle. The nozzle you selected is appropriate if all the observed velocity pressures during the preliminary test fall within the range of the Δp_{\min} and Δp_{\max} . Make sure the following requirements are met. Then follow the procedures in Sections 8.5.5.1 and 8.5.5.2.

(a) Choose an optimum nozzle that provides for isokinetic sampling conditions as close to 100 percent as possible. This is prudent because even if there are slight variations in the gas flow rate, gas temperature, or gas composition during the actual test, you have the maximum assurance of satisfying the isokinetic criteria. Generally, one of the two candidate nozzles selected will be closer to optimum (see Section 8.5.4).

(b) When testing is for $PM_{2.5}$ only, you may have only two traverse points out of 12 that are outside the range of the Δp_{\min} and Δp_{\max} (i.e., 16 percent failure rate rounded to the nearest whole number). If the coarse fraction for PM_{10} determination is included, only one traverse point out of 12 can fall outside the minimum-maximum velocity pressure

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range (i.e., 8 percent failure rate rounded to the nearest whole number).

8.5.5.1 *Precheck.* Visually check the selected nozzle for dents before use.

8.5.5.2 *Attach the pre-selected nozzle.* Screw the pre-selected nozzle onto the main body of cyclone I using Teflon[®] tape. Use a union and cascade adaptor to connect the cyclone IV inlet to the outlet of cyclone I (see Figure 2 of Section 17).

8.6 Sampling Train Preparation. A schematic of the sampling train used in this method is shown in Figure 1 of Section 17. First, assemble the train and complete the leak check on the combined cyclone sampling head and pitot tube. Use the following procedures to prepare the sampling train. [**Note:** Do not contaminate the sampling train during preparation and assembly. Keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.]

8.6.1 Sampling Head and Pitot Tube. Assemble the combined cyclone train. The O-rings used in the train have a temperature limit of approximately 205°C (400°F). Use cyclones with stainless steel sealing rings when stack temperatures exceed 205°C (400°F). This method may not be suitable for sources with stack gas temperatures exceeding

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260°C (500°F). You may need to take extraordinary measures including the use of specialty metals (e.g., Inconel) to achieve reliable particulate mass since the threads of the cyclones may gall or seize, thus preventing the recovery of the collected particulate matter and rendering the cyclone unusable for subsequent use. You must also keep the nozzle covered to protect it from nicks and scratches.

8.6.2 Filterable Particulate Filter Holder and Pitot Tube. Attach the pre-selected filter holder to the end of the combined cyclone sampling head (see Figure 2 of Section 17). Attach the S-type pitot tube to the combined cyclones after the sampling head is fully attached to the end of the probe. [**Note:** The pitot tube tip must be mounted slightly beyond the combined head cyclone sampling assembly and at least one inch off the gas flow path into the cyclone nozzle. This is similar to the pitot tube placement in Method 17.] Weld the sensing lines to the outside of the probe to ensure proper alignment of the pitot tube. Provide unions on the sensing lines so that you can connect and disconnect the S-type pitot tube tips from the combined cyclone sampling head before and after each run. [**Note:** Calibrate the pitot tube on the sampling head because the cyclone body is a potential source flow disturbance.]

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8.6.3 Filter. You must number and tare the filters before use. To tare the filters, desiccate each filter at $20 \pm 5.6^{\circ}\text{C}$ ($68 \pm 10^{\circ}\text{F}$) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., <0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing, the filter must not be exposed to the laboratory atmosphere for longer than 2 minutes and a relative humidity above 50 percent. Alternatively, the filters may be oven-dried at 104°C (220°F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Use tweezers or clean disposable surgical gloves to place a labeled (identified) and pre-weighed filter in both filterable and condensable particulate filter holders. You must center the filter and properly place the gasket so that the sample gas stream will not circumvent the filter. Check the filter for tears after the assembly is completed. Then screw the filter housing together to prevent the seal from leaking.

8.6.7 Moisture Trap. If you are measuring only filterable particulate (or you are sure that the filtration temperature will be maintained below 30°C (85°F)), then an empty modified Greenburg Smith impinger followed by an impinger containing silica gel is required. Alternatives described in Method 5 may also be used to collect moisture

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that passes through the ambient filter. If you are measuring condensable particulate matter in combination with this method, then follow the procedures in Method 202 for moisture collection.

8.6.8 Leak Check. Use the procedures outlined in Section 8.4 of Method 5 to leak check the entire sampling system. Specifically perform the following procedures:

8.6.8.1 *Sampling train.* You must pretest the entire sampling train for leaks. The pretest leak check must have a leak rate of not more than 0.02 ACFM or 4 percent of the average sample flow during the test run, whichever is less. Additionally, you must conduct the leak check at a vacuum equal to or greater than the vacuum anticipated during the test run. Enter the leak check results on the field test data sheet (see Section 11.1) for the specific test.

[**Note:** Do not conduct a leak check during port changes.]

8.6.8.2 *Pitot tube assembly.* After you leak check the sample train, perform a leak check of the pitot tube assembly. Follow the procedures outlined in Section 8.4.1 of Method 5.

8.6.9 Sampling Head. You must preheat the combined sampling head to the stack temperature of the gas stream at the test location ($\pm 10^{\circ}\text{C}$, $\pm 50^{\circ}\text{F}$). This will heat the sampling head and prevent moisture from condensing from the

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sample gas stream. Record the site barometric pressure and stack pressure on the field test data sheet.

8.6.9.1 *Unsaturated stacks.* You must complete a passive warmup (of 30-40 min) within the stack before the run begins to avoid internal condensation. [**Note:** Unsaturated stacks do not have entrained droplets and operate at temperatures above the local dew point of the stack gas.]

8.6.9.2 *Shortened warm-up of unsaturated stacks.* You can shorten the warmup time by thermostated heating outside the stack (such as by a heat gun). Then place the heated sampling head inside the stack and allow the temperature to equilibrate.

8.7 Sampling Train Operation. Operate the sampling train the same as described in Section 4.1.5 of Method 5, except use the procedures in this section for isokinetic sampling and flow rate adjustment. Maintain the flow rate calculated in Section 8.4.1 throughout the run, provided the stack temperature is within 28°C (50°F) of the temperature used to calculate ΔH . If stack temperatures vary by more than 28°C (50°F), use the appropriate ΔH value calculated in Section 8.5.3. Determine the minimum number of traverse points as in Figure 7 of Section 17. Determine the minimum total projected sampling time (t_r), based on

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achieving the data quality objectives or emission limit of the affected facility. We recommend you round the number of minutes sampled at each point to the nearest 15 seconds. Perform the following procedures:

8.7.1 Sample Point Dwell Time. You must calculate the dwell time (that is, sampling time) for each sampling point to ensure that the overall run provides a velocity-weighted average that is representative of the entire gas stream. Vary the dwell time, or sampling time, at each traverse point proportionately with the point velocity.

8.7.1.1 *Dwell time at first sampling point.*

Calculate the dwell time for the first point, t_1 , using Equation 22. You must use the data from the preliminary traverse. Here, N_{tp} equals the total number of traverse points.

8.7.1.2 *Dwell time at remaining sampling points.*

Calculate the dwell time at each of the remaining traverse points, t_n , using Equation 23. This time you must use the actual test run data. [**Note:** Round the dwell times to the nearest 15 seconds.] Each traverse point must have a dwell time of at least 2 minutes.

8.7.2 Adjusted Velocity Pressure. When selecting your sampling points using your preliminary velocity traverse data, your preliminary velocity pressures must be

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adjusted to take into account the increase in velocity due to blockage. Also, you must adjust your preliminary velocity data for differences in pitot tube coefficients. Use the following instructions to adjust the preliminary velocity pressure.

8.7.2.1 *Different pitot tube coefficient.* You must use Equation 24 to correct the recorded preliminary velocity pressures if the pitot tube mounted on the combined cyclone sampling head has a different pitot tube coefficient than the pitot tube used during the preliminary velocity traverse (see Section 8.3.4).

8.7.2.2 *Probe blockage factor.* You must use Equation 25 to calculate an average probe blockage correction factor (b_f) if the diameter of your stack or duct is between 18 and 24 inches. A probe blockage factor is calculated because of the flow blockage caused by the relatively large cross-sectional area of the combined cyclone sampling head, as discussed in Section 8.3.2.2 and illustrated in Figure 8 of Section 17. [**Note:** The sampling head (including the PM₁₀ cyclone, PM_{2.5} cyclone, pitot and filter holder) has a projected area of approximately 20.5 square inches when oriented into the gas stream. As the probe is moved from the most outer to the most inner point, the amount of blockage that actually occurs ranges from approximately 4

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square inches to the full 20.5 inches. The average cross-sectional area blocked is 12 square inches.]

8.7.2.3 *Final adjusted velocity pressure.* Calculate the final adjusted velocity pressure (Δp_{s2}) using Equation 26. [**Note:** Figure 8 of Section 17 illustrates that the blockage effect of the large combined cyclone sampling head increases rapidly below diameters of 18 inches. Therefore, you must follow the procedures outlined in Method 1A to conduct tests in small stacks (<18 inches diameter). You must conduct the velocity traverse downstream of the sampling location or immediately before the test run.]

8.7.3 *Sample Collection.* Collect samples the same as described in Section 4.1.5 of Method 5, except use the procedures in this section for isokinetic sampling and flow rate adjustment. Maintain the flow rate calculated in Section 8.5 throughout the run, provided the stack temperature is within 28°C (50°F) of the temperature used to calculate ΔH . If stack temperatures vary by more than 28°C (50°F), use the appropriate ΔH value calculated in Section 8.5.3. Calculate the dwell time at each traverse point as in Equations 22 and 23. In addition to these procedures, you must also use running starts and stops if the static pressure at the sampling location is more negative than 5 in. water column. This prevents back

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pressure from rupturing the sample filter. If you use a running start, adjust the flow rate to the calculated value after you perform the leak check (see Section 8.4).

8.7.3.1 *Level and zero manometers.* Periodically check the level and zero point of the manometers during the traverse. Vibrations and temperature changes may cause them to drift.

8.7.3.2 *Portholes.* Clean the portholes prior to the test run. This will minimize the chance of collecting deposited material in the nozzle.

