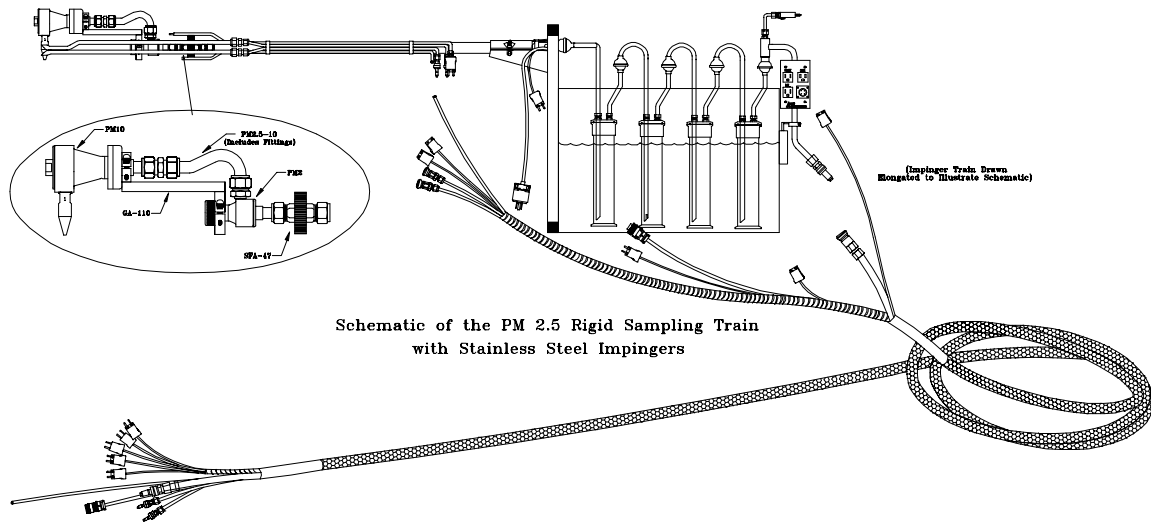


# OM

## PM2.5/10

### APEX INSTRUMENTS, INC.

### Method for Determination of PM10 / PM2.5 Emissions (Constant Sampling Rate Procedure)



# Operator's Manual



METHOD FOR DETERMINATION OF PM10 / PM2.5 EMISSIONS

# Operator's Manual

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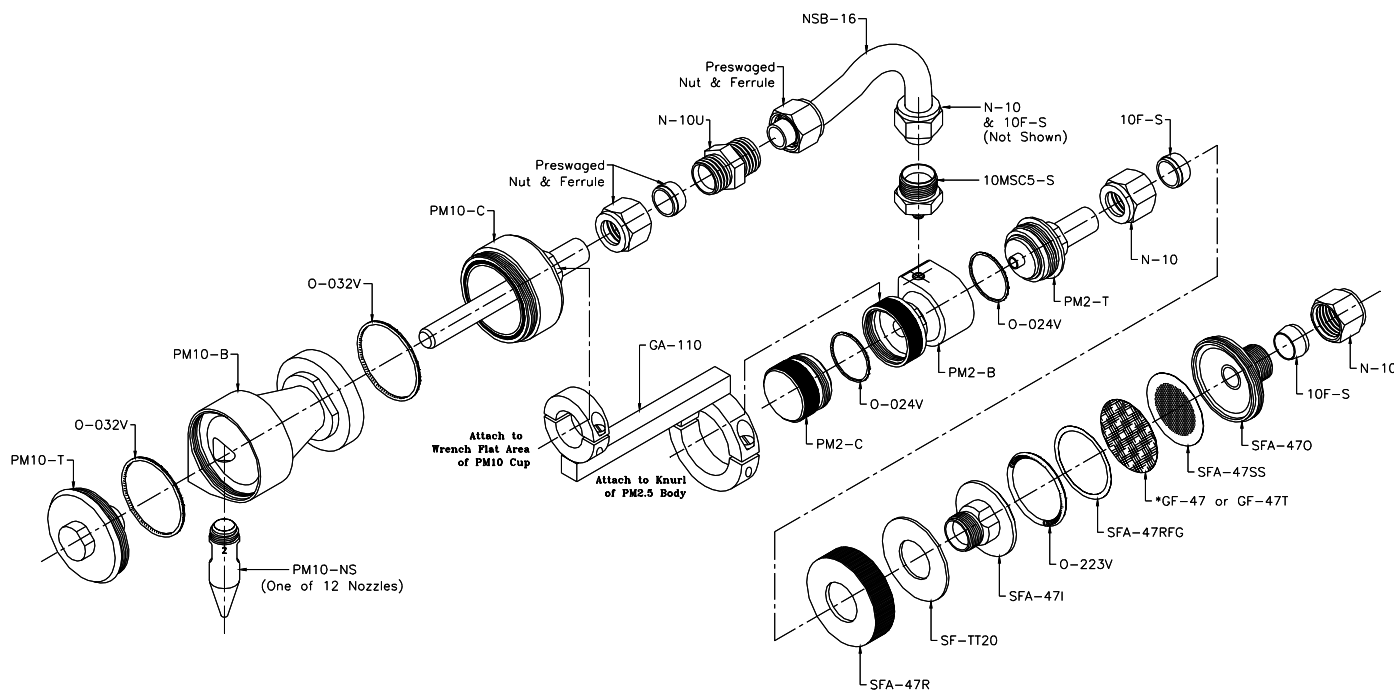




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## Simultaneous PM10 and PM2.5 Cyclone Kit #PM2.5-10K Packing List

<b>PM2.5-10K includes:</b>			
<b>Part #</b>	<b>Description</b>	<b>Quantity</b>	<b>Qty Shipped</b>
PM10 <i>Includes:</i>	PM10 Cyclone Body Only, SS, Method 201A	1	
	<b>PM10-B</b> Cyclone Body	1	
	<b>PM10-C</b> Collection Cup	1	
	<b>PM10-T</b> Cap	1	
	<b>O-032V</b> Viton O-ring for PM10 Cyclone	6	
PM10-NS <i>Includes:</i>	Nozzles, Set of 12 for PM10 Cyclone	1	
	<b>PM10-N0</b> Nozzle, PM10, SS, .125 Size 0	1	
	<b>PM10-N1</b> Nozzle, PM10, SS, .136 Size 1	1	
	<b>PM10-N2</b> Nozzle, PM10, SS, .150 Size 2	1	
	<b>PM10-N3</b> Nozzle, PM10, SS, .164 Size 3	1	
	<b>PM10-N4</b> Nozzle, PM10, SS, .180 Size 4	1	
	<b>PM10-N5</b> Nozzle, PM10, SS, .197 Size 5	1	
	<b>PM10-N6</b> Nozzle, PM10, SS, .215 Size 6	1	
	<b>PM10-N7</b> Nozzle, PM10, SS, .233 Size 7	1	
	<b>PM10-N8</b> Nozzle, PM10, SS, .264 Size 8	1	
	<b>PM10-N9</b> Nozzle, PM10, SS, .300 Size 9	1	
	<b>PM10-N10</b> Nozzle, PM10, SS, .342 Size 10	1	
	<b>PM10-N11</b> Nozzle, PM10, SS, .390 Size 11	1	
PM2 <i>Includes:</i>	PM2.5 Cyclone Body Only, SS	1	
	<b>PM2-B</b> Cyclone Body	1	
	<b>PM2-C</b> Collection Cup	1	
	<b>PM2-T</b> Top, Outlet for the PM2.5	1	
	<b>O-024V</b> O-ring, Viton, PM2.5	6	
N-10U	Union, 5/8 TU, SS	1	
NSB-16	Button Hook Adapter	1	
10MSC5-S	PM10-2.5 Connector	1	
GA-110	Adapter, Strain Relief for PM10 and PM2.5 Cyclones	1	
MPT-6-421	Extended Pitot Tip, PM2.5-10, SS	1	
SFA-47	Filter Assembly, 47mm, 5/8 TU, SS w/Viton O-rings	<b>1 (see Doc# Pack-SFA-47)</b>	
PM10-2 Case	Case, PM10-2.5 Kit, w/foam inserts	1	



**Exploded View of the PM10 and PM2.5 Combination**

<b>Options, Replacement Parts and Accessories</b>	
<b>Part #</b>	<b>Description</b>
MPT-6-421	Extended Pitot Tip for PM10-2.5 Combination, w/fittings
O-032V	O-ring, PM10, Viton (260 °C/500 °F)
O-032H	O-ring, PM10, Stainless Steel (650 °C/1200 °F)
O-223V	O-ring, SFA-47, Viton (260 °C/500 °F)
O-223H	O-ring, SFA-47, Stainless Steel (650 °C/1200 °F)
O-024V	O-ring, SFA-47, Viton
O-024H	O-ring, SFA-47, Stainless Steel
SF-TT20	Ring, Thrust, SFA-47, Teflon
SFA-47SS	Screen, Filter Support, 47mm, SS
SFA-47RFG	Filter Ring Guard, SS
GF-47	Filters, Glass Fiber, 47 mm
GF-47T	Filters, Teflon/Glass Fiber, 47 mm

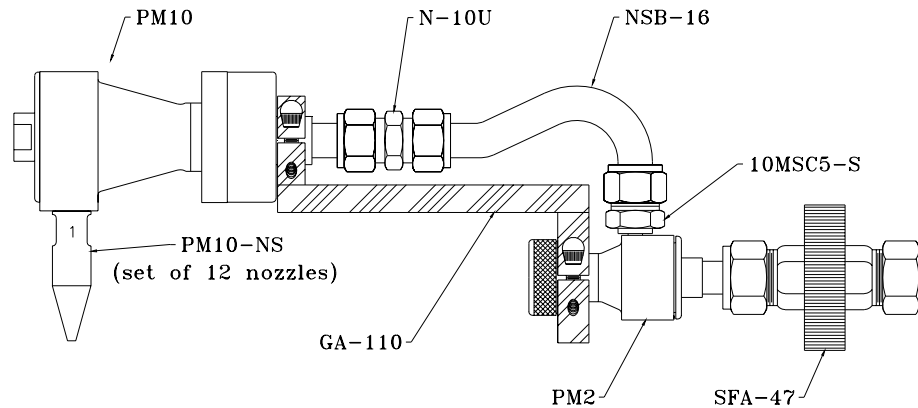
**Software**

Although it is possible to do the setup and data analysis calculations for the PM10 and PM2.5 by hand or with calculators, the number of calculations which must be done to treat the data from just one run make hand calculations impractical. Apex Instruments offers the PM-2.5-10C Particle Sizing Software which provides full support for the PM10 and PM2.5 sampling and analysis.

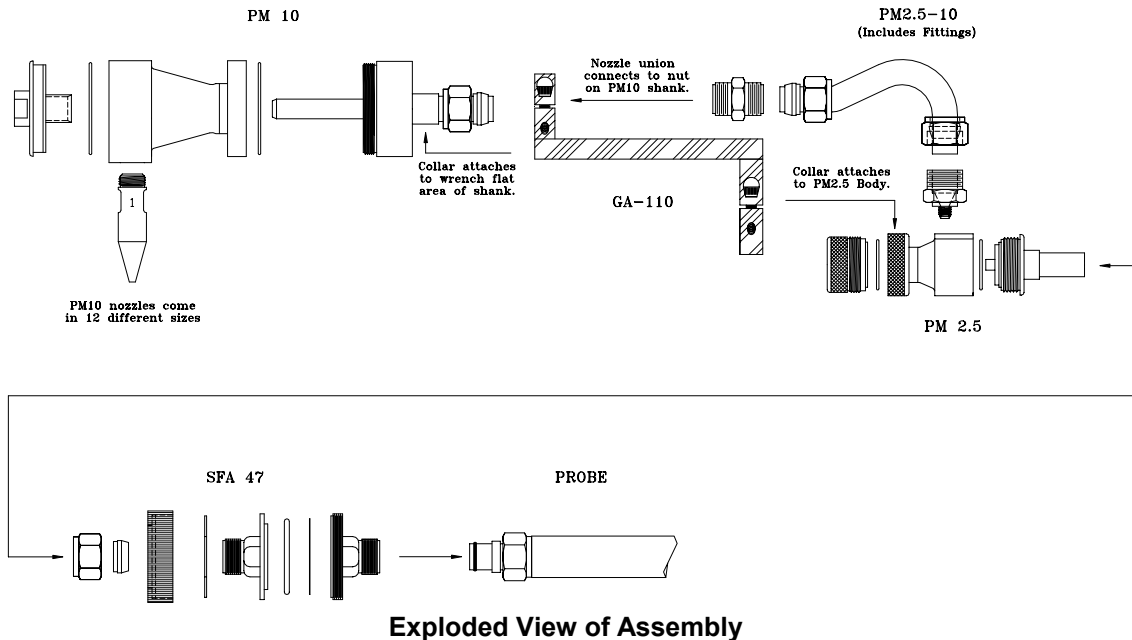
PM-2.5-10C	Particle Sizing Software for PM10 & PM2.5 Cyclones
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## Simultaneous PM10 and PM2.5 Cyclone Sampling Kit

The Apex Instruments' PM10 and PM2.5 configuration is attached to the standard Method 5 probe and must be used in conjunction with the extended pitot tip which is sold separately. This method applies to the in-stack measurement of particulate matter equal to or less than an aerodynamic diameter of nominally 10 (PM10) and 2.5 (PM2.5) micrometer from stationary sources. The EPA recognizes that condensable emissions not collected by an in-stack method are also PM10, and that emissions that contribute to ambient PM10 levels are the sum of condensable emissions and emissions measured by an in-stack PM10 method, such as Method 201A.



The PM10 serves as the sampling head followed by the PM2.5 that are attached using the PM2.5-10 gooseneck nozzle. The combined cyclones are then mounted on a 47mm Stainless Steel Filter that is then attached to the end of the Standard Method 5 probe.







