

METHOD FOR THE DETERMINATION OF PM₁₀ AND PM_{2.5} EMISSIONS

(CONSTANT SAMPLING RATE PROCEDURES)

1. SCOPE AND APPLICABILITY

This method describes the procedure that you--the tester--must follow to measure particulate matter emissions equal to or less than a nominal aerodynamic diameter of 10µm (PM₁₀) and 2.5µm (PM_{2.5}). You may use this method only with stationary sources.

1.1 Who must use this method?

Our emission factor program has identified the following sources as typical PM emitters where this method is applicable:

- (a) Industrial boilers
- (b) Fossil-fuel-fired steam generators (FFSGs)
- (c) Kilns
- (d) Clinker coolers
- (e) Finish mills
- (f) Raw mills
- (g) Coal mills
- (h) Silos
- (i) Bagging operations
- (j) Rail and truck load-out operations

1.2 What can I measure with this method?

Use this method to measure PM₁₀ and PM_{2.5} using an in-stack measurement device.

1.3 Can I use this method to measure condensible emissions?

You can't use this method to measure condensible emissions. We recognize that condensible emissions are also PM_{10} and $PM_{2.5}$, but this in-stack method measures only the component of particulate matter emissions that are solid or liquid at stack conditions. You must use Method 202 of appendix M to 40 CFR part 51 in combination with this method (or Method 201 of appendix M to 40 CFR part 51), to measure total PM_{10} and $PM_{2.5}$ emissions.

1.4 What am I responsible for?

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

1.5 How can I ensure reliable results?

To obtain reliable results, you must have a thorough knowledge of the test methods that appear in the following list.

- (a) Method 2 of Appendix A to 40 CFR part 60 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube).
- (b) Method 1 of Appendix A to 40 CFR part 60 - Sample and Velocity Traverses for Stationary Sources.
- (c) Method 3 of Appendix A to 40 CFR part 60 - Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight.
- (d) Method 4 of Appendix A to 40 CFR part 60 - Determination of Moisture Content in Stack Gases.

- (e) Method 5 of Appendix A to 40 CFR part 60 - Determination of Particulate Emissions from Stationary Sources.
- (f) Method 201A of Appendix M to 40 CFR part 51 - Determination of PM_{10} Emissions (Constant Sampling Rate Procedures).
- (g) Method 202 of Appendix M to 40 CFR part 51 - Determination of Condensable Particulate Emissions from Stationary Sources.

1.6 Do I need to incorporate additional test methods to measure ambient source contribution for particulate?

We don't anticipate that you will need additional test methods to measure ambient source contributions because these contributions are insignificant for most of the sources using this test method. However, when an adjustment for the ambient air particulate is needed, use the ambient air reference methods to quantify the ambient air contribution. Particulate collected by the ambient air samplers that vaporize at the process temperature require additional adjustments.

1.7 Can I use this method to measure emissions following a wet scrubber?

You can't 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 and these water droplets normally contain particles that are PM_{10} and $PM_{2.5}$. To measure PM_{10} and $PM_{2.5}$ in emissions where water droplets are known to exist, we recommend that you use Method 5 of Appendix A to 40 CFR part 60 (or a comparable method) and consider the particulate catch to be PM_{10} and $PM_{2.5}$ emissions.

1.8 Under what conditions can I use this method as an alternative to EPA Method 17 or EPA Method 5?

Technically, 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 are the same as Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60 requirements, and the filter temperature is within the acceptable range. However, to satisfy Method 5 criteria, you may need to remove the in-stack filter and use an out-of-stack filter and recover the probe between the PM_{2.5} particle sizer and the filter. Additionally, to satisfy Method 5 and Method 17 criteria, you may need to sample from more than 12 traverse points. The increased number of sampling points may require the use of multiple nozzles to maintain isokinetics between 90 and 110 percent and to maintain the minimum/maximum nozzle/stack velocity ratios within acceptable ranges. Be aware that this method determines in-stack PM₁₀ and PM_{2.5} 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. A Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60 train is operated isokinetically (with varying flow rates through the train), samples from as many as 24 sample points, and for Method 5 of Appendix A to 40 CFR part 60 an out-of-stack filter is maintained at a constant temperature of 248°F. Further, to use this method in place of Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60, you must extend the sampling time so that the minimum mass that you can weigh is collected on each of the portions of this sampling train. Also, if you are using this method as an alternative to a required

performance test, you must receive approval from the appropriate authorities prior to conducting the test.

2. SUMMARY OF METHOD

To measure PM_{10} and $PM_{2.5}$, extract a sample of gas at a predetermined constant flowrate through an in-stack sizing device. The sizing device separates particles with nominal aerodynamic diameters of PM_{10} and $PM_{2.5}$. 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. Figure 1 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents the schematic of this process.

This method combines Method 201A of Appendix M to 40 CFR part 51 with the $PM_{2.5}$ cyclone from a conventional five-stage cascade cyclone train that includes five cyclones of differing diameters in series. Insert the $PM_{2.5}$ cyclone between the PM_{10} cyclone and the filter of the sampling train defined by Method 201A of Appendix M to 40 CFR part 51. Without the addition of the $PM_{2.5}$ cyclone, the sampling train used in this method is the same sampling train found in Method 201A of Appendix M to 40 CFR part 51.

3. DEFINITIONS

[Reserved]

4. INTERFERENCES/LIMITATIONS

[Reserved]

5. SAFETY

Disclaimer. You may have to use hazardous materials, operations, and equipment while performing 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 appropriate safety and health practices. Handle materials and equipment properly.

6. EQUIPMENT AND SUPPLIES

6.1 What equipment do I need for the sampling train?

Figure 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents a sampling train schematic for use in this test method. This sampling train is the same sampling train described in Method 17 of Appendix A to 40 CFR part 60 with the exception of the PM₁₀ and PM_{2.5} sizing devices and in-stack filter. The following paragraphs describe the sampling train's primary design features in detail.

6.1.1 Nozzle. You must use nozzles that are stainless steel (316 or equivalent) or Teflon[®]-coated stainless steel with a sharp tapered leading edge. We recommend that you choose one of the 12 nozzles listed in Figure 3 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method because they meet design specifications. However, if you don't choose a nozzle from this list, then you must choose a nozzle that meets the criteria in paragraph 5.2 of EPA Method 201A of Appendix M to 40 CFR part 51. 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.

6.1.2 PM₁₀ and PM_{2.5} sizer. Choose a stainless steel (316 or equivalent) PM₁₀ and PM_{2.5} sizer. The sizing devices must be cyclones which meet the design specifications shown in Figures 3 and 4 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. Use a caliper to verify the dimensions of the PM₁₀ and PM_{2.5} sizers to within ± 0.02 cm of the design specifications. Example suppliers of PM₁₀ and PM_{2.5} sizers are:

(a) Environmental Supply Company, Inc.

2142 Geer Street

Durham, North Carolina 27704

(919) 956-9688

(919) 682-0333 (Fax)

(b) Apex Instruments

P.O. Box 727

125 Quantum Street

Holly Springs, North Carolina 27540

(919) 557-7300

(919) 557-7110 (Fax)

(c) Andersen Instruments Inc.