8.7.3.3 *Sampling procedures.* Verify that the combined cyclone sampling head temperature is at stack temperature ($\pm 10^{\circ}\text{C}$, $\pm 50^{\circ}\text{F}$). [**Note:** For many stacks, portions of the cyclones and filter will be external to the stack during part of the sampling traverse. Therefore, you must heat or insulate portions of the cyclones and filter that are not within the stack in order to maintain the sampling head temperature at the stack temperature. Maintaining the temperature will insure proper particle sizing and prevent condensation on the walls of the cyclones.] Remove the protective cover from the nozzle. To begin sampling, immediately start the pump and adjust the flow to calculated isokinetic conditions. Position the probe at the first sampling point with the nozzle pointing

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directly into the gas stream. Ensure the probe/pitot tube assembly is leveled. [**Note:** When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

(a) Traverse the stack cross-section, as required by Method 1 with the exception that you are only required to perform a 12-point traverse. Do not bump the cyclone nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes. This will minimize the chance of extracting deposited materials.

(b) Record the data required on the field test data sheet for each run. Record the initial dry gas meter reading. Then take dry gas meter readings at the following times: the beginning and end of each sample time increment; when changes in flow rates are made; and when sampling is halted. Compare the velocity pressure measurements (Equations 20 and 21) with the velocity pressure measured during the preliminary traverse. Keep the meter box ΔH at the value calculated in Section 8.5.3 for the stack temperature that is observed during the test. Record all the point-by-point data and other source test parameters on the field test data sheet. Do not leak check the sampling system during port changes.

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(c) Maintain the flow through the sampling system at the last sampling point. Remove the sampling train from the stack while it is still operating (running stop). Then stop the pump, and record the final dry gas meter reading and other test parameters on the field test data sheet.

8.7.4 Process Data. You must document data and information on the process unit tested, the particulate control system used to control emissions, any non-particulate control system that may affect particulate emissions, the sampling train conditions, and weather conditions. Discontinue the test if the operating conditions may cause non-representative particulate emissions.

8.7.4.1 *Particulate control system data.* Use the process and control system data to determine if representative operating conditions were maintained throughout the testing period.

8.7.4.2 *Sampling train data.* Use the sampling train data to confirm that the measured particulate emissions are accurate and complete.

8.7.5 Sample Recovery. First remove the sample head (combined cyclone/filter assembly) from the stack. After the sample head is removed, perform a post-test leak check of the probe and sample train. Then recover the components

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from the cyclone/filter. Refer to the following sections for more detailed information.

8.7.5.1 *Remove sampling head.* At the conclusion of the test, document final test conditions and remove the pitot tube and combined cyclone sampling head from the source. Make sure that you do not scrape the pitot tube or the combined cyclone sampling head against the port or stack walls. [**Note:** After you stop the gas flow, make sure you keep the combined cyclone head level to avoid tipping dust from the cyclone cups into the filter and/or down-comer lines.] After cooling and when the probe can be safely handled, wipe off all external surfaces near the cyclone nozzle, and cap the inlet to cyclone I. Remove the combined cyclone/filter sampling head from the probe. Cap the outlet of the filter housing to prevent particulate matter from entering the assembly.

8.7.5.2 *Leak check probe/sample train assembly (post-test).* Leak check the remainder of the probe and sample train assembly (including meter box) after removing the combined cyclone head/filter. You must conduct the leak rate at a vacuum equal to or greater than the maximum vacuum achieved during the test run. Enter the results of the leak check onto the field test data sheet. If the leak rate of the sampling train (without the combined cyclone

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sampling head) exceeds 0.02 ACFM or 4 percent of the average sampling rate during the test run (whichever is less), the run is invalid, and you must repeat it.

8.7.5.3 Weigh or measure the volume of the liquid collected in the water collection impingers and silica trap. Measure the liquid in the first impingers to within 1 ml using a clean graduated cylinder or by weighing it to within 0.5 g using a balance. Record the volume of the liquid or weight of the liquid present to be used to calculate the moisture content of the effluent gas.

8.7.5.4 If a balance is available in the field, weigh the silica impinger to within 0.5 g. Note the color of the indicating silica gel in the last impinger to determine whether it has been completely spent, and make a notation of its condition. If you are measuring condensable particulate matter in combination with this method, then leave the silica in the impinger for recovery after the post-test nitrogen purge is complete.

8.7.5.5 *Recovery of particulate matter.* Recovery involves the quantitative transfer of particles in the following size range: > 10 micrometers; ≤ 10 micrometers but > 2.5 micrometers; and ≤ 2.5 micrometers. You must use a Nylon or Teflon brush and an acetone rinse to recover

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particles from the combined cyclone/filter sampling head.

Use the following procedures for each container.

(a) Container #1, \leq PM_{2.5} micrometer filterable particulate - Use tweezers and/or clean disposable surgical gloves to remove the filter from the filter holder. Place the filter in the petri dish that you identified as Container #1. Using a dry Nylon bristle brush and/or a sharp-edged blade, carefully transfer any particulate matter and/or filter fibers that adhere to the filter holder gasket or filter support screen to the petri dish. Seal the container. This container holds particles \leq 2.5 micrometers that are caught on the in-stack filter.

(b) Container #2, $>$ PM₁₀ micrometer filterable particulate - Quantitatively recover the particulate matter from the cyclone I cup and acetone rinses (and brush cleaning) of the cyclone cup, internal surface of the nozzle, and cyclone I internal surfaces, including the outside surface of the downcomer line. Seal the container and mark the liquid level on the outside of the container. You must keep any dust found on the outside of cyclone I and cyclone nozzle external surfaces out of the sample. This container holds particulate matter $>$ 10 micrometers.

(c) Container #3, Filterable particulate \leq 10 micrometer and $>$ 2.5 micrometers - Place the solids from

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cyclone cup IV and the acetone (and brush cleaning) rinses of the cyclone I turnaround cup (above inner downcomer line), inside of the downcomer line, and interior surfaces of cyclone IV into Container #3. Seal the container and mark the liquid level on the outside. This container holds particulate matter ≤ 10 micrometers but > 2.5 micrometers.

(d) Container #4, \leq PM_{2.5} micrometers acetone rinses of the exit tube of cyclone IV and front half of the filter holder - Retrieve the acetone rinses (and brush cleaning) of the exit tube of cyclone IV and the front half of the filter holder in container #4. Seal the container and mark the liquid level on the outside of the container. This container holds particulate matter that is ≤ 2.5 micrometers.

(e) Container #5, Cold impinger water - If the water from the cold impinger used for moisture collection has been weighed in the field, it can be discarded. Otherwise quantitatively transfer liquid from the cold impinger that follows the ambient filter into a clean sample bottle (glass or plastic). Mark the liquid level on the bottle. This container holds the remainder of the liquid water from the emission gases.

(f) Container #6, Silica Gel Absorbent - Transfer the silica gel to its original container and seal. A funnel

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may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of silica gel dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If the silica gel has been weighed in the field to measure water content, it can be discarded. Otherwise the contents of Container #6 are weighed during sample analysis.

(g) Container #7, Acetone Rinse Blank - Take 100 ml of the acetone directly from the wash bottle you used, and place it in Container #7 labeled Acetone Rinse Blank.

8.7.6 Transport Procedures. Containers must remain in an upright position at all times during shipping. You do not have to ship the containers under dry or blue ice.

9.0 Quality Control

9.1 Daily Quality Checks. You must perform daily quality checks using data quality indicators that require review of recording and transfer of raw data, calculations, and documentation of testing procedures.

9.2 Calculation Verification. Verify the calculations by independent, manual checks. You must flag

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any suspect data and identify the nature of the problem and potential effect on data quality. After you complete the test, prepare a data summary, and compile all the calculations and raw data sheets.

9.3 Conditions. You must document data and information on the process unit tested, the particulate control system used to control emissions, any non-particulate control system that may affect particulate emissions, the sampling train conditions, and weather conditions. Discontinue the test if the operating conditions may cause non-representative particulate emissions.

9.4 Health and Safety Plan. Develop a health and safety plan to ensure the safety of your employees who are on site conducting the particulate emission test. Your plan must conform to all applicable OSHA, MSHA, and DOT regulatory requirements. The procedures must also conform to the plant health and safety requirements.

9.5 Calibration Checks. Perform calibration check procedures on analytical balances each time they are used.

9.6 Glassware. Use class A volumetric glassware for titrations, or calibrate your equipment against NIST traceable glassware.

10.0 Calibration and Standardization

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[**Note:** Maintain a laboratory log of all calibrations.]

10.1 Gas Flow Velocities. Measure the gas flow velocities at the sampling locations using Method 2. You must use an S-type pitot tube that meets the required EPA specifications (EPA Publication 600/4-77-0217b) during these velocity measurements. You must also complete the following:

(a) Visually inspect the S-type pitot tube before sampling.

(b) Leak check both legs of the pitot tube before and after sampling.

(c) Maintain proper orientation of the S-type pitot tube while making measurements.

10.1.1 S-type pitot tube orientation. The S-type pitot tube is oriented properly when the yaw and the pitch axis are 90 degrees to the air flow.

10.1.2 Average velocity pressure record. Instead of recording either high or low values, record the average velocity pressure at each point during flow measurements.

10.1.3 Pitot tube coefficient. Determine the pitot tube coefficient based on physical measurement techniques described in Method 2. [**Note:** You must calibrate the pitot tube on the sampling head because of potential

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interferences from the cyclone body. Refer to Section 8.7.2 for additional information.]

10.2 Thermocouple Calibration. Calibrate the thermocouples using the procedures described in Section 10.1.4.1.2 of Method 2 to calibrate the thermocouples. Calibrate each temperature sensor at a minimum of three points over the anticipated range of use against an NIST-traceable mercury-in-glass thermometer.

10.3 Nozzles. You may use stainless steel (316 or equivalent) or Teflon[®]-coated nozzles for isokinetic sampling. Make sure that all nozzles are thoroughly cleaned, visually inspected, and calibrated according to the procedure outlined in Section 10.1 of Method 5.

10.4 Dry Gas Meter Calibration. Calibrate your dry gas meter following the calibration procedures in Section 16.1 of Method 5. Also, make sure you fully calibrate the dry gas meter to determine the volume correction factor prior to field use. Post-test calibration checks must be performed as soon as possible after the equipment has been returned to the shop. Your pretest and post-test calibrations must agree within ± 5 percent.

