

CONDITIONAL TEST METHOD (CTM) 039
MEASUREMENT OF PM_{2.5} AND PM₁₀ EMISSIONS BY DILUTION SAMPLING
(CONSTANT SAMPLING RATE PROCEDURES)

1.0 SCOPE AND APPLICABILITY

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

1.1 Background. EPA developed a constant rate sampling procedure (Method 201A) to measure PM₁₀ at stationary sources. Subsequently, they added a PM_{2.5} cyclone (IV) between the PM₁₀ cyclone (I) and in-stack filter of Method 201A, added and modified various Method 201A procedures, initially labeled the new method Preliminary Method PRE 4, and then changed the label to CTM-040.

CTM-039 expands on the measurement capabilities of EPA Method 201A and EPA CTM-040 by:

- incorporating a PM_{2.5} sizer (cyclone IV) behind (or replacing) the PM₁₀ sizer (cyclone I) as in CTM-040,
- removing the in-stack filter,
- diluting the sample gas utilizing a mixing cone and residence chamber,
- using a dilution air system to supply clean air at a temperature less than 85°F (low enough to achieve a filtration temperature of less than 85°F) and a relative humidity less than 50%,
- adding a 142-mm filter to the residence chamber exit to capture any particulate that passes through the residence chamber, and
- providing a sample stream and extraction location for speciating PM_{2.5} in a manner similar to that utilized for ambient PM_{2.5} speciation.

The PM_{2.5} captured on the filter includes any particulate matter condensed and/or formed during the dilution and cooling of the sample gas. Because the sample gas is cooled and diluted

to near ambient conditions, aliquots of the diluted sample gas upstream of the 142-mm filter can be collected for analyses using ambient air methodologies. This method was designed specifically to allow for the collection of particulate matter samples for use in developing speciation profiles to be used in conjunction with the ambient air speciation sampling network.

The calculations and setup are essentially the same as for CTM-040 and Method 201A, with additional calculations added for the dilution system setup and the use of a venturi for monitoring the sampling rate. Due to the complexity of the calculations, it is recommended that computer software in conjunction with a data acquisition system be used to monitor, calculate, and record all the pertinent data and parameters necessary to operate and use this method.

The current design incorporates a mixing cone modified from a previous Southern Research Institute mixing cone design, a residence chamber, and a filter holder with speciation sample extraction ports. The mixing cone exit, residence chamber, and the filter holder inlet are nominally 4 inches in diameter. The residence chamber-filter holder inlet section provides a total length of 22 inches to allow for mixing of the sample gas and dilution air and for particle formation to occur. Speciation extraction ports (3/8-inch diameter) are evenly spaced around the circumference of the filter holder inlet to allow for extracting samples for chemical speciation analyses.

1.2 Who will use this method? This method will be used by operators of stationary sources needing to quantify their primary particulate matter emissions that are equal to or less than 2.5 and 10 μm in diameter. Primary particulate matter emissions include both filterable particulate matter (that material that is solid or liquid at stack conditions) and condensible particulate matter (material that is a gas or a vapor at stack condition but becomes solid or liquid at ambient temperature and pressure). This method does not quantify secondary particulate matter which is formed in the atmosphere through chemical reactions between emitted gases or vapors and other substances in the atmosphere. The sources for which this method is most applicable are those with exhaust gas temperatures above approximately 35°C (95°F) and below

425°C (797°F). The sources of particulate matter emissions that meet this criteria include but are not limited to the following:

- Fossil-fuel fired steam generators
- Industrial, Commercial and Institutional boilers
- Portland cement kilns and clinker coolers
- Municipal waste combustors
- Medical waste incinerators
- Stationary gas turbines
- Stationary reciprocating internal combustion engines
- Petroleum refinery catalytic cracking units
- Fertilizer (Nitrate, Sulfate & Phosphate) production facilities
- Acid (Nitric, Phosphoric & Sulfuric) production plants
- Chemical wood pulping plants
- Reconstituted wood products plants
- Lime manufacturing plants
- Wool fiberglass and mineral wool manufacturing plants
- Glass manufacturing plants
- Primary and secondary metals smelting and refining facilities
- Gray iron and steel foundries
- Carbon black production furnaces

1.3 What can I measure with this method? You can use this method to separate the coarse and the fine components of total particulate matter emissions. The coarse component includes that particulate matter that has an aerodynamic diameter equal to or less than 10 μm but greater than 2.5 μm . The coarse particulate matter is recovered from the back half of the PM_{10} sizing device (i.e., cyclone I turnaround cup and inner down-comer line), the front half of the $\text{PM}_{2.5}$ sizing device (i.e., cyclone IV cup) and the tubing connecting the two cyclones.

The fine component ($\text{PM}_{2.5}$) includes that particulate matter that has an aerodynamic diameter equal to or less than 2.5 μm . The fine particulate matter is recovered from the exit tube

of cyclone IV, the interior surfaces of all hardware between cyclone IV and the 142-mm Teflon[®] filter (probe, sample venturi, dilution chamber, mixing chamber and front half filter holder), and the 142-mm Teflon[®] filter. By summing the coarse and fine components, this method measures PM₁₀. If desired, the particulate matter greater than 10 µm may also be measured with the knowledge that the results may be biased from the potentially anisokinetic sampling and the incomplete traversing of the stack.

The measured PM_{2.5} consists of both PM_{2.5} that is solid or liquid at stack conditions and any particulate matter that condenses at near ambient conditions after dilution. There is no in-stack filter following cyclone IV as this would remove potential condensation nuclei.

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 What qualifications do I need to perform this test method and obtain reliable results? This is a complex test method. To obtain reliable results, you must be trained and experienced in the use of in-stack filtration systems and their operations, isokinetic sampling procedures in general, EPA Method 201A, and the procedures of this test method. You must have a thorough knowledge of the test methods that appear in the following list.

- Method 1 - Sample and Velocity Traverses for Stationary Sources (40 CFR Part 60, Appendix A).
- Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube) (CFR Part 60, Appendix A).
- Method 3 - Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight (40 CFR Part 60, Appendix A).
- Method 4 - Determination of Moisture Content in Stack Gases (40 CFR Part 60, Appendix A).
- Method 5 - Determination of Particulate Matter Emissions from Stationary Sources (40 CFR Part 60, Appendix A).

- Method 17 - Determination of Particulate Matter Emissions from Stationary Sources (40 CFR Part 60, Appendix A).
- Method 201A - Determination of PM₁₀ Emissions (Constant Sampling Rate Procedures) (40 CFR Part 51, Appendix M).
- EPA Method CTM-040 - DRAFT Method for Determination of PM₁₀/PM_{2.5} (<http://www.epa.gov/ttn/emc/prelim.html>)

1.6 Can I use this method to measure emissions in a stack containing water droplets? You can't use this method to measure emissions in stack gases containing water droplets. Stack gases with entrained water droplets may have droplets larger than the cut sizes for the cyclones and these droplets may contain solids, liquids and dissolved vapors that would become PM₁₀ and PM_{2.5} particulate matter when released to the ambient air and the water evaporates. Refer to EPA for additional guidance at <http://www.epa.gov/ttn/emc/informd.html>.

1.7 Can I use this method as an alternative to EPA Method 17 or EPA Method 5? No, this method is not an alternative to EPA Method 17 or EPA Method 5 primarily because it includes particulate matter that is considered condensible and may not satisfy all of the sampling and analysis criteria of the Method 5 or Method 17.

1.8 Can I use this method as an alternative to the combination of CTM-040/Method 202? Yes. Both CTM-039 and CTM-040/Method 202 have the capability to measure the coarse and fine components of particulate matter and are expected to provide comparable results. In CTM-039, the EPA is using a "dilution-based" approach to condense stack vapors to form fine particulate matter. However, the EPA recognizes that the capabilities of CTM-039 may not be required for all source categories and considers this method and CTM-040/202 as comparable provided the nitrogen purge procedure and the alternative ammonium hydroxide titration option incorporated within Method 202 are strictly followed.

The coarse and fine components of particulate matter are captured differently by the two methods. A comparison of key sample train components and differences in the two methods is presented in the listing that follows.

Component / Parameter	CTM-039	CTM-040/202
In-Stack Cyclone(s)?	Yes	Yes
In-Stack filter?	No	Yes
PM Filter Location	Following dilution/condensing	In-stack
PM Collection Temperature	≤ 85°F	Stack temperature for filterable PM and less than 68°F for condensibles
Condensing Method	Dilution w/ambient air at less than 85°F and evaporation at room temperature	Forced collection in D.I. water between 32 and 68°F and evaporation of water at room temperature
Separate Condensible Fractions?	No, condensed gaseous components & original PM captured together	Yes, condensed gaseous components are separated from filterable PM (at stack temperature)
Sample Speciation Capability?	Yes, elemental, ions, EC/OC	Yes, filterable elements, organic and inorganic condensibles

1.9 How do I select or locate the sampling points? You must select the appropriate sampling site in accordance with the standard procedures presented in EPA Method 1. The location will be at the maximum possible distances from upstream and downstream flow disturbances. You must use a maximum of 12 points and must use the percentages (4.4, 14.6, 29.6, 70.4, 85.4, and 95.6% for circular ducts) specified by Method 1 for the use of six points on a diameter to locate the traverse points. If the duct or stack is round with two ports located 90° apart, six sampling points are needed on each diameter. In the case of rectangular ducts or stacks, a 4x3 sampling point layout is most common.

1.10 What do I do if some of the traverse points have velocity pressures that make the isokinetic sampling rate outside of the acceptable range of 80 to 120%? For PM_{2.5}

testing, you may have two points that are outside the range. For PM_{10} testing, Method 201A criteria still applies and you may have only one point outside the range.

If you have more than the allowable number of points outside of the acceptable range, you must use as many nozzles as necessary to meet the criteria. You may simply change the nozzle of the existing train or you may use separate sampling trains with each nozzle. If more than one train is used, then a volume-weighted average of the concentrations of each train must be made to determine the concentration for the run. [NOTE: You must not perform leak checks of the train before or after changing the nozzle; leak check only after completing the run and only from the probe inlet and NOT through the sizing head.]

2.0 SUMMARY OF METHOD

This method combines portions of Method 201A with a system that dilutes and cools the sample gas prior to collection on a 142-mm filter. Figure 1 of Section 17, “Tables, Diagrams, Flowcharts, and Validation Data,” of this method presents the schematic of this sampling train. A $PM_{2.5}$ cyclone is located after the PM_{10} cyclone and the in-stack filter is removed. Stack gas is extracted at a pre-determined constant sampling rate to achieve near 100% isokinetic sampling ratios through the in-stack PM_{10} and $PM_{2.5}$ cyclones. The cyclones separate particles with nominal aerodynamic diameters of greater than 10 μm , less than 10 μm and greater than 2.5 μm , and allow particles less than or equal to 2.5 μm and stack gases to continue through the heated sample probe and heated sample venturi to be diluted and cooled in the mixing cone and residence chamber before being captured by the 142-mm filter.

Filtered, dehumidified, and temperature adjusted dilution air is added to the stack gas sample (now containing only the particles of less than 2.5 μm) in a mixing cone. After mixing of the dilution air and stack sample gas to allow for particulate condensation, $PM_{2.5}$ is captured on a glass fiber filter bonded with polytetrafluoroethylene (PFTE).

The exposed surfaces of the cyclones, probe, sample venturi, and venturi-cone connector tube are rinsed with acetone. The mixing cone, residence chamber, and filter holder inlet are first rinsed with DI water and then followed with acetone. The rinses are evaporated to dryness, desiccated and weighed to determine the particulate mass ($PM_{2.5}$) for each sample fraction. The

filter is desiccated and weighed to determine the particulate mass ($PM_{2.5}$). The water, acetone, and filter masses are summed to determine $PM_{2.5}$.

3.0 DEFINITIONS [Reserved]

4.0 INTERFERENCES/LIMITATIONS [Reserved]

5.0 SAFETY

Disclaimer. You will have to use hazardous materials (e.g. acetone) and operate test 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.

6.0 EQUIPMENT AND SUPPLIES

6.1 What equipment do I need for the sampling train? Figures 1 and 2 of the Section 17 of this method presents a sampling train schematic for this test method. The sampling train consists of sample extraction and collection equipment as well as dilution supply air equipment for supplying clean, dry mixing air. The following paragraphs describe the sampling train's primary design features in detail.

6.1.1 Stack Gas Sample Extraction and Collection Equipment

6.1.1.1 *PM₁₀ and PM_{2.5} Sizers.* Choose a stainless steel (316 or equivalent) PM_{10} and $PM_{2.5}$ sizer that is electropolished. Use a caliper to verify the dimensions of the sizers to within ± 0.02 cm (± 0.01 inch) of the design specifications in Figures 3 and 4 of Section 17. It is recommended that the sizers be limited for use at sources with exhaust gas temperatures below 425°C (797°F).

NOTE: Example suppliers of PM₁₀ and PM_{2.5} sizers are:

- Environmental Supply Company, Inc.
2142 Geer Street
Durham, North Carolina 27704
(919) 956-9688

- Apex Instruments, Inc.
P.O. Box 727
125 Quantum Street
Holly Springs, North Carolina 27540
(919) 557-7300

- Thermo Andersen Instruments, Inc.
500 Technology Court
Smyrna, Georgia 30082
(770) 319-9999

6.1.1.2 *Nozzle*. You must use a nozzle with a sharp tapered leading edge that is stainless steel (316 or equivalent). We also recommend that you have a large number of nozzles in small diameter increments available for the sizer being used to ensure that you can select the appropriate nozzle for your field test conditions. Note that when only the PM_{2.5} sizer is used, you must use a nozzle made for the PM_{2.5} sizer.

We recommend that you choose one of the nozzles listed in Figures 5 or 6 of Section 17 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.

6.1.1.3 *Pitot Tube*. You must use a pitot tube made of heat resistant tubing. The pitot tube can be welded to the probe sheath or attached using appropriate 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.

6.1.1.4 *Probe Liner*. You will need a probe liner made of either borosilicate or quartz glass with a heating system capable of maintaining a probe exit gas temperature during sampling

within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) of the desired temperature setting of at least 5°C (9°F) above the stack gas temperature.

Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the APTD-0576 procedures) will be considered acceptable. Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480°C (900°F). Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners.

Alternatively, metal liners (e.g., 316 stainless steel, Incolloy 825 or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

6.1.1.5 Differential Pressure Transducers. You will need pressure transducers or equivalent devices. Transducers shall be used for measuring the pitot velocity head (Δp) pressure, the sample venturi and dilution venturi differential pressure, the stack gas static pressure, the static pressure at the mixed/exhaust air relative humidity sensor (blower/pump inlet), and the differential pressure between the dilution air and mixed air relative humidity sensor locations.

6.1.1.6 Heating System/Compartment. Any heating system capable of maintaining a temperature around the sample venturi within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) of the desired temperature setting of 5.6°C (10°F) above the stack gas temperature or some other temperature as specified by an applicable subpart of the standards or as approved by the Administrator for a particular application.

6.1.1.7 Temperature Sensors. You will need temperature sensors capable of measuring temperature to within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) for the probe and heating compartment temperature monitoring and $\pm 1^{\circ}\text{C}$ ($\pm 1.8^{\circ}\text{F}$) when monitoring stack gas, sample gas, and dilution air

temperature. The temperature sensors will be installed so that the sensing tip is in direct contact with the sample gas.

6.1.1.8 *Sample Venturi.* You will need a Herschel-type sample venturi consisting of a converging cone, venturi throat, and diffuser. The venturi tube will be constructed of stainless steel. The inlet section to the sample venturi will consist of a converging cone that has an included angle of 21°. The outlet section of the venturi tube will consist of a diverging cone that has an included angle of 7° to 8°.