500 Technology Court

Smyrna, Georgia 30082

(770) 319-9999

(770) 319-0336 (Fax)

- 6.1.3 Filter holder. You must use a filter holder that is either stainless steel (316 or equivalent) or Teflon®-coated stainless steel. Commercial size filter holders are available depending upon project requirements. You should be able to find a commercial filter holder to support 25-mm, 47-mm, and 63-mm diameter filters. Commercial size filter holders contain a Teflon® O-ring, stainless steel screen which 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 paragraph 6.1.1.3 of Method 5 of Appendix A to 40 CFR part 60.
- 6.1.5 Probe liner. You do not have to use a probe liner. However, if you choose to do so, follow the specifications in paragraph 6.1.1.2 of Method 5 of Appendix A to 40 CFR part 60.
- 6.1.6 Differential pressure gauge, condensers, metering systems, barometer, and gas density determination equipment. Follow the requirements in paragraphs 6.1.1.4 through 6.1.3 of Method 5 of Appendix A to 40 CFR part 60, as applicable.

6.2 What equipment do I need for sample recovery?

You will need the following equipment to quantitatively determine the amount of particulate matter recovered from the sampling train. Follow the requirements specified in paragraphs 6.2.1 through 6.2.8 of Method 5 of Appendix A to 40 CFR part 60, 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. REAGENTS AND STANDARDS

7.1 What reagents do I need for sample collection?

To collect a sample you will need a filter, silica gel, and stopcock grease. You must also have water and crushed ice. You will find additional information on each of these items in the following summaries.

- 7.1.1 Filter. You must 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 D 2986-71, 78, 95a (incorporated by reference). Alternatively, you may use test data from the supplier's quality control program. If the source you are sampling has SO₂ or SO₃ emissions, you must use a filter that will not react to SO₂ or SO₃. Depending on your application and project data quality objectives (DQOs), filters are commercially available in 25-mm, 47-mm, and 63-mm sizes.

- 7.1.2 Silica gel. You must choose an indicating-type silica gel of 6 to 16 mesh. We must approve other types of desiccants (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 Water (optional). Use deionized distilled water (to conform to ASTM D 1193-77, 91 Type 3) to recover material caught in the impinger, if required. If you use water to recover this material, then you must run blanks before you begin your testing. Running blanks before field use will verify low blank concentrations thereby reducing the potential for a high field blank on test samples.
- 7.1.4 Crushed ice. Obtain this from the best readily available source.
- 7.1.5 Stopcock grease (optional). The stopcock grease must be a heat-stable silicone grease that is acetone-insoluble. This is not necessary if you are using screw-on connectors with Teflon[®] sleeves, or similar. We must approve other types of stopcock grease before you use them.

7.2 What reagents do I need for sample recovery?

You must use acetone, reagent grade, ≤ 0.001 percent residue that is stored in glass bottles. Do not use acetone from metal containers because it normally has a high residue blank. We are aware that suppliers may transfer acetone to glass bottles from metal containers. Therefore you must run acetone blanks prior to field use to make sure your acetone has a low blank value. Do not subtract a blank value greater than 0.001 weight percent of acetone used from the sample weight.

7.3 What reagents do I need for sample analysis?

You will need acetone and anhydrous calcium sulfate for the sample analysis. Refer to the following summaries for additional information.

7.3.1 Acetone. Refer to paragraph 2.0 of this section.

7.3.2 Desiccant. Use indicating-type anhydrous calcium sulfate. We must approve other desiccants before you use them.

8. SAMPLE COLLECTION, PRESERVATION, STORAGE, AND TRANSPORT

8.1 What qualifications do I need to perform this test method?

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 What preparations must I do prior to the test?

Follow the pretest preparation instructions in paragraph 8.1 of Method 5 of Appendix A to 40 CFR part 60.

8.3 What must I determine to properly set up the test?

You must perform the following items 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(s).

- 8.3.1 Sampling site location and traverse point determination. Follow the standard procedures in Method 1 of Appendix A to 40 CFR part 60 to select the appropriate sampling site. Then do all of the following:
- (a) *Sampling site.* Choose a location that maximizes the distance from upstream and downstream flow disturbances.
 - (b) *Traverse points.* Select the same number of traverse points described in paragraph 4.1.2 of Method 201A of Appendix M to 40 CFR part 51 and shown in Figure 5 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. The recommended maximum number of traverse points at any location is 12. 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° 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.* You will need new sampling ports in most of the sampling port locations installed for sampling by Method 5 of Appendix A to 40 CFR part 60 or Method 17 of Appendix A to 40 CFR part 60 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 four inch diameter port because it will not

support the length of the nozzle extending from the PM₁₀ cyclone. [**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. Following the procedures in the next two paragraphs, 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 24 and 18 inches.* Ducts with diameters between 24 inches to 18 inches have blockage effects ranging from 3 percent to 6 percent, as illustrated in Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. 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 paragraphs 7.2.2 and 7.2.3 of this section 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 flow. Also, you must follow Method 2 procedures to determine the presence or absence of cyclonic flow. Then perform the following calculations. [**Note:** You can minimize cyclonic flow conditions by placing gas flow straighteners upstream of the sampling location.]
- (a) *Find the angle that has a null velocity pressure.* Insert the S-type pitot tube at each of the traverse points and rotate until you locate the angle that has a null velocity pressure.
 - (b) *Determining a sampling location.* 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°.
- 8.3.4 Preliminary velocity profile. Conduct a preliminary Method 2 of Appendix A to 40 CFR part 60 velocity traverse, as well as the measurements below. The purpose of the velocity profile is to determine all of the following:
- (a) The gas sampling rate for the combined probe/cyclone sampling head.
 - (b) The appropriate nozzle(s) to maintain the required velocity pressure range and isokinetic range.
 - (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 $\pm 20\%$ and/or gas temperature variations of approximately $\pm 50^\circ\text{F}$. Follow the following instructions. [**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 the Method 2 of Appendix A to 40 CFR part 60 data form. You will use this later to select the appropriate nozzle(s).
- 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 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 160°F .]
- 8.3.4.4 *Particulate matter concentration in the gas stream.* Determine the particulate matter concentration in the gas stream through qualitative measurements or estimates. Having an idea of what the particulate concentration is in the gas stream 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 chemical analyses 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.

8.4 Why must I perform 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 the Tables, Diagrams, Flowcharts, and Validation Data section of this method.

8.4.1 Gas sampling rate. The gas sampling rate is defined by the performance curves for both cyclones, as illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. You must use the calculations in paragraph 5 of this section 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 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method).

8.4.2 Choosing the appropriate sampling rate. You must select a gas sampling rate in the middle of the overlap zone (discussed in paragraph 4.1 of this section), as

illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method 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: You should be aware that the acceptable range is limited, especially for gas streams with temperatures less than approximately 100°F.]

8.5 What pre-test calculations must I perform?

You must perform all of the calculations in Table 1 of this paragraph, and the calculations described in paragraphs 8.5.1 through 8.5.5 of this section.

Table 1. Pretest Calculations

If you are using...	To calculate...	Then use...
Preliminary data	dry gas molecular weight, M_d	Equation 1
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}) $N_{re} < 3162$	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

Table 1. Pretest Calculations

If you are using...	To calculate...	Then use...
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 of Appendix A to 40 CFR part 60 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 paragraph 5.1, below, before proceeding to Equation 9.

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 use Table 2 of this paragraph to determine if the N_{re} used in Equation 5 was correct.

Table 2. Verification of the Assumed Reynolds Number

If the N_{re} is ...	Then ...	And ...
< 3162	Calculate ΔH for the meter box	
\geq 3162	Recalculate D_{50LL} using Equation 10	Substitute the “new” D_{50LL} into Equation 6 to recalculate D_{50T}

- 8.5.2 Final sampling rate. You must recalculate the final sampling rate(Q_s) if the assumed Reynold's 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 this occurs, 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 paragraph 3.4.1 of this section) and document this information in the Tables, Diagrams, Flowcharts, and Validation Data section of this method under Table 3.]
- 8.5.4 Choosing a sampling nozzle. You must select one or more nozzle sizes to provide for near isokinetic sampling rate (that is, 80% to 120%). This will also minimize anisokinetic sampling errors for the 10 micrometer particles at each point. First calculate the mean stack gas velocity, v_s , using Equation 11. Look at paragraph 7.2 of this section for information on correcting for blockage and use of different pitot tube 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(s). Perform the following steps for the selected nozzle(s).