METHOD FOR THE DETERMINATION OF PM<sub>10</sub> AND PM<sub>2.5</sub> EMISSIONS

(CONSTANT SAMPLING RATE PROCEDURES)

**1. SCOPE AND APPLICABILITY**

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

1.1 Who must use this method?

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

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

1.2 What can I measure with this method?

Use this method to measure PM<sub>10</sub> and PM<sub>2.5</sub> using an in-stack measurement device.

### 1.3 Can I use this method to measure condensible emissions?

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

### 1.4 What am I responsible for?

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

### 1.5 How can I ensure reliable results?

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

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

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

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

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

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

You can't use this method to measure emissions following a wet scrubber because this method is not applicable for in-stack gases containing water droplets. Stacks with entrained moisture droplets may have water droplets larger than the cut sizes for the cyclones and these water droplets normally contain particles that are PM<sub>10</sub> and PM<sub>2.5</sub>. To measure PM<sub>10</sub> and PM<sub>2.5</sub> in emissions where water droplets are known to exist, we recommend that you use Method 5 of Appendix A to 40 CFR part 60 (or a comparable method) and consider the particulate catch to be PM<sub>10</sub> and PM<sub>2.5</sub> emissions.

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

Technically, you can use this method to obtain both particle sizing and total filterable particulate if the isokinetics are within 90-110 percent, the number of sampling points are the same as Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60 requirements, and the filter temperature is within the acceptable range. However, to satisfy Method 5 criteria, you may need to remove the in-stack filter and use an out-of-stack filter and recover the probe between the PM<sub>2.5</sub> particle sizer and the filter. Additionally, to satisfy Method 5 and Method 17 criteria, you may need to sample from more than 12 traverse points. The increased number of sampling points may require the use of multiple nozzles to maintain isokinetics between 90 and 110 percent and to maintain the minimum/maximum nozzle/stack velocity ratios within acceptable ranges. Be aware that this method determines in-stack PM<sub>10</sub> and PM<sub>2.5</sub> emissions by sampling from a recommended maximum of 12 sample points, at a constant flow rate through the train (the constant flow is necessary to maintain the size cuts of the cyclones), and with a filter that is at the stack temperature. A Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60 train is operated isokinetically (with varying flow rates through the train), samples from as many as 24 sample points, and for Method 5 of Appendix A to 40 CFR part 60 an out-of-stack filter is maintained at a constant temperature of 248°F. Further, to use this method in place of Method 17 of Appendix A to 40 CFR part 60 or Method 5 of Appendix A to 40 CFR part 60, you must extend the sampling time so that the minimum mass that you can weigh is collected on each of the portions of this sampling train. Also, if you are using this method as an alternative to a required

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

## 2. SUMMARY OF METHOD

To measure  $PM_{10}$  and  $PM_{2.5}$ , extract a sample of gas at a predetermined constant flowrate through an in-stack sizing device. The sizing device separates particles with nominal aerodynamic diameters of  $PM_{10}$  and  $PM_{2.5}$ . To minimize variations in the isokinetic sampling conditions, you must establish well-defined limits. Once a sample is obtained, remove uncombined water from the particulate. Then use gravimetric analysis to determine the particulate mass for each size fraction. Figure 1 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents the schematic of this process.

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

## 3. DEFINITIONS

[Reserved]

## 4. INTERFERENCES/LIMITATIONS

[Reserved]

## 5. SAFETY

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

## 6. EQUIPMENT AND SUPPLIES

### 6.1 What equipment do I need for the sampling train?

Figure 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents a sampling train schematic for use in this test method. This sampling train is the same sampling train described in Method 17 of Appendix A to 40 CFR part 60 with the exception of the PM<sub>10</sub> and PM<sub>2.5</sub> sizing devices and in-stack filter. The following paragraphs describe the sampling train's primary design features in detail.

6.1.1 Nozzle. You must use nozzles that are stainless steel (316 or equivalent) or Teflon<sup>®</sup>-coated stainless steel with a sharp tapered leading edge. We recommend that you choose one of the 12 nozzles listed in Figure 3 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method because they meet design specifications. However, if you don't choose a nozzle from this list, then you must choose a nozzle that meets the criteria in paragraph 5.2 of EPA Method 201A of Appendix M to 40 CFR part 51. We also recommend that you have a large number of nozzles in small diameter increments available to increase the likelihood of using a single nozzle for the entire traverse.

6.1.2 PM<sub>10</sub> and PM<sub>2.5</sub> sizer. Choose a stainless steel (316 or equivalent) PM<sub>10</sub> and PM<sub>2.5</sub> sizer. The sizing devices must be cyclones which meet the design specifications shown in Figures 3 and 4 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. Use a caliper to verify the dimensions of the PM<sub>10</sub> and PM<sub>2.5</sub> sizers to within  $\pm 0.02$  cm of the design specifications. Example suppliers of PM<sub>10</sub> and PM<sub>2.5</sub> sizers are:

(a) Environmental Supply Company, Inc.

2142 Geer Street

Durham, North Carolina 27704

(919) 956-9688

(919) 682-0333 (Fax)

(b) Apex Instruments

P.O. Box 727

125 Quantum Street

Holly Springs, North Carolina 27540

(919) 557-7300

(919) 557-7110 (Fax)

(c) Andersen Instruments Inc.

500 Technology Court

Smyrna, Georgia 30082

(770) 319-9999

(770) 319-0336 (Fax)

- 6.1.3 Filter holder. You must use a filter holder that is either stainless steel (316 or equivalent) or Teflon®-coated stainless steel. Commercial size filter holders are available depending upon project requirements. You should be able to find a commercial filter holder to support 25-mm, 47-mm, and 63-mm diameter filters. Commercial size filter holders contain a Teflon® O-ring, stainless steel screen which supports the filter, and a final Teflon® O-ring. Screw the assembly together and attach to the outlet of cyclone IV.
- 6.1.4 Pitot tube. You must use a pitot tube made of heat resistant tubing. Attach the pitot tube to the probe with stainless steel fittings. Follow the specifications for the pitot tube and its orientation to the inlet nozzle given in paragraph 6.1.1.3 of Method 5 of Appendix A to 40 CFR part 60.
- 6.1.5 Probe liner. You do not have to use a probe liner. However, if you choose to do so, follow the specifications in paragraph 6.1.1.2 of Method 5 of Appendix A to 40 CFR part 60.
- 6.1.6 Differential pressure gauge, condensers, metering systems, barometer, and gas density determination equipment. Follow the requirements in paragraphs 6.1.1.4 through 6.1.3 of Method 5 of Appendix A to 40 CFR part 60, as applicable.

## 6.2 What equipment do I need for sample recovery?

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

- (a) Filter holder brushes



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

## 7. REAGENTS AND STANDARDS

### 7.1 What reagents do I need for sample collection?

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

- 7.1.1 Filter. You must use a glass fiber, quartz, or Teflon<sup>®</sup> filter that does not have an organic binder. The filter must also have an efficiency of at least 99.95 percent (<0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. Conduct the filter efficiency test in accordance with ASTM Method D 2986-71, 78, 95a (incorporated by reference). Alternatively, you may use test data from the supplier's quality control program. If the source you are sampling has SO<sub>2</sub> or SO<sub>3</sub> emissions, you must use a filter that will not react to SO<sub>2</sub> or SO<sub>3</sub>. Depending on your application and project data quality objectives (DQOs), filters are commercially available in 25-mm, 47-mm, and 63-mm sizes.

- 7.1.2 Silica gel. You must choose an indicating-type silica gel of 6 to 16 mesh. We must approve other types of desiccants (equivalent or better) before you use them. Allow the silica gel to dry for 2 hours at 175°C (350°F) if it is being reused. You do not have to dry new silica gel.
- 7.1.3 Water (optional). Use deionized distilled water (to conform to ASTM D 1193-77, 91 Type 3) to recover material caught in the impinger, if required. If you use water to recover this material, then you must run blanks before you begin your testing. Running blanks before field use will verify low blank concentrations thereby reducing the potential for a high field blank on test samples.
- 7.1.4 Crushed ice. Obtain this from the best readily available source.
- 7.1.5 Stopcock grease (optional). The stopcock grease must be a heat-stable silicone grease that is acetone-insoluble. This is not necessary if you are using screw-on connectors with Teflon<sup>®</sup> sleeves, or similar. We must approve other types of stopcock grease before you use them.

## 7.2 What reagents do I need for sample recovery?

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

### 7.3 What reagents do I need for sample analysis?

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

7.3.1 Acetone. Refer to paragraph 2.0 of this section.

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

## **8. SAMPLE COLLECTION, PRESERVATION, STORAGE, AND TRANSPORT**

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

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

### 8.2 What preparations must I do prior to the test?

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

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

You must perform the following items to properly set up for this test:

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

- 8.3.1 Sampling site location and traverse point determination. Follow the standard procedures in Method 1 of Appendix A to 40 CFR part 60 to select the appropriate sampling site. Then do all of the following:
- (a) *Sampling site.* Choose a location that maximizes the distance from upstream and downstream flow disturbances.
  - (b) *Traverse points.* Select the same number of traverse points described in paragraph 4.1.2 of Method 201A of Appendix M to 40 CFR part 51 and shown in Figure 5 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. The recommended maximum number of traverse points at any location is 12. Prevent the disturbance and capture of any solids accumulated on the inner wall surfaces by maintaining a 1 inch distance from the stack wall ( $\frac{1}{2}$  inch for sampling locations less than 24 inches in diameter).
  - (c) *Round or rectangular duct or stack.* If a duct or stack is round with two ports located  $90^\circ$  apart, use six sampling points on each diameter. Use a 3x4 sampling point layout for rectangular ducts or stacks. Consult with the administrator to receive approval for other layouts before you use them.
  - (d) *Sampling ports.* You will need new sampling ports in most of the sampling port locations installed for sampling by Method 5 of Appendix A to 40 CFR part 60 or Method 17 of Appendix A to 40 CFR part 60 for total filterable particulate sampling. When you must use nozzles smaller

than 0.16 inch in diameter, the sampling port diameter must be 6 inches.

Do not use the conventional four inch diameter port because it will not support the length of the nozzle extending from the PM<sub>10</sub> cyclone. [**Note:** If the port nipple is short, you may be able to “hook” the sampling head through a smaller port into the duct or stack.]

8.3.2 Probe/cyclone blockage calculations. Following the procedures in the next two paragraphs, as appropriate.

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

8.3.2.2 *Ducts with diameters between 24 and 18 inches.* Ducts with diameters between 24 inches to 18 inches have blockage effects ranging from 3 percent to 6 percent, as illustrated in Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. Therefore, when you conduct tests on these small ducts, you must adjust the observed velocity pressures for the estimated blockage factor whenever the combined sampling apparatus blocks more than 3 percent of the stack or duct (see paragraphs 7.2.2 and 7.2.3 of this section on the probe blockage factor and the final adjusted velocity pressure, respectively).

- 8.3.3 Cyclonic flow. Do not use the combined cyclone sampling head at sampling locations subject to cyclonic flow. Also, you must follow Method 2 procedures to determine the presence or absence of cyclonic flow. Then perform the following calculations. [**Note:** You can minimize cyclonic flow conditions by placing gas flow straighteners upstream of the sampling location.]
- (a) *Find the angle that has a null velocity pressure.* Insert the S-type pitot tube at each of the traverse points and rotate until you locate the angle that has a null velocity pressure.
  - (b) *Determining a sampling location.* Average the absolute values of the angles that have a null velocity pressure. Do not use the sampling location if the average absolute value exceeds 20°.
- 8.3.4 Preliminary velocity profile. Conduct a preliminary Method 2 of Appendix A to 40 CFR part 60 velocity traverse, as well as the measurements below. The purpose of the velocity profile is to determine all of the following:
- (a) The gas sampling rate for the combined probe/cyclone sampling head.
  - (b) The appropriate nozzle(s) to maintain the required velocity pressure range and isokinetic range.
  - (c) The necessary sampling duration to obtain sufficient particulate catch weights.
- 8.3.4.1 *Preliminary traverse.* You must use an S-type pitot tube with a conventional thermocouple to conduct the traverse. Conduct the preliminary traverse as close as possible to the anticipated testing time on

sources that are subject to hour-by-hour gas flow rate variations of approximately  $\pm 20\%$  and/or gas temperature variations of approximately  $\pm 50^\circ\text{F}$ . Follow the following instructions. [**Note:** You should be aware that these variations can cause errors in the cyclone cut diameters and the isokinetic sampling velocities.]

- 8.3.4.2 *Velocity pressure range.* Insert the S-type pitot tube at each traverse point and record the range of velocity pressures measured on the Method 2 of Appendix A to 40 CFR part 60 data form. You will use this later to select the appropriate nozzle(s).
- 8.3.4.3 *Initial gas stream viscosity and molecular weight.* Determine the average gas temperature, average gas oxygen content, average carbon dioxide content, and estimated moisture content. You will use this information to calculate the initial gas stream viscosity (Equation 3) and molecular weight (Equations 1 and 2). [**Note:** You must follow the instructions outlined in Method 4 to estimate the moisture content. You may use a wet bulb-dry bulb measurement or hand-held hygrometer measurement to estimate the moisture content of sources with gas temperatures less than  $160^\circ\text{F}$ .]
- 8.3.4.4 *Particulate matter concentration in the gas stream.* Determine the particulate matter concentration in the gas stream through qualitative measurements or estimates. Having an idea of what the particulate concentration is in the gas stream will help you determine the appropriate

sampling time to acquire sufficient particulate matter weight for better accuracy at the source emission level. The collectable particulate matter weight requirements depend primarily on the types of chemical analyses needed to characterize the emissions. Estimate the collectable particulate matter concentrations in the  $>10$  micrometer,  $\leq 10$  and  $> 2.5$  micrometers, and  $\leq 2.5$  micrometer size ranges.

#### 8.4 Why must I perform pre-test calculations.

You must perform pre-test calculations to help select the appropriate gas sampling rate through cyclone I ( $PM_{10}$ ) and cyclone IV ( $PM_{2.5}$ ). Choosing the appropriate sampling rate will allow you to maintain the appropriate particle cut diameters based upon preliminary gas stream measurements, as specified in Table 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method.