6.1.1.9 *Couplers, Fittings, Reducers, and Unions.* You will need connectors or couplers to assemble the portions of the sampling train (e.g., to connect the PM_{2.5} cyclone IV to the probe, to connect the probe to the sample venturi, and to connect the sample venturi to the mixing chamber, etc.) You will need stainless steel sanitary flange fittings with seal rings to connect the dilution hose to the inlet of the mixing cone holder and to connect the residence chamber between the cone holder exit and the 142-mm filter holder inlet.

You will need couplers, reducers, and unions to connect the 2.5-inch diameter flexible polyvinyl hoses to the dilution venturi, HEPA filter, air conditioning/dehumidifying system, air blowers, and any other component to be connected. Where possible, the assembly will use sanitary flange fittings for a leak-free seal. [NOTE: This section does not attempt to address every coupler, fitting, reducer, and/or union necessary to assemble the sampling train. You will need an assortment of such hardware in the field.]

6.1.1.10 *Mixing Cone and Holder.* You will need a mixing assembly to mix the clean dry dilution air with the stack sample gas in order to achieve a uniform concentration of the PM. The mixing assembly consists of a mixing cone and holder where the dilution air makes initial contact with the stack sample gas.

The mixing cone is placed in the cone holder. The cone holder is constructed of stainless steel; the cone may be made of stainless steel or aluminum and must be coated with an inert non-reactive material such as Teflon®. The mixing cone holder is round with a 4-inch (nominal)

inside diameter and is approximately 5 inches long. The base (or inlet end) of the cone holder has a circular opening to allow the connection of the sample venturi-cone connector tubing and the inlet of the mixing cone. Near its base, the cone holder has a 1½ inch diameter sanitary flange connection for the dilution air supply line.

A 3/8 inch diameter slipstream of the dilution supply air is diverted through the sample venturi heated compartment, allowing the slipstream of dilution air to be preheated and provide an annulus of heated air to surround the exit of the sample line at the mixing cone. The open face (or exit end) of the cone holder is flanged to allow for a connection to the residence chamber.

The mixing cone is constructed so that it fits firmly inside the cone holder. The cone sides are perforated so that the dilution supply air can enter the cone and begin mixing with the sample gas stream. [NOTE: The sum of the cross-sectional area of the perforations must be less than the cross-sectional area of the dilution supply line connection opening in order to maintain a positive pressure inside the cone holder and thus force an equal distribution of the dilution air through all of the cone's perforation holes.]

6.1.1.11 *Residence Chamber.* The residence chamber is used to allow the completion of the mixing of the dilution air and stack gas and for any particulate condensation or formation to occur. The residence chamber is constructed of stainless steel and has sanitary flange-type fittings at both ends to allow for connections to the mixing cone holder and the 142-mm filter inlet. It has a nominal diameter of 4 inches and a length of approximately 17 inches. The chamber is coated with an inert non-reactive material such as Teflon®.

6.1.1.12 *Filter Holder Assembly.* Use a filter holder made of aluminum or stainless steel. The inlet or front half of the filter holder is constructed so that it has a sanitary flange for connecting to the residence chamber and is coated with an inert non-reactive material such as Teflon®. [NOTE: A modified filter inlet will be used for speciation sampling.] The filter support will include a stainless steel screen frit support, a fine mesh frit, a Viton® O-ring, and a

sanitary flange clamp. The filter holder exit will be of a diameter to allow connecting to a 2.5 inch diameter flexible hose coupler.

You may use other materials of construction subject to the approval of the Administrator. The holder design should provide a positive seal against leakage from the outside or around the filter. You should be able to find a commercial filter holder to support 142-mm diameter filters. Commercial filter holders typically consist of a Teflon[®] O-ring, stainless steel screen which supports the filter, and a final Teflon[®] O-ring.

6.1.1.13 *Mixed/Exhaust Air Blower with DC Motor Control.* You will need a regenerative air blower for creating the main air flow through the sampling train. The blower will be at least 1 Hp and be able to provide 30 cubic feet per minute (cfm) at 30 inches of water column. The blower will also be equipped with direct current (DC) motor control so that the blower motor hertz setting can be automatically adjusted by a computer program to maintain target dilution ratios and particle cut sizes in the sizers.

6.1.1.14 *Relative Humidity (RH) Sensor.* You will need an RH sensor for real-time monitoring of the amount of water vapor (i.e., moisture) in the mixed gas (i.e., stack sample gas and dilution supply air mixture). The RH sensor will have an accuracy of $\pm 2\%$ between 0-90% RH. The operating temperature range of the RH sensor will be from -10 to 50°C (14 to 122°F).

6.1.1.15 *Flexible Hoses.* You will need six foot sections of 2.5 inch diameter flexible polyvinyl hoses (e.g., Shop-Vac[®]) to connect the 142-mm filter holder exit to the mixed/exhaust air blower inlet.

6.1.2 Dilution Supply Air Equipment.

6.1.2.1 *Dehumidifier/Cooler.* If the humidity of the dilution air is greater than 50%, you will need a dehumidifier. If the dilution air temperature is greater than 80°F, you will need an air conditioning system to cool the dilution air such that the temperature of the resulting mixed dilution and stack gas sample at the PM filter is less than or equal to 85°F. If the ambient

conditions are favorable, you may not need to use either a dehumidifier or air conditioning system or both.

6.1.2.2 *Dilution Air Blower with DC Motor Control.* You will need a regenerative air blower to supply dilution air to the mixing chamber. The blower will be at least 1 Hp and be able to provide 30 cfm at 30 inches of water. The blower should also be equipped with direct current (DC) motor control so that flow can be adjusted during the test to maintain the necessary particulate cut sizes.

6.1.2.3 *RH Sensor.* You will need an RH sensor for real-time monitoring of the dilution air moisture. The RH sensor will have an accuracy of $\pm 2\%$ between 0-90% RH. The operating temperature range of the RH sensor will be from -10 to 50°C (14 to 122°F).

6.1.2.4 *HEPA Filter.* You will need a HEPA filter for the dilution air. The HEPA filter will be rated for a minimum of 40 cfm and provide a minimum efficiency of 99.97% on 0.3 μ m dioctyl-phthalate aerosol particles (DOP).

6.1.2.5 *Dilution Venturi.* You will need a calibrated 2-inch Herschel-type venturi consisting of a converging cone, venturi throat, and diffuser. Since only dry clean air will be contacting the venturi surfaces, the dilution venturi tube may be constructed of any non-reactive material (PVC, stainless steel, aluminum, etc.). The inlet section to the venturi tube will consist of a converging cone that has an included angle of 21°. The outlet section of the venturi tube will consist of a diverging cone that has an included angle of 7° to 8°.

6.1.2.6 *Temperature Sensors.* You will need to monitor temperature near the relative humidity sensor (see Figure 2 and Table 4 in Section 17). You will need a temperature sensor similar to those in Section 6.1.1.6.

6.1.2.7 *2.5-to-1.5 inch Reducer.* You will need a reducer made of a material such as aluminum or stainless steel. One end is 2.5 inch diameter for connecting to the flexible hose from the HEPA filter exit. The other end is a 1.5 inch sanitary flange type fitting that connects to the 1.5 inch dilution air supply port in the mixing cone holder.

6.1.2.8 *Flexible Hoses.* You will need three or four six foot sections of 2.5 inch diameter flexible polyvinyl hoses (e.g., Shop-Vac[®]) to connect the dehumidifier, dilution air blower, dilution venturi, HEPA filter, and mixing chamber.

6.1.2.9 *Hose Couplers.* You will need multiple hose couplers that are 2.5 inches in diameter. These are used for connecting the flexible hoses to the various train components. In addition, you will need several couplers that have been modified by plugging the interior. These are used for sealing or capping off various parts of the train during setup, leak checking, transporting of recovered samples, etc. It is recommended that these plugged couplers be CLEARLY differentiated from the normal hose coupler to avoid using a plugged coupler in place of a normal coupler.

6.2 What equipment do I need for leak checking the equipment before and after performing a test.? You will need the following equipment to leak check the hardware.

6.2.1 Pump. You may use a vacuum gauge, leak-free pump, and a dry gas meter (DGM) capable of measuring volume to within 2%, and related equipment, (See Figure 5-1 of Method 5).

6.2.2 Leak Check Assembly. You will need a leak check assembly to attach to the exit of the 142-mm filter holder to perform leak checks. The assembly consists of a 2.5 inch PVC tube section with a port connection with a female quick-connect fitting, a normal hose coupler, and a plugged coupler.

6.2.3 Umbilical Line. You will need an umbilical line to connect to the leak check assembly quick-connect and the pump.

6.3 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.

6.3.1 Probe Nozzle, PM_{2.5} and PM₁₀ sizers, Probe Liner, Sample Venturi, Mixing Cone, Residence Chamber, and Filter Holder Brushes. You will need nylon or Teflon[®] bristle brushes with stainless steel wire or Teflon[®] handles. The probe brush will have extensions (slightly longer than the probe) constructed of stainless steel, Teflon[®], or similarly inert material. The brushes will be properly sized and shaped to brush out the nozzles, PM_{2.5} and PM₁₀ sizers, probe liner, sample venturi tube, sample venturi-cone connector, mixing cone, residence chamber, and 142-mm filter holder inlet.

6.3.2 Wash Bottles. We recommend that you have two glass or Teflon[®] wash bottles. Alternatively, polyethylene wash bottles may be used. We recommend that acetone not be stored in polyethylene bottles for longer than a month.

6.3.3 Glass Sample Storage Containers. You will use chemically resistant, borosilicate glass bottles with screw-on caps, to collect the water and acetone rinses of the sampling train. You will need 125 ml and 250 ml bottles. The screw cap liners will be constructed of either rubber-backed Teflon[®] or constructed to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles are less prone to leakage.) Alternatively, polyethylene bottles may be used but acetone must not be stored in polyethylene bottles for longer than a month.

6.3.4 Petri dishes. We recommend that you use glass or polystyrene petri dishes for storing the 142-mm Teflon[®] filter samples.

6.3.5 Funnel. You should use a glass or polyethylene funnel to aid in collecting acetone rinses into the sample bottles.

6.4 What equipment will I need for sample analysis? You will need a desiccator and containers of low weight such as aluminum weighing pans or Teflon baggies. Aluminum weighing pans 11.1 cm in diameter and 3.0 cm deep with fluted sides and flat bottoms have been used successfully. You will need an analytical balance capable of measuring particulate mass to within 0.01 milligram (mg). The balance should be in a controlled environment capable of maintaining a relative humidity of less than 50% and a temperature of $20^{\circ}\text{C} \pm 5.6^{\circ}\text{C}$ ($68^{\circ}\text{F} \pm 10^{\circ}\text{F}$).

6.5 Can I use additional equipment in the sample train?

6.5.1 Data Acquisition (DAQ) Module (Optional). You may want to use a DAQ module capable of monitoring and recording flow velocities, absolute and differential pressures, and temperatures at various locations in your sampling train. To help you maintain your PM_{10} and $\text{PM}_{2.5}$ cut sizes during sampling, the DAQ can also be programmed to perform real-time calculations for stack gas velocity, sampling isokinetics, flow rate through the cyclones, sample flow rate, dilution ratio, dilution air flow rate, and cyclones cut sizes. In addition, the DAQ may also be programmed to automatically maintain the blower motors settings.

6.5.2 Speciation Sampling (Optional). You may want to use additional sampling hardware to extract samples from the filter holder inlet and perform speciation analyses on the collected samples. Specifications on the sampling and analytical procedures are not provided in this method. A draft method for performing speciation sampling in conjunction with CTM-039 is scheduled for comment by October 2004.

7.0 REAGENTS AND STANDARDS

7.1 What reagents do I need for sample collection? You must use a 142-mm filter made of borosilicate microfibers reinforced with woven glass cloth and bonded with PTFE. The filter must also have an efficiency of at least 99.95% (< 0.05% 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. Depending on your application and project data quality objectives (DQOs), filters are commercially available in a variety of sizes. The filter setup in this method specifies a 142-mm filter. Other filter sizes may be used depending upon your hardware.

7.2 What reagents do I need for sample recovery? You must use acetone, reagent grade, less than or equal to (\leq) 0.001% (1 ppm) residue that is stored in glass bottles and deionized distilled water that conforms to the ASTM Specification D 1193-74, Type II. You must run acetone and water blanks and may subtract the blank contributions from the acetone and water rinse sample catch weights. 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 a desiccant such as anhydrous calcium sulfate, indicating type. You will weigh the beakers and filters after being held in the desiccator containing the desiccant material using the analytical balance described in Section 6.3.

8.0 SAMPLE COLLECTION, PRESERVATION, STORAGE, AND TRANSPORT

8.1 What preparations must I do prior to the test?

8.1.1 Filter Check. Check filters visually against light for irregularities, flaws, or pinhole leaks. Label the shipping containers (glass or polystyrene petri dishes, etc.), and keep each filter in its identified container at all times except during sampling and weighing.

8.1.2 Filter Weighing. Desiccate the filters at $20 \pm 5.6^{\circ}\text{C}$ ($68 \pm 10^{\circ}\text{F}$) and ambient pressure for at least 24 hours. Weigh each filter (or filter and shipping container) at intervals of at least 6 hours to a constant weight (i.e., ≤ 0.05 mg change from previous weighing). Record results to the nearest 0.01 mg. During each weighing, the period for which the filter is exposed to the laboratory atmosphere shall be less than 2 minutes.

8.1.3 Sampling Train Cleaning. Rinse all portions of the train from which PM_{10} and $\text{PM}_{2.5}$ will be recovered (e.g., nozzle, PM_{10} and $\text{PM}_{2.5}$ sizers, probe, sample venturi, connectors, mixing cone, residence chamber, and filter holder inlet) with hot tap water and then wash in hot soapy water. Next, rinse with tap water, followed by additional rinses with deionized, distilled water. Rinse with acetone and allow to air dry. The sections of flexible hose that will be used between the HEPA filter exit and the mixing cone holder must be washed in hot soapy water, rinsed with deionized, distilled water, and allowed to air dry. Cover all openings where contamination can occur until the sampling train is assembled for sampling.

8.2 What must I do before I can make the pretest calculations? You must do the following to gather the necessary data for the pretest calculations:

- (a) Determine the sampling site location and traverse points.
 - Calculate probe/cyclone blockage for stacks between 18 and 24 inches in diameter.
 - Verify the absence of cyclonic flow.
 - Complete a preliminary velocity and temperature profile and select a nozzle(s).
 - Estimate the stack gas moisture content.

8.2.1 Sampling Site Location and Traverse Point Determination. Follow the standard procedures in Method 1 to select the appropriate sampling site. Choose a location that maximizes the distance from upstream and downstream flow disturbances.

You must use a maximum of 12 points and must use the percentages (4.4, 14.6, 29.6, 70.4, 85.4, and 95.6% for circular ducts) specified by Method 1 for the use of six points on a diameter to locate the traverse points. In the case of rectangular ducts or stacks, a 4x3 sampling

point layout is most common. One of the ports should be located in the plane of the bend of the duct to ensure that the traverse is crossing an area of maximum concentration. 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).

When you are using only the $PM_{2.5}$ sizer (cyclone IV), you can use 4-inch diameter ports if the ports are clean. If the PM_{10} sizer is used and the nozzles are smaller than 0.16 inches in diameter, the sampling port diameter must be at least 6 inches since the nozzle-cyclone assembly will not fit into the conventional 4-inch diameter ports. [**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.]