11.0 Analytical Procedures

11.1 Analytical Data Sheet. Record all data on the analytical data sheet. Obtain the data sheet from Figure 5-6 of Method 5. Alternatively, data may be recorded electronically using software applications such as the Electronic Reporting Tool (ERT) located at the following internet address:

(www.epa.gov/ttn/chief/ert/ert_tool.html).

11.2 Dry Weight of Particulate Matter. Determine the dry weight of particulate following procedures outlined in this section.

11.2.1 Container #1, \leq PM_{2.5} micrometer filterable particulate. Transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate or indicating silica gel. Weigh to a constant weight, and report the results to the nearest 0.1 mg. For the purposes of this section, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

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11.2.2 Container #2, $> PM_{10}$ micrometer filterable particulate acetone rinse. Separately treat this container like Container #1.

11.2.3 Container #3, Filterable particulate ≤ 10 micrometer and ≥ 2.5 micrometers acetone rinse. Separately treat this container like Container #1.

11.2.4 Container #4, $\leq PM_{2.5}$ micrometers acetone rinse of the exit tube of cyclone IV and front half of the filter holder. Note the level of liquid in the container, and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Quantitatively transfer the contents to a tared 250 ml beaker, and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours, and weigh to a constant weight. Report the results to the nearest 0.1 g.

11.2.5 Container #5, Cold impinger water. If the amount of water has not been determined in the field, note the level of liquid in the container, and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the

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Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ± 1 ml or gravimetrically to ± 0.5 g.

11.2.6 Container #6, Silica gel absorbent. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

11.2.7 Container #7, Acetone rinse blank. Use 100 ml of acetone from the blank container for this analysis. If insufficient liquid is available or if the acetone has been lost due to container breakage, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Transfer 100 ml of the acetone to a clean 250 ml beaker. Evaporate the acetone at room temperature and pressure in a laboratory hood to approximately 10 ml. Quantitatively transfer the beaker contents to a 50 ml preweighed tin, and evaporate to dryness at room temperature and pressure in a laboratory hood. Following evaporation, desiccate the residue for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh and report the results to the nearest 0.1 mg.

12.0 Calculations and Data Analysis

12.1 Nomenclature. Report results in International System of Units (SI units) unless the regulatory authority

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for compliance testing specifies English units. The following nomenclature is used.

A	= Area of stack or duct at sampling location, square inches.
A_n	= Area of nozzle, square feet.
b_f	= Average blockage factor calculated in Equation 25, dimensionless.
B_{ws}	= Moisture content of gas stream, fraction (e.g., 10% H ₂ O is $B_{ws} = 0.10$).
C	= Cunningham correction factor for particle diameter, D_p , and calculated using the actual stack gas temperature, dimensionless.
%CO ₂	= Carbon Dioxide content of gas stream, % by volume.
C_a	= Acetone blank concentration, mg/mg.
C_{fPM10}	= Conc. of filterable PM ₁₀ particulate matter, gr/DSCF.
$C_{fPM2.5}$	= Conc. of filterable PM _{2.5} particulate matter, gr/DSCF.
C_p	= Pitot coefficient for the combined cyclone pitot, dimensionless.
C_p'	= Coefficient for the pitot used in the preliminary traverse, dimensionless.
C_r	= Re-estimated Cunningham correction factor for particle diameter equivalent to the actual cut size diameter and calculated using the actual stack gas temperature, dimensionless.
C_{tf}	= Conc. of total filterable particulate matter, gr/DSCF.
C_1	= -150.3162 (micropoise)
C_2	= 18.0614 (micropoise/K ^{0.5}) = 13.4622 (micropoise/R ^{0.5})
C_3	= 1.19183 × 10 ⁶ (micropoise/K ²) = 3.86153 × 10 ⁶ (micropoise/R ²)
C_4	= 0.591123 (micropoise)
C_5	= 91.9723 (micropoise)
C_6	= 4.91705 × 10 ⁻⁵ (micropoise/K ²) = 1.51761 × 10 ⁻⁵ (micropoise/R ²)
D	= Inner diameter of sampling nozzle mounted on Cyclone I, in.
D_p	= Physical particle size, micrometers.
D_{50}	= Particle cut diameter, micrometers.

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D_{50-1}	= Re-calculated particle cut diameters based on re-estimated C_r , micrometers.
D_{50LL}	= Cut diameter for cyclone I corresponding to the 2.25 micrometer cut diameter for cyclone IV, micrometers.
D_{50N}	= D_{50} value for cyclone IV calculated during the Nth iterative step, micrometers.
$D_{50(N+1)}$	= D_{50} value for cyclone IV calculated during the N+1 iterative step, micrometers.
D_{50T}	= Cyclone I cut diameter corresponding to the middle of the overlap zone shown in Figure 9 of Section 17, micrometers.
I	= Percent isokinetic sampling, dimensionless.
in.	= Inches
K_p	= 85.49, [(ft/sec)/(pounds/mole $^{-\circ}R$)].
m_a	= Mass of residue of acetone after evaporation, mg.
M_d	= Molecular weight of dry gas, pounds/pound mole.
M_w	= Molecular weight of wet gas, pounds/pound mole.
M_1	= Milligrams of particulate matter collected on the filter, ≤ 2.5 micrometers.
M_2	= Milligrams of particulate matter recovered from Container #2 (acetone blank corrected), >10 micrometers.
M_3	= Milligrams of particulate matter recovered from Container #3 (acetone blank corrected), ≤ 10 and >2.5 micrometers.
M_4	= Milligrams of particulate matter recovered from Container #4 (acetone blank corrected), ≤ 2.5 micrometers.
N_{tp}	= Number of iterative steps or total traverse points.
N_{re}	= Reynolds number, dimensionless.
$\%O_{2,wet}$	= Oxygen content of gas stream, % by volume of wet gas.

[**Note:** The oxygen percentage used in Equation 3 is on a wet gas basis. That means that since oxygen is typically measured on a dry gas basis, the

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measured %O₂ must be multiplied by the quantity (1 - B_{ws}) to convert to the actual volume fraction. Therefore,

$$\%O_{2,\text{wet}} = (1 - B_{\text{ws}}) * \%O_{2,\text{dry}}$$

P _{bar}	= Barometric pressure, in. Hg.
P _s	= Absolute stack gas pressure, in. Hg.
Q _s	= Sampling rate for cyclone I to achieve specified D ₅₀ , ACFM.
Q _{sST}	= Dry gas sampling rate through the sampling assembly, DSCFM.
Q _I	= Sampling rate for cyclone I to achieve specified D ₅₀ , ACFM.
Q _{IV}	= Sampling rate for cyclone IV to achieve specified D ₅₀ , ACFM.
R _{max}	= Nozzle/stack velocity ratio parameter, dimensionless.
R _{min}	= Nozzle/stack velocity ratio parameter, dimensionless.
T _m	= Meter box and orifice gas temperature, °R.
t _n	= Sampling time at point n, min.
t _r	= Total projected run time, min.
T _s	= Absolute stack gas temperature, °R.
t ₁	= Sampling time at point 1, min.
V _{max}	= Maximum gas velocity calculated from Equations 18 or 19, ft/sec.
V _{min}	= Minimum gas velocity calculated from Equations 16 or 17, ft/sec.
V _n	= Sample gas velocity in the nozzle, ft/sec.
v _s	= Velocity of stack gas, ft/sec.
V _a	= Volume of acetone blank, ml.
V _{aw}	= Volume of acetone used in blank wash, ml.
V _c	= Quantity of water captured in impingers and silica gel, ml.
V _m	= Dry gas meter volume sampled, ACF.
V _{ms}	= Dry gas meter volume sampled, corrected to standard conditions, DSCF.
V _{ws}	= Volume of water vapor, SCF.
V _b	= Volume of aliquot taken for IC analysis, ml.
V _{ic}	= Volume of impinger contents sample, ml.
W _a	= Weight of residue in acetone blank wash, mg.
Z	= Ratio between estimated cyclone IV D ₅₀ values, dimensionless.

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ΔH	= Meter box orifice pressure drop, in. W.C.
ΔH_{θ}	= Pressure drop across orifice at flow rate of 0.75 SCFM at standard conditions, in. W.C. [Note: specific to each orifice and meter box.]
$[(\Delta p)^{0.5}]_{avg}$	= Average of square roots of the velocity pressures measured during the preliminary traverse, in. W.C.
Δp_m	= Observed velocity pressure using S-type pitot tube in preliminary traverse, in. W.C.
Δp_{max}	= Maximum velocity pressure, in. W.C.
Δp_{min}	= Minimum velocity pressure, in. W.C.
Δp_n	= Velocity pressure measured at point n during the test run, in. W.C.
Δp_s	= Velocity pressure calculated in Equation 24, in. W.C.
Δp_{s1}	= Velocity pressure adjusted for combined cyclone pitot tube, in. W.C.
Δp_{s2}	= Velocity pressure corrected for blockage, in. W.C.
Δp_1	= Velocity pressure measured at point 1, in. W.C.
γ	= Dry gas meter gamma value, dimensionless.
μ	= Gas viscosity, micropoise.
θ	= Total run time, minutes.
ρ_a	= Density of acetone, mg/ml (see label on bottle).
12.0	= Constant calculated as 60 percent of 20.5 square inch cross-sectional area of combined cyclone head, square inches.

12.2 Calculations. Perform all of the calculations found in Table 6 of Section 17. Table 6 of Section 17 also provides instructions and references for the calculations.

12.3 Analyses. Analyze D_{50} of cyclone IV and the concentrations of the particulate matter in the various size ranges.

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12.3.1 D_{50} of cyclone IV. To determine the actual D_{50} for cyclone IV, recalculate the Cunningham correction factor and the Reynolds number for the best estimate of cyclone IV D_{50} . The following sections describe additional information on how to recalculate the Cunningham correction factor and determine which Reynolds number to use.

12.3.1.1 *Cunningham correction factor.* Recalculate the initial estimate of the Cunningham correction factor using the actual test data. Insert the actual test run data and D_{50} of 2.5 micrometers into Equation 4. This will give you a new Cunningham correction factor that is based on actual data.

12.3.1.2 *Initial D_{50} for cyclone IV.* Determine the initial estimate for cyclone IV D_{50} using the test condition Reynolds number calculated with Equation 8 as indicated in Table 3 of Section 17. Refer to the following instructions.

(a) If the Reynolds number is less than 3,162, calculate the D_{50} for cyclone IV with Equation 33, using actual test data.