- 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} .
- 8.5.4.5 Compare minimum and maximum velocity pressures with the observed velocity pressures at all traverse points during the preliminary test (see paragraph 3.4.2 of this section).
- 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 paragraphs 5.5.1 and 5.5.2 of this section.
- (a) Choose an optimum nozzle that provides for isokinetic sampling conditions as close to 100% 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 paragraph 5.4 of this section).

(b)

8.5.5(b) When testing is for PM_{2.5} only, you can only have two traverse points that are outside the range of the Δp_{min} and Δp_{max} . If the coarse fraction for PM₁₀ determination is included, only one traverse point can fall outside the minimum-maximum velocity pressure range. However, you can select two or more nozzles so that the traverse points will be within the criteria calculated for each nozzle.

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 the Tables, Diagrams, Flowcharts, and Validation Data section of this method).

8.6 How do I prepare the sampling train?

First, you must 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. You must 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 400°F. However, Teflon® O-rings can withstand 600°F without sealing problems. You must use cyclones with stainless steel sealing rings when stack temperatures exceed 600°F. You must also keep the nozzle covered to protect it from nicks and scratches.
- 8.6.2 Filter holder and pitot tube. Attach the pre-selected filter holder to the end of the combined cyclone sampling head (see Figure 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method). You must number and tare the filter before use. 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 (1) slightly beyond the combined head cyclone sampling assembly and (2) at least one inch off the gas flow path into the cyclone nozzle. This is similar to the pitot tube placement in Method 17 of Appendix A to 40 CFR part 60.] 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 of interference.]

- 8.6.3 Filter. Use tweezers or clean disposable surgical gloves to place a labeled (identified) and pre-weighed filter in the filter holder. 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.
- 8.6.4 Leak check. Use the procedures outlined in paragraph 8.4 of Method 5 of Appendix A to 40 CFR part 60 to leak check the entire sampling system. Specifically perform the following procedures:
- 8.6.4.1 *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% 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 for the specific test. [**Note:** Do not conduct a leak check during port changes.]
- 8.6.4.2 *Pitot tube assembly*. After you leak check the sample train, you must perform a leak check of the pitot tube assembly. Follow the procedures outlined in paragraph 8.4.1 of Method 5 of Appendix A to 40 CFR part 60.
- 8.6.5 Sampling head. You must preheat the combined sampling head to the stack temperature of the gas stream at the test location ($\pm 10^{\circ}\text{C}$). This will heat the sampling head and prevent moisture from condensing from the sample gas

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

8.6.5.1 *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.]

8.6.5.2 *Shortened warm-up of unsaturated stacks.* You can shorten the warmup time by unthermostated 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 How do I operate the sample train?

You must follow the procedures outlined in paragraph 4.1.5 of Method 201A of Appendix M to 40 CFR part 51 to operate the sample train. You 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. The dwell time calculations are identical to those used in paragraph 4.1.2.2.5 of Method 201A of Appendix M to 40 CFR part 51.

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 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 1/4 minutes.] Each traverse point must have a dwell time of at least two minutes.

8.7.2 Adjusted velocity pressure. When selecting your sampling points using your preliminary velocity traverse data, your preliminary velocity pressures must be 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 paragraph 3.1 of this section).

8.7.2.2 *Probe blockage factor.* You must use Equation 25 to calculate an average probe blockage correction factor (b_p) 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 paragraph

3.2 of this section and illustrated in Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. [Note: The sampling head (including the 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 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 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method 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 train operation. You must follow the procedures outlined in paragraph 4.1.5 of Method 201A of Appendix M to 40 CFR part 51 to operate the sample train. In addition to these procedures, you must also use running starts and stops on both small and large stacks if the static pressure at the sampling location is more negative than 5 in. water column (WC). This prevents back 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 paragraph 7.4 of this section).

- 8.7.3.1 *Level and zero manometers.* Make periodic checks of 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 ($\pm 10^{\circ}\text{C}$). 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 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) You must traverse the stack cross-section, as required by Method 5 of Appendix A to 40 CFR part 60. 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) You must record the data required on the field test data sheet for each run. Record the initial dry gas meter (DGM) reading. Then take a DGM readings at the following times: (1) the beginning and end of each sample time increment, (2) when changes in flow rates are made, and (3) 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 paragraph 5.3 of this section 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.
- (c) Maintain the flow through the sampling system at the last sampling point. Remove the sampling train from the stack while you are still operating (running stop). Then stop the pump and record the final DGM reading and other test parameters on the field test data sheet.

8.7.4 Process data. You must fully document the process and air pollution control system operating conditions during the test. This is important. You will need data and information on the process unit tested, the particulate control system used to control emissions, and the sampling train conditions.

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

8.7.4.2 *Sampling train data.* You will 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 gas. After the sample head is removed, you must perform a post-test leak check of the probe and sample train. Then recover the components from the cyclone/filter. Refer to the following summaries 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.* 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 sampling head) exceeds 0.02 ACFM or 4% 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 *Recovery of particulate matter.* Recovery involves the quantitative transfer of particles in the following size range: (1) greater than 10 micrometers, (2) less than or equal to 10 micrometers but greater than 2.5 micrometers, and (3) less than or equal to 2.5 micrometers. You must use a Nylon brush and an ultrapure acetone rinse to recover particles from the combined cyclone/filter sampling head. Use the following procedures for each container.

Container #1 - Use tweezers and/or clean disposable surgical gloves to remove the filter from the filter holder. Place the filter in the petri dish 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 less than 2.5 micrometers that are caught on the in-stack filter.

Container #2 - Quantitatively recover the (1) particulate matter from the cyclone I cup and acetone rinses (and brush cleaning) of the cyclone cup, (2) internal surface of the nozzle, and (3) 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 greater than 10 micrometers.

Container #3 - Place the solids from 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 your #3 container. Seal the container and mark the liquid level on the outside. This container holds particulate matter less than 10 micrometers and greater than 2.5 micrometers.

Container #4 - 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 less than 2.5 micrometers.

Container #5 - Follow the recovery instructions for Container #3 from paragraph 8.7.6.3 of Method 5 of Appendix A to 40 CFR part 60. This container holds the silica gel.

Container #6 - Take 50 ml of the acetone directly from the wash bottle you used, and place it in Container #6, labeled Acetone Rinse Blank.

Container #7 - Refer to paragraph 8.7.6.4 of Method 5 of Appendix A to 40 CFR part 60, under “Impinger Water” for instructions. This container holds the Impinger Water.

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. QUALITY CONTROL

9.1 What do I use to perform daily quality audits?

Conduct daily quality audits using data quality indicators that require review of (1) recording and transfer of raw data, (2) calculations, and (3) documentation of testing procedures.

9.2 How do I verify the calculations?

Verify the calculations by independent, manual checks. You must flag 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 When must I record operating conditions?

You must record any unusual process operating conditions or adverse weather conditions that occur during testing. Discontinue the test if the operating conditions may cause non-representative particulate emissions.

9.4 When must I develop a health and safety plan?

You must 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 with all applicable OSHA, MSHA, and DOT regulatory requirements. The procedures must also conform to the plant health and safety requirements.