8.2.2 Probe/Cyclone Blockage Calculations. Ducts with diameters from 18 inches to 24 inches have blockage effects ranging from 3% to 6%, as illustrated in Figure 7 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% of the stack or duct (see Section 8.6.3 regarding the probe blockage factor and the final adjusted velocity pressure). Ducts less than 18 inches in diameter can not be tested.

8.2.3 Cyclonic Flow Check. Do not use the combined cyclone sampling head at sampling locations subject to cyclonic flow. Also, you must follow Method 1 procedures to determine the presence or absence of cyclonic flow. [**NOTE:** You can minimize cyclonic flow conditions by placing gas flow straighteners upstream of the sampling location.]

You do this by inserting the S-type pitot tube into the stack and at each of the traverse points rotate the pitot tube until you locate the angle that has a null velocity pressure. Record the angle and 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° .

8.2.4 Preliminary Velocity Profile. Conduct a preliminary Method 2 of velocity traverse, as well as the measurements below. The purpose of the velocity profile is to determine all of the following:

- The gas sampling rate for the combined probe/cyclone sampling head.
- The appropriate nozzle(s) to maintain the required velocity pressure range and isokinetic range.
- The necessary sampling duration to obtain sufficient particulate catch weights.

8.2.4.1 *Preliminary Traverse.* You must use an S-type pitot tube with a conventional thermocouple to conduct the preliminary 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 $\pm 50^\circ\text{F}$. [NOTE: You should be aware that these variations can cause errors in the cyclone cut diameters and the isokinetic sampling rates.]

8.2.4.2 *Velocity Pressure Range.* Insert the S-type pitot tube into the stack and record the velocity pressure measured at each traverse point on the Method 2 data form. You will use this later to select the appropriate nozzles(s).

8.2.4.3 *Initial Gas Stream Viscosity and Molecular Weight.* Determine the average stack gas temperature; estimate the stack gas oxygen, carbon dioxide, and moisture content. You will use this information to calculate the initial gas stream viscosity (Equation 3) and molecular weight (Equations 1 and 2). [NOTE: For these initial calculations, you must either assume a moisture content (based on prior knowledge of the process); estimate moisture following the procedures outlined in EPA Method 4 or use a wet bulb-dry bulb measurement device or a hand-held hygrometer measurement device for stack gas temperatures less than 71°C (160°F).]

8.2.4.4 *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 mass of particulate matter 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 $>10\ \mu\text{m}$, ≤ 10 and $>2.5\ \mu\text{m}$, and $\leq 2.5\ \mu\text{m}$ size ranges.

8.2.5 Estimate Stack Gas Moisture. Estimate the moisture content of the stack gas using Approximation Method 4 or its alternatives (e.g., use historical moisture data)

8.2.6 Stack Gas Pressure (absolute). Determine the stack pressure using the barometric pressure and measured stack static gauge pressure.

8.3 What pretest calculations must I make? You must perform various pretest calculations in order to calculate the appropriate gas sampling rate through cyclone I (PM_{10}) and cyclone IV ($\text{PM}_{2.5}$), to select the most appropriate size nozzle(s), and to set the minimum-maximum velocity criteria. Calculating the appropriate sampling rate will allow you to meet the particle cut size specification for each cyclone as listed in Table 2 of Section 17. The gas sampling rate is defined by the performance curves for both cyclones, as illustrated in Figure 8 of Section 17. The optimum gas sampling rate is the overlap zone defined as the range below the 2.25 micrometer curve of cyclone IV down to the 11.0 micrometer curve of cyclone I (area between the two dark, solid lines in Figure 8 of Section 17).

You must calculate a gas sampling rate in the middle of the overlap zone 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 38°C (100°F).]

You must perform the calculations listed below and the calculations described in paragraphs 8.3.1 through 8.3.7 of this section.

If you are using...	To calculate...	Then use...
Preliminary data	dry stack gas molecular weight, M_{ds}	Equation 1
Dry gas molecular weight (M_d) and preliminary moisture content of the gas stream	wet stack and sample gas molecular weight, M_{w1} and M_w	Equation 2 ^a
Stack gas temperature, oxygen and preliminary moisture content of the gas stream	gas viscosity, μ	Equation 3
Barometric pressure and average static (gauge) stack gas pressure	stack gas pressure (absolute), P_s	Equation 4
Gas viscosity, μ	Cunningham correction factor ^b , C	Equation 5
Assumed Reynolds number ^c (N_{re}) $N_{re} < 3162$	preliminary lower limit cut diameter for cyclone I, D_{50LL}	Equation 6
D_{50LL} from Equation 6	cut diameter for cyclone I for middle of the overlap zone, D_{50t}	Equation 7
D_{50t} from Equation 7	final sampling rate for cyclone I, $Q_I(Q_s)$	Equation 8
$Q_I(Q_s)$ from Equation 8	(verify) the assumed Reynolds number	Equation 9
Assumed Reynolds number ^c (N_{re}) $N_{re} \geq 3162$	lower limit cut diameter for cyclone I, D_{50LL}	Equation 10
Q_s from Equation 8 and estimated stack moisture content	estimated sampling rate through cyclones I and IV (at standard conditions, dry basis), $Q_{st(std)}$	Equation 11
$Q_{st(std)}$ from Equation 11	estimated dilution air flow rate (at standard conditions, dry basis), $Q_{dt(std)}$	Equation 12
Sampling rate through cyclones I and IV (Q_s); stack pressure and temperature; and estimated, molecular weight, temperature and pressure at the sample venturi	target sample venturi pressure differential setting, ΔH_1	Equation 13

If you are using...	To calculate...	Then use...
Dilution air flow rate ($Q_{dt(std)}$) and estimated molecular weight, temperature and pressure at the dilution venturi	target dilution venturi pressure differential setting, ΔH_2	Equation 14
Use preliminary data to calculate initial stack gas velocity (v_s)	velocity of stack gas (v_s)	Equation 15
Use Equations 16, 17, and 18 to recalculate v_s for C_p and probe blockage (b_f) prior to calculating the nozzle diameter for the acceptable sampling rate	adjusted velocity of stack gas (v_s)	Equations 16, 17, and 18 (Adjusted)
Sampling rate through cyclones (Q_s) and adjusted stack gas velocity (v_s)	nozzle diameter for acceptable sampling rate (D_n)	Equation 19
Nozzle diameter (D_n)	nozzle area (A_n)	Equation 20
Sampling rate through cyclones (Q_s) and nozzle diameter (D_n)	sample gas velocity in nozzle (v_n)	Equation 21
Gas viscosity (μ), sampling rate through cyclones (Q_s), and nozzle velocity (v_n)	minimum (R_{min}) and maximum (R_{max}) nozzle/stack velocity ratio parameter to maintain isokinetic range of 80 to 120%.	Equations 22 and 23
Nozzle velocity calculated in Equation 21 and R_{min}	minimum stack gas velocity (v_{min}) if R_{min} (Equation 22) is an imaginary number (value under the square root function is negative) or less than 0.5	Equation 24
	or	
	minimum stack gas velocity (v_{min}) if R_{min} (Equation 22) is greater than 0.5	Equation 25

If you are using...	To calculate...	Then use...
Nozzle velocity calculated in Equation 21 and R_{\max}	maximum stack gas velocity (v_{\max}) if R_{\max} is equal to or less than 1.5 or maximum stack gas velocity (v_{\max}) if R_{\max} is greater than 1.5	Equation 26 Equation 27
Preliminary data (i.e., P_s , T_s , and M_w), C_p , and v_{\min}	minimum stack gas velocity pressure (Δp_{\min}) which will maintain an isokinetic range of 80% to 120%	Equation 28
Preliminary data (i.e., P_s , T_s , and M_w), C_p , and v_{\max}	maximum stack gas velocity pressure (Δp_{\max}) which will maintain an isokinetic range of 80% to 120%	Equation 29
Preliminary traverse data ($\Delta p'$), number of traverse points (N), and total run time (t_r)	sampling time at point 1 (t_1) rounded to the nearest 1/4 minutes (15 seconds).	Equation 30

^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 paragraph 8.3.1, below, before proceeding to Equation 12.

8.3.1 Verify Reynolds Number. Verify the assumed Reynolds number (N_{re}) by substituting the sampling rate (Q_s) calculated in Equation 8 into Equation 9. Then use the following procedures to determine if the N_{re} used in Equation 6 was correct.

If the N_{re} is ...	Then ...	And ...
< 3162	Calculate ΔH_1 for the sample venturi	
\geq 3162	Recalculate D_{50LL} using Equation 10	Substitute the “new” D_{50LL} into Equation 7 to recalculate D_{50t}

8.3.2 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 8 to recalculate the optimum sampling rate (Q_s).

8.3.3 Dilution Air Supply Rate. You should use a dilution ratio in the range of approximately 10:1 to 40:1 to achieve near ambient conditions. The appropriate dilution ratio will allow you to cool the stack gas sample to near ambient temperature in order to mimic $PM_{2.5}$ formation that occurs downstream of the stack exit. You must calculate using Equation 12 the rate of dilution air required to achieve the desired dilution ratio to keep condensation of moisture from occurring in the mixing cone or residence chamber. [NOTE: If condensation is observed after a test, the dilution ratio should be increased. The dilution air supply rate must be recalculated.]

8.3.4 Sample Venturi Pressure Setting. Use Equation 13 to calculate the sample venturi pressure setting (ΔH_1) 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 to the blower controls to achieve the sample venturi ΔH_1 to maintain the correct constant cut diameters. Therefore, use Equation 13 to recalculate the ΔH_1 values for 28°C (50°F) above and below the stack temperature measured during the preliminary traverse. You may document the information on a form similar to Table 3 in Section 17.]

8.3.5 Dilution Venturi Pressure Setting. Use Equation 14 to calculate the dilution venturi ΔH_2 after you calculate the optimum dilution air supply rate based on the desired dilution ratio.

8.3.6 Choosing a Sampling Nozzle. You must select one or more nozzle sizes to provide for near isokinetic sampling rates (that is, 80% to 120%). This will also minimize any isokinetic sampling errors for the 10 μm and 2.5 μm particles at each point. First calculate the

mean stack gas velocity, v_s , using Equation 15. Look at Section 8.6.3 for information on correcting for blockage and use of different pitot tube coefficients. Then use Equation 19 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).

8.3.6.1 *Nozzle Area.* Calculate the nozzle opening cross-sectional area using Equation 20.

8.3.6.2 *Velocity of Gas in Nozzle.* Calculate the velocity of the gases entering the nozzle using Equation 21.

8.3.6.3 *Minimum/Maximum Nozzle/Stack Velocity Ratio.* Use Equation 22 to calculate the minimum nozzle/stack velocity ratio, R_{\min} . Use Equation 23 to calculate the maximum nozzle/stack velocity ratio, R_{\max} .

8.3.6.4 *Minimum Gas Velocity.* Use Equation 24 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 25 to calculate v_{\min} if R_{\min} is greater than or equal to 0.5.

8.3.6.5 *Maximum Stack Velocity.* Use Equation 26 to calculate the maximum stack velocity (v_{\max}) if R_{\max} is less than 1.5. Use Equation 27 to calculate the stack velocity if R_{\max} is greater than or equal to 1.5.

8.3.6.6 *Conversion of Gas Velocities to Velocity Pressure.* Use Equation 28 to convert v_{\min} to minimum velocity pressure, Δp_{\min} . Use Equation 29 to convert v_{\max} to maximum velocity pressure, Δp_{\max} .

8.3.6.7 *Comparison of Minimum and Maximum Velocity Pressures.* Compare minimum and maximum velocity pressures with the observed velocity pressures at all traverse points during the test (see section 8.2.4.1 of this section).

8.3.7 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} .

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 potential of satisfying the isokinetic criteria. Generally, one of the two candidate nozzles selected will be closer to optimum (see Section 8.3.6).

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 PM_{10} 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.

Visually check the selected nozzle for dents before use. Screw the pre-selected nozzle into the main body of the cyclone using Teflon[®] tape. If you are using both sizes, connect the cyclone IV inlet to the outlet of cyclone I (see Figure 3 of Section 17).

8.4 How do I assemble the sampling train? First, you must assemble the train and then leak check the train from the cyclone nozzle tip; if necessary, perform a separate leak check on the diluted section of the train (mixing cone, residence chamber, filter). Leak check the dilution and sample venturi pressure lines; leak check the pitot tubes following Section 8.1 of EPA Method 2. Use the following procedures to prepare as much of the sampling train as possible in a controlled environment. [**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.]

8.4.1 Sampling Head. Assemble the combined cyclone sizers. 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 keep the nozzle covered to protect it from nicks and scratches and keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

8.4.2 Filter (142-mm) and Filter Holder. Use tweezers or clean disposable surgical gloves to place a pre-weighed filter on the filter support screen of the filter holder. You must center the filter so that the sample gas stream will not circumvent the filter. After placing the O-ring on the holder correctly, join the two filter holder halves by placing the front half (or inlet) filter holder on top of the filter and back half filter holder. Clamp the two filter holder halves together using the 6-inch sanitary flange clamp. [NOTE: Place Teflon® tape around the circumference of the joint prior to clamping if leak checking becomes a problem.]

8.4.3 Residence Chamber and Filter Holder (142-mm). Place the residence chamber exit flange on the filter holder inlet flange, making sure the Viton® seal ring is properly seated between the two flanges. [NOTE: If leak checking becomes a problem, tape the joints with Teflon® tape prior to clamping.] Place a 4-inch diameter (nominal) stainless steel sanitary clamp over the flanges to complete the seal.

[NOTE: If speciation sampling is being performed, the filter inlet can be constructed with taps or connectors so that filter holders or denuder systems can be attached directly to the filter holder inlet. The filter holder must be properly aligned with the residence chamber support brackets to allow the vertical placement of any denuder sampling legs being utilized.]

8.4.4 Probe-Heated Compartment-Mixing Cone Holder. Insert the sample venturi-cone connector (SVCC) tubing through the tee used to create the annulus space for the preheated dilution air slipstream. Connect the tubing to the mixing cone holder tubing and to the tee. Connect the sample venturi ball fitting to the SVCC socket fitting with a pinch clamp. Attach

the inlet socket of the sample venturi to the probe's exit ball fitting with a pinch clamp and secure the probe with the probe holder bracket.

Attach the sanitary flange end of the reducer to the 1.5-inch flange on the mixing cone holder, making sure the gasket seal ring is properly placed between the flanges; use a 1.5-inch clamp to complete the seal. Confirm that the 2.5-inch end of the reducer is capped by a plugged hose coupler (which will be replaced prior to the testing).

8.4.5 Mixing Cone-Residence Chamber-Filter Holder. Place the mixing cone inside the cone holder as shown in Figure 2. Join the cone holder flange to the residence chamber flange, making sure the gasket seal ring is correctly located between the two flanges using a 4-inch diameter (nominal) stainless steel sanitary clamp to complete the seal. Join the sanitary flange end of the filter holder inlet to the residence chamber exit flange with the Viton[®] seal ring between and seal with a sanitary flange clamp. Confirm that the filter holder exit is capped by a plugged hose coupler (which will be replaced prior to the testing).

8.4.6 Mixed/Exhaust Air Blower. Attach one of the 6-foot (typical) sections of 2.5-inch diameter flexible polyvinyl hose (Shop-Vac[®] type) to the inlet of the exhaust air blower using a hose coupler. The other end will be connected to the filter holder exit (after removing the plugged coupler) after the probe is inserted into the stack port (after leak checking).

8.4.7 Dehumidifier-Dilution Air Blower-Dilution Venturi. Using one of the flexible hose sections, connect the dilution air blower to the dehumidifier exhaust. Connect the upstream end of the dilution venturi directly to the exit of the dilution air blower using a hose coupler.