- 8.4.1 Gas sampling rate. The gas sampling rate is defined by the performance curves for both cyclones, as illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. You must use the calculations in paragraph 5 of this section to achieve the appropriate cut size specification for each cyclone. The optimum gas sampling rate is the overlap zone defined as the range below the cyclone IV 2.25 micrometer curve down to the cyclone I 11.0 micrometer curve (area between the two dark, solid lines in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method).
- 8.4.2 Choosing the appropriate sampling rate. You must select a gas sampling rate in the middle of the overlap zone (discussed in paragraph 4.1 of this section), as



illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method to maximize the acceptable tolerance for slight variations in flow characteristics at the sampling location. The overlap zone is also a weak function of the gas composition. [Note: You should be aware that the acceptable range is limited, especially for gas streams with temperatures less than approximately 100°F.]

8.5 What pre-test calculations must I perform?

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

Table 1. Pretest Calculations

<b>If you are using...</b>	<b>To calculate...</b>	<b>Then use...</b>
Preliminary data	dry gas molecular weight, $M_d$	Equation 1
Dry gas molecular weight ( $M_d$ ) and preliminary moisture content of the gas stream	wet gas molecular weight, $M_w$	Equation 2 <sup>a</sup>
Stack gas temperature, and oxygen and moisture content of the gas stream	gas viscosity, $\mu$	Equation 3
Gas viscosity, $\mu$	Cunningham correction factor <sup>b</sup> , $C$	Equation 4
Reynolds Number <sup>c</sup> ( $N_{re}$ ) $N_{re} < 3162$	preliminary lower limit cut diameter for cyclone I, $D_{50LL}$	Equation 5
$D_{50LL}$ from Equation 5	cut diameter for cyclone I for middle of the overlap zone, $D_{50T}$	Equation 6

Table 1. Pretest Calculations

<b>If you are using...</b>	<b>To calculate...</b>	<b>Then use...</b>
$D_{50T}$ from Equation 6	final sampling rate for cyclone I, $Q_I(Q_s)$	Equation 7
$Q_I(Q_s)$ from Equation 7	(verify) the assumed Reynolds number	Equation 8

<sup>a</sup> 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.

<sup>b</sup> For the lower cut diameter of cyclone IV, 2.25 micrometer.

<sup>c</sup> Verify the assumed Reynolds number using the procedure in paragraph 5.1, below, before proceeding to Equation 9.

8.5.1 The assumed Reynolds number. Verify the assumed Reynolds number ( $N_{re}$ ) by substituting the sampling rate ( $Q_s$ ) calculated in Equation 7 into Equation 8. Then use Table 2 of this paragraph to determine if the  $N_{re}$  used in Equation 5 was correct.

Table 2. Verification of the Assumed Reynolds Number

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

- 8.5.2 Final sampling rate. You must recalculate the final sampling rate( $Q_s$ ) if the assumed Reynold's number used in your initial calculation is not correct. Use Equation 7 to recalculate the optimum sampling rate ( $Q_s$ ).
- 8.5.3 Meter box  $\Delta H$ . Use Equation 9 to calculate the meter box  $\Delta H$  after you calculate the optimum sampling rate and confirm the Reynolds number. [**Note:** The stack gas temperature may vary during the test which could affect the sampling rate. If this occurs, you must make slight adjustments in the meter box  $\Delta H$  to maintain the correct constant cut diameters. Therefore, use Equation 9 to recalculate the  $\Delta H$  values for 50°F above and below the stack temperature measured during the preliminary traverse (see paragraph 3.4.1 of this section) and document this information in the Tables, Diagrams, Flowcharts, and Validation Data section of this method under Table 3.]
- 8.5.4 Choosing a sampling nozzle. You must select one or more nozzle sizes to provide for near isokinetic sampling rate (that is, 80% to 120%). This will also minimize anisokinetic sampling errors for the 10 micrometer particles at each point. First calculate the mean stack gas velocity,  $v_s$ , using Equation 11. Look at paragraph 7.2 of this section for information on correcting for blockage and use of different pitot tube coefficients. Then use Equation 12 to calculate the diameter of a nozzle that provides for isokinetic sampling at the mean stack gas velocity at flow  $Q_s$ . From the available nozzles just smaller and just larger of this diameter,  $D$ , select the most promising nozzle(s). Perform the following steps for the selected nozzle(s).

- 8.5.4.1 *Minimum/maximum nozzle/stack velocity ratio.* Use Equation 14 to calculate the minimum nozzle/stack velocity ratio,  $R_{\min}$ . Use Equation 15 to calculate the maximum nozzle/stack velocity ratio,  $R_{\max}$ .
- 8.5.4.2 *Minimum gas velocity.* Use Equation 16 to calculate the minimum gas velocity ( $v_{\min}$ ) if  $R_{\min}$  is an imaginary number (negative value under the square root function) or if  $R_{\min}$  is less than 0.5. Use Equation 17 to calculate  $v_{\min}$  if  $R_{\min}$  is greater than or equal to 0.5.
- 8.5.4.3 *Maximum stack velocity.* Use Equation 18 to calculate the maximum stack velocity ( $v_{\max}$ ) if  $R_{\max}$  is less than 1.5. Use Equation 19 to calculate the stack velocity if  $R_{\max}$  is greater than or equal to 1.5.
- 8.5.4.4 *Conversion of gas velocities to velocity pressure.* Use Equation 20 to convert  $v_{\min}$  to minimum velocity pressure,  $\Delta p_{\min}$ . Use Equation 21 to convert  $v_{\max}$  to maximum velocity pressure,  $\Delta p_{\max}$ .
- 8.5.4.5 Compare minimum and maximum velocity pressures with the observed velocity pressures at all traverse points during the preliminary test (see paragraph 3.4.2 of this section).
- 8.5.5 Optimum sampling nozzle. The nozzle you selected is appropriate if all the observed velocity pressures during the preliminary test fall within the range of the  $\Delta p_{\min}$  and  $\Delta p_{\max}$ . Make sure the following requirements are met. Then follow the procedures in paragraphs 5.5.1 and 5.5.2 of this section.
- (a) Choose an optimum nozzle that provides for isokinetic sampling conditions as close to 100% as possible. This is prudent because even if

there are slight variations in the gas flow rate, gas temperature, or gas composition during the actual test, you have the maximum assurance of satisfying the isokinetic criteria. Generally, one of the two candidate nozzles selected will be closer to optimum (see paragraph 5.4 of this section).

- (b) You can only have one point that is outside the minimum-to-maximum range. However, you can select two or more nozzles to achieve the isokinetic specification.

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

8.5.5.2 *Attach the pre-selected nozzle.* Screw the pre-selected nozzle onto the main body of cyclone I using Teflon<sup>®</sup> tape. Use a union and cascade adaptor to connect the cyclone IV inlet to the outlet of cyclone I (see Figure 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method).

## 8.6 How do I prepare the sampling train?

First, you must assemble the train and complete the leak check on the combined cyclone sampling head and pitot tube. Use the following procedures to prepare the sampling train.

[**Note:** Do not contaminate the sampling train during preparation and assembly. You must keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.]

8.6.1 Sampling head and pitot tube. Assemble the combined cyclone train. The O-rings used in the train have a temperature limit of approximately 400°F.

However, Teflon<sup>®</sup> O-rings can withstand 600°F without sealing problems. You must use cyclones with stainless steel sealing rings when stack temperatures exceed 600°F. You must also keep the nozzle covered to protect it from nicks and scratches.

- 8.6.2 Filter holder and pitot tube. Attach the pre-selected filter holder to the end of the combined cyclone sampling head (see Figure 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method). You must number and tare the filter before use. Attach the S-type pitot tube to the combined cyclones after the sampling head is fully attached to the end of the probe. [**Note:** The pitot tube tip must be mounted (1) slightly beyond the combined head cyclone sampling assembly and (2) at least one inch off the gas flow path into the cyclone nozzle. This is similar to the pitot tube placement in Method 17 of Appendix A to 40 CFR part 60.] Weld the sensing lines to the outside of the probe to ensure proper alignment of the pitot tube. Provide unions on the sensing lines so that you can connect and disconnect the S-type pitot tube tips from the combined cyclone sampling head before and after each run. [**Note:** Calibrate the pitot tube on the sampling head because the cyclone body is a potential source of interference.]
- 8.6.3 Filter. Use tweezers or clean disposable surgical gloves to place a labeled (identified) and pre-weighed filter in the filter holder. You must center the filter and properly place the gasket so that the sample gas stream will not circumvent

the filter. Check the filter for tears after the assembly is completed. Then screw the filter housing together to prevent the seal from leaking.

8.6.4 Leak check. Use the procedures outlined in paragraph 8.4 of Method 5 of Appendix A to 40 CFR part 60 to leak check the entire sampling system.

Specifically perform the following procedures:

8.6.4.1 *Sampling train*. You must pretest the entire sampling train for leaks. The pretest leak check must have a leak rate of not more than 0.02 ACFM or 4% of the average sample flow during the test run, whichever is less.

Additionally, you must conduct the leak check at a vacuum equal to or greater than the vacuum anticipated during the test run. Enter the leak check results on the field test data sheet for the specific test. [**Note:** Do not conduct a leak check during port changes.]

8.6.4.2 *Pitot tube assembly*. After you leak check the sample train, you must perform a leak check of the pitot tube assembly. Follow the procedures outlined in paragraph 8.4.1 of Method 5 of Appendix A to 40 CFR part 60.

8.6.5 Sampling head. You must preheat the combined sampling head to the stack temperature of the gas stream at the test location ( $\pm 10^{\circ}\text{C}$ ). This will heat the sampling head and prevent moisture from condensing from the sample gas stream. Record the site barometric pressure and stack pressure on the field test data sheet.

8.6.5.1 *Unsaturated stacks*. You must complete a passive warmup (of 30-40 min) within the stack before the run begins to avoid internal condensation.

[**Note:** Unsaturated stacks do not have entrained droplets and operate at temperatures above the local dew point of the stack gas.]

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

## 8.7 How do I operate the sample train?

You must follow the procedures outlined in paragraph 4.1.5 of Method 201A of Appendix M to 40 CFR part 51 to operate the sample train. You perform the following procedures:

- 8.7.1 Sample point dwell time. You must calculate the dwell time (that is, sampling time) for each sampling point to ensure that the overall run provides a velocity-weighted average that is representative of the entire gas stream. The dwell time calculations are identical to those used in paragraph 4.1.2.2.5 of Method 201A of Appendix M to 40 CFR part 51.

- 8.7.1.1 *Dwell time at first sampling point.* Calculate the dwell time for the first point,  $t_1$ , using Equation 22. You must use the data from the preliminary traverse. Here,  $N$  equals the total number of traverse points.
- 8.7.1.2 *Dwell time at remaining sampling points.* Calculate the dwell time at each of the remaining traverse points,  $t_n$ , using Equation 23. This time you



must use the actual test run data. [**Note:** Round the dwell times to 1/4 minutes.] Each traverse point must have a dwell time of at least two minutes.

8.7.2 Adjusted velocity pressure. When selecting your sampling points using your preliminary velocity traverse data, your preliminary velocity pressures must be adjusted to take into account the increase in velocity due to blockage. Also, you must adjust your preliminary velocity data for differences in pitot tube coefficients. Use the following instructions to adjust the preliminary velocity pressure.

8.7.2.1 *Different pitot tube coefficient.* You must use Equation 24 to correct the recorded preliminary velocity pressures if the pitot tube mounted on the combined cyclone sampling head has a different pitot tube coefficient than the pitot tube used during the preliminary velocity traverse (see paragraph 3.1 of this section).

8.7.2.2 *Probe blockage factor.* You must use Equation 25 to calculate an average probe blockage correction factor ( $b_f$ ) 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 paragraph 3.2 of this section and illustrated in Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. [**Note:** The

sampling head (including the filter holder) has a projected area of approximately 20.5 square inches when oriented into the gas stream. As the probe is moved from the most outer to the most inner point, the amount of blockage that actually occurs ranges from approximately 4 square inches to the full 20.5 inches. The average cross-sectional area blocked is 12 square inches.]

8.7.2.3 *Final adjusted velocity pressure.* Calculate the final adjusted velocity pressure ( $\Delta p_{s2}$ ) using Equation 26. [**Note:** Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method illustrates that the blockage effect of the large combined cyclone sampling head increases rapidly below diameters of 18 inches. Therefore, you must follow the procedures outlined in Method 1A to conduct tests in small stacks (<18 inches diameter). You must conduct the velocity traverse downstream of the sampling location or immediately before the test run.]

8.7.3 Sample train operation. You must follow the procedures outlined in paragraph 4.1.5 of Method 201A of Appendix M to 40 CFR part 51 to operate the sample train. In addition to these procedures, you must also use running starts and stops on both small and large stacks if the static pressure at the sampling location is more negative than 5 in. water column (WC). This prevents back pressure from rupturing the sample filter. If you use a running start, adjust the flow rate to the

calculated value after you perform the leak check (see paragraph 7.4 of this section).

- 8.7.3.1 *Level and zero manometers.* Make periodic checks of the level and zero point of the manometers during the traverse. Vibrations and temperature changes may cause them to drift.
- 8.7.3.2 *Portholes.* Clean the portholes prior to the test run. This will minimize the chance of collecting deposited material in the nozzle.
- 8.7.3.3 *Sampling procedures.* Verify that the combined cyclone sampling head temperature is at stack temperature ( $\pm 10^{\circ}\text{C}$ ). Remove the protective cover from the nozzle. To begin sampling, immediately start the pump and adjust the flow to calculated isokinetic conditions. Position the probe at the first sampling point with the nozzle pointing directly into the gas stream. Ensure the probe/pitot tube assembly is leveled. [**Note:** When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.]
- (a) You must traverse the stack cross-section, as required by Method 5 of Appendix A to 40 CFR part 60. Do not bump the cyclone nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes. This will minimize the chance of extracting deposited materials.