(b) If the Reynolds number is equal to or greater than 3,162, calculate the D_{50} for cyclone IV with Equation 34, using actual test data.

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(c) Insert the "new" D_{50} value calculated by either Equation 33 or 34 into Equation 35 to re-establish the Cunningham Correction Factor (C_r). [**Note:** Use the test condition calculated Reynolds number to determine the most appropriate equation (Equation 33 or 34).]

12.3.1.3 *Re-establish cyclone IV D_{50} .* Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynolds number to determine D_{50-1} .

(a) Use Equation 36 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is less than 3,162.

(b) Use Equation 37 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is equal to or greater than 3,162.

12.3.1.4 *Establishing "Z" values.* The "Z" value is the result of an analysis that you must perform to determine if the Cunningham correction factor is acceptable. Compare the calculated cyclone IV D_{50} (either Equation 33 or 34) to the re-established cyclone IV D_{50-1} (either Equation 36 or 37) values based upon the test condition calculated Reynolds number (Equation 38). Follow these procedures.

(a) Use Equation 38 to calculate the "Z". If the "Z" value is between 0.99 and 1.01, the D_{50-1} value is the best

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estimate of the cyclone IV D_{50} cut diameter for your test run.

(b) If the "Z" value is greater than 1.01 or less than 0.99, re-establish a Cunningham correction factor based on the D_{50-1} value determined in either Equations 36 or 37, depending upon the test condition Reynolds number.

(c) Use the second revised Cunningham correction to re-calculate the cyclone IV D_{50} .

(d) Repeat this iterative process as many times as necessary using the prescribed equations until you achieve the criteria documented in Equation 39.

12.3.2 Particulate concentration. Use the particulate catch weights in the combined cyclone sampling train to calculate the concentration of particulate matter in the various size ranges. You must correct the concentrations for the acetone blank.

12.3.2.1 *Acetone blank concentration.* Use Equation 41 to calculate the acetone blank concentration (C_a).

12.3.2.2 *Acetone blank weight.* Use Equation 42 to calculate the acetone blank weight (W_a). [**Note:** Correct each of the particulate matter weights per size fraction by subtracting the acetone blank weight (that is, $M_{2,3,4}-W_a$)].

12.3.2.3 *Particulate weight catch per size fraction.* Subtract the weight of the acetone blank from the

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particulate weight catch in each size fraction. [**Note:** Do not subtract a blank value of greater than 0.001 percent of the weight of the acetone used from the sample weight].

Use the following procedures.

(a) Use Equation 43 to calculate the particulate matter recovered from Containers #1, #2, #3, and #4. This is the total collectable particulate matter (C_{tf}).

(b) Use Equation 44 to determine the quantitative recovery of PM_{10} particulate matter (C_{fPM10}) from Containers #1, #3, and #4.

(c) Use Equation 45 to determine the quantitative recovery of $PM_{2.5}$ particulate ($C_{fPM2.5}$) recovered from Containers #1 and #4.

12.4 Reporting. You must include the following list of conventional elements in the emissions test report.

- (a) Emission test description including any deviations from this protocol
- (b) Summary data tables on a run-by-run basis
- (c) Flowchart of the process or processes tested
- (d) Sketch of the sampling location
- (e) Preliminary traverse data sheets including cyclonic flow checks
- (f) Raw field data sheets
- (g) Laboratory analytical sheets and case narratives

- (h) Sample calculations
- (i) Pretest and post-test calibration data
- (j) Chain of custody forms
- (k) Documentation of process and air pollution control system data

12.5 Equations. Use the following equations to complete the calculations required in this test method.

Molecular Weight of Dry Gas. Calculate the molecular weight of the dry gas using Equation 1.

$$M_d = 0.44 (\% \text{CO}_2) + 0.32 (\% \text{O}_2) + 0.28 (100 - \% \text{O}_2 - \% \text{CO}_2) \quad \text{Eq. 1}$$

Molecular Weight of Wet Gas. Calculate the molecular weight of the stack gas on a wet basis using Equation 2.

$$M_w = M_d (1 - B_{ws}) + 18 (B_{ws}) \quad \text{Eq. 2}$$

Gas Viscosity. Calculate the gas viscosity using Equation 3. This equation uses constants for gas temperatures in °R.

$$\mu = C_1 + C_2 \sqrt{T_s} + C_3 T_s^{-2} + C_4 (\% \text{O}_{2,\text{wet}}) - C_5 B_{ws} + C_6 B_{ws} T_s^2 \quad \text{Eq. 3}$$

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Cunningham Correction Factor. The Cunningham correction factor is calculated for a 2.25 micrometer diameter particle.

$$C = 1 + 0.0057193 \left[\frac{\mu}{P_s D_p} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Eq. 4}$$

Lower Limit Cut Diameter for Cyclone I for $N_{re} < 3,162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

$$D_{50LL} = 9.507 C^{0.3007} \left[\frac{M_w P_s}{T_s} \right]^{0.1993} \quad \text{Eq. 5}$$

($N_{re} < 3,162$)

Cut Diameter for Cyclone I for the Middle of the Overlap Zone.

$$D_{50T} = \left(\frac{11 + D_{50LL}}{2} \right) \quad \text{Eq. 6}$$

Sampling Rate.

$$Q_s = Q_I = 0.07296 (\mu) \left[\frac{T_s}{M_w P_s} \right]^{0.2949} \left[\frac{1}{D_{50T}} \right]^{1.4102} \quad \text{Eq. 7}$$

Reynolds Number.

$$N_{re} = 8.64 \times 10^5 \left[\frac{P_s M_w}{T_s} \right] \left[\frac{Q_s}{\mu} \right] \quad \text{Eq. 8}$$

Meter Box Orifice Pressure Drop.

$$\Delta H = \left[\frac{Q_s (1 - B_{ws}) P_s}{T_s} \right]^2 \left[\frac{1.083 T_m M_d \Delta H_e}{P_{bar}} \right] \quad \text{Eq. 9}$$

Lower Limit Cut Diameter for Cyclone I for $N_{re} \geq 3,162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

$$D_{50LL} = 10.0959 C^{0.4400} \left[\frac{M_w P_s}{T_s} \right]^{0.0600} \quad \text{Equation 10} \\ (N_{re} \geq 3162)$$

Velocity of Stack Gas. Correct the mean preliminary velocity pressure for C_p and blockage using Equations 24, 25, and 26.

$$v_s = K_p C_p \left(\sqrt{(\Delta p)} \right)_{avg} \left[\sqrt{\frac{T_s}{P_s M_w}} \right] \quad \text{Eq. 11}$$

Calculated Nozzle Diameter for Acceptable Sampling Rate.

$$D = \left[\frac{3.056 Q_s}{v_s} \right]^{0.5} \quad \text{Eq. 12}$$

Velocity of Gas in Nozzle.

$$V_n = \frac{\left(\frac{Q_s}{60} \right)}{A_n} \quad \text{Eq. 13}$$

Minimum Nozzle/Stack Velocity Ratio Parameter.

$$R_{\min} = \left[0.2457 + \left(0.3072 - \frac{0.2603 (\mu) (Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Eq. 14}$$

Maximum Nozzle/Stack Velocity Ratio Parameter.

$$R_{\max} = \left[0.4457 + \left(0.5690 + \frac{0.2603 (\mu) (Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Eq. 15}$$

Minimum Gas Velocity for $R_{\min} < 0.5$.

$$v_{\min} = v_n (0.5) \quad \text{Eq. 16}$$

Minimum Gas Velocity for $R_{\min} \geq 0.5$.

$$v_{\min} = v_n R_{\min} \quad \text{Eq. 17}$$

Maximum Gas Velocity for $R_{\max} < 1.5$.

$$v_{\max} = v_n R_{\max} \quad \text{Eq. 18}$$

Maximum Gas Velocity for $R_{\max} \geq 1.5$.

$$v_{\max} = v_n (1.5) \quad \text{Eq. 19}$$

Minimum Velocity Pressure.

$$\Delta p_{\min} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\min}}{C_p} \right]^2 \quad \text{Eq. 20}$$

Maximum Velocity Pressure.

$$\Delta p_{\max} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\max}}{C_p} \right]^2 \quad \text{Eq. 21}$$

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Sampling Time at Point 1. N_{tp} is the total number of traverse points. You must use the preliminary velocity traverse data.

$$t_1 = \left[\frac{\sqrt{\Delta p_1}}{(\sqrt{\Delta p})_{avg}} \right] \left[\frac{t_r}{N_{tp}} \right] \quad \text{Eq. 22}$$

Sampling Time at Point n. You must use the actual test run data at each point, n , and test run point 1.

$$t_n = t_1 \frac{\sqrt{\Delta p_n}}{\sqrt{\Delta p_1}} \quad \text{Eq. 23}$$

Adjusted Velocity Pressure.

$$\Delta p_s = \Delta p_m \left[\frac{C_p}{C'_p} \right]^2 \quad \text{Eq. 24}$$

Average Probe Blockage Factor.

$$b_f = \frac{12.0}{A} \quad \text{Eq. 25}$$

Velocity Pressure.

$$\Delta p_{s2} = \Delta p_{s1} \left[\frac{1}{(1 - b_f)} \right]^2 \quad \text{Eq. 26}$$

Dry Gas Volume Sampled at Standard Conditions.

$$V_{ms} = \left[\frac{528}{29.92} \right] [\gamma V_m] \left[\frac{\left(P_{bar} + \frac{\Delta H}{13.6} \right)}{T_m} \right] \quad \text{Eq. 27}$$

Sample Flow Rate at Standard Conditions.

$$Q_{sST} = \frac{V_{ms}}{\theta} \quad \text{Eq. 28}$$

Volume of Water Vapor.

$$V_{ws} = 0.04707 V_c \quad \text{Eq. 29}$$

Moisture Content of Gas Stream.

$$B_{ws} = \left[\frac{V_{ws}}{V_{ms} + V_{ws}} \right] \quad \text{Eq. 30}$$

Sampling Rate.

$$Q_s = \frac{29.92}{528} Q_{sST} \left[\frac{1}{(1 - B_{ws})} \right] \left[\frac{T_s}{P_s} \right] \quad \text{Eq. 31}$$

Note: The viscosity and Reynolds Number must be recalculated using the actual stack temperature, moisture, and oxygen content.