8.4.8 HEPA Filter Housing. Insert one end of a section of flexible hose into the inlet of the HEPA filter housing and connect the other end to the exit of the dilution venturi. Insert the end of a cleaned flexible hose section into the exit of the HEPA filter housing and place a plugged hose coupler on the opposite end to seal the hose until testing begins. This end will be

connected to the reducer attached to the mixing cone holder, after the probe is inserted into the stack.

8.5 How do I leak check the sampling train? You must conduct a pretest leak check of the sampling train. You may leak check the diluted section separately from the non-diluted section or you may choose to leak check both together. Use the procedures outlined below to leak check the entire sampling system, including pressure lines.

8.5.1 Pretest Leak Checks. A leak check of the two hardware sections (non-diluted and diluted) is required. You may leak check both sections together or separately; each section has a different maximum allowed leak rate - 0.02 acfm for the non-diluted section and 0.05 acfm for the diluted section. If separately, you will perform a leak check of the non-diluted (stack gas sample) section of the sampling train that includes the nozzle to the mixing cone holder exit. Similarly, you will perform a leak check of the diluted (mixed/exhaust) section of the sampling train.

If the first leak check performed is a combined leak check of both sections (from the nozzle to the filter holder exit), the maximum allowable leak rate is the same as for the non-diluted section only, 0.02 cfm.

The maximum allowable rate for the mixed section is 0.05 cfm. This is loosely based on the criteria from Method 5 (maximum leak rate of 0.02 cfm) and an estimated maximum sampling rate of 1.5 cfm yielding a rate percentage of 1.33% ($0.02 / 1.5$) and a minimum flow rate through the mixed section of 4 cfm (dilution ratio of 10); specifically, $0.0133 \times 4 = 0.052$ which is rounded to 0.05 cfm.

8.5.1.1 *Non-diluted Section Leak Check.* You must plug the sample venturi pressure taps (one way is to connect the two taps with rubber tubing) and the mixing cone holder exit (a 4-inch cap designed for use with sanitary flange fittings works well). Connect the leak check assembly to the dilution air supply inlet port of the mixing cone holder. Connect the umbilical line from

the pump to the leak check assembly. Leak check the train by plugging the nozzle and pulling a 76 mm (3 in.) Hg vacuum.

Leakage rates in excess of 0.02 cfm are unacceptable. 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.]

8.5.1.2 *Diluted Section Leak Check.* You must leak check the diluted section either from the nozzle or from the residence chamber inlet through the filter holder exit. If you leak check from the nozzle, the non-diluted section of the train (nozzle to mixing cone holder) must have a leak rate less than or equal to 0.02 cfm; also, the dilution air supply inlet to the mixing cone holder must be plugged.

Connect the leak check assembly to the filter holder exit. Connect the umbilical line from the pump to the leak check assembly. Leak check the train by plugging either the nozzle or the residence chamber inlet and pulling a 76 mm (3 in.) Hg vacuum.

Leakage rates in excess of 0.05 cfm are unacceptable (0.07 cfm if the leak check is from the nozzle). 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.]

8.5.2 Pitot Tube Assembly. You must perform a leak check of the pitot tube assembly. Conduct a pretest leak check as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3.0 in.) H₂O velocity head registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3.0 in.) H₂O. Other leak check procedures, subject to the approval of the Administrator, may be used.

8.5.3 Venturi Pressure Lines. You must perform a leak check of the sample and dilution venturi pressure lines. Conduct a pretest leak check as follows for each venturi: (1) blow through the positive pressure line until at least 7.6 cm (3.0 in.) H₂O pressure registers on the manometer; then, close off the tubing. The pressure shall remain stable for at least 15 seconds; (2) do the same for the negative or low pressure side, except using suction to obtain

the minimum of 7.6 cm (3.0 in.) H₂O. Other leak check procedures, subject to the approval of the Administrator, may be used.

8.6 How do I operate the sample train? You must maintain nominal cut sizes at the cyclones of 10 µm and 2.5 µm and keep the isokinetic sampling ratios as close to 100% as possible. Maintain the probe and heated compartment temperatures at least 5.6°C (10°F) greater than the stack gas temperature. Maintain the relative humidity of the dilution supply air at less than 50% and the exhaust or mixed air temperature at less than 29.4°C (85°F). For each run, record the site barometric pressure (adjust for elevation) on a field test data sheet; record additional required data at the beginning and end of each time increment (dwell time). You perform the following procedures:

8.6.1 Preheating Operations. You must preheat the combined sampling head to within 10°C (18°F) of the stack temperature of the gas stream. You must insert the sizing head-probe assembly into the stack, with the nozzle rotated away from the gas flow direction, for 30 to 40 minutes. You must preheat the probe and the sample venturi compartment to 5.6°C (10°F) higher than the stack gas temperature.

This will help prevent moisture from condensing from the stack sample gas stream at unsaturated stacks. [NOTE: Unsaturated stacks do not have entrained droplets and operate at temperatures above the local dew point of the stack gas.] You can shorten the warmup time by heating outside the stack (such as by a heat gun). Place the heated sampling head inside the stack and allow the temperature to equilibrate.

8.6.2 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 at each traverse point proportionately with the sample traverse point velocity. Use the Equations 30 and 31 to calculate the dwell time at the first point and at each subsequent point. It is recommended that the number of minutes sampled at each point be rounded to the nearest 15 seconds.

8.6.2.1 *Dwell Time at First Sampling Point.* Calculate the dwell time for the first point, t_1 , using Equation 30. This becomes the baseline time per point used in calculating the dwell time for the subsequent points. You must use the data from the preliminary traverse. N equals the total number of traverse points to be sampled.

8.6.2.2 *Dwell Time at Remaining Sampling Points.* Calculate the dwell time at each of the remaining traverse points, t_n , using Equation 31. This time you must use the actual test run data and the dwell time calculated for the first point. [NOTE: Round the dwell times to 1/4 minutes (15 seconds).] Each traverse point must have a dwell time of at least two minutes.

8.6.3 Adjusted Velocity Pressures. When selecting your sampling points using your preliminary velocity traverse data if the stack diameter is less than 24 inches, your preliminary velocity pressures must be adjusted to take into account the increase in velocity due to blockage. For rectangular ducts you must adjust your preliminary velocity pressures if the duct area is less than 3.14 square feet. If necessary, you must adjust your preliminary velocity data for differences in pitot tube coefficients. Use the following instructions to adjust the preliminary velocity pressure.

8.6.3.1 *Different Pitot Tube Coefficient.* You must use Equation 16 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.

8.6.3.2 *Probe Blockage Factor.* You must use Equation 17 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 8.2.2 and illustrated in Figure 8 of Section 17.

[**NOTE:** The sampling head has a projected area of approximately 17 square inches when oriented into the gas stream. As the probe is moved from the most outer to the most inner point (towards the center of the stack), the amount of blockage that actually occurs ranges from approximately 4 square inches to the full 17 square inches. The average cross-sectional area blocked is approximately 10 square inches.]

8.6.3.3 *Final Adjusted Velocity Pressure.* Calculate the final adjusted velocity pressure (Δp_{s2}) using Equation 18. [**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, when the stack diameter is less than 18 inches, you must use the procedures of Method 1A to conduct tests. You must conduct the velocity traverse downstream of the sampling location or immediately before the test run.]

8.6.4 Sample Train Operation. You must follow the procedures outlined in paragraph 4.1.5 of Method 201A to operate the sample train. Maintain the sampling flow rate calculated in Section 8.3.2 throughout the run provided the stack temperature is within 28°C (50°F) of the temperature used to calculate ΔH_1 . If stack temperatures vary by more than 28°C (50°F), use the appropriate ΔH_1 value calculated in Section 8.3.4. Calculate the dwell time at each traverse point as each point is traversed.

8.6.4.1 *Startup.* Clean the portholes prior to the test run. This will minimize the chance of collecting deposited material from the port in the nozzle. Confirm that the probe and sample venturi compartment temperatures are within 5°C (9°F) of stack temperature and that the cyclone heads have had sufficient time to preheat. 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, seal off the openings around the probe and porthole to prevent air leakage into or out of the port.] To begin sampling, adjust the motor control settings of each blower to reach the dilution ratio and sampling head cut sizes desired.

8.6.4.2 *Begin Sampling.* You must start the exhaust blower first and adjust the sampling rate by changing the motor control setting of the mixed/exhaust air blower until the pressure reading of the sample venturi is close to the target ΔH_1 calculated previously for the desired particulate cut sizes. Then start the dilution blower and adjust the dilution air supply rate by changing the motor control setting of the dilution blower until the pressure reading of the dilution venturi is close to the target ΔH_2 calculated previously for the desired dilution ratio.

At this time, both blower settings must be adjusted until the software calculations give the desired cut sizes and dilution ratio. It is helpful to have an estimate of the motor control settings needed for the target dilution ratio and cut sizes before the test so that the settings may be quickly reached (to minimize the amount of test time not meeting the criteria of the method).

8.6.4.3 *Traversing.* You must traverse the stack cross-section, sampling the previously selected points (maximum of 12 points). After the first point, position the nozzle at the next traverse point, measure the velocity pressure, and calculate the dwell time for that point. 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.

8.6.4.4 *Data Recording.* You must either record the data required on the field test data sheet for each run or store the data electronically in a data acquisition system (DAS). If you record the data on field test data sheets, record the initial data readings. Then take 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 28 and 29) with the velocity pressure measured during the preliminary traverse. Keep the sample venturi ΔH_1 at the value calculated in Section 8.3.4 for the stack temperature that is observed during the test. Keep the dilution venturi ΔH_2 at the value calculated in Section 8.3.5. Record all the point-by-point data and other source test parameters on the field test data sheet. Maintain the flow through the

sampling system until the last traverse point is sampled. Do not leak check the sampling system during port changes.

8.6.4.5 End of Run Procedures. First stop the dilution blower and then the exhaust blower. Remove the sampling train from the stack. Depending on the flexible hose lengths and platform geometry, it may be necessary for you to disconnect the dilution air supply hose and the exhaust hose from the train before the probe can be removed from the stack. If so, be sure to cap or plug the openings.

Use care so that you do not scrape the pitot tube or the combined sampling head against the port or stack walls. Record the final readings and other test parameters on the field test data sheet. After you stop the gas flow, make sure you keep the cyclone head level to avoid tipping dust from one section of the sampling head to another.

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 sampling head from the probe. Cap the nozzle and exit of cyclone IV to prevent particulate matter from entering the assembly.

8.6.4.6 Post-Sampling Leak Check. Leak check the non-diluted sampling train section as described in Section 8.5.1.1, after removing the combined cyclone head. Leak check the diluted sampling train section as described in Section 8.5.1.2. Conduct the leak checks at a vacuum of 3 inches (76 mm) Hg. Enter the results of the leak checks onto the field test data sheet. If the leak rate of the non-diluted sampling train section (without the combined cyclone sampling head) exceeds 0.02 cfm, the run is invalid and you must repeat it.

8.7 How do I recover particulate matter from the sample train? Recovery involves the quantitative transfer by brushing and rinsing with acetone of particles in the following size ranges: (1) $> 10 \mu\text{m}$, (2) $\leq 10 \mu\text{m}$ but $> 2.5 \mu\text{m}$ (coarse), and (3) $\leq 2.5 \mu\text{m}$. You must use a Nylon or Teflon[®] bristle brush and ultra-pure acetone rinse to recover particles from the nozzle, cyclone heads, probe, sample venturi, mixing cone, residence chamber, and front half

of the filter holder. Sample recovery should take place in a clean environment and not on the stack.

8.7.1 Container No. 1 (Nozzle and Cyclone I Particulate > 10 μm). This particulate size fraction recovery is optional. Quantitatively recover the (1) particulate matter from the cyclone I cup and acetone rinses (and brush cleaning) of the cyclone I cup, (2) internal surface of the nozzle, and (3) cyclone I internal surfaces, including the inside surface of the down-comer line, into Container No. 1. 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 μm .

8.7.2 Container No. 2 (Cyclones I and IV Particulate ≤ 10 and > 2.5 μm). This particulate size fraction is optional. Place in Container No. 2 the solids from the cyclone IV cup and the acetone (and brush cleaning) rinses of the cyclone I turnaround cup (above inner down-comer line), cyclone I exit tube, and cyclone IV excluding the exit tube interior surface. Seal the container and mark the liquid level on the outside of the container. This container holds “coarse” particulate matter (≤ 10 and > 2.5 μm).

8.7.3 Container No. 3 (Mixing Cone, Residence Chamber, and Filter Holder Inlet Particulate $\leq 2.5 \mu\text{m}$). Rinse with DI water, brush, and recover the interior surfaces exposed to the sample gas in Container No. 3. Specific components are the mixing cone, residence chamber, and the front half (inlet) of the filter holder. Seal the container and mark the liquid level on the outside of the container. This container holds particulate matter that is $\leq 2.5 \mu\text{m}$.

8.7.4 Container No. 4 (Cyclone IV, Probe, Sample Venturi, Mixing Cone, Residence Chamber, and Filter Holder Inlet Particulate $\leq 2.5 \mu\text{m}$). Rinse with acetone, brush, and recover all the interior surfaces exposed to the sample gas in Container No. 4. This will include all components from the exit tube of cyclone IV up to and including the filter holder inlet (142-mm). Specific components are the exit tube of cyclone IV, probe, sample venturi, and sample

venturi cone connector; after the DI water rinse, rinse the mixing cone, residence chamber, and the front half (inlet) of the filter holder with acetone. Seal the container and mark the liquid level on the outside of the container. This container holds particulate matter that is $\leq 2.5 \mu\text{m}$.

8.7.5 Container No. 5 (Filter Particulate $\leq 2.5 \mu\text{m}$). Use tweezers and/or clean disposable surgical gloves to remove the filter from the filter holder. Place the filter in its petri dish you identified as Container No. 5. Using a dry Nylon or Teflon[®] 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 $\leq 2.5 \mu\text{m}$.

8.7.6 Container No. 6 (Acetone Blank). Take 100 ml of the acetone directly from the wash bottle you used, and place it in Container No. 6, labeled Acetone Blank.

8.7.7 Container No. 7 (DI Water Blank). Take 100 ml of the DI water directly from the wash bottle you used, and place it in Container No. 7, labeled DI Water Blank.

8.8 How do I store and transport the samples? During transport to the laboratory, the filters should be placed in their petri dishes or other protective containers. Any protective containers that protect the filters from contamination may be used. The protective container must be appropriately sized so that the collected sample does not directly touch the interior surface of the container.

Filter samples, accompanied by the completed chain of custody record, can be packed in an insulated protective container (a cooler for example) with as many containers of frozen ice substitute as needed to keep the samples at 26.7°C (80°F) or less during the transport period. The temperature inside the transport container may be monitored with a maximum/minimum thermometer or other indicator of temperature, especially of maximum temperature.

Package and handle the samples in a manner that reduces vibrations that may dislodge particles from the filters or cause breakage of the rinse containers. Upon arrival at the laboratory, the samples must be stored at approximately 26.7°C (80°F) or less.

9.0 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 using the equations found in Section 12. 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 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.

9.5 How do I minimize contamination of and preserve the samples?

9.5.1 Filter Handling Procedures. Because the filter samples are collected at ambient temperatures [less than 29.4°C (85°F)], you must take precautions to keep the filters from experiencing temperatures higher than the filtration temperatures. Higher temperatures may cause the loss of condensed particulate. Upon removal of the filter from the sampler, insert the

filter into a clean, protective container, and place it in the filter transport container with appropriate cooling.