10. CALIBRATION AND STANDARDIZATION

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

10.1 How do I measure the gas flow velocities?

Measure the gas flow velocities at the sampling locations using Method 2 of Appendix A to 40 CFR part 60. 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:

- (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 of Appendix A to 40 CFR part 60. [**Note:** You must calibrate the pitot tube on the sampling head because of potential interferences from the cyclone body. Refer to paragraph 7.2 under the Sample Collection, Preservation, Storage and Transport section of this method for additional information.]

10.2 What procedures must I follow to calibrate the thermocouples?

You must use the procedures described in paragraph 10.1.4.1.2 of Method 2 of Appendix A to 40 CFR part 60 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 What types of nozzles must I use for sampling?

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 paragraph 10.1 of Method 5 of Appendix A to 40 CFR part 60.

10.4 What procedures must I follow to calibrate the dry gas meter?

You must follow the calibration procedures documented in paragraph 16.1 of Method 5 of Appendix A to 40 CFR part 60. 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. ANALYTICAL PROCEDURES

11.1 What procedures must I follow to record data?

Record all data on the analytical data sheet. You can obtain the data sheet from Figure 5-6 of Method 5 of Appendix A to 40 CFR part 60.

11.2 What procedure must I follow for the container analysis?

Follow the analysis procedures outlined in paragraph 11.2 of Method 5 of Appendix A to 40 CFR part 60 and make the following exceptions:

- (a) Container #1 must be treated like Container #1 described in Method 5 of Appendix A to 40 CFR part 60.
- (b) Containers #2, #3, #4, and #6 must be treated separately like Container #2 described in Method 5 of Appendix A to 40 CFR part 60.
- (c) Container #5 must be treated like Container #3 described in Method 5 of Appendix A to 40 CFR part 60.

12. CALCULATIONS AND DATA ANALYSIS

12.1 What do I need to calculate?

You need to perform all of the calculations found in Table 3 of this paragraph. Table 3 of this paragraph also provides instructions and references for the calculations.

Table 3. 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.

Table 3. Calculations for Recovery of PM₁₀ and PM_{2.5}

Calculations	Instructions and References
Moisture content of stack gas (B_{ws})	Calculate this with Equation 30.
Gas sampling rate (Q_s)	Calculate this with Equation 31.
Test condition Reynolds number ¹	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.
Stack gas velocity (v_s)	Calculate this with Equation 11.
Percent isokinetic rate (%I)	Calculate this with Equation 40.

¹ 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.

12.2 What data must I analyze?

You must analyze D_{50} of Cyclone IV and the concentrations of the particulate matter in the various size ranges.

- 12.2.1 D_{50} of cyclone IV. To determine the actual D_{50} for cyclone IV, you must recalculate the Cunningham correction factor and the Reynolds number for the best estimate of cyclone IV D_{50} . The following paragraphs summarize additional

information on how to recalculate the Cunningham correction factor and determine which Reynold's number to use.

- 12.2.1.1 *Cunningham correction factor.* You must 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.
- 12.2.1.2 *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 this section. Refer to the following instructions.
- (a) If the Reynold's number is less than 3162, calculate the D_{50} for cyclone IV with Equation 33, using actual test data.
 - (b) If the Reynold's number is equal to or greater than 3162, calculate the D_{50} for cyclone IV with Equation 34, using actual test data.
 - (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).]
- 12.2.1.3 *Re-establish cyclone IV D_{50} .* Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynold's 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 3162.

- (b) Use Equation 37 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is equal to or greater than 3162.

12.2.1.3 *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, refer to 2.1.2 for additional information). Follow these procedures.

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

12.2.2 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 .

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

12.2.2.2 *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, $M_{2,3,4} - W_a$)].

12.2.2.3. *Particulate weight catch per size fraction*. Subtract the weight of the acetone blank from the 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_{total}).
- (b) Use Equation 44 to determine the quantitative recovery of PM_{10} particulate matter (C_{PM10}) from Containers #1, #3, and #4.
- (c) Use Equation 45 to determine the quantitative recovery of $PM_{2.5}$ particulate ($C_{PM2.5}$) recovered from Containers #1 and #4.

12.3 What must I include in the emissions test report?

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

12.4 What nomenclature do I use in this method?

You must use the following nomenclature:

- 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% H₂O is $B_{ws} = 0.10$).
- C = Cunningham correction factor for particle diameter, D_p , and calculated using the actual stack gas temperature, dimensionless.
- %CO₂ = Carbon Dioxide content of gas stream, % by volume.

- C_a = Acetone blank concentration, mg/mg.
- C_{PM10} = Conc. of PM_{10} collectable particulate matter, gr/DSCF.
- $C_{PM2.5}$ = Conc. of $PM_{2.5}$ collectable 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_{total} = Conc. of total collectable 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.

- D_{50-1} = Re-calculated particle cut diameters based on re-estimated C_p , 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 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method, micrometers.
- I = Percent isokinetic sampling, dimensionless.
- 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 = 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 O_2 is typically measured on a dry gas basis, the measured $\%O_2$ must be multiplied by the quantity $(1 - B_{ws})$ to convert to the actual volume fraction. Therefore $\%O_{2,wet} = (1 - B_{ws}) * \%O_{2,dry}$]

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, SCF.
- V_{ws} = Volume of water vapor, SCF.
- W_a = Weight of residue in acetone blank wash, mg.
- Z = Ratio between estimated cyclone IV D_{50} values, dimensionless.
- ΔH = Meter box orifice pressure drop, in. W.C.
- $\Delta H_{@}$ = 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]
- $[(\Delta p)^{0.5}]_{\text{avg}}$ = 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% of 20.5 square inch cross-sectional area of combined cyclone head, square inches.

12.5 What equations will I use in this method?

You will use the following equations to complete the calculations required in this test method.

Molecular Weight of Dry Gas. This equation is similar to the equation in Method 201A of Appendix M to 40 CFR part 51.

$$M_d = 0.44 (\%CO_2) + 0.32 (\%O_2) + 0.28 (100 - \%O_2 - \%CO_2) \quad \text{Equation 1}$$

Molecular Weight of Wet Gas. This equation is identical to the equation shown in Method 201A of Appendix M to 40 CFR part 51.

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

Gas Viscosity. This equation is identical to the equation shown in previous versions of Method 201A of Appendix M to 40 CFR part 51 with the exception that the constants shown above are used for gas temperatures in °R, while the equation shown in Method 201A of Appendix M to 40 CFR part 51 had constants intended for gas temperatures in °F. The latest released version of Method 201A of Appendix M to 40 CFR part 51 has a viscosity equation that predicts values within 0.5% of Equation 1.

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

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

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

Lower Limit Cut Diameter for Cyclone I for $N_{re} < 3162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

$$D_{50LL} = 9.507 C^{0.3007} \left[\frac{M_w P_s}{T_s} \right]^{0.1993} \quad \text{Equation 5} \\ (N_{re} < 3162)$$

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

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

Sampling Rate.

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

Reynolds Number.

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

Meter Box Orifice Pressure Drop. This equation is identical to the equation presented in Method 201A of Appendix M to 40 CFR part 51.

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

Lower Limit Cut Diameter for Cyclone I for $N_{re} \geq 3162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

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

Velocity of Stack Gas. Correct the mean preliminary velocity pressure for Cp and blockage using Equations 23, 24, and 25.

$$v_s = K_p C_p (\sqrt{(\Delta P)})_{avg} \sqrt{\frac{T_s}{P_s M_w}} \quad \text{Equation 11}$$

Calculated Nozzle Diameter for Acceptable Sampling Rate.