Actual Particle Cut Diameter for Cyclone I. This is based on actual temperatures and pressures measured during the test run.

$$D_{50} = 0.15625 \left[\frac{T_s}{M_w P_s} \right]^{0.2091} \left[\frac{\mu}{Q_s} \right]^{0.7091} \quad \text{Eq. 32}$$

Particle Cut Diameter for $N_{re} < 3,162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \quad \text{Equation 33}$$

($N_{re} < 3162$)

Particle Cut Diameter for $N_{re} \geq 3,162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{0.8058} \left[\frac{1}{C} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.3058} \quad \text{Equation 34}$$

($N_{re} \geq 3162$)

Re-estimated Cunningham Correction Factor. You must use the actual test run Reynolds Number (N_{re}) value and select the appropriate D_{50} from Equation 33 or 34 (or Equation 36 or 37 if reiterating).

$$C_r = 1 + 0.0057193 \left[\frac{\mu}{P_s D_{50}} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Eq. 35}$$

Re-calculated Particle Cut Diameter for $N_{re} < 3,162$.

$$D_{50-1} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \quad \text{Equation 36}$$

($N_{re} < 3162$)

Re-calculated Particle Cut Diameter for $N_{re} \geq 3,162$.

$$D_{50-1} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{0.8058} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.3058} \quad \text{Equation 37}$$

($N_{re} \geq 3162$)

Ratio (Z) Between D_{50} and D_{50-1} Values.

$$Z = \frac{D_{50-1}}{D_{50}} \quad \text{Eq. 38}$$

Acceptance Criteria for Z Values. The number of iterative steps is represented by N.

$$0.99 \leq \left[Z = \left(\frac{D_{50N}}{D_{50N+1}} \right) \right] \leq 1.01 \quad \text{Eq. 39}$$

Percent Isokinetic Sampling.

$$I = \left(\frac{100 T_s V_{ms} 29.92}{60 v_s \theta A_n P_s (1 - B_{ws}) 528} \right) \quad \text{Eq. 40}$$

Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a} \quad \text{Eq. 41}$$

Acetone Blank Weight.

$$W_a = C_a V_{aw} \rho_a \quad \text{Eq. 42}$$

Concentration of Total Filterable Particulate Matter.

$$C_{t f} = \left(\frac{7000}{453,592} \right) \left[\frac{M_1 + M_2 + M_3 + M_4}{V_{ms}} \right] \quad \text{Eq. 43}$$

Concentration of Filterable PM₁₀ Particulate Matter.

$$C_{fPM10} = \left(\frac{7000}{453,592} \right) \left[\frac{M_1 + M_3 + M_4}{V_{ms}} \right] \quad \text{Eq. 44}$$

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Concentration of Filterable PM_{2.5} Particulate Matter.

$$C_{\text{FPM } 2.5} = \left(\frac{7000}{453,592} \right) \left[\frac{M_1 + M_4}{V_{\text{ms}}} \right] \quad \text{Eq. 45}$$

13.0 Method Performance

(a) Field evaluation of PM₁₀ and total particulate matter showed that the precision of constant sampling rate method was the same magnitude as Method 17 (approximately 5 percent). Precision in PM₁₀ and PM₁₀ fraction between multiple trains showed standard deviations of 2 to 4 percent and total mass compared to 4.7 percent observed for Method 17 in simultaneous test runs at a Portland cement clinker cooler exhaust. The accuracy of the constant sampling rate PM₁₀ method for total mass, referenced to Method 17, was -2± 4.4 percent. A small bias was found between Method 201A and Method 17 total particulate matter (10%) (Farthing, 1988).

(b) Laboratory evaluation and guidance for PM₁₀ cyclones were designed to limit error due to spatial variations to 10 percent. The maximum allowable error due to anisokinetic sampling was limited to ±20 percent for 10 μm particles in laboratory tests (Farthing, 1988b).

14.0 Pollution Prevention

[Reserved]

15.0 Waste Management

[Reserved]

16.0 References

We used the following references to develop this test method:

1. Dawes, S.S., and W.E. Farthing. "Application Guide for Measurement of PM_{2.5} at Stationary Sources," U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, 27511, EPA-600/3-90/057 (NTIS No.: PB 90-247198), November 1990.
2. U.S. Environmental Protection Agency, Federal Reference Methods 1 through 5 and Method 17, 40 CFR 60, Appendix A.
3. Richards, J.R. "Test protocol: PCA PM₁₀/PM_{2.5} Emission Factor Chemical Characterization Testing," PCA R&D Serial No. 2081, Portland Cement Association, 1996.
4. Farthing and Co-workers, 1988a "PM₁₀ Source Measurement Methodology: Field Studies," EPA 600/3-88/055, NTIS PB89-194287 /AS, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

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5. Farthing and Dawes, 1988b "Application Guide for Source PM₁₀ Measurement with Constant Sampling Rate," EPA/600/3-88-057, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

17.0 Tables, Diagrams, Flowcharts, and Validation Data

You must use the following tables, diagrams, flowcharts, and data to complete this test method successfully.

Table 1. Typical Particulate Matter Concentrations

Particle Size Range	Concentration and % by Weight
Total collectable particulate	0.015 gr/DSCF
≤ 10 and > 2.5 micrometers	40% of total collectable particulate matter
≤ 2.5 micrometers	20% of total collectable particulate matter

Table 2. Required Cyclone Cut Diameters (D₅₀)

Cyclone	Min. cut Diameter (Micrometer)	Max. Cut Diameter (Micrometer)
PM ₁₀ Cyclone (Cyclone I from five stage cyclone)	9	11
PM _{2.5} Cyclone (Cyclone IV from five stage cyclone)	2.25	2.75

Table 3. Pretest Calculations

If you are using...	To calculate...	Then use...
Preliminary data	dry gas molecular weight, M _d	Equation 1

Table 3. Pretest Calculations

If you are using...	To calculate...	Then use...
Dry gas molecular weight (M_d) and preliminary moisture content of the gas stream	wet gas molecular weight, M_w	Equation 2 ^a
Stack gas temperature, and oxygen and moisture content of the gas stream	gas viscosity, μ	Equation 3
Gas viscosity, μ	Cunningham correction factor ^b , C	Equation 4
Reynolds Number ^c (N_{re}) $N_{re} < 3,162$	preliminary lower limit cut diameter for cyclone I, D_{50LL}	Equation 5
D_{50LL} from Equation 5	cut diameter for cyclone I for middle of the overlap zone, D_{50T}	Equation 6
D_{50T} from Equation 6	final sampling rate for cyclone I, $Q_I(Q_s)$	Equation 7
$Q_I(Q_s)$ from Equation 7	(verify) the assumed Reynolds number	Equation 8

^a Use Method 4 to determine the moisture content of the stack gas. Use a wet bulb-dry bulb measurement device or hand-held hygrometer to estimate moisture content of sources with gas temperature less than 160°F.

^b For the lower cut diameter of cyclone IV, 2.25 micrometer.

^c Verify the assumed Reynolds number using the procedure in Section 8.5.1, before proceeding to Equation 9.

Table 4. ΔH Values Based on Preliminary Traverse Data

Stack Temperature (°R)	$T_s - 50^\circ$	T_s	$T_s + 50^\circ$
ΔH , (in. W.C.)	-	-	-

Table 5. Verification of the Assumed Reynolds Number

If the N_{re} is ...	Then ...	And ...
< 3,162	Calculate ΔH for the meter box	
\geq 3,162	Recalculate D_{50LL} using Equation 10	Substitute the "new" D_{50LL} into Equation 6 to recalculate D_{50T}

Table 6. Calculations for Recovery of PM_{10} and $PM_{2.5}$

Calculations	Instructions and References
Average dry gas meter temperature	See field test data sheet.
Average orifice pressure drop	See field test data sheet.
Dry gas volume (V_{ms})	Use Equation 27 to correct the sample volume measured by the dry gas meter to standard conditions (20°C, 760 mm Hg or 68°F, 29.92 in. Hg).
Dry gas sampling rate (Q_{sST})	Must be calculated using Equation 28.
Volume of water condensed (V_{ws})	Use Equation 29 to determine the water condensed in the impingers and silica gel combination. Determine the total moisture catch by measuring the change in volume or weight in the impingers and weighing the silica gel.
Moisture content of gas stream (B_{ws})	Calculate this with Equation 30.
Sampling rate (Q_s)	Calculate this with Equation 31.
Test condition Reynolds number ^a	Use Equation 8 to calculate the actual Reynolds number during test conditions.
Actual D_{50} of Cyclone I	Calculate this with Equation 32. This calculation is based on the average temperatures and pressures measured during the test run.

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Table 6. Calculations for Recovery of PM₁₀ and PM_{2.5}

Calculations	Instructions and References
Stack gas velocity (v_s)	Calculate this with Equation 11.
Percent isokinetic rate (%I)	Calculate this with Equation 40.

^a Calculate the Reynolds number at the cyclone IV inlet during the test based on: (1) The sampling rate for the combined cyclone head, (2) the actual gas viscosity for the test, and (3) the dry and wet gas stream molecular weights.