You must document the custody transfer of the filters on chain of custody forms. Include enough coolant packages or other cooling means in the transport container to maintain filters as cool as practical; less than 26.7°C (80°F) during transport. Transport the filters in the transport container to the laboratory expeditiously.

Transfer the filters to a desiccator maintained at 26.7°C (80°F) or lower for drying until the beginning of the weighing process. Weigh as soon as practical after 24 hours of dessication.

9.5.2 Rinse Samples Handling Procedures. You must document custody transfer of the rinse samples on chain of custody forms. Package the samples in a manner to prevent breakage during transport. Promptly transfer the rinse containers in the transport container to the laboratory.

Upon arrival at the lab, verify that no leakage of samples from the containers has occurred. Keep the samples at 26.7°C (80°F) or lower for storage until the samples are transferred to tared beakers prior to the evaporation of the samples.

10.0 CALIBRATION AND STANDARDIZATION

[NOTE: Maintain a laboratory log of all calibrations.]

10.1 How do I calibrate and use S-type pitots to measure the stack 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:

- (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 stack axis.

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. [Otherwise, you must calibrate the pitot tube on the sampling head because of potential interferences from the cyclone body.]

10.2 What procedures must I follow to calibrate the temperature measurement system (i.e., temperature sensor)? You must use the procedures described in paragraph 10.3 of Method 2 to calibrate the temperature measurement system. Check each temperature sensor at a minimum of three points over the anticipated range of use against an NIST-traceable mercury-in-glass thermometer or a thermocouple simulator. You may also use the EPA EMC Alternate Method 2 Thermocouple Calibration Procedure Alt-011 to calibrate the thermocouples..

10.3 What types of nozzles must I use for sampling? Use electro-polished 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.

10.4 What procedures must I follow to calibrate the sample and dilution venturis? You must calibrate each venturi over the expected range of flow rates to be encountered. For the sample venturi, this will be 0.35 to 0.45 standard cfm or 0.35 to 1.0 actual cfm at stack temperatures; for the dilution venturi, this will be 3.6 to 20 actual cfm. Each venturi should be fabricated so that the typical pressure differentials are in the optimal operating range of the devices used to monitor the pressures. Because of the wide range of expected dilution air supply flow rates, a single dilution venturi is not practical. It is recommended that you have a 1/2-inch and a 5/8-inch venturi calibrated and available for use.

10.4.1 Sample Venturi Calibration. You must calibrate the sample venturi using procedures similar to those in EPA Method 5 for calibrating the meter orifice using a dry gas meter. You must generate a curve of pressure versus flow rate and calculate a power curve equation.

10.4.2 Dilution Venturi Calibration. You must calibrate the sample venturi using procedures similar to those in EPA Method 5 for calibrating the meter orifice but using a Roots meter instead of a dry gas meter. You must generate a curve of pressure versus flow rate and calculate a power curve equation.

10.5 What procedures must I follow to calibrate the relative humidity transmitters? You may use the manufacturers calibration information for the relative humidity (RH) sensors. Because it is the difference between the two RH sensors that is important, it is necessary that the two RH sensors agree when monitoring the same gas stream.

11.0 ANALYTICAL PROCEDURES

11.1 What procedures must I follow to record analytical data? Record all data on the analytical data sheet. You can obtain the data sheet from Figure 5-6 of Method 5.

11.2 What procedure must I follow for the container analysis? Follow the analysis procedures outlined below:

11.2.1 Container Nos. 1, 2, 3, 4, 6, and 7. 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. Measure the liquid in the container either volumetrically to ± 1 ml or gravimetrically to ± 0.5 g. Transfer the contents to a tared aluminum pan, and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours, and weigh to a constant weight. For the purposes of this section, the term "constant weight" means a

difference of no more than 0.05 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. Report the results to the nearest 0.01 mg.

11.2.2 Container No. 5. Leave the contents in the shipping container or transfer the filter and any loose PM from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Desiccate to a constant weight, and report the results to the nearest 0.01 mg. Constant weight is defined the same as above.

12.0 CALCULATIONS AND DATA ANALYSIS

12.1 What do I need to calculate after the run? After the run is completed, you need to perform all of the calculations listed in this section. Also provided are instructions and references for the calculations.

Calculations	Instructions and References
Mixed gas blower pressure, absolute (P_3)	Use Equation 32
Sample venturi gas pressure, absolute (P_1)	Equation 33
Dilution venturi air pressure, absolute (P_2)	Equation 34
Moisture fraction of dilution air, dimensionless (B_{wdil})	Equation 35
Molecular weight of dry stack and sample gas (M_{ds})	Recalculate with Equation 36 using actual dry gas composition data for the run.
Molecular weight of wet stack and sample gas (M_{w1})	Recalculate with Equation 37 using actual moisture data for the run.
Molecular weight of wet dilution air (M_{w2})	Equation 38
Sampling rate at actual conditions (Q_1)	Equation 39
Gas sampling rate at stack conditions through cyclones I (Q_S)	Recalculate Q_S with Equation 40 using actual temperatures and pressures measured during run.

Calculations	Instructions and References
Dilution air flow rate at venturi (Q_2)	Equation 41
Dilution air flow rate at dry standard conditions ($Q_{d(std)}$)	Equation 42
Sample gas flow rate at dry standard conditions ($Q_{s(std)}$)	Equation 43
Dilution ratio (DR)	Equation 44
Gas viscosity (μ)	Recalculate viscosity using Equation 3 using actual stack temperature, moisture, and oxygen content.
Actual particle cut diameter for cyclone I (D_{50})	Calculate this using Equation 45 and using the average temperatures and pressures measured during each test run.
Test condition Reynolds number	Use Equation 9 to calculate the actual Reynolds number during test conditions 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.
Cunningham correction factor (C_r)	Recalculate the Cunningham correction factor using Equation 48 using actual test run data and a D_p of 2.5.
Particle cut diameter for $N_{re} < 3162$ for cyclone IV (D_{50})	Depending on the N_{re} value, use Equation 46 or 47 and the recalculated Cunningham factor (C_r) to recalculate the particle cut diameter.
or	
Particle cut diameter for $N_{re} \geq 3162$ for cyclone IV (D_{50}) of 2.5	
Re-establish cyclone IV D_{50} (D_{50-1})	Use Equations 49 or 50 to recalculate the particle cut diameter. Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynold's number to determine D_{50-1} .

Calculations	Instructions and References
Establish “Z” values. The “Z” value is the result of an analysis that you must perform to determine if the Cunningham correction factor is acceptable.	Use Equation 51 to establish “Z” values. Compare the calculated cyclone IV D_{50} (either Equation 46 or 47) to the re-established cyclone IV D_{50-1} (either Equation 49 or 50) values based upon the test condition calculated Reynolds number. Acceptable “Z” value is determined by Equation 52.
Volume sampled, dry SCF ($V_{s(std)}$)	Use Equation 53.
Percent isokinetic rate (I)	Calculate this with Equation 54.
Acetone blank concentration (C_a)	Calculate this with Equation 55.
Water blank concentration (C_w)	Calculate this with Equation 56.
Acetone blank weight (W_a)	Calculate this with Equation 57.
Water blank weight (W_w)	Calculate this with Equation 58.
Concentration of $PM_{2.5}$ particulate matter ($C_{PM2.5}$)	Calculate this with Equation 59.
Concentration of coarse particulate matter < 10 and $\geq 2.5 \mu m$ ($C_{PM10-2.5}$)	Calculate this with Equation 60.
Concentration of collectible PM_{10} matter (C_{PM10})	Calculate this with Equation 61.

12.1.1.1 Gas Pressure in Sampling Train.

12.1.1.1.1 *Mixed Air RH Sensor Gas Pressure.* Calculate the mixed gas absolute pressure at the RH sensor (P_3) using Equation 32.

12.1.1.1.2 *Sample Venturi Gas Pressure.* Calculate the sample venturi gas absolute pressure (P_1) using Equation 33.

12.1.1.1.3 *Dilution Venturi Air Pressure.* Calculate the dilution venturi air absolute pressure (P_2) using Equation 34.

12.1.1.4 *Moisture Content of Dilution Air.* Calculate the moisture content (B_{wdil}) of the dilution air expressed as a decimal fraction using Equation 35.

12.1.2 Molecular Weight of Stack Gas, Sample Gas, and Dilution Air.

12.1.2.1 *Molecular Weight of Stack and Sample Gas, Dry.* Recalculate the molecular weight of the stack and sample gas (M_{ds}) using Equation 36 (same as Equation 1). Use the actual dry gas composition data determined for the run using Method 3 or other acceptable method.

12.1.2.2 *Molecular Weight of Stack and Sample Gas, Wet.* Recalculate the wet molecular weight of the stack and sample gas (M_{w1}) using Equation 37. Use actual moisture data determined for the run using Method 4 or other acceptable method.

12.1.2.3 *Molecular Weight of Dilution Air, Wet.* Calculate the molecular weight of the dilution air (M_{w2}) using Equation 38.

12.1.3 Gas Flow Rates

12.1.3.1 *Sampling Flow Rate at Actual Conditions.* Calculate the sampling flow rate (Q_1) at actual conditions using Equation 39.

12.1.3.2 *Sampling Flow Rate at Cyclones.* Calculate the sampling flow rate through the Cyclones (Q_s) at actual conditions using Equation 40.

12.1.3.3 *Dilution Air Flow Rate at Ambient Conditions.* Calculate the dilution air flow rate (Q_2) at ambient conditions using Equation 41.

12.1.3.4 *Dilution Air Flow Rate at Dry Standard Conditions.* Calculate the dilution air flow rate ($Q_{d(std)}$) at dry standard conditions using Equation 42.

12.1.3.5 *Sample Gas Flow Rate at Dry Standard Conditions.* Calculate the dilution air flow rate ($Q_{s(\text{std})}$) at dry standard conditions using Equation 43.

12.1.4 Dilution Ratio. Calculate the dilution ratio (DR) using Equation 44.

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

12.1.5.1 *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 μm into Equation 48. This will give you a new Cunningham correction factor that is based on actual data.

12.1.5.2 *Initial D_{50} for Cyclone IV.* Determine the initial estimate for cyclone IV D_{50} using the test condition Reynolds number calculated with Equation 9 as indicated in the listing of calculations in Section 12.1. Refer to the following instructions.

- (a) If the Reynold's number is less than 3162, calculate the D_{50} for cyclone IV with Equation 46, 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 47, using actual test data.
- (c) Insert the "new" D_{50} value calculated by either Equation 46 or 47 into Equation 48 to re-establish the Cunningham Correction Factor (C_r).
[NOTE: Use the test condition calculated Reynolds number to determine the most appropriate equation (Equation 46 or 47).]

12.1.5.3 *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 49 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is less than 3162.
- (b) Use Equation 50 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is equal to or greater than 3162.

12.1.5.4 *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 46 or 47) to the re-established cyclone IV D_{50-1} (either Equation 49 or 50) values based upon the test condition calculated Reynolds number (Equation 51). Follow these procedures:

- (a) Use Equation 51 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 49 or 50, 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 52.

12.1.6 Particulate Concentration. Use the particulate catch weights from the sampling train (including any particulate catch weights from speciation train components) to calculate the concentration of particulate matter in the various size ranges. You must correct the catch weights for the acetone and water blanks.

12.1.6.1 *Blank Concentrations.* Use Equations 55 and 56 to calculate the acetone blank (C_a) and water blank (C_w) concentrations, respectively.

12.1.6.2 *Blank Weights.* Use Equation 57 to calculate the acetone blank weight (W_a) and Equation 58 for the water blank weight (W_w) calculation.

12.1.6.3 *Particulate Weight Catch Per Size Fraction.* Subtract the weight of the appropriate blanks from the particulate weight catch in each size fraction that used acetone and/or water in the recovery. [**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 59 to calculate the concentration of $PM_{2.5}$ particulate ($C_{PM_{2.5}}$) recovered quantitatively from Container Nos. 3, 4, and 5.
- (b) Use Equation 60 to determine the concentration of coarse particulate from the quantitative recovery of $PM_{<10>2.5}$ particulate matter ($C_{PM_{<10>2.5}}$) from Container No. 2.
- (c) Use Equation 61 to calculate the concentration of PM_{10} particulate ($C_{PM_{10}}$) recovered quantitatively from Container Nos. 2, 3, 4, and 5.

12.2 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(s)
- (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

12.3 What nomenclature do I use in this method? You must use the following nomenclature. Variables are listed alphabetically; symbols and numerical constants are last. Excluding the viscosity coefficients ($C_{\#}$), the subscript “s” refers to stack gas; subscript “1” is for

sample venturi; subscript "2" refers to the dilution venturi or dilution air; and subscript "3" denotes mixed or exhaust air stream.

- 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 17, dimensionless.
- B_{wdil} = Moisture content of dilution air, fraction, dimensionless (e.g. ½ % H₂O is $B_{wdil} = 0.005$).
- B_{ws} = Moisture content of stack gas, fraction, dimensionless (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.
- C_a = Acetone blank concentration, mg/mg.
- C_p = Pitot coefficient for the combined cyclone pitot, dimensionless.
- C_p' = Coefficient for the pitot used in the preliminary traverse, dimensionless.
- $C_{PM2.5}$ = Concentration of PM_{2.5} particulate matter, gr/DSCF.
- C_{PM10} = Concentration of PM₁₀ particulate matter, gr/DSCF.
- $C_{PM<10>2.5}$ = Concentration of coarse particulate matter between 10 and 2.5 micrometers, gr/DSCF.
- 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_w = Water blank concentration, mg/mg.
- C_1 = -150.3162 (micropoise), gas viscosity equation coefficient
- C_2 = 18.0614 (micropoise/K^{0.5}), gas viscosity equation coefficient
= 13.4622 (micropoise/R^{0.5})

- C_3 = 1.19183×10^6 (micropoise K^2), gas viscosity equation coefficient
 = 3.86153×10^6 (micropoise R^2)
- C_4 = 0.591123 (micropoise), gas viscosity equation coefficient
- C_5 = 91.9723 (micropoise), gas viscosity equation coefficient
- C_6 = 4.91705×10^{-5} (micropoise/ K^2), gas viscosity equation coefficient
 = 1.51761×10^{-5} (micropoise/ R^2)
- D_n = Inner diameter of sampling nozzle mounted on cyclone I or IV, inches.
- 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_r , micrometers.
- D_{50LL} = Cut diameter for cyclone I corresponding to the 2.25 μm cut diameter for cyclone IV.
- 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.
- DR = Dilution Ratio, dry basis, dimensionless.
- I = Percent isokinetic sampling, dimensionless.
- k_1 = coefficient for sample venturi flow rate equation (Equation 13), dimensionless.
- k_2 = coefficient for dilution venturi flow rate equation (Equation 14), dimensionless.
- K_p = 85.49, [(ft/sec)/(pounds/mole $^\circ R$)].