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

Velocity of Gas in Nozzle.

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

Minimum Nozzle/Stack Velocity Ratio Parameter.

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

Maximum Nozzle/Stack Velocity Ratio Parameter. Equations 14 and 15 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

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

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

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

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

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

Equations 16 and 17 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

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

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

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

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

Minimum Velocity Pressure.

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

Maximum Velocity Pressure.

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

Sampling Time at Point 1. N is the total number of traverse points. Equation 22 is

identical to an equation presented in Method 201A of Appendix M to 40 CFR part 51. You must use the preliminary velocity traverse data.

$$t_1 = \left[\frac{\sqrt{\Delta P_1}}{(\sqrt{\Delta P})_{\text{avg}}} \right] \left[\frac{t_r}{N} \right] \quad \text{Equation 22}$$

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

$$t_n = t_1 \frac{\sqrt{\Delta P_n}}{\sqrt{\Delta P_1}} \quad \text{Equation 23}$$

Adjusted Velocity Pressure.

$$\Delta P_s = \Delta P_m \left[\frac{C_p}{C_p'} \right]^2 \quad \text{Equation 24}$$

Average Probe Blockage Factor.

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

Velocity Pressure.

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

Dry Gas Volume Sampled at Standard Conditions.

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

Sample Flow Rate at Standard Conditions.

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

Volume of Water Vapor.

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

Moisture Content of Gas Stream.

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

Sampling Rate.

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

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.

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

Particle Cut Diameter for $N_{re} < 3162$ 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 $N_{re} \geq 3162$ 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 32 or 33 (or Equation 36 or 37 if reiterating).

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

Re-calculated Particle Cut Diameter for $N_{re} < 3162$.

$$D_{50-1} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \quad \text{Equation 36} \\ (N_{re} < 3162)$$

Re-calculated Particle Cut Diameter for $N_{re} \geq 3162$.

$$D_{50-1} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{0.8058} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.3058} \quad \text{Equation 37} \\ (N_{re} \geq 3162)$$

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

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

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

$$0.99 \leq \left| Z = \left(\frac{D_{50N}}{D_{50N+1}} \right) \right| \leq 1.01 \quad \text{Equation 39}$$

Percent Isokinetic Sampling.

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

Acetone Blank Concentration.

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

Acetone Blank Weight.

$$W_a = C_a V_{awpa} \quad \text{Equation 42}$$

Concentration of Total Collectable Particulate Matter.

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

Concentration of PM_{10} Collectable Particulate Matter.

$$C_{PM10} = \left(\frac{7000}{453,592} \right) \left[\frac{M_1 + M_3 + M_4}{V_{ms}} \right] \quad \text{Equation 44}$$

Concentration of PM_{2.5} Collectable Particulate Matter.

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

13. METHOD PERFORMANCE

[Reserved]

14. POLLUTION PREVENTION

[Reserved]

15. WASTE MANAGEMENT

[Reserved]

16. REFERENCES

We used the following references in the development of this test method:

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.

U.S. Environmental Protection Agency, Federal Reference Methods 1 through 5 and Method 17, 40 CFR 60, Appendix A.

U.S. Environmental Protection Agency, Federal Reference Method 201A, 40 CFR 51, Appendix M.

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.

17. 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 (D_{50})

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. ΔH Values Based on Preliminary Traverse Data