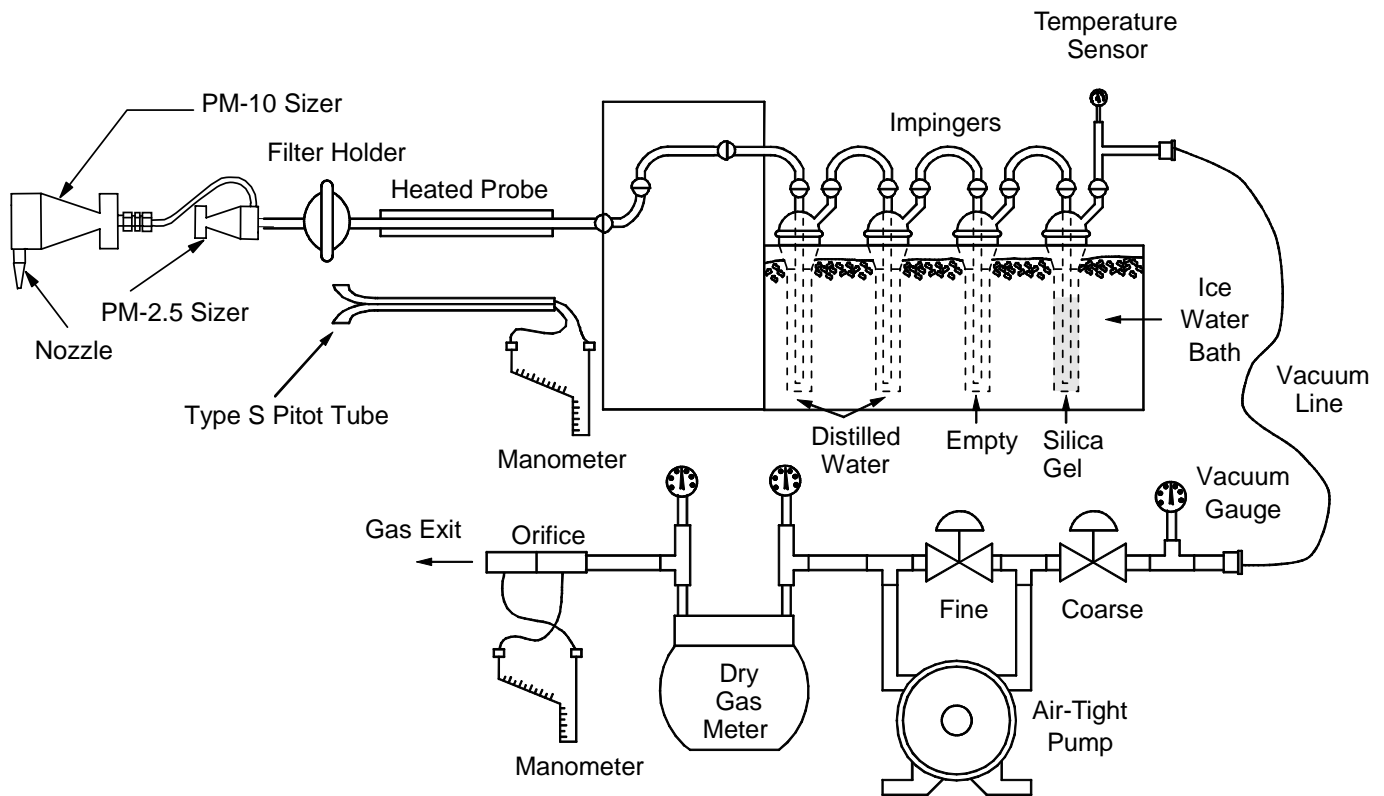


Figure 1. In-stack PM₁₀ and PM_{2.5} Sampling Train

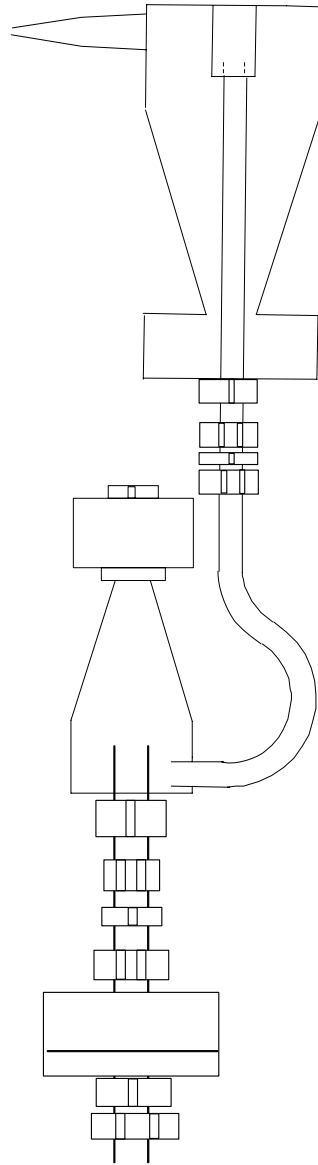
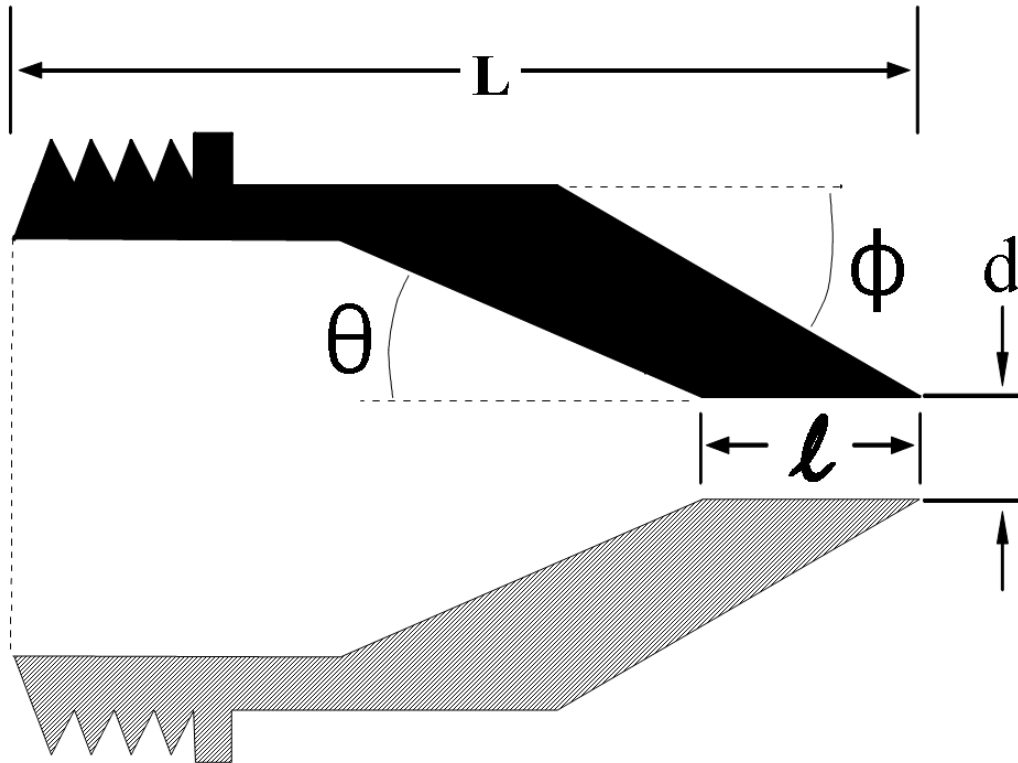
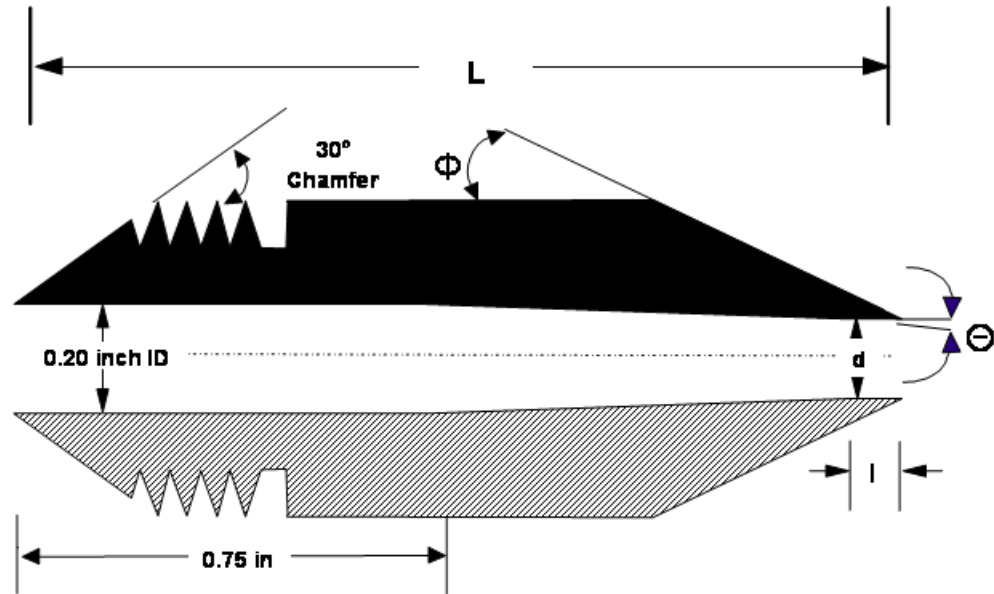


Figure 2. Combined Cyclone Sampling Head



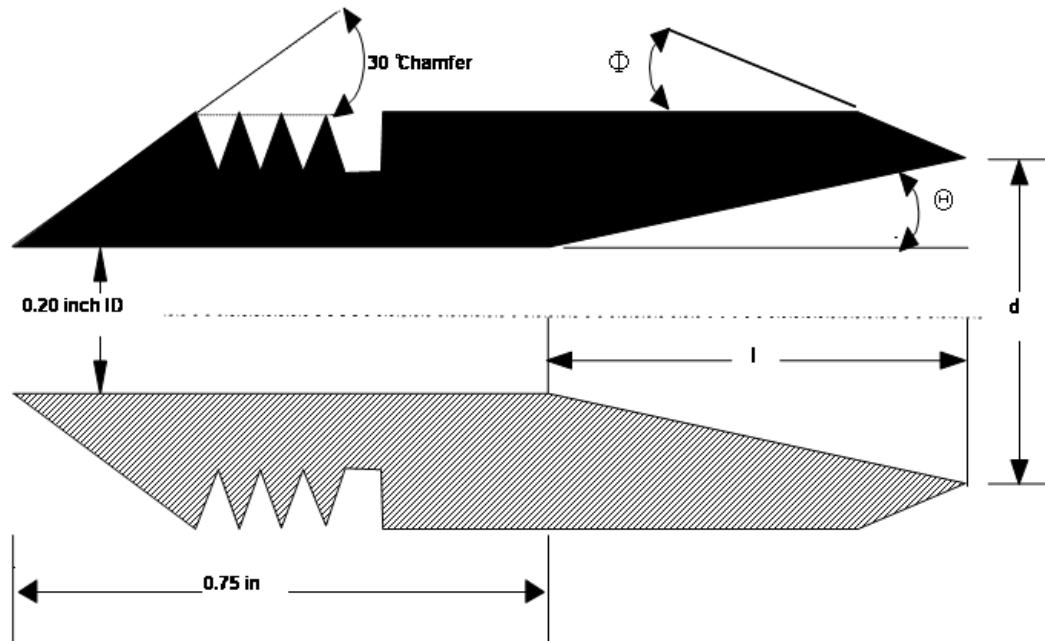
Nozzle Diameter, d (inches)	Cone Angle, θ (degrees)	Outside Taper, ϕ (degrees)	Straight Inlet Length, l (inches)	Total Length, L (inches)
0.125	4	15	<0.05	2.710±0.05
0.136	4	15	<0.05	2.653±0.05
0.150	4	15	<0.05	2.553±0.05
0.164	5	15	<0.05	1.970±0.05
0.180	6	15	<0.05	1.572±0.05
0.197	6	15	<0.05	1.491±0.05
0.215	6	15	<0.05	1.450±0.05
0.233	6	15	<0.05	1.450±0.05
0.264	5	15	<0.05	1.450±0.05
0.300	4	15	<0.05	1.480±0.05
0.342	4	15	<0.05	1.450±0.05
0.390	3	15	<0.05	1.450±0.05