- m_a = Mass of residue of acetone blank after evaporation, mg.
- m_f = Mass of particulate matter (mg) collected on the filter (Container No. 5), ≤ 2.5 micrometers.
- m_w = Mass of residue of water blank after evaporation, mg.
- m_1 = Mass of particulate matter (mg) recovered from Container No. 1 (acetone blank corrected), >10 micrometers, optional.
- m_2 = Mass of particulate matter (mg) recovered from Container No. 2 (acetone blank corrected), ≤ 10 and >2.5 micrometers, optional.
- m_3 = Mass of particulate matter (mg) recovered from Container No. 3 (DI water blank corrected), ≤ 2.5 micrometers.
- m_4 = Mass of particulate matter (mg) recovered from Container No. 4 (acetone blank corrected), ≤ 2.5 micrometers.
- M_{ds} = Molecular weight of dry stack and sample gas, pounds/pound mole.
- M_w = Molecular weight of wet stack and sample gas, pounds/pound mole.
- M_{w1} = Molecular weight of wet sample gas, pounds/pound mole.
- M_{w2} = Molecular weight of wet dilution air, pounds/pound mole.
- n_1 = Exponent for sample venturi flow rate equation (Equation 13), dimensionless.
- n_2 = Exponent for dilution venturi flow rate equation (Equation 14), dimensionless.
- N = Number of iterative steps or total traverse points.
- N_{re} = Reynolds number, dimensionless.
- P_1 = Absolute sample venturi gas pressure, in. Hg.
- P_2 = Absolute dilution venturi gas pressure, in. Hg.
- P_3 = Absolute mixed gas pressure at RH sensor, in. Hg.

P_b	=	Barometric pressure, in. Hg.
P_g	=	Stack gas static gauge pressure, in H ₂ O.
P_s	=	Absolute stack gas pressure, in. Hg.
$Pump_g$	=	Static pressure (gauge) of exhaust blower, in. Hg.
Q_1	=	Sample gas flow rate at sample venturi, ACFM wet.
Q_2	=	Dilution air flow rate at dilution venturi, ACFM wet.
$Q_{d(std)}$	=	Dilution air flow rate, SCFM dry.
$Q_{dt(std)}$	=	Target dilution air flow rate based on assumed dilution ratio, dry, SCFM (Equation 12).
Q_I	=	Sampling rate for cyclone I to achieve specified D_{50} , ACFM wet.
Q_s	=	Sample flow rate at cyclone I to achieve specified D_{50} , wet, ACFM.
$Q_{s(std)}$	=	Sample flow rate (standard conditions), SCFM dry.
$Q_{st(std)}$	=	Target sample flow rate (standard conditions), SCFM dry.
R_{max}	=	Nozzle/stack velocity ratio parameter, maximum, dimensionless.
R_{min}	=	Nozzle/stack velocity ratio parameter, minimum, dimensionless.
RH_{dil}	=	Relative humidity of dilution air, % full scale.
RH_{mix}	=	Relative humidity of mixed air, % full scale.
t_1	=	Dwell (sampling) time at point 1, minutes.
t_n	=	Dwell (sampling) time at point n, minutes.
t_r	=	Total projected run time, minutes.
t_{run}	=	Total actual run time, minutes.
T_1	=	Absolute sample gas temperature at sample venturi (°R).

- T_2 = Absolute dilution air temperature at dilution blower RH sensor ($^{\circ}\text{R}$).
- T_3 = Absolute temperature of mixed air at mixed air blower RH sensor ($^{\circ}\text{R}$).
- T_s = Absolute stack gas temperature ($^{\circ}\text{R}$).
- v_{max} = Maximum gas velocity calculated from Equations 26 or 27, ft/sec.
- v_{min} = Minimum gas velocity calculated from Equations 24 or 25, 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_{ar} = Volume of acetone used in sample recovery of each fraction, mL.
- $V_{\text{s(std)}}$ = Volume of stack gas sampled, SCF dry.
- V_w = Volume of water blank, mL.
- V_{wr} = Volume of water used in sample recovery of each fraction, mL.
- W_a = Weight of residue in sample contributed by acetone blank, mg.
- W_w = Weight of residue in sample contributed by water blank, mg.
- W.C. = Water column.
- Z = Ratio between estimated cyclone IV D_{50} values, dimensionless.
- $\% \text{CO}_2$ = Carbon dioxide content of gas stream, % by volume.
- $\% \text{O}_2$ = Oxygen content of gas stream, % by volume of dry gas.
- $\% \text{O}_{2,\text{wet}}$ = 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 $\% \text{O}_2$ must be multiplied by the quantity $(1 - B_{\text{WS}})$ to convert to a wet basis. Therefore $\% \text{O}_{2,\text{wet}} = (1 - B_{\text{WS}}) * \% \text{O}_{2,\text{dry}}$]

ΔH_1	=	Sample venturi pressure drop, in. W.C.
ΔH_2	=	Dilution venturi pressure drop, in. W.C.
Δp_1	=	Stack gas velocity pressure measured at point 1 during the run, in. W.C.
$\Delta p'_{avg}$	=	Square of the average square root of the $\Delta p'$ (from the previous velocity traverse), in. W.C.
$\Delta p'_1$	=	Stack gas velocity pressure measured at point 1 during the previous velocity traverse (preliminary traverse), in. W.C.
Δp_m	=	Observed stack gas velocity pressure using S-type pitot tube in preliminary traverse, in. W.C.
Δp_{max}	=	Maximum stack gas velocity pressure, in. W.C.
Δp_{min}	=	Minimum stack gas velocity pressure, in. W.C.
Δp_{mix}	=	Pressure differential across mixed air and dilution air blower, in. W.C.
Δp_n	=	Stack gas velocity pressure at point n during the test run, in. W.C.
Δp_s	=	Stack gas velocity pressure calculated in Equation 16, in. W.C.
Δp_{s1}	=	Stack gas velocity pressure adjusted for combined cyclone pitot tube, in. W.C.
Δp_{s2}	=	Stack gas velocity pressure corrected for blockage, in. W.C.
μ	=	Gas viscosity, micropoise.
μm	=	Micrometers
ρ_a	=	Density of acetone, mg/mL (see label on bottle).
0.99	=	Estimated dry mole fraction of the dilution air; used in calculating target dilution venturi pressure differential.
10.0	=	Constant calculated as 60% of 17 square inch cross-sectional area of combined cyclone head, square inches.

- 13.6 = Conversion constant, inches of water per inch of mercury.
- 18 = Molecular weight of water, pounds per pound mole.
- 29.92 = EPA defined standard pressure, inches of mercury (in.Hg).
- 144 = Conversion constant, square inches per square foot.
- 528 = EPA defined standard absolute temperature, (°R).
- 7000 = Conversion constant, grains per pound.
- 453,592 = Conversion constant, milligrams per pound.

12.4 What equations will I use in this method? You will use the following equations to complete the calculations required in this test method. You will need to perform some calculations prior to the test (e.g., pretest calculations), during the test, and after the test (e.g., post-test).

12.4.1 PreTest Calculations. The following calculations must be performed prior to the test in order to determine appropriate sampling and dilution supply rates for the test.

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

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

[NOTE: Use estimated %CO₂ and %O₂ to calculate initial M_{ds} prior to the test run.]

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

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

[NOTE: For these initial calculations, you must either assume a moisture content (based on prior knowledge of the process); estimate moisture following the procedures outlined in EPA Method 4 in 40 CFR 60, Appendix A; use a wet bulb-dry bulb measurement

device; or use a hand-held hygrometer measurement device for stack gas temperatures less than 160°F.)]

Gas Viscosity. This equation uses 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 expressed in °F.

$$\mu = C_1 + C_2\sqrt{T_s} + C_3T_s^{-2} + C_4(\%O_{2,wet}) - C_5B_{ws} + C_6B_{ws}T_s^2 \quad \text{Equation 3}$$

[**NOTE:** 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 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 expressed 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 3.]

Stack Gas Pressure (absolute).

$$P_s = P_b + \frac{P_g}{13.6} \quad \text{Equation 4}$$

Cunningham Correction Factor. The Cunningham correction factor is calculated for a 2.25 µm diameter particle. Assume that $D_p = 2.25$.

$$C = 1 + 0.0057193 \left[\frac{\mu}{P_s D_p} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Equation 5}$$

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

$$D_{50LL} = 9.507 C^{0.3007} \left[\frac{M_w P_s}{T_s} \right]^{0.1993} \quad (N_{re} < 3162) \quad \text{Equation 6}$$

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

$$D_{50t} = \left(\frac{11 + D_{50LL}}{2} \right) \quad \text{Equation 7}$$

Target Sampling Rate through Cyclone I (at stack conditions, wet basis).

$$Q_s = Q_I = 0.07296(\mu) \left[\frac{T_s}{M_w P_s} \right]^{0.2949} \left[\frac{1}{D_{50t}} \right]^{1.4102} \quad \text{Equation 8}$$

Reynolds Number.

$$N_{re} = 8.64 \times 10^5 \left[\frac{P_s M_w}{T_s} \right] \left[\frac{Q_s}{\mu} \right] \quad \text{Equation 9}$$

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

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

Target Sampling Rate through Cyclones I and IV (at Standard Conditions, Dry Basis).

$$Q_{st(std)} = Q_s \left(\frac{528}{29.92} \right) \left(\frac{P_s}{T_s} \right) (1 - B_{ws}) \quad \text{Equation 11}$$

Target Dilution Air Flow Rate, SCFM Dry.

$$Q_{dt(std)} = Q_{st(std)} (DR - 1) \quad \text{Equation 12}$$

[NOTE: Assume a dilution ratio (DR) of between 10 and 50 in order to cool the stack gas to near ambient temperature.]

Target Sample Venturi Pressure Differential Setting.

$$\Delta H_1 = \left[\frac{29.92 Q_s P_s}{528 k_1 T_s} \left(\frac{M_{w1} T_1}{P_1} \right)^{0.5} \right]^{\frac{1}{n_1}} \quad \text{Equation 13}$$

[NOTE: For Equation 13, M_{w1} is estimated to be equal to M_w which is calculated in Equation 2; T_1 is estimated to be 5 degrees higher than T_s ; and P_1 is estimated to be equal to P_b .]

Target Dilution Venturi Pressure Differential Setting.

$$\Delta H_2 = \left[\frac{29.92}{528} \frac{Q_{dt(std)}}{(0.99) k_2} \left(\frac{M_{W2} T_2}{P_2} \right)^{0.5} \right] \frac{1}{n_2} \quad \text{Equation 14}$$

[NOTE: For this equation, M_{W2} is estimated to be 28.73 (assuming a moisture content (B_{wdil}) of 1%); T_2 should be slightly higher (5 degrees) than ambient temperature (or higher if the dilution air is heated); and P_2 is estimated to be equal to P_b . The 0.99 is used to correct the dilution flow from a dry to wet basis.]

Velocity of Stack Gas. Correct the mean preliminary velocity pressure for C_p and blockage using Equations 16, 17, and 18.

$$v_s = K_p C_p (\sqrt{(\Delta p')})_{avg} \left[\sqrt{\frac{T_s}{P_s M_w}} \right] \quad \text{Equation 15}$$

Adjusted Velocity Pressure.

$$\Delta p_s = \Delta p_m \left[\frac{C_p}{C_p'} \right]^2 \quad \text{Equation 16}$$

Average Probe Blockage Factor.

$$b_f = \frac{10.0}{A} \quad \text{Equation 17}$$

Adjusted Velocity Pressure. Substitute Δp_{s2} for the Δp 's measured during the preliminary traverse.

$$\Delta p_{s2} = \Delta p_{s1} \left[\frac{1}{(1 - b_f)} \right]^2 \quad \text{Equation 18}$$

Calculated Nozzle Diameter for Acceptable Sampling Rate.

$$D_n = \left[\frac{3.056 Q_s}{v_s} \right]^{0.5} \quad \text{Equation 19}$$

Nozzle Area.

$$A_n = \pi \frac{D_n^2}{4} \frac{1}{144} \quad \text{Equation 20}$$

Velocity of Gas in Nozzle.

$$v_n = \frac{\left(\frac{Q_s}{60}\right)}{A_n} \quad \text{Equation 21}$$

Minimum Nozzle/Stack Velocity Ratio Parameter. Equations 22 and 23 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

$$R_{\min} = \left[0.2457 + \left(0.3072 - \frac{0.2603(\mu)(Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Equation 22}$$

Maximum Nozzle/Stack Velocity Ratio Parameter.

$$R_{\max} = \left[0.4457 + \left(0.5690 + \frac{0.2603(\mu)(Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Equation 23}$$

Minimum Gas Velocity for $R_{\min} \leq 0.5$. Equations 24, 25, 26, and 27 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

$$v_{\min} = v_n(0.5) \quad \text{Equation 24}$$

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

$$v_{\min} = v_n R_{\min} \quad \text{Equation 25}$$

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

$$v_{\max} = v_n R_{\max} \quad \text{Equation 26}$$

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

$$v_{\max} = v_n(1.5) \quad \text{Equation 27}$$

Minimum Velocity Pressure.

$$\Delta p_{\min} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\min}}{C_p} \right]^2 \quad \text{Equation 28}$$

Maximum Velocity Pressure.

$$\Delta p_{\max} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\max}}{C_p} \right]^2 \quad \text{Equation 29}$$

Sampling Time at Point 1. Equation 30 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.

$$t_1 = \left(\frac{\Delta p'_1}{\Delta p'_{\text{avg}}} \right)^{0.5} \left(\frac{t_r}{N} \right) \quad \text{Equation 30}$$

12.4.2 Calculations During the Test.

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

$$t_n = t_1 \frac{\sqrt{\Delta p_n}}{\sqrt{\Delta p_1}} \quad n = 2, 3, \dots, N \quad \text{Equation 31}$$

12.4.3 Calculations After the Conclusion of the Test The following calculations must be performed after the test in order to determine if the appropriate PM₁₀ and PM_{2.5} cut sizes were sampled and the method criteria met.

Mixed Gas At RH Sensor Pressure (absolute).

$$P_3 = P_b - \frac{\text{Pump}_g}{13.6} \quad \text{Equation 32}$$

Sample Venturi Gas Pressure (absolute).

$$P_1 = P_3 + \frac{\Delta P_{\text{mix}} + \frac{\Delta H_1}{2.5}}{13.6} \quad \text{Equation 33}$$

NOTE: For equations 33 and 34, Δp_{mix} is the pressure differential measured across the mixed air blower (after the filter holder) and dilution air blower.