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

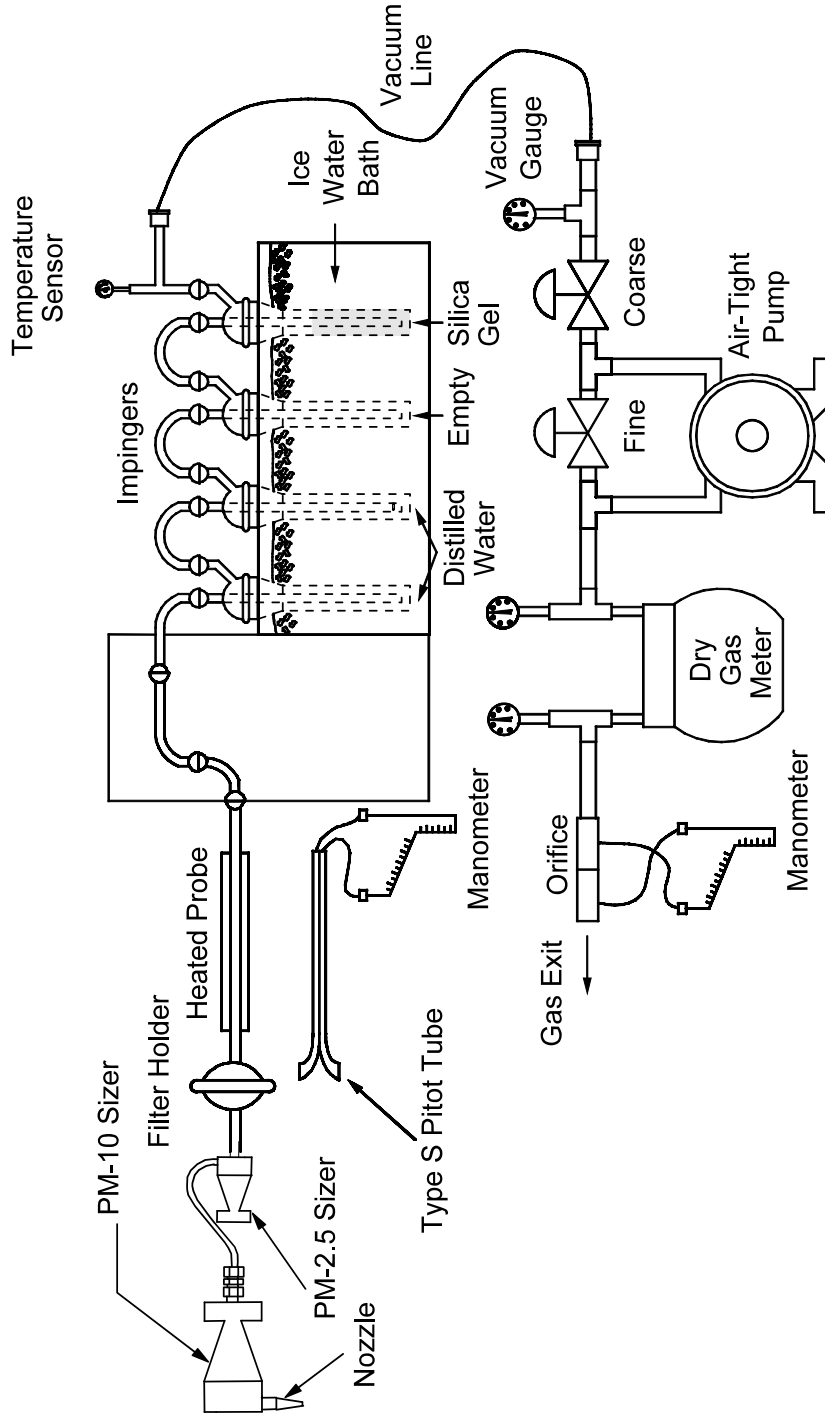


Figure 1. In-Stack Sizing Device

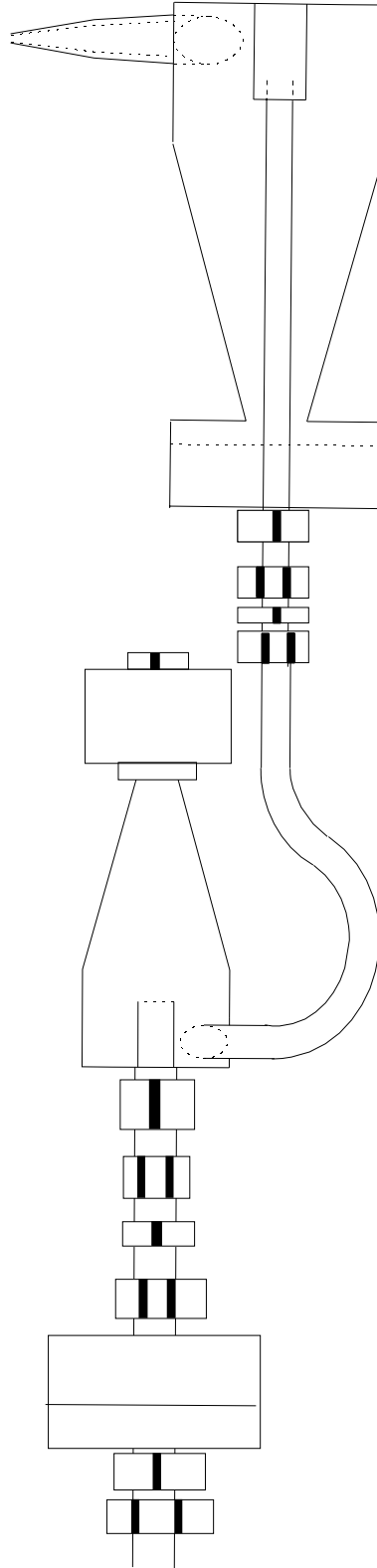
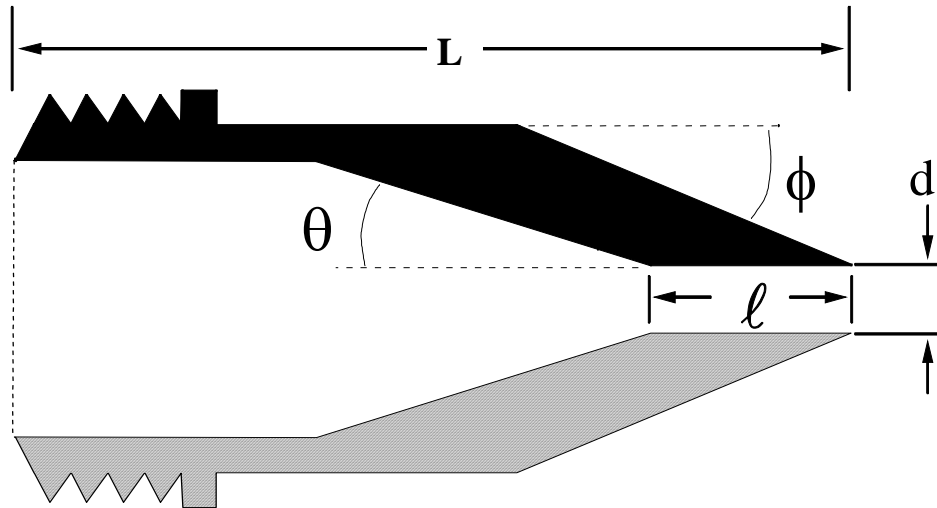
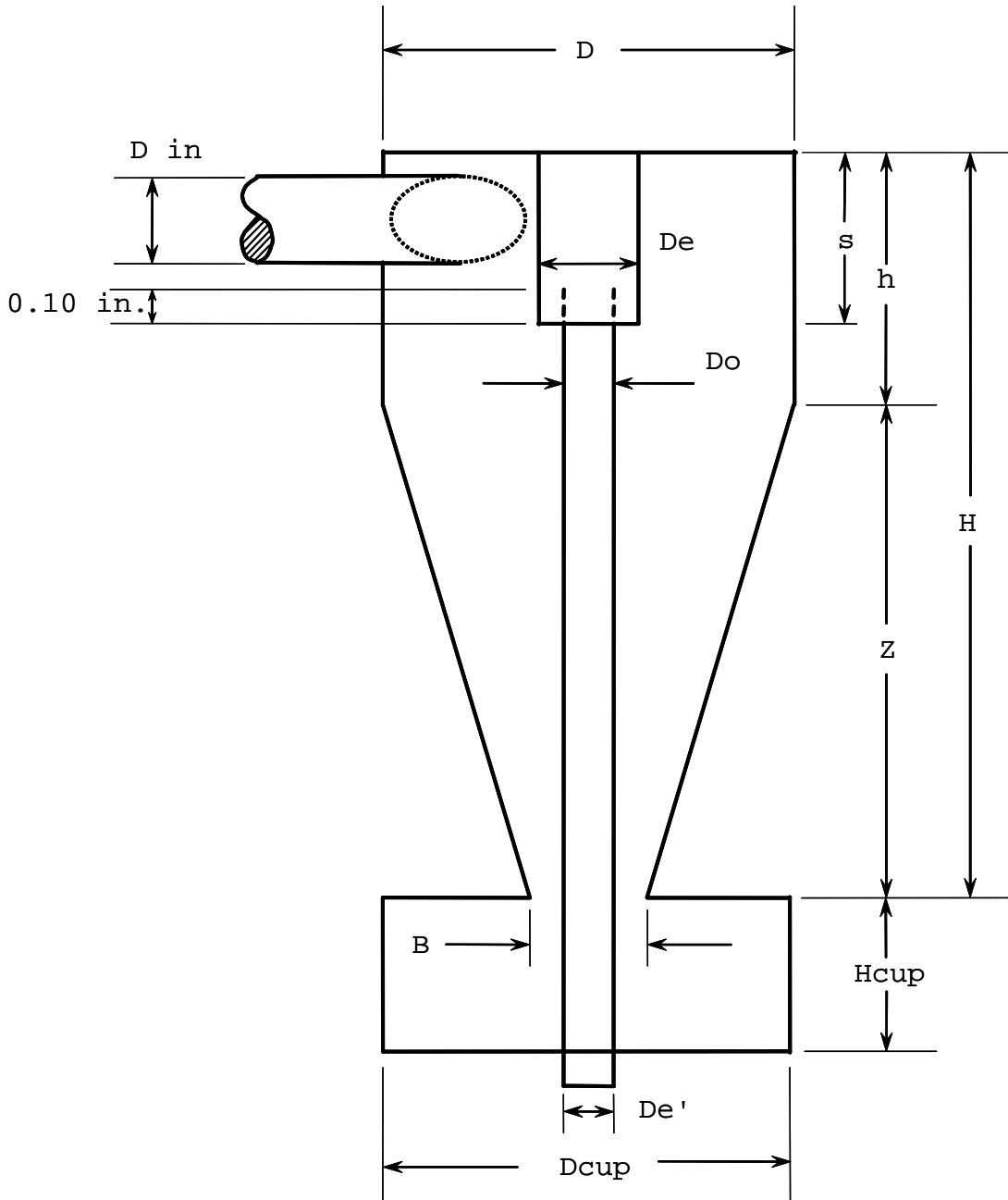