- (b) You must record the data required on the field test data sheet for each run. Record the initial dry gas meter (DGM) reading. Then take a DGM readings at the following times: (1) the beginning and end of each sample time increment, (2) when changes in flow rates are made, and (3) when sampling is halted. Compare the velocity pressure measurements (Equations 20 and 21) with the velocity pressure measured during the preliminary traverse. Keep the meter box  $\Delta H$  at the value calculated in paragraph 5.3 of this section for the stack temperature that is observed during the test. Record all the point-by-point data and other source test parameters on the field test data sheet. Do not leak check the sampling system during port changes.
- (c) Maintain the flow through the sampling system at the last sampling point. Remove the sampling train from the stack while you are still operating (running stop). Then stop the pump and record the final DGM reading and other test parameters on the field test data sheet.

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

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

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

8.7.5 Sample recovery. First remove the sample head (combined cyclone/filter assembly) from the stack gas. After the sample head is removed, you must perform a post-test leak check of the probe and sample train. Then recover the components from the cyclone/filter. Refer to the following summaries for more detailed information.

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

8.7.5.2 *Leak check probe/sample train assembly.* Leak check the remainder of the probe and sample train assembly (including meter box) after removing the combined cyclone head/filter. You must conduct the leak rate at a vacuum equal to or greater than the maximum vacuum achieved during the test

run. Enter the results of the leak check onto the field test data sheet. If the leak rate of the sampling train (without the combined cyclone sampling head) exceeds 0.02 ACFM or 4% of the average sampling rate during the test run (whichever is less), the run is invalid and you must repeat it.

8.7.5.3 *Recovery of particulate matter.* Recovery involves the quantitative transfer of particles in the following size range: (1) greater than 10 micrometers, (2) less than or equal to 10 micrometers but greater than 2.5 micrometers, and (3) less than or equal to 2.5 micrometers. You must use a Nylon brush and an ultrapure acetone rinse to recover particles from the combined cyclone/filter sampling head. Use the following procedures for each container.

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

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

including the outside surface of the downcomer line. Seal the container and mark the liquid level on the outside of the container. You must keep any dust found on the outside of cyclone I and cyclone nozzle external surfaces out of the sample. This container holds particulate matter greater than 10 micrometers.

Container #3 - Place the solids from cyclone cup IV and the acetone (and brush cleaning) rinses of the cyclone I turnaround cup (above inner downcomer line), inside of the downcomer line, and interior surfaces of cyclone IV into your #3 container. Seal the container and mark the liquid level on the outside. This container holds particulate matter less than 10 micrometers and greater than 2.5 micrometers.

Container #4 - Retrieve the acetone rinses (and brush cleaning) of the exit tube of cyclone IV and the front half of the filter holder in container #4. Seal the container and mark the liquid level on the outside of the container. This container holds particulate matter that is less than 2.5 micrometers.

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

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

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

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

## 9. QUALITY CONTROL

9.1 What do I use to perform daily quality audits?

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

9.2 How do I verify the calculations?

Verify the calculations by independent, manual checks. You must flag any suspect data and identify the nature of the problem and potential effect on data quality. After you complete the test, prepare a data summary and compile all the calculations and raw data sheets.

9.3 When must I record operating conditions?

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

9.4 When must I develop a health and safety plan?

You must develop a health and safety plan to ensure the safety of your employees who are on-site conducting the particulate emission test. Your plan must conform with all applicable OSHA, MSHA, and DOT regulatory requirements. The procedures must also conform to the plant health and safety requirements.



## 10. CALIBRATION AND STANDARDIZATION

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

### 10.1 How do I measure the gas flow velocities?

Measure the gas flow velocities at the sampling locations using Method 2 of Appendix A to 40 CFR part 60. You must use an S-type pitot tube that meets the required EPA specifications (EPA Publication 600/4-77-0217b) during these velocity measurements. You must also:

- (a) Visually inspect the S-type pitot tube before sampling.
- (b) Leak check both legs of the pitot tube before and after sampling.
- (c) Maintain proper orientation of the S-type pitot tube while making measurements.

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

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

10.1.3 Pitot tube coefficient. Determine the pitot tube coefficient based on physical measurement techniques described in Method 2 of Appendix A to 40 CFR part 60. [**Note:** You must calibrate the pitot tube on the sampling head because of potential interferences from the cyclone body. Refer to paragraph 7.2 under the Sample Collection, Preservation, Storage and Transport section of this method for additional information.]

10.2 What procedures must I follow to calibrate the thermocouples?

You must use the procedures described in paragraph 10.1.4.1.2 of Method 2 of Appendix A to 40 CFR part 60 to calibrate the thermocouples. Calibrate each temperature sensor at a minimum of three points over the anticipated range of use against an NIST-traceable mercury-in-glass thermometer.

10.3 What types of nozzles must I use for sampling?

Use stainless steel (316 or equivalent) or Teflon<sup>®</sup>-coated nozzles for isokinetic sampling. Make sure that all nozzles are thoroughly cleaned, visually inspected, and calibrated according to the procedure outlined in paragraph 10.1 of Method 5 of Appendix A to 40 CFR part 60.

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

You must follow the calibration procedures documented in paragraph 16.1 of Method 5 of Appendix A to 40 CFR part 60. Also, make sure you fully calibrate the dry gas meter to determine the volume correction factor prior to field use. Post-test calibration checks must be performed as soon as possible after the equipment has been returned to the shop. Your pretest and post-test calibrations must agree within  $\pm 5$  percent.

## 11. ANALYTICAL PROCEDURES

11.1 What procedures must I follow to record data?

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

11.2 What procedure must I follow for the container analysis?

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

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

## 12. CALCULATIONS AND DATA ANALYSIS

### 12.1 What do I need to calculate?

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

Table 3. Calculations for Recovery of  $PM_{10}$  and  $PM_{2.5}$

Calculations	Instructions and References
Average dry gas meter temperature	See field test data sheet.
Average orifice pressure drop	See field test data sheet.
Dry gas volume ( $V_{ms}$ )	Use Equation 27 to correct the sample volume measured by the dry gas meter to standard conditions (20°C, 760 mm Hg or 68°F, 29.92 in. Hg).
Dry gas sampling rate ( $Q_{SST}$ )	Must be calculated using Equation 28.
Volume of water condensed ( $V_{ws}$ )	Use Equation 29 to determine the water condensed in the impingers and silica gel combination. Determine the total moisture catch by measuring the change in volume or weight in the impingers and weighing the silica gel.

Table 3. Calculations for Recovery of PM<sub>10</sub> and PM<sub>2.5</sub>

Calculations	Instructions and References
Moisture content of stack gas ( $B_{ws}$ )	Calculate this with Equation 30.
Gas sampling rate ( $Q_s$ )	Calculate this with Equation 31.
Test condition Reynolds number <sup>1</sup>	Use Equation 8 to calculate the actual Reynolds number during test conditions.
Actual $D_{50}$ of Cyclone I	Calculate this with Equation 32. This calculation is based on the average temperatures and pressures measured during the test run.
Stack gas velocity ( $v_s$ )	Calculate this with Equation 11.
Percent isokinetic rate (%I)	Calculate this with Equation 40.

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

## 12.2 What data must I analyze?

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

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

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

- 12.2.1.1 *Cunningham correction factor.* You must recalculate the initial estimate of the Cunningham correction factor using the actual test data. Insert the actual test run data and  $D_{50}$  of 2.5 micrometers into Equation 4. This will give you a new Cunningham correction factor that is based on actual data.
- 12.2.1.2 *Initial  $D_{50}$  for cyclone IV.* Determine the initial estimate for cyclone IV  $D_{50}$  using the test condition Reynolds number calculated with Equation 8 as indicated in Table 3 of this section. Refer to the following instructions.
- (a) If the Reynold's number is less than 3162, calculate the  $D_{50}$  for cyclone IV with Equation 33, using actual test data.
  - (b) If the Reynold's number is equal to or greater than 3162, calculate the  $D_{50}$  for cyclone IV with Equation 34, using actual test data.
  - (c) Insert the "new"  $D_{50}$  value calculated by either Equation 33 or 34 into Equation 35 to re-establish the Cunningham Correction Factor ( $C_r$ ).
- [**Note:** Use the test condition calculated Reynolds number to determine the most appropriate equation (Equation 33 or 34).]
- 12.2.1.3 *Re-establish cyclone IV  $D_{50}$ .* Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynold's number to determine  $D_{50-1}$ .
- (a) Use Equation 36 to calculate the re-established cyclone IV  $D_{50-1}$  if the Reynolds number is less than 3162.

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

12.2.1.3 *Establishing “Z” values.* The “Z” value is the result of an analysis that you must perform to determine if the Cunningham correction factor is acceptable. Compare the calculated cyclone IV  $D_{50}$  (either Equation 33 or 34) to the re-established cyclone IV  $D_{50-1}$  (either Equation 36 or 37) values based upon the test condition calculated Reynolds number (Equation 38, refer to 2.1.2 for additional information). Follow these procedures.

- (a) Use Equation 38 to calculate the “Z”. If the “Z” value is within 0.99 and 1.01, then the  $D_{50-1}$  value is the best estimate of the cyclone IV  $D_{50}$  cut diameter for your test run.
- (b) If the “Z” value is greater than 1.01 or less than 0.99, re-establish a Cunningham correction factor based on the  $D_{50-1}$  value determined in either Equations 36 or 37, depending upon the test condition Reynolds number.
- (c) Use the second revised Cunningham correction to re-calculate the cyclone IV  $D_{50}$ .
- (d) Repeat this iterative process as many times as necessary using the prescribed equations until you achieve the criteria documented in Equation 39.

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

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

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

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

- (a) Use Equation 43 to calculate the particulate matter recovered from Containers #1, #2, #3, and #4. This is the total collectable particulate matter ( $C_{total}$ ).
- (b) Use Equation 44 to determine the quantitative recovery of  $PM_{10}$  particulate matter ( $C_{PM10}$ ) from Containers #1, #3, and #4.
- (c) Use Equation 45 to determine the quantitative recovery of  $PM_{2.5}$  particulate ( $C_{PM2.5}$ ) recovered from Containers #1 and #4.

12.3 What must I include in the emissions test report?

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

- (a) Emission test description including any deviations from this protocol
- (b) Summary data tables on a run-by-run basis
- (c) Flowchart of the process or processes tested
- (d) Sketch of the sampling location
- (e) Preliminary traverse data sheets including cyclonic flow checks
- (f) Raw field data sheets
- (g) Laboratory analytical sheets and case narratives
- (h) Sample calculations
- (i) Pretest and post-test calibration data
- (j) Chain of custody forms
- (k) Documentation of process and air pollution control system data

#### 12.4 What nomenclature do I use in this method?

You must use the following nomenclature:

- A = Area of stack or duct at sampling location, square inches.
- $A_n$  = Area of nozzle, square feet.
- $b_f$  = Average blockage factor calculated in Equation 25, dimensionless.
- $B_{ws}$  = Moisture content of gas stream, fraction  
(e.g. 10% H<sub>2</sub>O is  $B_{ws} = 0.10$ ).
- C = Cunningham correction factor for particle diameter,  $D_p$ , and calculated using the actual stack gas temperature, dimensionless.
- %CO<sub>2</sub> = Carbon Dioxide content of gas stream, % by volume.



$C_a$	=	Acetone blank concentration, mg/mg.
$C_{PM10}$	=	Conc. of $PM_{10}$ collectable particulate matter, gr/DSCF.
$C_{PM2.5}$	=	Conc. of $PM_{2.5}$ collectable particulate matter, gr/DSCF.
$C_p$	=	Pitot coefficient for the combined cyclone pitot, dimensionless.
$C_p'$	=	Coefficient for the pitot used in the preliminary traverse, dimensionless.
$C_r$	=	Re-estimated Cunningham correction factor for particle diameter equivalent to the actual cut size diameter and calculated using the actual stack gas temperature, dimensionless.
$C_{total}$	=	Conc. of total collectable particulate matter, gr/DSCF.
$C_1$	=	-150.3162 (micropoise)
$C_2$	=	18.0614 (micropoise/ $K^{0.5}$ )
	=	13.4622 (micropoise/ $R^{0.5}$ )
$C_3$	=	$1.19183 \times 10^6$ (micropoise/ $K^2$ )
	=	$3.86153 \times 10^6$ (micropoise/ $R^2$ )
$C_4$	=	0.591123 (micropoise)
$C_5$	=	91.9723 (micropoise)
$C_6$	=	$4.91705 \times 10^{-5}$ (micropoise/ $K^2$ )
	=	$1.51761 \times 10^{-5}$ (micropoise/ $R^2$ )
$D$	=	Inner diameter of sampling nozzle mounted on Cyclone I, in.
$D_p$	=	Physical particle size, micrometers.
$D_{50}$	=	Particle cut diameter, micrometers.

- $D_{50-1}$  = Re-calculated particle cut diameters based on re-estimated  $C_p$ , micrometers.
- $D_{50LL}$  = Cut diameter for cyclone I corresponding to the 2.25 micrometer cut diameter for cyclone IV, micrometers.
- $D_{50N}$  =  $D_{50}$  value for cyclone IV calculated during the Nth iterative step, micrometers.
- $D_{50(N+1)}$  =  $D_{50}$  value for cyclone IV calculated during the N+1 iterative step, micrometers.
- $D_{50T}$  = Cyclone I cut diameter corresponding to the middle of the overlap zone shown in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method, micrometers.
- $I$  = Percent isokinetic sampling, dimensionless.
- $K_p$  = 85.49, [(ft/sec)/(pounds/mole  $^{\circ}$ R)].
- $m_a$  = Mass of residue of acetone after evaporation, mg.
- $M_d$  = Molecular weight of dry gas, pounds/pound mole.
- $M_w$  = Molecular weight of wet gas, pounds/pound mole.
- $M_1$  = Milligrams of particulate matter collected on the filter,  $\leq 2.5$  micrometers.
- $M_2$  = Milligrams of particulate matter recovered from Container #2 (acetone blank corrected),  $>10$  micrometers.
- $M_3$  = Milligrams of particulate matter recovered from Container #3 (acetone blank corrected),  $\leq 10$  and  $>2.5$  micrometers.