Dilution Venturi Air Pressure (absolute).

$$P_2 = P_3 + \frac{\Delta P_{\text{mix}} + \frac{\Delta H_2}{2.5}}{13.6} \quad \text{Equation 34}$$

Dilution Air Moisture Content Fraction.

$$B_{wdil} = \frac{\frac{RH_{dil}}{100} \times 10^{\left(6.6911 - \frac{3144}{T_2 - 69.14}\right)}}{P_2} \quad \text{Equation 35}$$

Molecular Weight of Stack and Sample Gas, Dry. Recalculate M_{ds} using dry gas composition data determined during the run. The equation is the same as Equation 1.

$$M_{ds} = 0.44 (\%CO_2) + 0.32(\%O_2) + 0.28 (100 - \%O_2 - \%CO_2) \quad \text{Equation 36}$$

Molecular Weight of Stack and Sample Gas, Wet. Recalculate M_{w1} using moisture data determined during the run.

$$M_{w1} = M_{ds} (1 - B_{ws}) + 18 (B_{ws}) \quad \text{Equation 37}$$

Molecular Weight of Dilution Air, Wet.

$$M_2 = 28.84 (1 - B_{wdil}) + 18 (B_{wdil}) \quad \text{Equation 38}$$

Sample Flow Rate At Sample Venturi Conditions, ACFM Wet.

$$Q_1 = k_1 \Delta H_1^{(n_1)} \left(\sqrt{\left(\frac{T_1}{M_{w1} P_1} \right)} \right) \quad \text{Equation 39}$$

Sample Flow Rate At Cyclone (Stack) Conditions, ACFM Wet. Q_s is recalculated using actual stack temperatures and pressures measured during the run.

$$Q_s = Q_1 \left(\frac{T_s}{T_1} \right) \left(\frac{P_1}{P_s} \right) \quad \text{Equation 40}$$

Dilution Air Flow Rate At Dilution Venturi Conditions, ACFM Wet.

$$Q_2 = k_2 \Delta H_2^{(n_2)} \left(\sqrt{\left(\frac{T_2}{M_{w2} P_2} \right)} \right) \quad \text{Equation 41}$$

Dilution Air Flow Rate (at dry standard conditions), SCFM Dry.

$$Q_{d(\text{std})} = Q_2 \frac{528}{29.92} \left[\frac{P_2}{T_2} \right] (1 - B_{\text{wdil}}) \quad \text{Equation 42}$$

Sample Flow Rate At Standard Conditions, SCFM Dry. B_{ws} is the stack gas moisture content decimal fraction as measured using another method.

$$Q_{s(\text{std})} = Q_1 \frac{528}{29.92} \left[\frac{P_1}{T_1} \right] (1 - B_{\text{ws}}) \quad \text{Equation 43}$$

Dilution Ratio.

$$\text{DR} = \frac{Q_{s(\text{std})} + Q_{d(\text{std})}}{Q_{s(\text{std})}} \quad \text{Equation 44}$$

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

$$D_{50} = 0.15625 \left[\frac{T_s}{M_w P_s} \right]^{-0.2091} \left[\frac{\mu}{Q_s} \right]^{-0.7091} \quad \text{Equation 45}$$

Particle Cut Diameter for $N_{\text{re}} < 3162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C} \right]^{-0.5} \left[\frac{T_s}{P_s M_w} \right]^{-0.6790} \quad (N_{\text{re}} < 3162) \quad \text{Equation 46}$$

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

Particle Cut Diameter for $N_{\text{re}} \geq 3162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{-0.8058} \left[\frac{1}{C} \right]^{-0.5} \left[\frac{T_s}{P_s M_w} \right]^{-0.3058} \quad (N_{\text{re}} \geq 3162) \quad \text{Equation 47}$$

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 46 or 47 (or Equation 49 or 50 if reiterating).

$$C_r = 1 + 0.0057193 \left[\frac{\mu}{P_s D_{50}} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Equation 48}$$

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

$$D_{50-1} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \cdot \left[\frac{1}{C_r} \right]^{0.5} \cdot \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \cdot (N_{re} < 3162) \quad \text{Equation 49}$$

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

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

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

$$Z = \frac{D_{50-1}}{D_{50}} \quad \text{Equation 51}$$

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

$$0.99 \leq \left[Z = \left(\frac{D_{50N}}{D_{50N+1}} \right) \right] \leq 1.01 \quad \text{Equation 52}$$

Volume Sampled At Standard Conditions, Dry SCF.

$$V_{s(std)} = Q_{s(std)} t_{run} \quad \text{Equation 53}$$

Percent Isokinetic Sampling.

$$I = \left(\frac{100 T_s V_{s(std)} 29.92}{60 v_s t_{run} A_n P_s (1 - B_{ws}) 528} \right) \quad \text{Equation 54}$$

Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a} \quad \text{Equation 55}$$

Water Blank Concentration.

$$C_w = \frac{m_w}{V_w} \quad \text{Equation 56}$$

Acetone Blank Weight To Be Subtracted. For V_{ar} , use the volume of acetone used for each sample fraction recovered and use each W_a only for the appropriate fraction.

$$W_a = C_a V_{ar} \rho_a \quad \text{Equation 57}$$

Water Blank Weight To Be Subtracted. For V_{wr} , use the volume of water used for each sample fraction recovered and use each W_w only for the appropriate fraction.

$$W_w = C_w V_{wr} \quad \text{Equation 58}$$

Concentration of $PM_{2.5}$ Collectable Particulate Matter, gr/DSCF. All of the masses (m) in the following equations are to be corrected as appropriate for the acetone and/or water blank contributions.

$$C_{PM2.5} = \left(\frac{7000}{453,592} \right) \left(\frac{m_3 + m_4 + m_f}{V_{s(std)}} \right) \quad \text{Equation 59}$$

Concentration of Coarse $PM_{<10>2.5}$ Collectable Particulate Matter, gr/DSCF.

$$C_{PM<10>2.5} = \left(\frac{7000}{453,592} \right) \left(\frac{m_2}{V_{s(std)}} \right) \quad \text{Equation 60}$$

Concentration of PM_{10} Collectable Particulate Matter, gr/DSCF.

$$C_{PM10} = \left(\frac{7000}{453,592} \right) \left(\frac{m_2 + m_3 + m_4 + m_f}{V_{s(std)}} \right) \quad \text{Equation 61}$$

13.0 METHOD PERFORMANCE [Reserved]**14.0 POLLUTION PREVENTION** [Reserved]

15.0 WASTE MANAGEMENT [Reserved]**16.0 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.

Hawks, Bruce, "Water Saturation Vapor Pressure Calculation," Stack Sampling Newsletter; July, 1979.

Mobley, D.J., "Additional Guidance on PM_{2.5} Cassette Handling and Transportation," U.S. Environmental Protection Agency; Emissions, Monitoring & Analysis Division; January 19, 2000.

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.

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.

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 μm	40% of total collectable particulate matter
≤ 2.5 μm	20% of total collectable particulate matter

Table 2. Required Cyclone Cut Diameters (D_{50})

Cyclone	Min. Cut Diameter, μm	Max. Cut Diameter, μm
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_1 Values Based on Preliminary Traverse Data

Stack Temperature, ($^{\circ}\text{R}$)	$T_s - 50^{\circ}$	T_s	$T_s + 50^{\circ}$
ΔH_1 (inches W.C.)	-	-	-

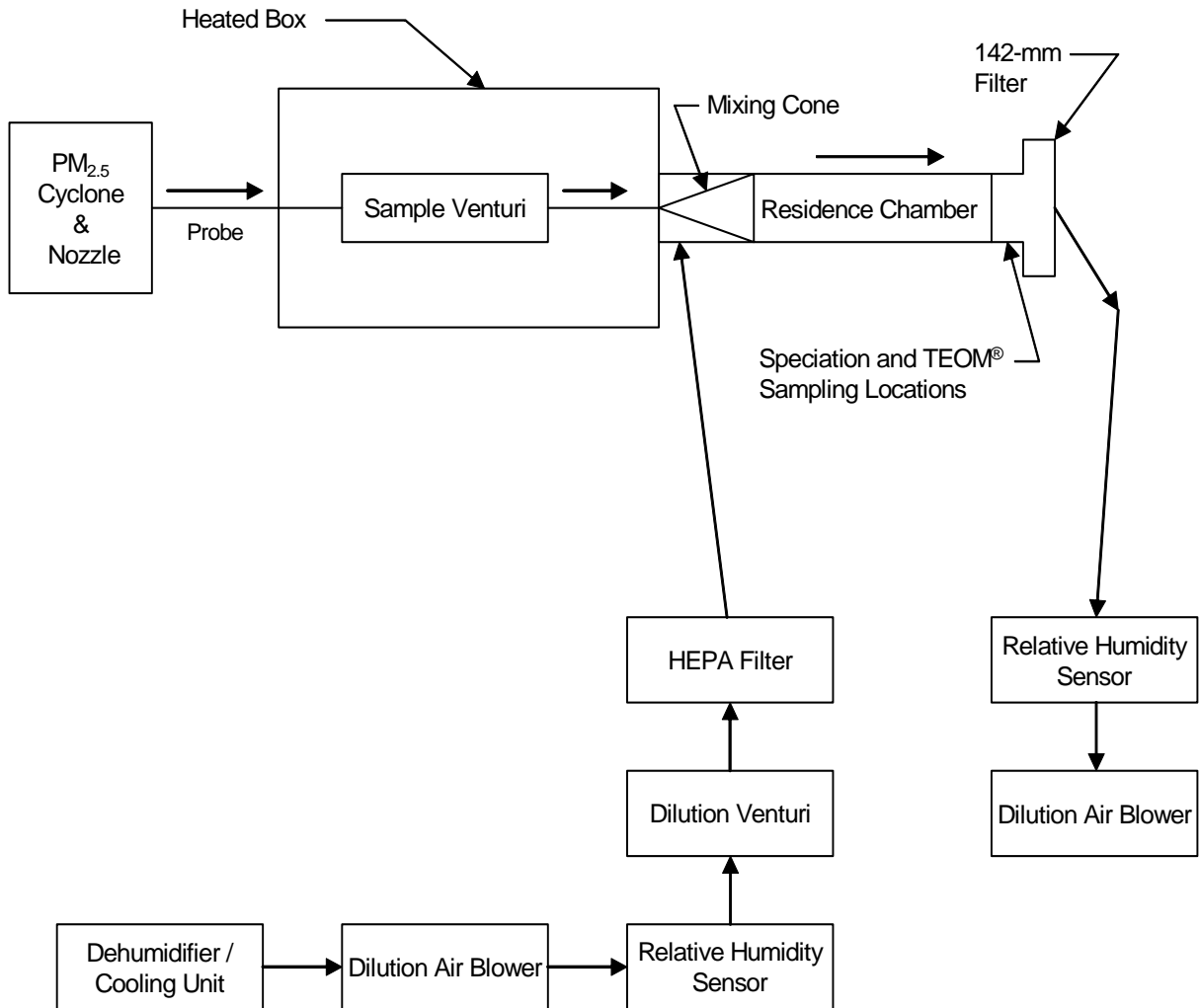


Figure 1. FPM-DST Schematic

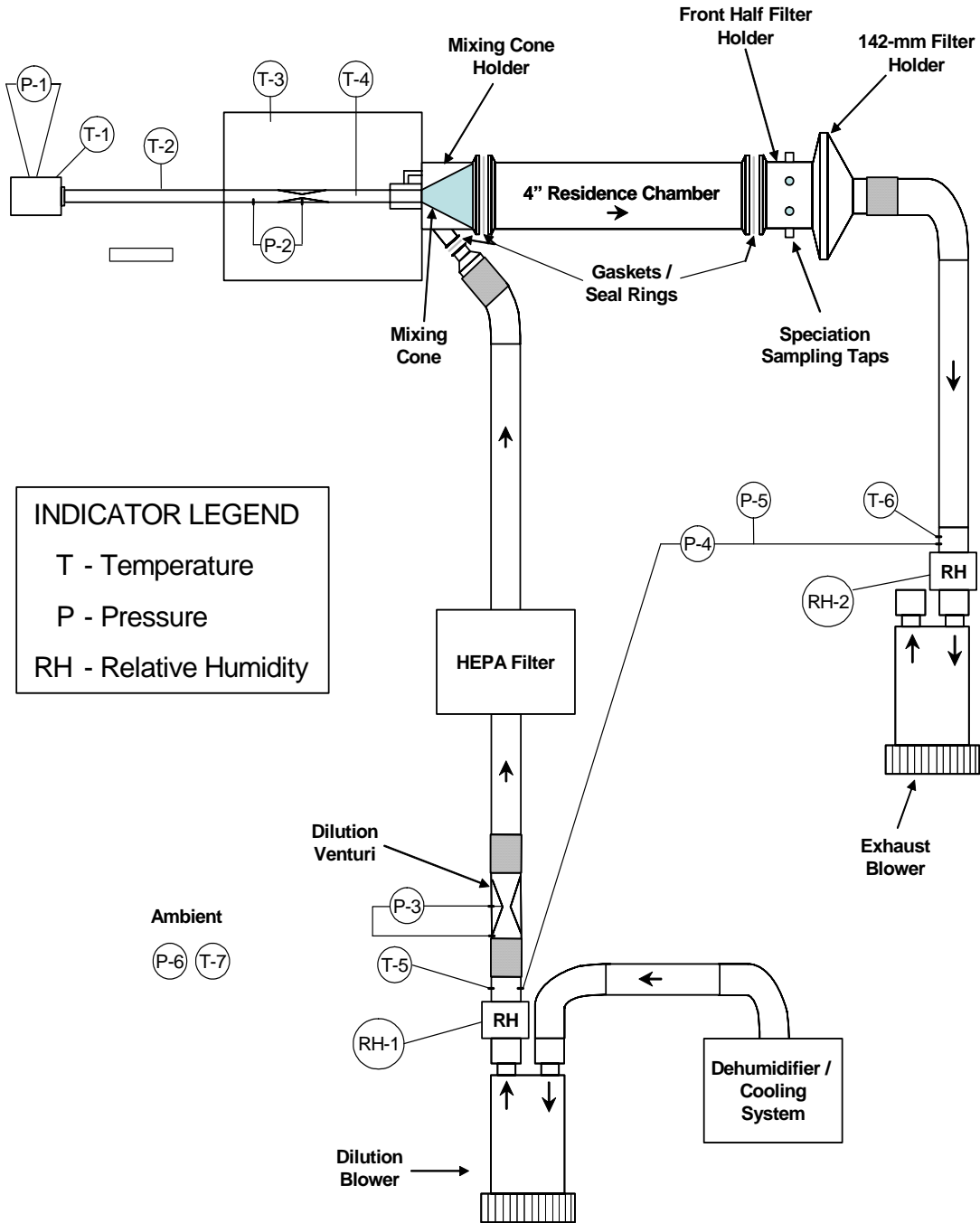
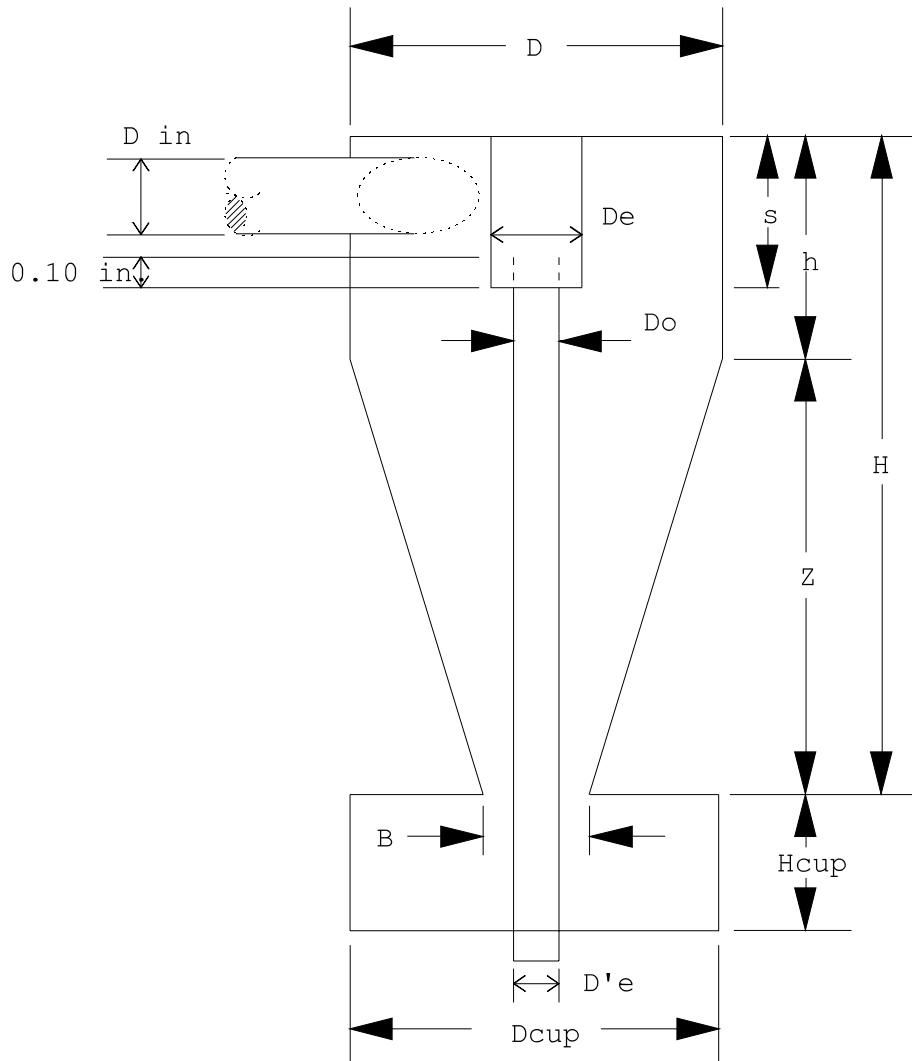


Figure 2. FPM-DST Pressure and Sensor Lines Layout.