Figure 3. Nozzle Design Specifications for PM₁₀ Cyclone



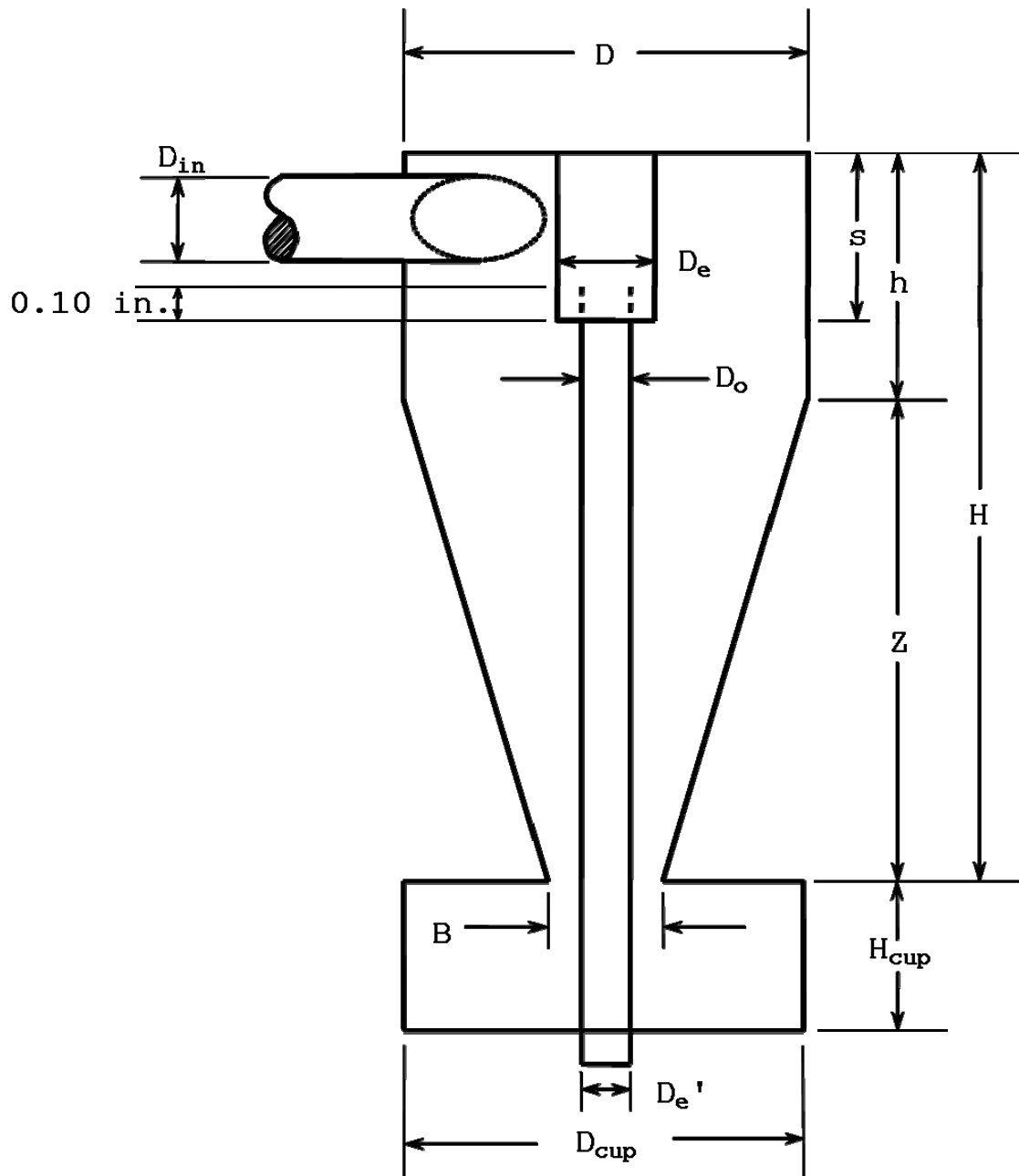
Nozzle Diameter, d (in.)	Internal Cone Angle, θ (degrees)	Outside Taper, ϕ (degrees)	Straight Inlet Length, l (in.)	Total Length, L (in.)
0.125	3	15	≤ 0.05	1.45 ± 0.05
0.138	2	15	≤ 0.05	1.45 ± 0.05
0.156	1	15	≤ 0.05	1.45 ± 0.05
0.172	1	15	≤ 0.05	1.45 ± 0.05
0.188	1	15	≤ 0.05	1.45 ± 0.05
0.200	0	15	≤ 0.05	1.45 ± 0.05

Figure 4A. Nozzle Design for PM_{2.5} Cyclone (Higher Stack Flow)



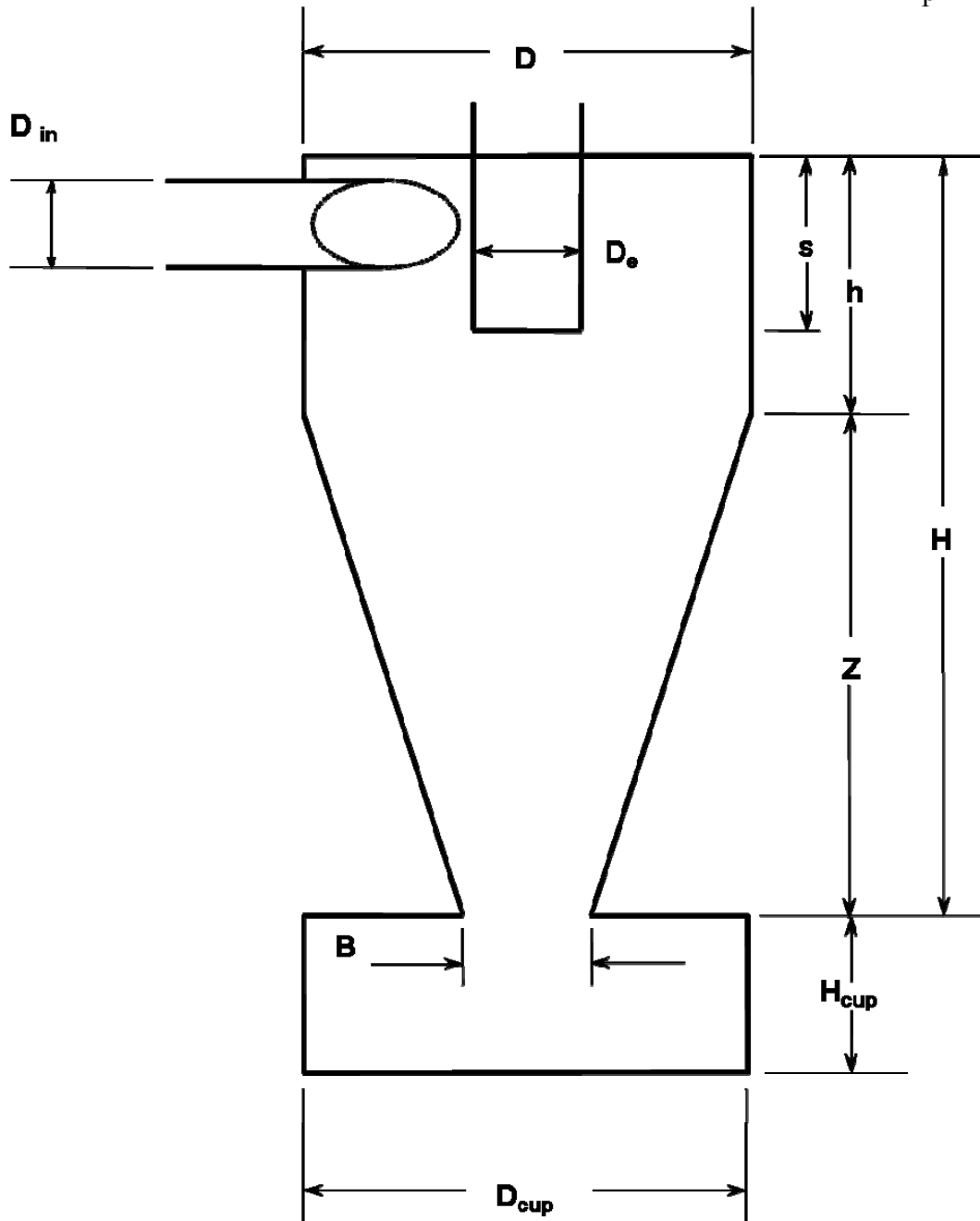
Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Internal Taper length, l (inches)
0.216	5	15	0.093
0.234	5	15	0.194
0.253	5	15	0.304
0.274	5	15	0.422
0.296	5	15	0.549
0.320	5	15	0.688

Figure 4B. Nozzle Design for PM_{2.5} Cyclone (Lower Stack Flow)