- $M_4$  = Milligrams of particulate matter recovered from Container #4 (acetone blank corrected),  $\leq 2.5$  micrometers.
- $N$  = Number of iterative steps or total traverse points.
- $N_{re}$  = Reynolds number, dimensionless.
- $\%O_{2,wet}$  = Oxygen content of gas stream, % by volume of wet gas.
- [**Note:** the oxygen percentage used in equation 3 is on a WET gas basis; that means that since  $O_2$  is typically measured on a dry gas basis, the measured  $\%O_2$  must be multiplied by the quantity  $(1 - B_{ws})$  to convert to the actual volume fraction. Therefore  $\%O_{2,wet} = (1 - B_{ws}) * \%O_{2,dry}$ ]
- $P_{bar}$  = Barometric pressure, in. Hg.
- $P_s$  = Absolute stack gas pressure, in. Hg.
- $Q_s$  = Sampling rate for cyclone I to achieve specified  $D_{50}$ , ACFM.
- $Q_{sST}$  = Dry gas sampling rate through the sampling assembly, DSCFM.
- $Q_I$  = Sampling rate for cyclone I to achieve specified  $D_{50}$ , ACFM.
- $Q_{IV}$  = Sampling rate for cyclone IV to achieve specified  $D_{50}$ , ACFM.
- $R_{max}$  = Nozzle/stack velocity ratio parameter, dimensionless.
- $R_{min}$  = Nozzle/stack velocity ratio parameter, dimensionless.
- $T_m$  = Meter box and orifice gas temperature, °R.
- $t_n$  = Sampling time at point n, min.
- $t_r$  = Total projected run time, min.
- $T_s$  = Absolute stack gas temperature, °R.

$t_1$	=	Sampling time at point 1, min.
$v_{\max}$	=	Maximum gas velocity calculated from Equations 18 or 19, ft/sec.
$v_{\min}$	=	Minimum gas velocity calculated from Equations 16 or 17, ft/sec.
$v_n$	=	Sample gas velocity in the nozzle, ft/sec.
$v_s$	=	Velocity of stack gas, ft/sec.
$V_a$	=	Volume of acetone blank, mL.
$V_{aw}$	=	Volume of acetone used in blank wash, mL.
$V_c$	=	Quantity of water captured in impingers and silica gel, mL.
$V_m$	=	Dry gas meter volume sampled, ACF.
$V_{ms}$	=	Dry gas meter volume sampled, corrected to standard conditions, SCF.
$V_{ws}$	=	Volume of water vapor, SCF.
$W_a$	=	Weight of residue in acetone blank wash, mg.
$Z$	=	Ratio between estimated cyclone IV $D_{50}$ values, dimensionless.
$\Delta H$	=	Meter box orifice pressure drop, in. W.C.
$\Delta H_{@}$	=	Pressure drop across orifice at flow rate of 0.75 SCFM at standard conditions, in. W.C. [ <b>Note:</b> specific to each orifice and meter box]
$[(\Delta p)^{0.5}]_{\text{avg}}$	=	Average of square roots of the velocity pressures measured during the preliminary traverse, in. W.C.
$\Delta p_m$	=	Observed velocity pressure using S-type pitot tube in preliminary traverse, in. W.C.
$\Delta p_{\max}$	=	Maximum velocity pressure, in. W.C.
$\Delta p_{\min}$	=	Minimum velocity pressure, in. W.C.

- $\Delta p_n$  = Velocity pressure measured at point n during the test run, in. W.C.
- $\Delta p_s$  = Velocity pressure calculated in Equation 24, in. W.C.
- $\Delta p_{s1}$  = Velocity pressure adjusted for combined cyclone pitot tube, in. W.C.
- $\Delta p_{s2}$  = Velocity pressure corrected for blockage, in. W.C.
- $\Delta p_1$  = Velocity pressure measured at point 1, in. W.C.
- $\gamma$  = Dry gas meter gamma value, dimensionless.
- $\mu$  = Gas viscosity, micropoise.
- $\theta$  = Total run time, minutes.
- $\rho_a$  = Density of acetone, mg/mL (see label on bottle).
- 12.0 = Constant calculated as 60% of 20.5 square inch cross-sectional area of combined cyclone head, square inches.

### 12.5 What equations will I use in this method?

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

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

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

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

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

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

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

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

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

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

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

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

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

Sampling Rate.

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

Reynolds Number.

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

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

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

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

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

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

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

Calculated Nozzle Diameter for Acceptable Sampling Rate.

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

Velocity of Gas in Nozzle.

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

Minimum Nozzle/Stack Velocity Ratio Parameter.

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

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

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



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

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

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

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

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

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

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

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

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

Minimum Velocity Pressure.

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

Maximum Velocity Pressure.

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

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

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

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

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

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

Adjusted Velocity Pressure.

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

Average Probe Blockage Factor.

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

Velocity Pressure.

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

Dry Gas Volume Sampled at Standard Conditions.

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

Sample Flow Rate at Standard Conditions.

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

Volume of Water Vapor.

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

Moisture Content of Gas Stream.

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

Sampling Rate.

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

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

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

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

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

$$D_{50} = 0.0024302 \left[ \frac{\mu}{Q_s} \right]^{1.1791} \left[ \frac{1}{C} \right]^{0.5} \left[ \frac{T_s}{P_s M_w} \right]^{0.6790} \quad \text{Equation 33} \\ (N_{re} < 3162)$$

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

$$D_{50} = 0.019723 \left[ \frac{\mu}{Q_s} \right]^{0.8058} \left[ \frac{1}{C} \right]^{0.5} \left[ \frac{T_s}{P_s M_w} \right]^{0.3058} \quad \text{Equation 34} \\ (N_{re} \geq 3162)$$

Re-estimated Cunningham Correction Factor. You must use the actual test run Reynolds Number ( $N_{re}$ ) value and select the appropriate  $D_{50}$  from Equation 32 or 33 (or Equation 36 or 37 if reiterating).

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

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

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

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

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

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

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

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

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

Percent Isokinetic Sampling.

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

Acetone Blank Concentration.

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

Acetone Blank Weight.

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

Concentration of Total Collectable Particulate Matter.

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

Concentration of  $PM_{10}$  Collectable Particulate Matter.

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

Concentration of PM<sub>2.5</sub> Collectable Particulate Matter.

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

**13. METHOD PERFORMANCE**

[Reserved]

**14. POLLUTION PREVENTION**

[Reserved]

**15. WASTE MANAGEMENT**

[Reserved]

**16. REFERENCES**

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

Dawes, S.S., and W.E. Farthing. "Application Guide for Measurement of PM<sub>2.5</sub> at Stationary Sources," U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, 27511,

EPA-600/3-90/057 (NTIS No.: PB 90-247198), November 1990.

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

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

Richards, J.R. "Test protocol: PCA PM<sub>10</sub>/PM<sub>2.5</sub> Emission Factor Chemical Characterization Testing," PCA R&D Serial No. 2081, Portland Cement Association, 1996.

**17. TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA**

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

Table 1. Typical Particulate Matter Concentrations

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

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

Cyclone	Min. Cut Diameter, Micrometer	Max. Cut Diameter, Micrometer
PM <sub>10</sub> Cyclone (Cyclone I from five stage cyclone)	9	11
PM <sub>2.5</sub> Cyclone (Cyclone IV from five stage cyclone)	2.25	2.75

Table 3.  $\Delta H$  Values Based on Preliminary Traverse Data

Stack Temperature, ( $^{\circ}$ R)	$T_s - 50^{\circ}$	$T_s$	$T_s + 50^{\circ}$
$\Delta H_s$ (in. W.C.)	-	-	-