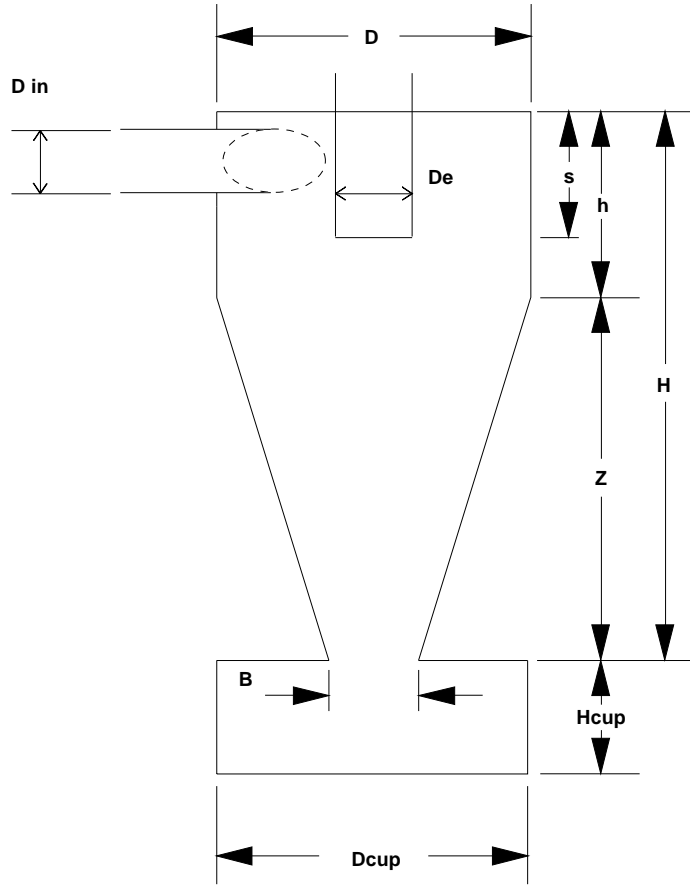
Table 4. Dilution Sampler Instrument List

Instrument Code (Figure 2)	Description	Suggested Range	Corresponding Equation Variables
T-1	Stack Gas Temperature	0-300°C	T_s
T-2	Stack Probe Temperature	0-300°C	---
T-3	Sample Venturi Enclosure Temperature	0-300°C	---
T-4	Sample Venturi Temp	0-300°C	T_{sv}
T-5	Dilution Air Temp	0-50°C	T_{dil}
T-6	Mixed Air Temperature	0-50°C	T_{mix}
T-7	Ambient Temperature	0-50°C	---
P-1	Stack Pressure	0-50 inches water Δp_m	P_g
P-2	Sample Venturi	0-5 inches water Δp	ΔH_1
P-3	Dilution Venturi Pressure Differential	0-5 inches water Δp	ΔH_2
P-4	Dilution Air/Mixed Air Pressure Differential	0-30 inches water Δp	Δp_{mix}
P-5	Pump Pressure	0-30 inches water Δp	P_{pump_g}
P-6	Atmospheric Pressure		P_{bar}
RH-1	Relative Humidity of Dilution Air	0-100 %	RH_1
RH-2	Relative Humidity of Mixed Air	0-100 %	RH_2



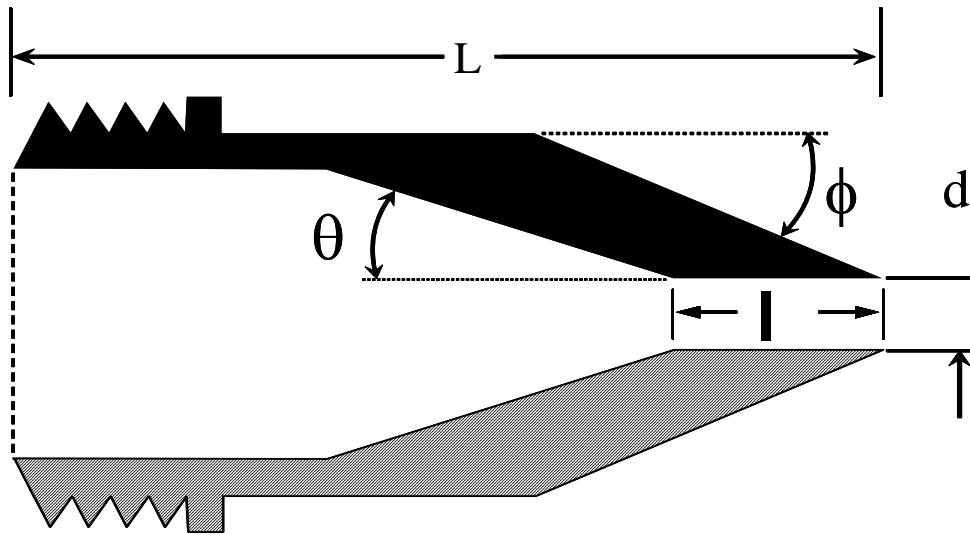
Cyclone I (10 Micrometer)	Cyclone Interior Dimensions (cm \pm 0.02 cm)											
	Din	D	De	B	H	h	Z	S	Hcup	Dcup	De'	Do
	1.27	4.47	1.50	1.88	6.95	2.24	4.71	1.57	2.25	4.45	1.02	1.24

Figure 3. Design specifications for Cyclone I (10 Micrometer)



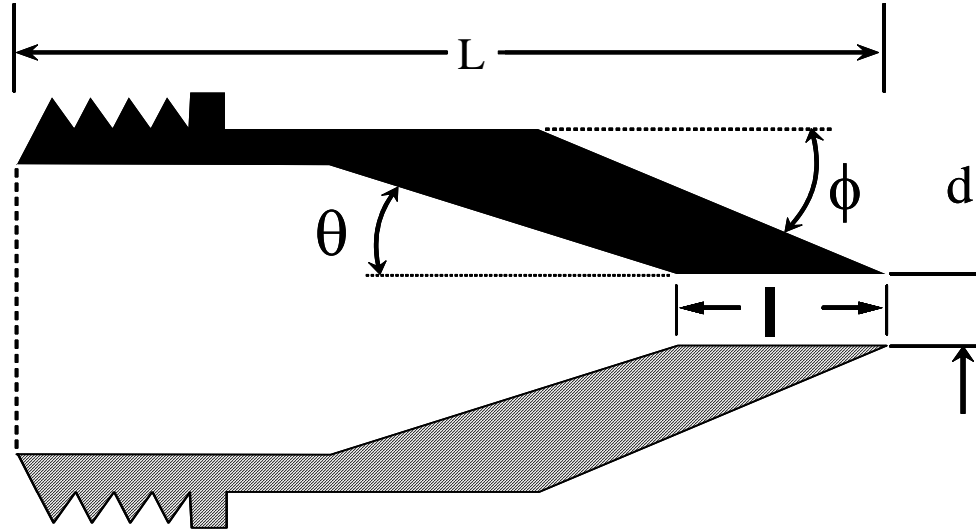
Cyclone	Cyclone Interior Dimensions (cm ± 0.02 cm)									
	Din	D	De	B	H	h	Z	S	Hcup	Dcup
IV (2.5 Micrometer)	0.51	2.54	0.59	1.09	2.68	1.03	1.65	0.58	2.22	2.62

Figure 4. Design Specifications for Cyclone IV (2.5 Micrometer) Sizing Device



Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, l (inches)	Total Length, L (inches)
For PM ₁₀ Sizer				
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 5. PM₁₀ Sizer Nozzle Design Specifications



Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, l (inches)	Total Length, L (inches)
For PM _{2.5} Sizer				
0.125	3	15	<0.05	1.450±0.05
0.138	2	15	<0.05	1.450±0.05
0.156	1	15	<0.05	1.450±0.05
0.172	1	15	<0.05	1.450±0.05
0.188	1	15	<0.05	1.450±0.05
0.200	0	15	<0.05	1.450±0.05

Figure 6. PM_{2.5} Sizer Nozzle Design Specifications

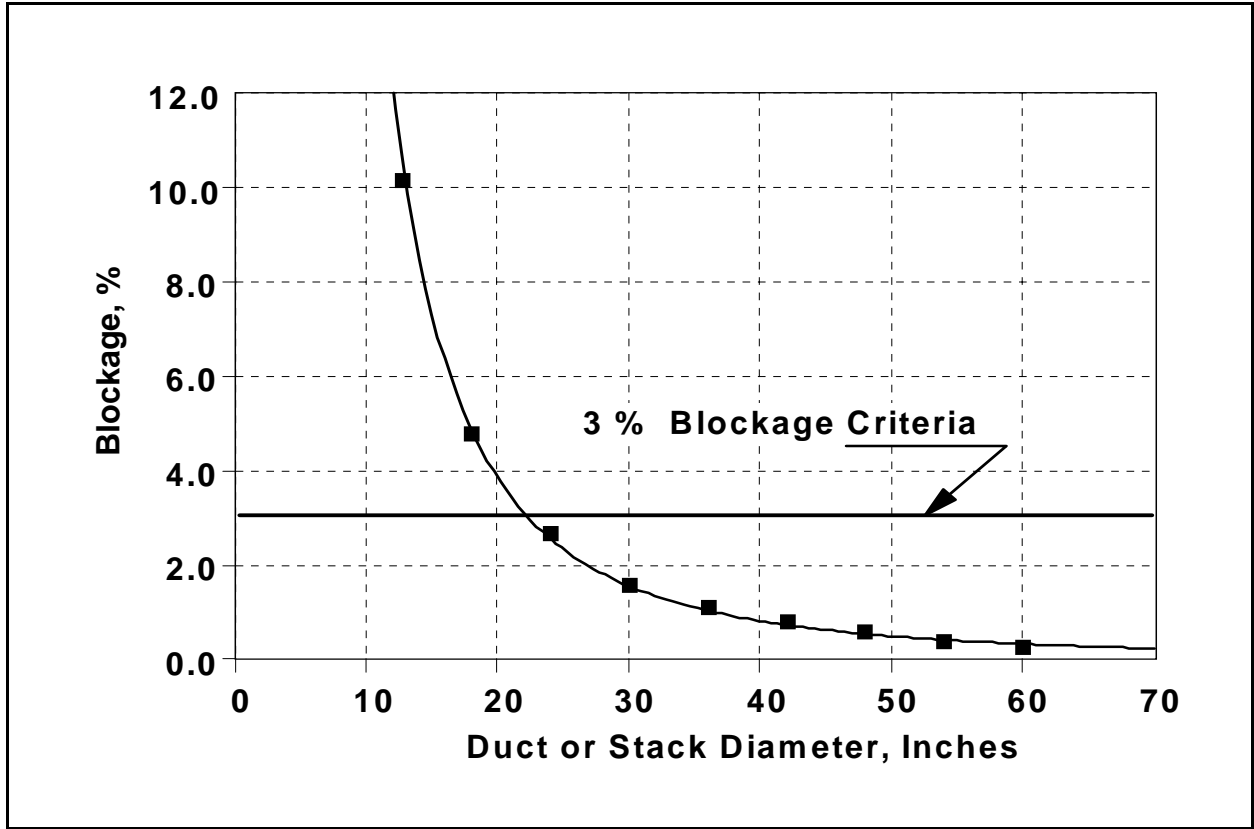


Figure 7. Gas Flow Blockage by the Combined Cyclone Sampling Head

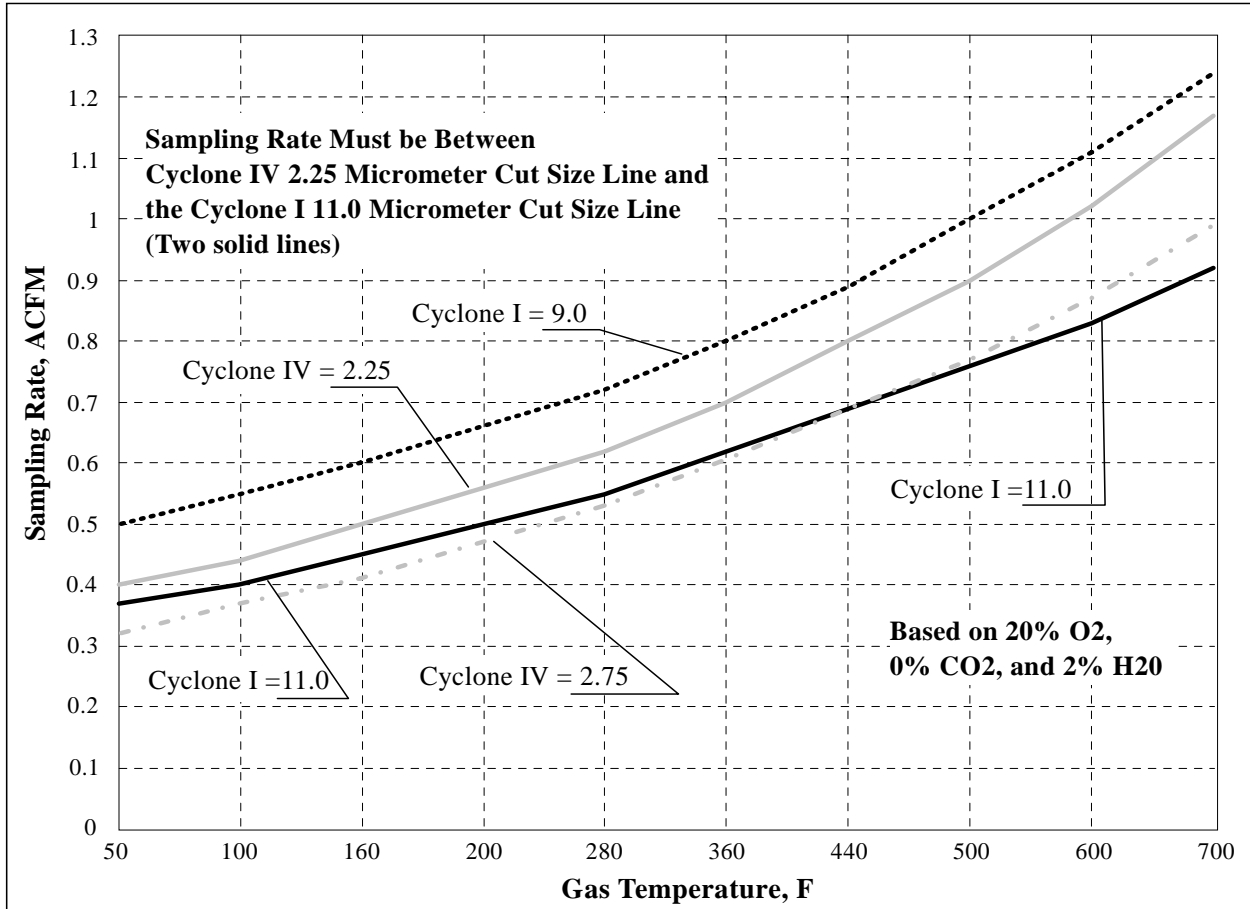


Figure 8. Acceptable Sampling Rate for Combined Cyclone Heads