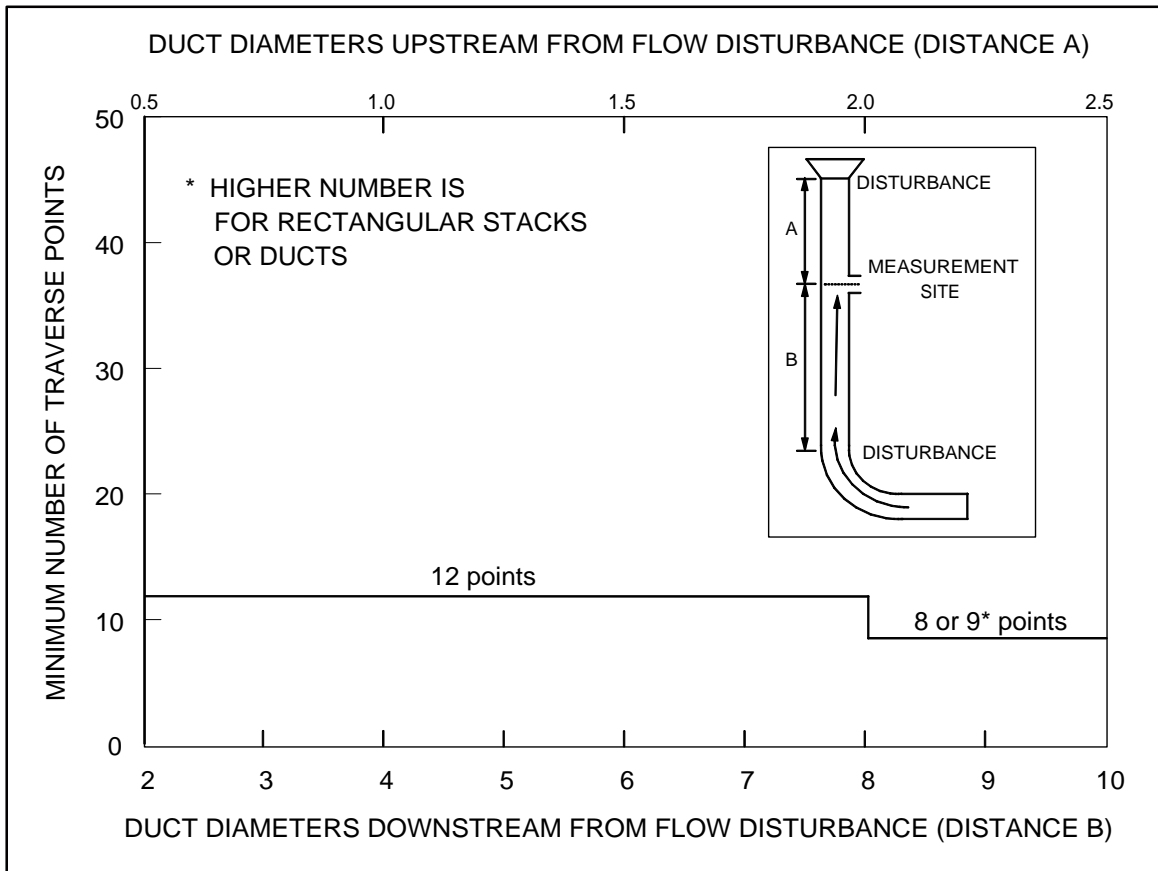
Cyclone I (10 Micrometer)	Cyclone Interior Dimensions (cm \pm 0.02 cm)											
	D_{in}	D	D_e	B	H	h	Z	S	H_{cup}	D_{cup}	D_e'	D_o
	1.27	4.47	1.50	1.88	6.95	2.24	4.71	1.57	2.25	4.45	1.02	1.24

Figure 5. Design Specifications for Cyclone I
(10 Micrometer)



Cyclone	Cyclone Interior Dimensions (cm \pm 0.02 cm)									
	D_{in}	D	D_e	B	H	h	Z	S	H_{cup}	D_{cup}
IV (2.5 Micrometer)	0.51	2.54	0.59	1.09	2.68	1.03	1.65	0.58	2.22	2.62

Figure 6. Design Specifications for Cyclone IV (2.5 Micrometer) Sizing Device



**Figure 7. Minimum Number of Traverse Points
for Preliminary Method 4 Traverse**

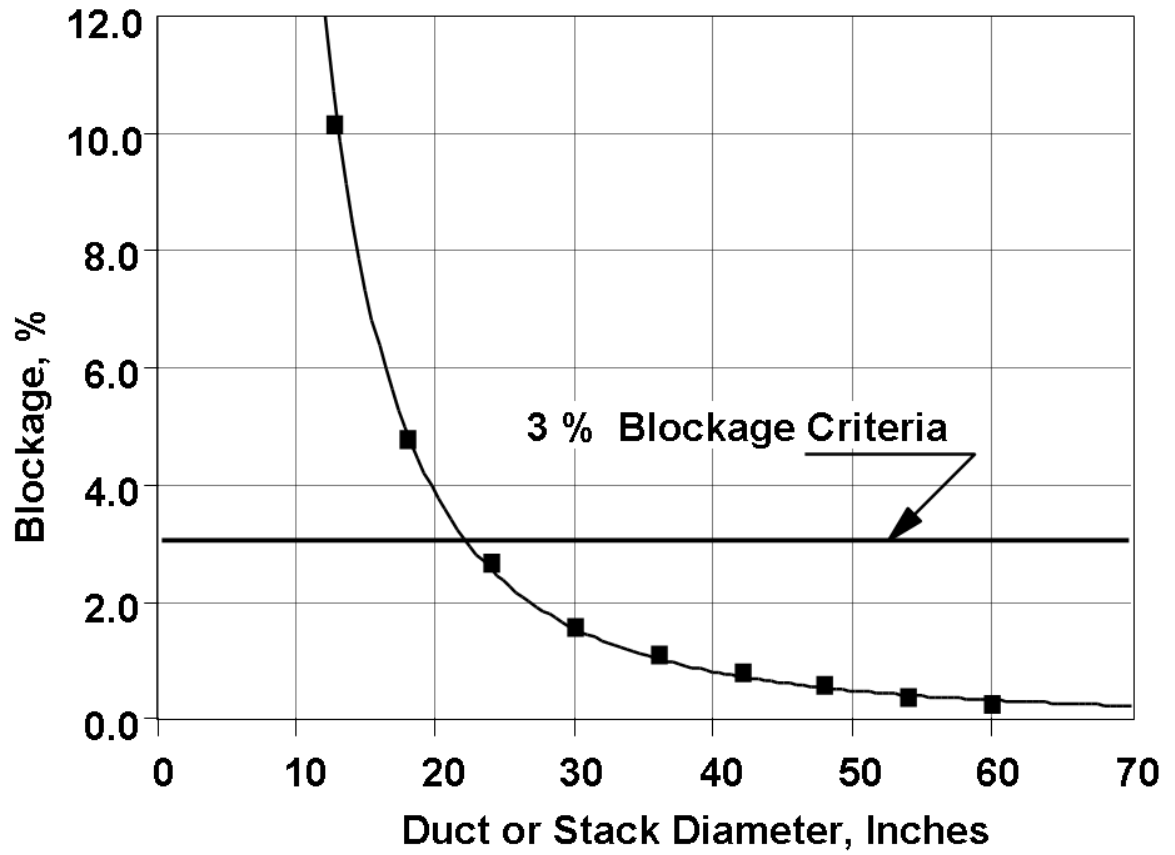


Figure 8. Gas Flow Blockage by the Combined Cyclone Sampling Head

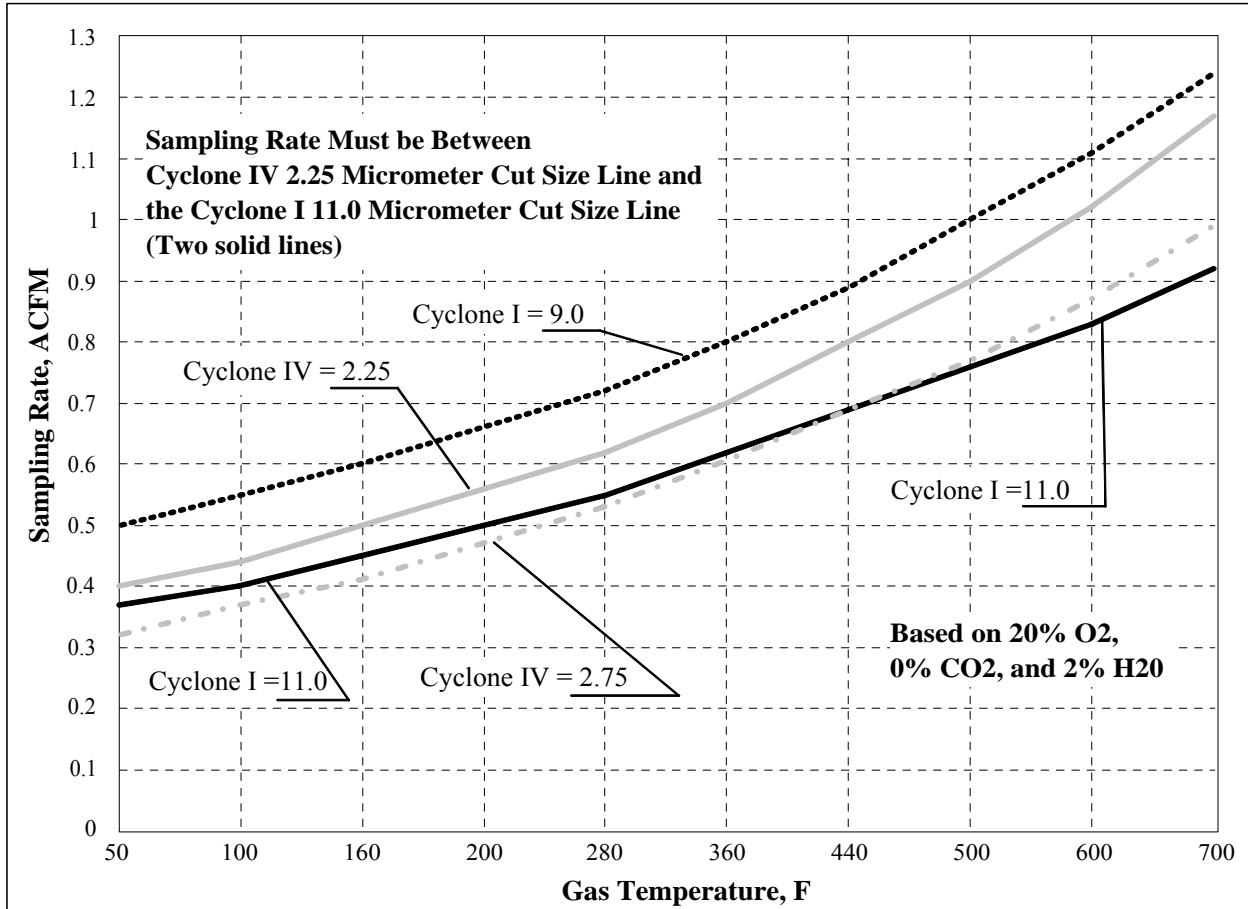


Figure 9. Acceptable Sampling Rate for Combined Cyclone Heads