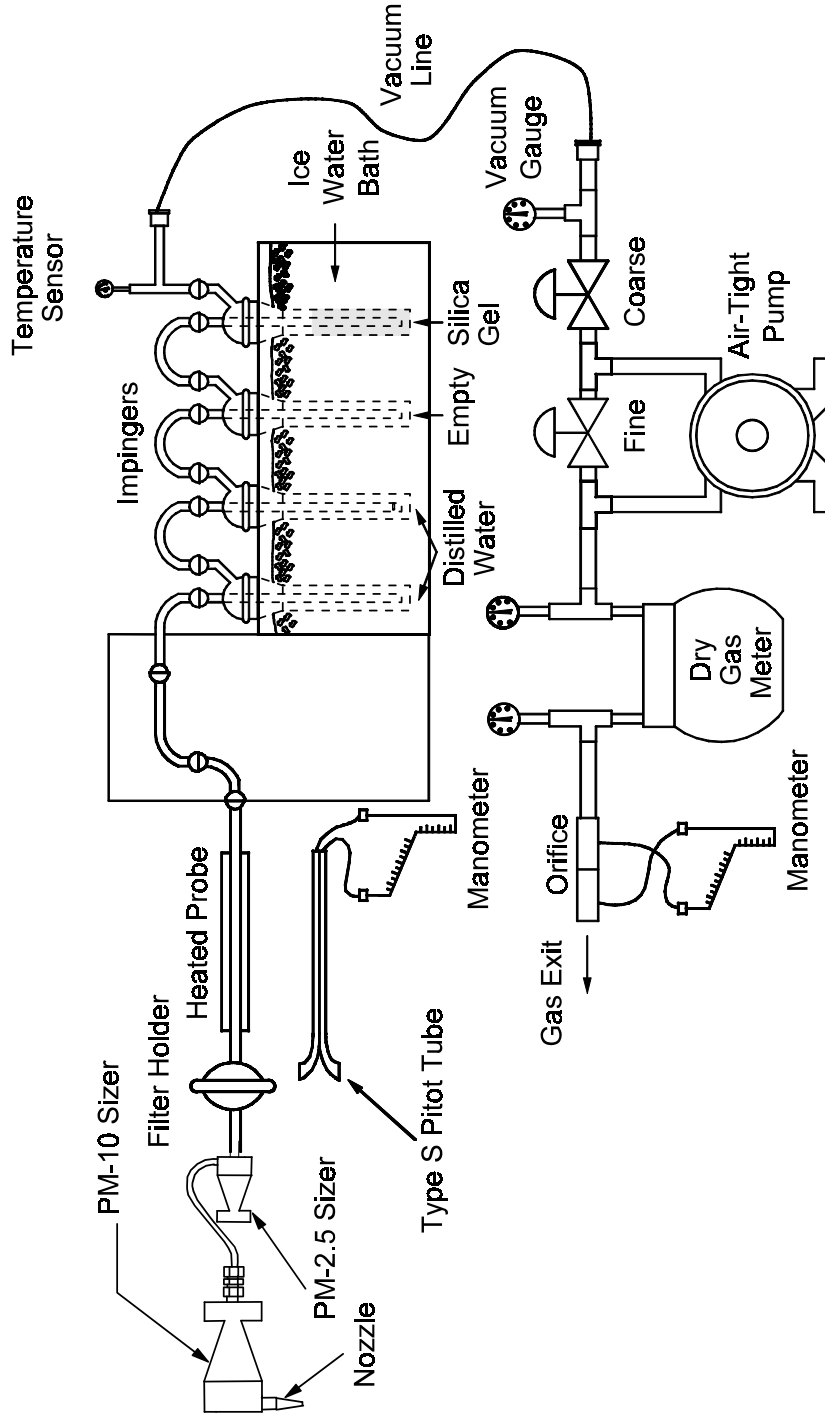


Figure 1. In-Stack Sizing Device

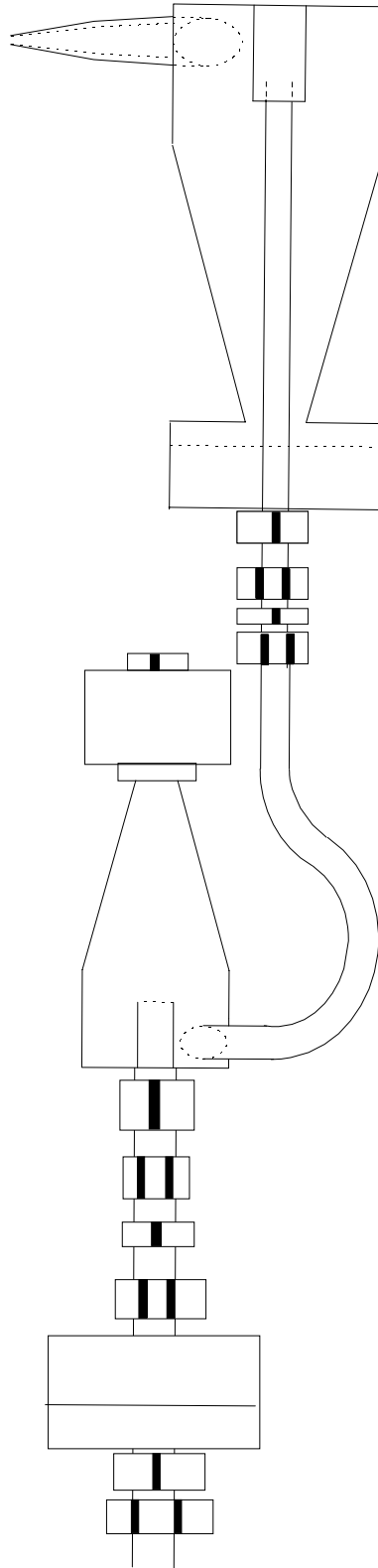
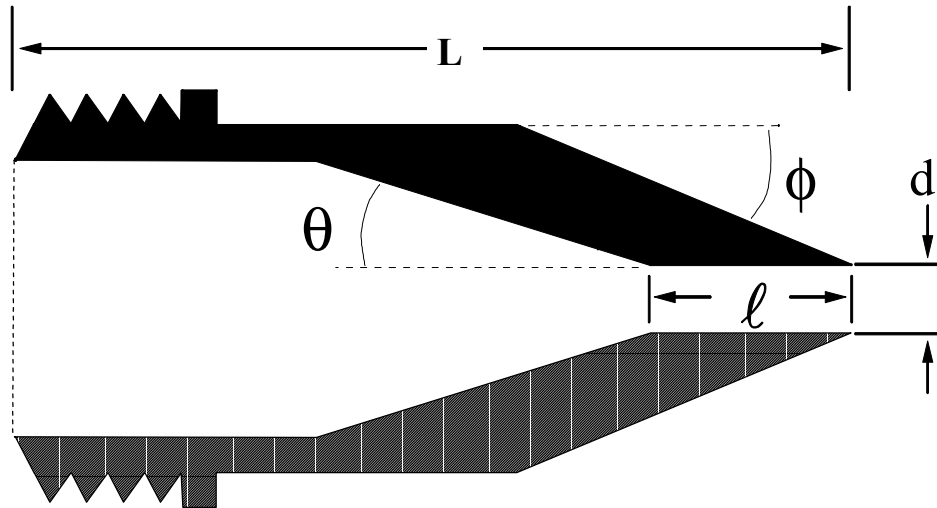
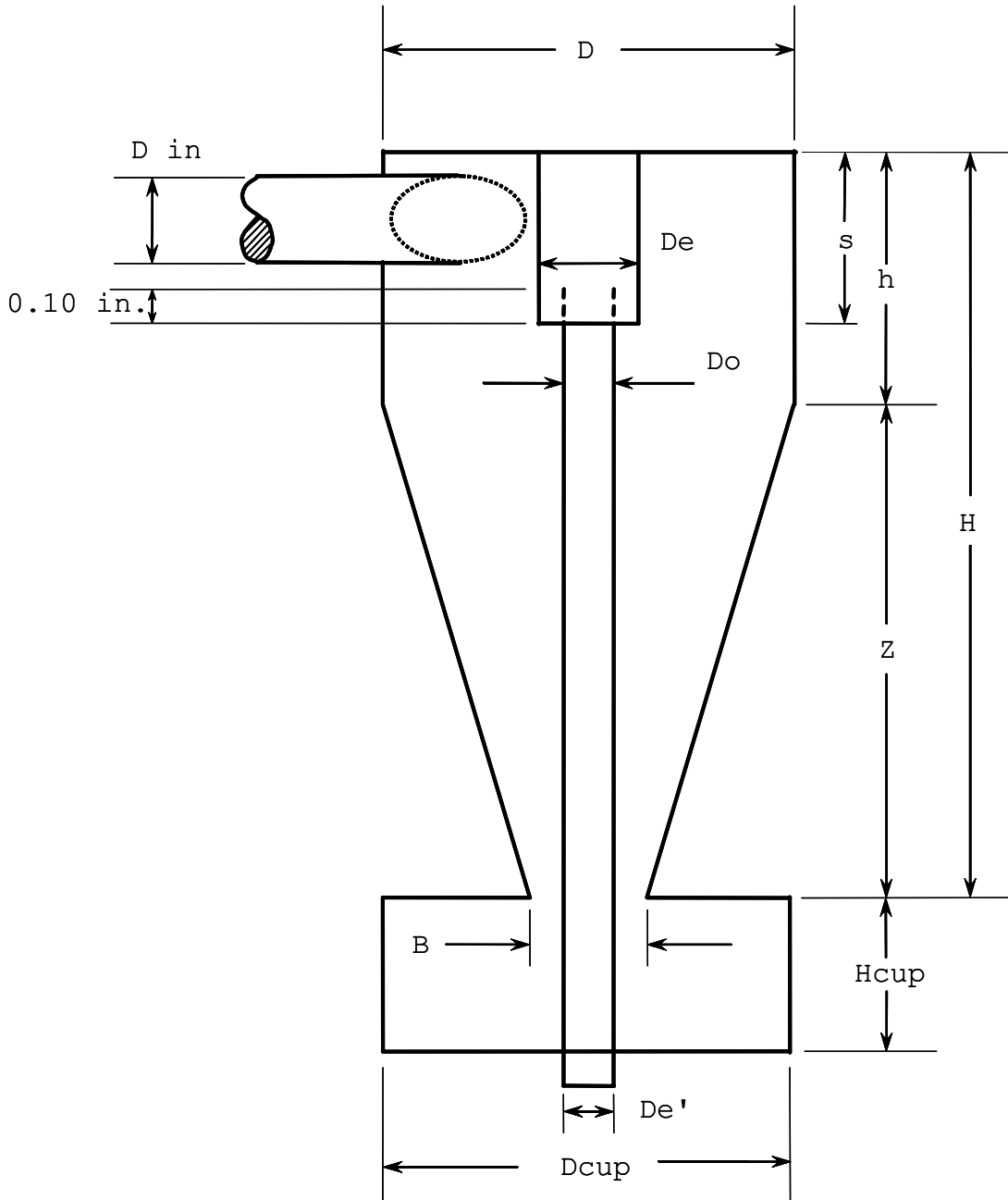


Figure 2. Combined Cyclone Sampling Head



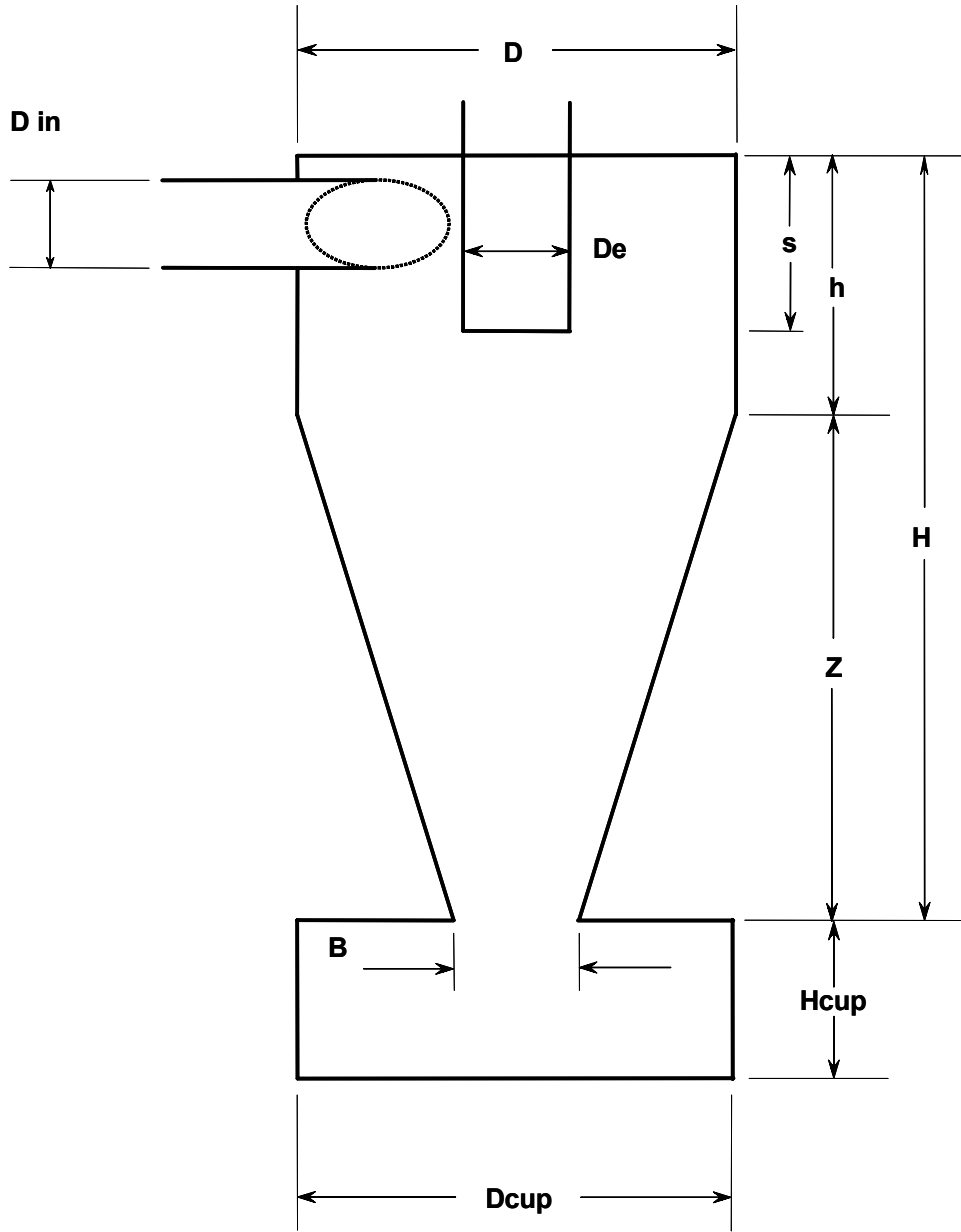
Nozzle diameter, d (inches)	Cone Angle, $\theta$ (degrees)	Outside taper, $\phi$ (degrees)	Straight inlet length, $l$ (inches)	Total Length, L (inches)
0.125	4	15	<0.05	2.710±0.05
0.136	4	15	<0.05	2.653±0.05
0.150	4	15	<0.05	2.553±0.05
0.164	5	15	<0.05	1.970±0.05
0.180	6	15	<0.05	1.572±0.05
0.197	6	15	<0.05	1.491±0.05
0.215	6	15	<0.05	1.450±0.05
0.233	6	15	<0.05	1.450±0.05
0.264	5	15	<0.05	1.450±0.05
0.300	4	15	<0.05	1.480±0.05
0.342	4	15	<0.05	1.450±0.05
0.390	3	15	<0.05	1.450±0.05

Figure 3. Nozzle Design Specifications



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

Figure 4. Design specifications for Cyclone I (10 Micrometer)