Figure 2. Combined Cyclone Sampling Head



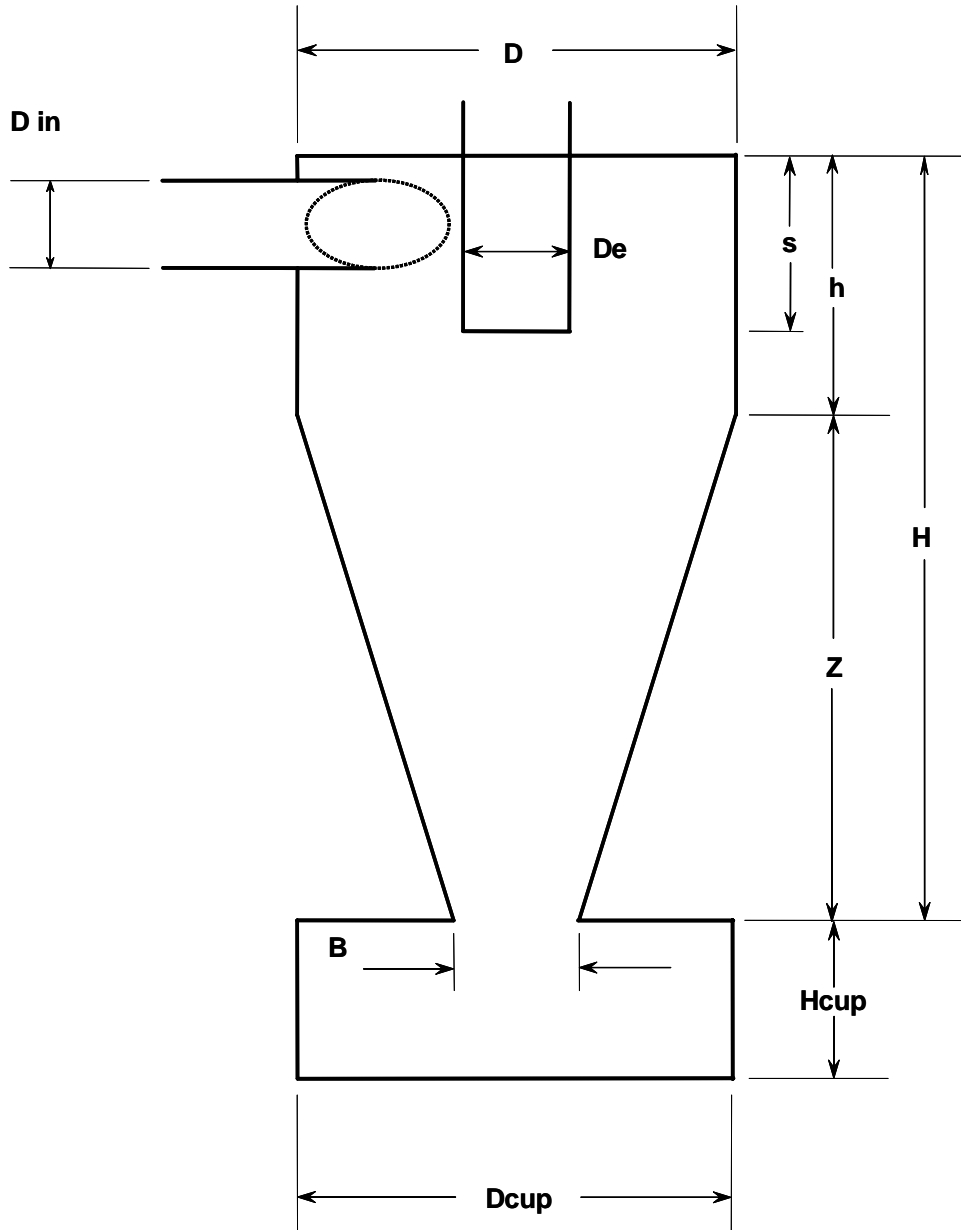
Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, l (inches)	Total Length, L (inches)
0.125	4	15	<0.05	2.710±0.05
0.136	4	15	<0.05	2.653±0.05
0.150	4	15	<0.05	2.553±0.05
0.164	5	15	<0.05	1.970±0.05
0.180	6	15	<0.05	1.572±0.05
0.197	6	15	<0.05	1.491±0.05
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



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 4. Design specifications for Cyclone I (10 Micrometer)



Cyclone	Cyclone Interior Dimensions (cm ± 0.02 cm)									
	Din	D	De	B	H	h	Z	S	Hcup	Dcup
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 5. Design Specifications for Cyclone IV (2.5 Micrometer) Sizing Device