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

Figure 5. Design Specifications for Cyclone IV (2.5 Micrometer) Sizing Device

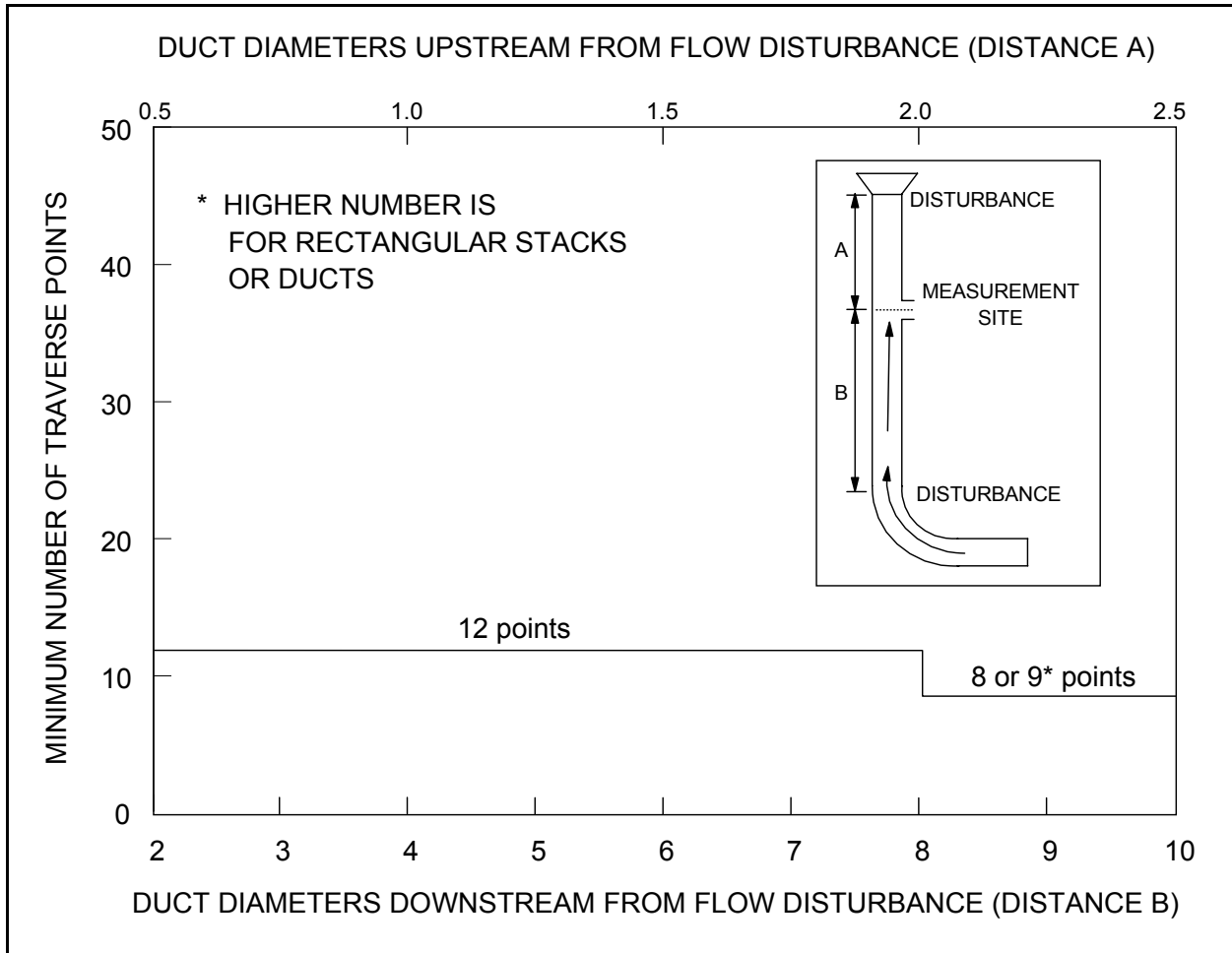


Figure 6. Minimum Number of Traverse Points for Preliminary Method 4 Traverse

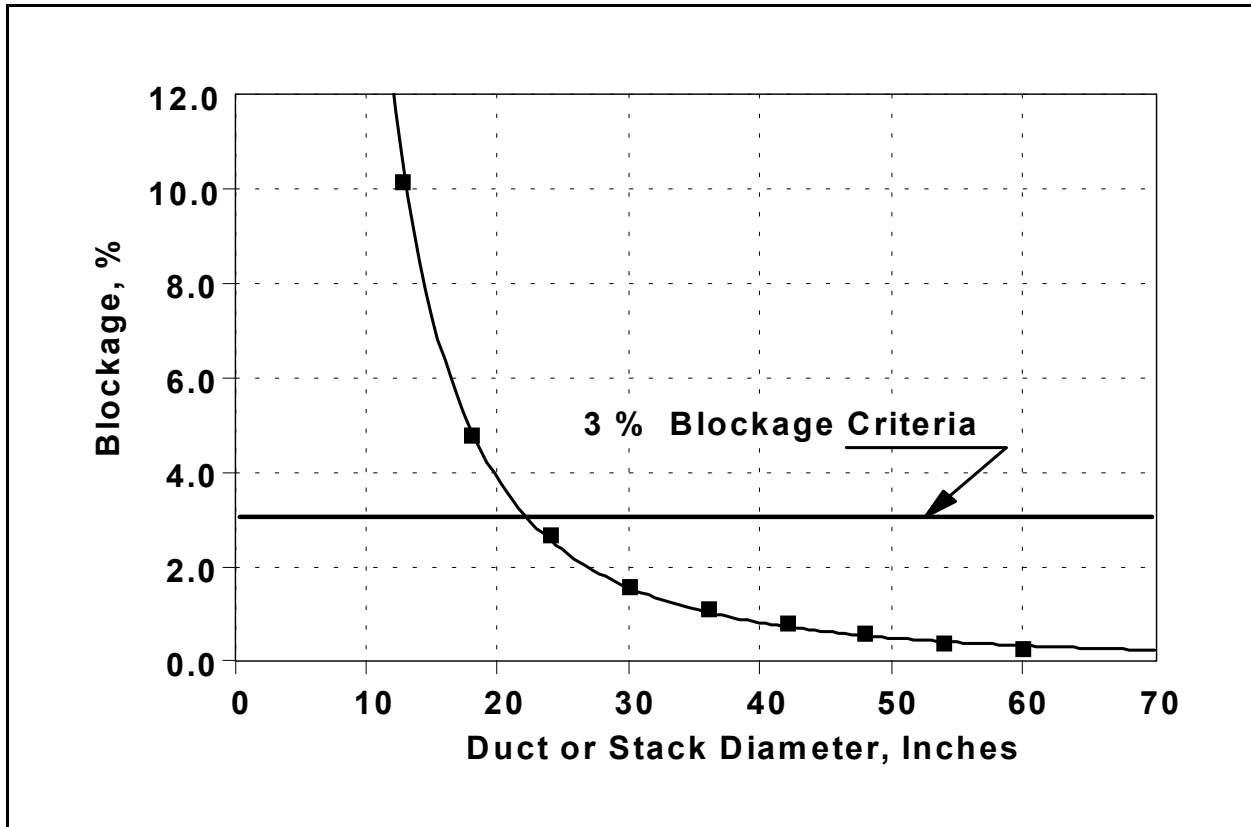


Figure 7. Gas Flow Blockage by the Combined Cyclone Sampling Head

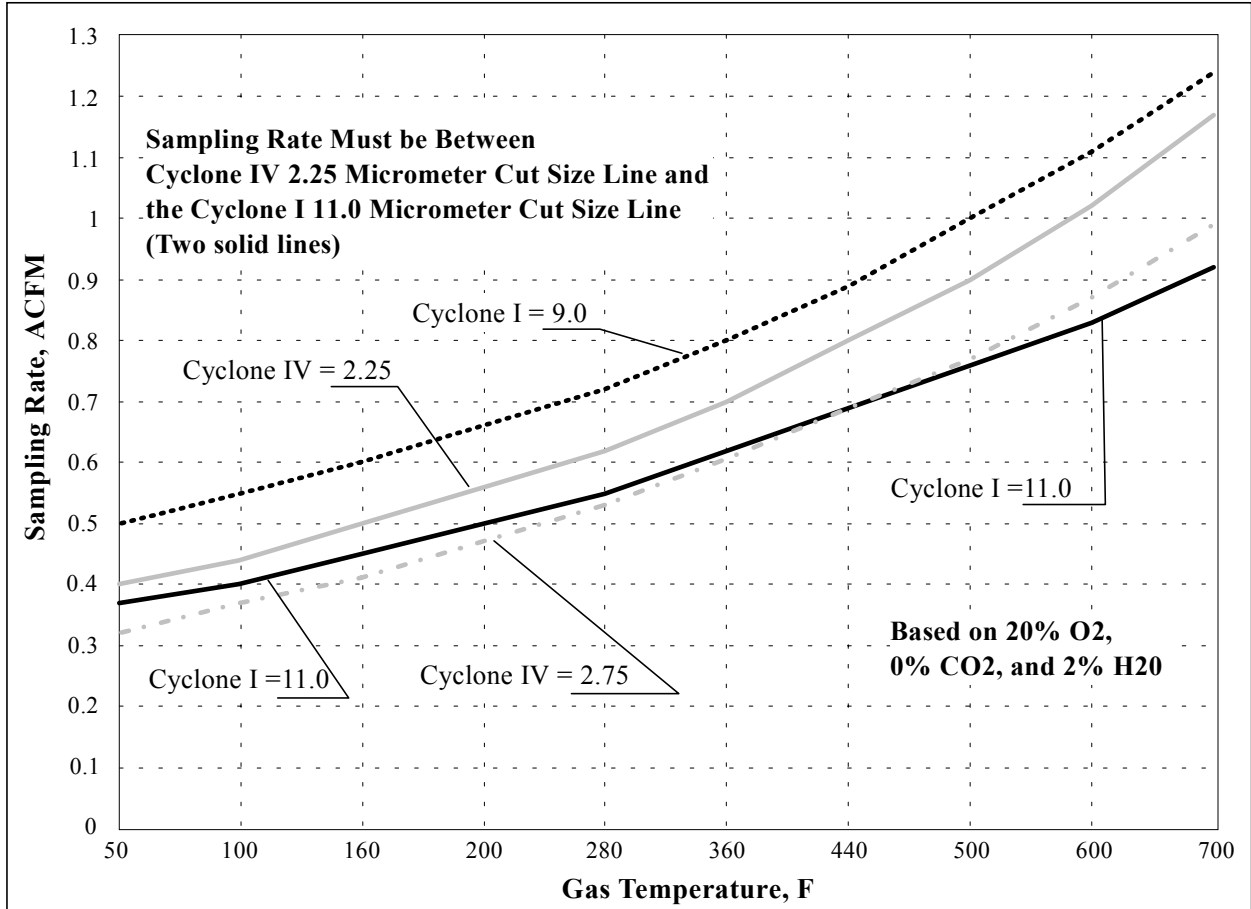


Figure 8. Acceptable Sampling Rate for Combined Cyclone Heads



# **PM10/2.5 for Windows**

**PM10 and PM2.5 Operation  
and Data Analysis**

**for use under the  
MS Windows  
Operating System**

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J.D. McCain**

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# General Overview of PM10&2.5

Although it is possible to do the setup and data analysis calculations for PM10 and PM2.5 sampling by hand or with calculators, the number of calculations which must be done to treat the data from just one run make hand calculations impractically laborious. When the treatment of data from multiple runs is considered it becomes obvious that a computer is required. In March 1978 a system of programs known by the acronym "CIDRS" (for Cascade Impactor Data Reduction System), written by Southern Research Institute, was published for use in handling particle size data by the U.S. EPA. CIDRS was written in Fortran for use on large "main-frame" computers and was later adapted for use on some minicomputers. Denver Research Institute released an adaptation of CIDRS written in BASIC for the TRS-80 micro-computer in March 1980. The current PM10/2.5 program was developed from an outgrowth of the original CIDRS program called WinCIDRS. The core elements that make up WinCIDRS were first written in BASIC for the Apple II micro-computer series and were released for that computer in 1983. Subsequently an updated and expanded adaptation of CIDRS, pcCIDRS, for use with IBM PCs and compatibles, was released in January 1992. WinCIDRS is an enhanced adaptation of pcCIDRS that was developed to take advantage of the ease of use and other features of the MS Windows operating system. One of the major enhancements was the inclusion of data analysis and operating assistance for cyclone samplers including the Southern Research Institute/EPA 5-Series Cyclone and the EPA PM10 and PM2.5 cyclone samplers. The cyclone provisions included rudimentary operational setup calculations for PM10 and PM2.5 sampling which has since been expanded to provide full support for PM10 and PM2.5 sampling and analysis. The PM10&2.5 program described here is a simplified version of WinCIDRS that deals only with PM10 and PM2.5 sampling and analysis.

The PM10/2.5 package consists of a group of integrated program elements (or modules) which together provide the capabilities to:

1. Calculate and store the values of needed ancillary data such as dry gas composition and moisture content of stack gases (Methods 3 & 4).
2. Reduce velocity (pitot) traverse data (Method 2) and aid in the selection of sampling flow rates and nozzle dimensions PM10 and PM2.5 sampling. The program also includes routines for calculating the flowrates and dwell times needed for performing Method 201A (Constant Flow Rate) PM10/2.5 sampling traverses.
3. Reduce the data from individual PM10/2.5 cyclone runs.

4. Results can be printed directly from within the program but can also be pasted into other Windows applications (e.g. Spreadsheets and Word Processors) through the Windows Clipboard and/or saved in text files for later import to such applications.

## Distribution Disk Contents and Installation of Programs

The program was written to be used with an IBM compatible microcomputer operating under MS Windows Version 3.1 or higher. It will also run under Windows95 but cannot make use of all features of Windows95 (e.g., long file names). The system is supplied on two disks and is installed by inserting Disk 1 into the appropriate floppy drive and running Setup from the Windows Program Manager in Windows 3x or the **Run** command in the Win95 Start Menu. For instance, if the PM10/2.5 Install Disk 1 is in Drive A, Select **R**un under **F**ile in the Program Manager Menus and type **A:setup**, then follow the instructions given by the setup program. The entire installed system requires about 4 Mbytes of disk space. The main program, PM10\_2p5.EXE and several subdirectories and data files will be installed in a directory named WinCIDRS on the hard-drive selected by the user. (WinCIDRS is used as the directory name in order to maintain compatibility with the remainder of the WinCIDRS system.) Several other Windows system routines will also be installed in the directory containing the Windows operating system. The installation disks are all copyable and it is recommended that the originals be write protected and preserved as master copies and duplicates be used as working copies. Some sample data sets have been included in the **RESULTS** and **ARUNDATA** subdirectories. The sample data-set files may be deleted at the user's discretion but the three subdirectories (Samplers, Rundata, and Results) must be retained as these are routinely used by the program. The **SAMPLERS** subdirectory contains the hardware configuration for the PM10 and PM2.5 cyclone set. (If the full WinCIDRS system is installed, it also contains a hardware configurations for a number of popular cascade impactor and cyclone setups.) All files other than the cyclone hardware configurations on the installation disks are in a compressed format and cannot be used directly.

Details on the experimental and theoretical foundations on which particle sizing with cyclones is based may be found in "Procedures Manual for the Recommended ARB Sized Chemical Sampling Method (Cascade Cyclones)". The latter document was written by Southern Research Institute for the California Air Resources Board in 1986 and is available through NTIS as publication PB 86-218674/WEP. This document can also be supplied by the author of WinCIDRS and PM10/2.5 for a moderate fee. The Portland Cement Association (5420 Old Orchard Road, Skokie, IL U.S.A., 6077-1083, Fax (847) 966 9781, (847) 966 6200) has generated another useful document, A Test Protocol: PCA PM<sub>10</sub>/PM<sub>2.5</sub> Emission Factor and Chemical Characterization Testing, PCA R&D Serial Number 2081.

## Online Help

An on-line help system is provided with the program which can be invoked from the PM10/2.5 menu listing. It can also be invoked for context sensitive help by pressing the F1 function key at any time, from any page (and entry cell) of the program. Brief explanations of the currently active data entry cell or the currently high-lighted command, etc. are also provided in the Title Bar across the top of the PM10/2.5 window. The Help System also includes information on a number of topics related to the use of inertial impactors and cyclones that may aid the user in obtaining the best data possible.

**Note:** The illustrations of the program screen displays used in this manual and in the program Help File differ slightly from those of the current version of the program. Six Atabbed≡ screen pages were used in previous versions of the program with one doing Adouble duty≡ by being switched between entry of stage weight data and velocity traverse data depending on the program operating mode that was in use. In the current version of the program a seventh Atabbed≡ page has been added for the velocity traverse data so both the stage weight and velocity traverse data entry pages are always available now.

# How to Use PM10/2.5:

<b>Analysis of Data from a Sampling Run:</b>	1
<b>Entering Field Data for Sampling Run:</b>	1
General Information about the Run	1
Retrieving Data from Previous Runs	3
Gas Composition	4
Hardware Details	6
Sampling Details	7
Stage Catch Weights	9
Providing Blank Corrections	10
<b>Choosing Analysis Options:</b>	
Doing Setup Calculations for Sampling Runs:	12
Analyzing Data from a Sampling Run:	12
Showing Intermediate Results	13
Velocity Traverses, PM10, and PM2.5	
Pre-Sampling Calculations	14
<b>Tabular Presentation of Results</b>	16
<b>Printing</b>	16
<b>File System and Directory Structure:</b>	17
<b>Drop-down Menus</b>	
File	18
Calculate	18
Mode	19
Help	19

# Analysis of Data from a Sampling Run:

Analyzing data from a particle sizing run requires that the particulars of the sampling circumstances be entered together with information on the particle sizing hardware that was used and the weights of the material collected by each stage of the sampling device. This information is entered in a series of seven Atabbed dialog pages, the first of which, shown below, is presented when the program is started.

^ ^ PM10/2.5 Main (Data Input and Reduction) Press F1 for Help

File Calculate Mode Help

### General Information on Sampling Run

Test Desig.:  Run No.:

Sample Type:  Inlet  Outlet  Stack Units:  English  Metric

File Name: Dummy.D10 Std. Temp.:  68F/20C  0C  25C

Date:

Start Time:  End Time:

Location:

Weight Units

- milligrams
- micrograms
- nanograms
- picograms

Remarks:

<b>General Information</b>	Gas Composition	Hardware Details
Sampling Details	Stage Weights	Analysis Options

## General Information:

This, the AGeneral Information dialog page, provides entries for several items that are not essential for calculating the results of a sampling run. However, some are needed if the data and/or results are to be saved for use later and others are simply intended to provide a means of compiling and saving pertinent information regarding the sampling run with its associated data. Information that is considered essential by the program is labeled in bold face while non-essential information is in plain type.