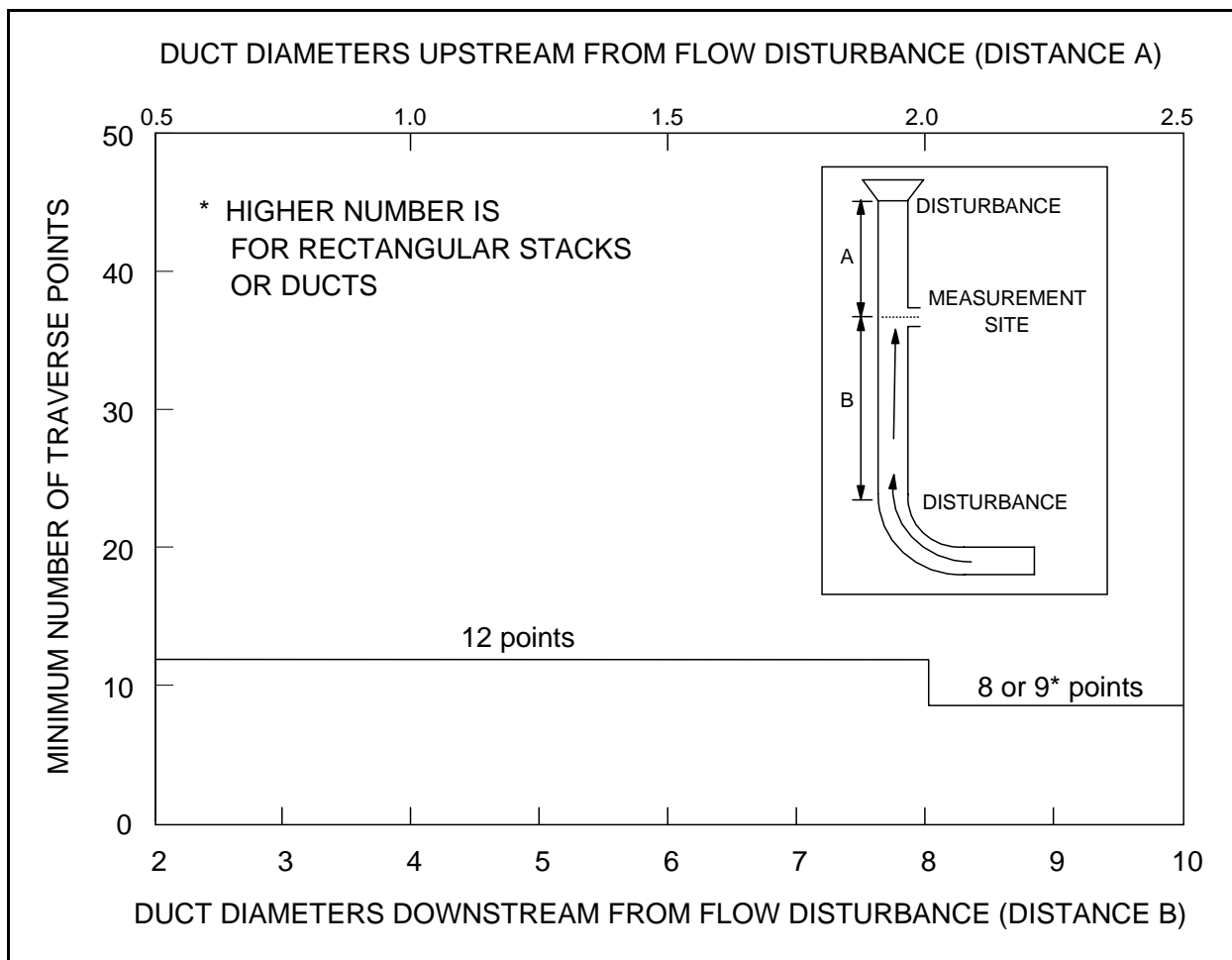


Figure 6. Minimum Number of Traverse Points for Preliminary Method 4 Traverse

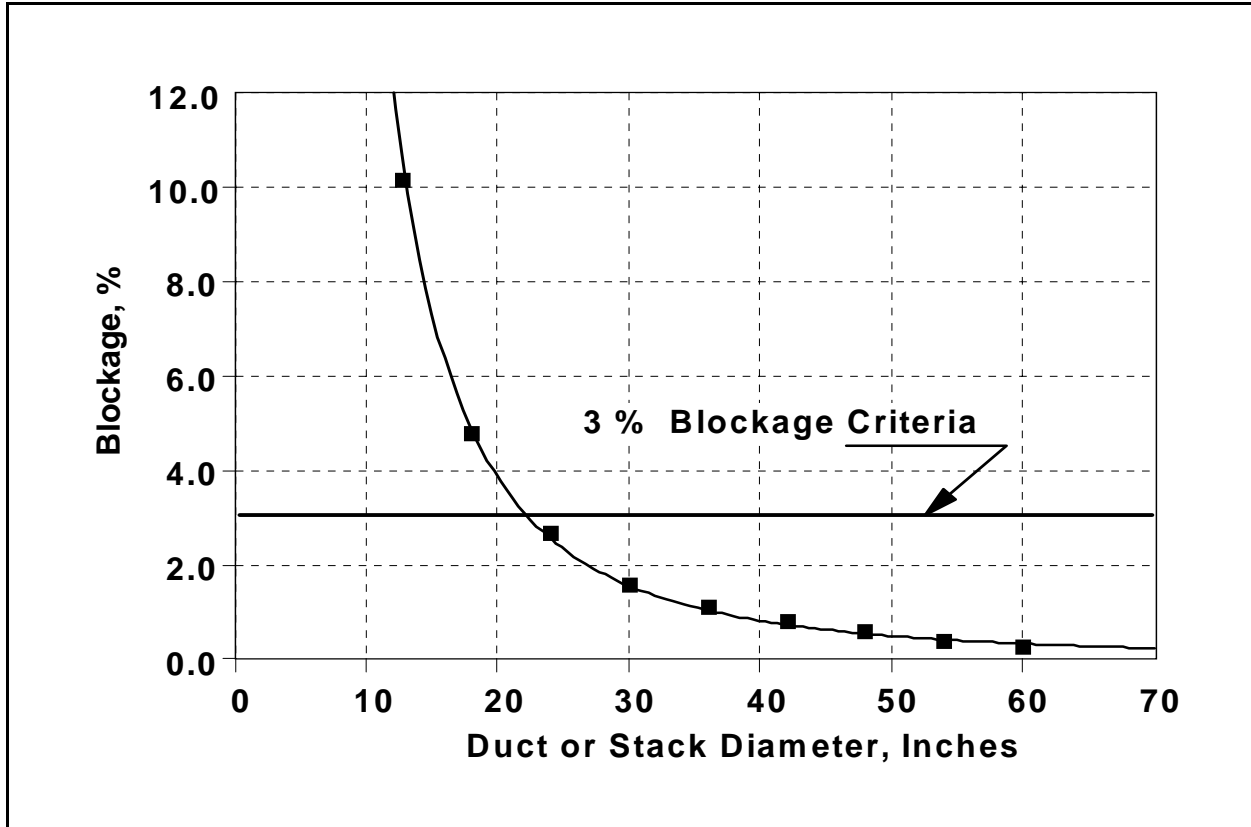


Figure 7. Gas Flow Blockage by the Combined Cyclone Sampling Head

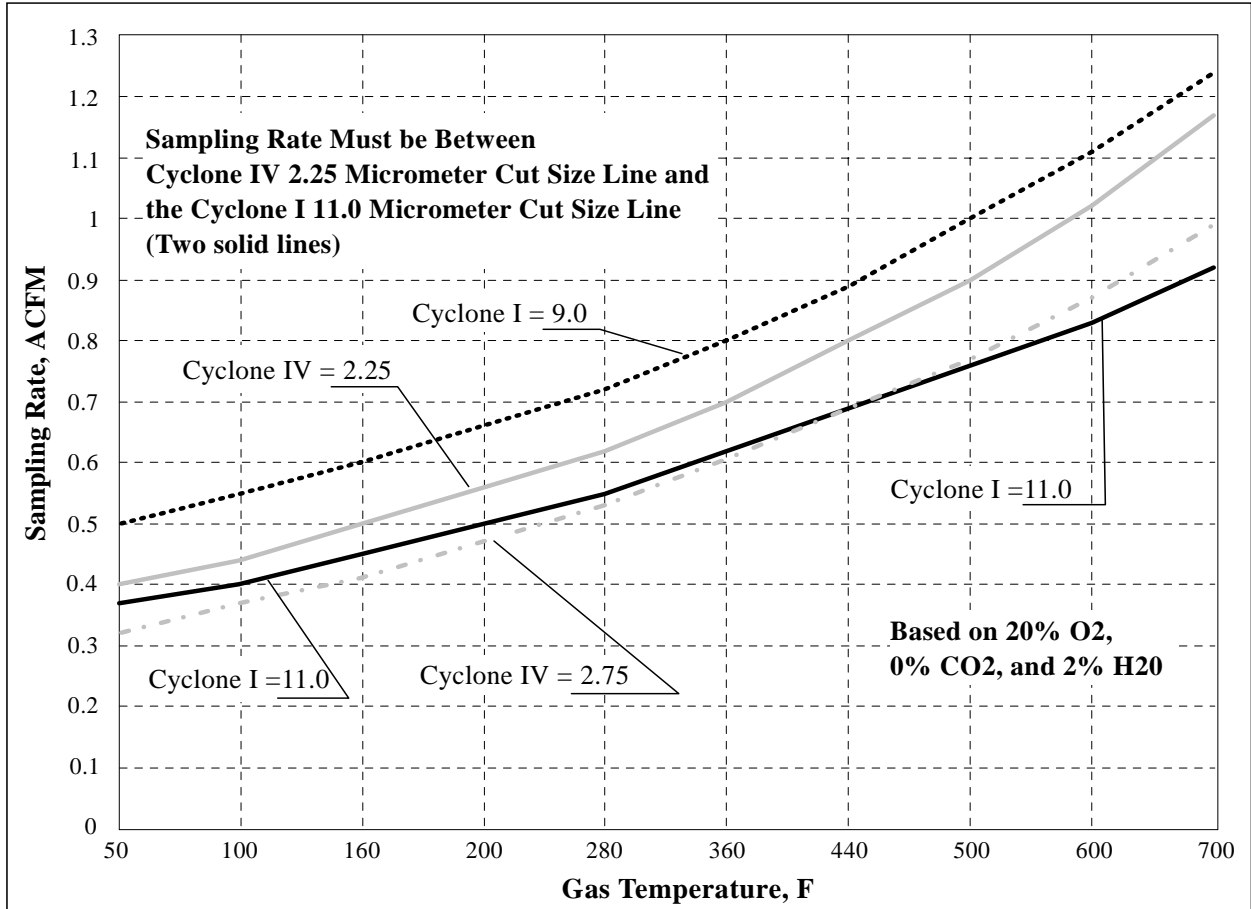


Figure 8. Acceptable Sampling Rate for Combined Cyclone Heads