If the results for the run are not to be saved, the only essential items on this page are the selection of the units to be used for data entry, the temperature to be used for

standard conditions, and the units to be used for the particulate masses collected by the various stages of the sampler. Either Metric or English units can be used for entering data such as gas volumes, gas velocities, temperatures, pressures, flow rates, etc. The user selects the system for the units by clicking the appropriate button in the Units selection box. If the user changes the selection of English or Metric units, all affected entries in the current data set will automatically be converted to the selected basis. The specific units to be used for each data entry are given in the individual entry prompts as appropriate for the selected system of units. Only metric units are allowed for the amounts of material collected by the various stages of a sampler. However, the user may select either milligrams, micrograms, nanograms, or picograms as entry units for collected particle masses for any individual sampling run. This choice is made by clicking the appropriate button in the Mass Units selection box. The heading of the Stage Weights data entry page will change to reflect the choice made here. Concentrations will be expressed in terms of the input mass units selected for each individual runs. Depending on the organization for which the sampling is being done and/or the country in which the program is to be used, the temperature used in defining standard conditions may be 20 degrees Celcius (68 degrees F.), zero degrees Celcius, or 25 degrees Celcius. The program uses 20 degrees Celcius as the default value but either of the other two may be selected by clicking the appropriate button in the Std. Temp. selection box.

If the data and/or the results are to be saved on disk for later use, a file name is required and this is constructed from three other items on this page:

The Test Designation - This is comprised of up to six alphanumeric characters that can be selected by the user. These might be a shorthand code for a test site, a contract or job number, or any other combination of letters and numbers that the user chooses. This entry cell, like most data entry cells in the program, will permit entry of only those characters that the program considers legal for the data item. (For instance, the Test Designation will be used in constructing the file name so characters such as #, >, <space>, etc., are disallowed. The cell will accept entry of six or fewer characters only.)

The Run No. (or Run Number) - a two digit number designating a Run sequence number, permitting up to 100 runs (numbers 00 through 99) to be entered under a common Test Designation. (In fact, up to 300 runs can be entered under a common Test Designation when the next entry item is taken into account.) If a single digit number is entered, the program will add a leading zero to make it a two digit number.

The Test Type - Most sampling at industrial sources involves measurements at either the inlet or outlet of a control device (eg. an electrostatic precipitator, a baghouse, etc.), or at a stack. By clicking on the appropriate button, the user



selects one of the three as appropriate for the run being processed. One of these MUST be selected.

The file names used for storing the raw data and results are constructed from the former three items plus two more pieces of information to be discussed later. The ATest Designation≡ and ARun Number≡ are combined (in that sequence) to produce what is commonly thought of as the Afile name,≡ while the ATest Type≡ and the other two pieces of information form keys for constructing the three character Afile extension≡ that are appended to the Afile name≡ beyond the A.≡ in the complete specification of the file name.

The last item to discuss on the AGeneral Information≡ dialog page is the AGet Previous File≡ command button. Clicking on this button starts a AFile Open≡ dialog from which the user can load a previously stored set of run data. Saving the data allows an analysis to be repeated later with a different set of options. A data-file can also be used as a template for a set of similar samples. The latter can be particularly useful if several sampling runs have been done under similar conditions as only the items that changed from run to run have to be entered while those that did not will remain at their original values. The sampling hardware specifics, gas composition, etc., that pertained to the previous run are all picked up when the run is loaded. If a series of sampling runs for a particular job or test program are processed in this fashion the data for each run can be saved in an easily identifiable way by simply changing the Run Number and then doing a File Save operation. The Run Number then becomes an index to the data sets for the test series. The files of sampling run data are located in the WinCIDRS\RUNDATA subdirectory (or folder in Windows95).

When the AGet Previous Data≡ button is clicked, a >File Open= dialog box will appear which lists the available runs. Initially the list will include files for cyclone runs of all types (Inlet, Outlet, and Stack). This list can be changed to just impactor or cyclone runs of a single type (Inlet, Outlet, or Stack) by clicking the AList Files of Type≡ cell in the dialog box and clicking the type desired.

Note: Pressing the Escape key, <Esc>, during entry of any typed data input to the program will cancel the current changes that are being made and reset the contents of the entry to its original value.

## Gas Composition:

PM10/2.5 Main (Data Input and Reduction) Press F1 for Help

File Calculate Mode Help

### Composition of Sampled Gas Stream

Bulk Gas Composition Basis:

Dry  Wet

Component Percentages on Volume Basis:

O2	<input type="text" value="20"/>	N2	<input type="text" value="79"/>
CO2	<input type="text" value="1"/>		
CO	<input type="text" value="0"/>		
H2	<input type="text" value="0"/>		
CH4	<input type="text" value="0"/>		
H2O	<input type="text" value="16.6"/>		

General Information      Gas Composition      Hardware Details  
Sampling Details      Stage Weights      Analysis Options

As in other forms of source sampling, the composition of the gas stream being sampled is needed for data analysis (at least the composition in terms of major constituents) and this information is entered on this dialog page.

The bulk gas composition is entered in terms of percentages by volume (NOT mass!) either treating moisture (water vapor) like the other constituents, in which case the AWet≡ basis option is selected, or by entering the non-moisture constituents as percentages of the total ADry≡ gases. In either case the moisture (H2O) content is entered as a percentage of the total gas volume, but when the Adry basis≡ is used the non-moisture constituents total 100% among themselves, while in the Awet basis≡ case the entries are all expressed as percentages of the total gas volume, including moisture. In either case, the percentages for all constituents but nitrogen (N2) are entered by the user and the program calculates the value for nitrogen by difference as appropriate for the selected Awet≡ or Adry≡ basis. Great accuracy is not required for the values to be entered in terms of the particle size calculations, but the calculations are somewhat sensitive to them through their effects on gas viscosity and gas density.

Hydrogen (H<sub>2</sub>) and methane (CH<sub>4</sub>) have been included because some users of this software are working in coal gasification processes. (Other gases can be accommodated as well in special application versions of the program, should a user have such a need. If so, see the sections [AObtaining Technical Information](#) and [AConsulting Services](#) in the Help Menu.)

If the volume of condensed water was measured as part of the field data obtained during a particle sizing run, the measured amount of water can be entered as part of the [ASampling Details](#). If this is done, the moisture content will be calculated for the sampling run and the result of the calculation will replace the value entered here.

Hardware Details:

The screenshot shows the WinCIDRS Main (Data Input & Reduction) software interface. The title bar is black with white text. Below the title bar is a menu bar with the following items: File, Calculate, Mode, Help. The main window is titled "Sampling System Hardware Details". Inside this window, there is a section for "Sizing Device". Under "Sizing Device", there is a label "Current Imp./Cyc.:" followed by a text box containing "PM10-2P5.CYC". To the right of this text box is a button labeled "Get New Imp/Cyc". Below the text box, there is a line of text: "PM10 and PM2.5 cyclones". At the bottom of the window, there is a tabbed interface with three tabs: "General Information", "Gas Composition", and "Hardware Details". The "Hardware Details" tab is currently selected and active. Below the "Hardware Details" tab, there is a sub-tabbed interface with two sub-tabs: "Sampling Details" and "Analysis Options".

The PM10 and PM2.5 cyclone sampler information is automatically loaded from a disk file located in the WinCIDRS/SAMPLERS subdirectory when the PM10/2.5 program is started. This will be reflected in the sampler selection entry box. In the PM10/2.5 program this entry is informational only and cannot be changed by the user.

## Sampling Details:

This is the data entry page for most of the specific details concerning the circumstances of how the sample was taken.

Barometric pressure, stack ( or duct) differential pressure to ambient, stack temperature and impactor (or cyclone) temperature, the sampling duration, and either the sampling flow rate or information from which the program can calculate the flowrate must be

WinCIDRS Main [Data Input & Reduction]

File Calculate Mode Help

### Specific Details of Sampling Run

DGM Volume (cf):	Start <input type="text" value="0"/>	End <input type="text" value="0"/>	Net <input type="text" value="4.425"/>
GM Corr. Factor	<input type="text" value="1.043"/>		
GM Temp. (deg F)	<input type="text" value="80"/>		
Orifice DH (in.H2O)	<input type="text" value=".18"/>	Orifice DH@ <input type="text" value="1.84"/>	
Stack Temp. (deg F)	<input type="text" value="170"/>		
Impactor Temp. (deg F)	<input type="text" value="170"/>		
Stack Diff. Pres. (in. wc)	<input type="text" value="-25"/>	Flow Rate and Sample Volume From:	
Barometric Pres. (in. Hg)	<input type="text" value="30.05"/>	<input checked="" type="radio"/> DGM <input type="radio"/> Orifice <input type="radio"/> Manual Entry	
Nozzle Dia. (in.)	<input type="text" value=".128"/>		
Sample Duration (min.)	<input type="text" value="18"/>	Sample Flow Rate (acfm)	<input type="text" value=".381545"/>
Pitot DP (in. wc)	<input type="text" value="0"/>	Pitot Const. <input type="text" value=".84"/>	Gas Velocity (fps) <input type="text" value="67"/>
Cond. H2O (g or ml)	<input type="text" value="0"/>		

Sampling Details    Stage Weights    Analysis Options  
General Information    Gas Composition    Hardware Details

provided. (The flowrate is not required if the program is being used in the APreliminary (or Setup) Calculations≡ mode.)

The nozzle diameter is required for calculating the isokinetic sampling ratio (percent isokinetic).

It should be noted that the cyclone temperature can be different from the stack (flue gas) temperature. This allows for situations in which the sampling device is heated to temperatures above that of the gas being sampled such as might be done if sampling

downstream of a scrubber or when sampling a gas stream with a temperature close to that of some condensible vapor (SO<sub>3</sub> for instance). Conversely, the sampling device might be operated at a lower temperature than the flue gas as might be the case with an extractive system in which the particle sizing device is located outside the duct and is at a temperature below that of the duct. The appropriate temperatures are then used for the respective portions of the sampling system (the nozzle and entry portions and the remainder of the particle sizing system).

Note: The Flow Rate entry used in PM<sub>10/2.5</sub> is the flow rate at the conditions of the sampling nozzle. The sampling flow rate can be entered directly in the AFlow Rate≡ entry cell or it can be calculated in several ways. If the sampling-start and sampling-end readings of a dry gas meter are entered in the appropriate cells(DGM Start and DGM End), the program will calculate the net meter volume. Alternatively, the net meter volume can be entered directly in the ADGM Net Vol≡ cell. In either case, the net meter volume and the ADGM Corr(ection) Fact(or),≡ or Gamma, will then be used to calculate a corrected meter volume. The total sample volume at sampling conditions can also be calculated from direct entry of the corrected meter volume in the DGM Net Volume cell. If the corrected volume is entered directly, the DGM Correction Factor should be set to unity (value = 1). If the dry gas meter information is provided, the program will calculate the total sample volume at flue gas and standard conditions based on the gas meter data and the flow rate from the latter and the sample duration. Alternatively an orifice meter pressure drop (Orifice DH) and orifice meter calibration constant (Orifice DH@) can be entered and the program can calculate the flow rate from these. In the latter case, the total sample volume will be calculated from the flowrate and sample duration. As the required information for obtaining the sample flow rate is entered for each of the ways it can be done, that option will become available in the ACalculate Flow From≡ options box. If the flow can be obtained in more than one way, the user can select the means the program is to use by clicking the appropriate option button.

The flue gas velocity can be entered directly in the AGas Vel(ocity)≡ cell or the program will calculate it if appropriate entries are made in the APitot DP≡ and APitot Const(ant)≡ boxes. If the AVelocity Traverse≡ mode of the program is used for reducing data from a pitot and temperature traverse of the duct or stack, the appropriate averages will automatically be calculated by the program and inserted into their respective cells on the ASampling Specifics≡ data entry page.

## Stage Weights:

PM10/2.5 Main (Data Input and Reduction) Press F1 for Help

File Calculate Mode Help

### Stage Catch Weights

**Net Wgts From:**  Manual Entry  
 Init. + Fin. Wgts

**Blank Corr. From:**  Manual Entry  
 Blank Stg + Fil.

**Active Cell Contents:**

Edit contents of active cell in upper box. Press Enter to accept. Use arrow keys to move from cell to cell. Do not use Tab Key.

Stage	Initial Wgt.	Final Wgt	Gross Gain	Blank Corr.	Net Gain
Cyclone 1					
Cyclone 2					
Blank Stage					
Filter					
Blank Filter					

Sampling Details

**Stage Weights**

Analysis Options

General Information

Gas Composition

Hardware Details

Stage catch weights are entered in a spreadsheet-like form as shown above. Two of these rows will always be for entry of information regarding ABlank Corrections and the remainder will be for the sampler stages and a backup (or final) filter. If initial and final weights are entered, the program will calculate the gross and net weights from the initial and final values. If net weights have already been calculated outside the program, they should be entered as AFinal Weights with the initial weights being left blank or entered as zero. If values are entered directly in the ABlank Correction cells, the program will subtract the blank correction values from the stage and filter weights to obtain net weights to use for the particulate concentration calculations. For a discussion of blank corrections look under that topic under Help.

Movement between cells in the table is made using the arrow keys (Note: the TAB key will take you out of the Stage Weight entry table to the Page Selection tabs at the bottom of the entry form.) To enter new data and/or edit a cell value simply use the arrow keys to reach the desired cell and begin typing. The current contents of the

selected cell will then appear in the Edit Cell above the table and the actual editing/entry is done there. Press <Enter> ( the enter key) to return the completed entry to the table at which time the table will be updated and the arrow keys can once more be used to move around in it. Negative and/or zero net stage weights (except for stage and filter blanks, of course) are not allowed and calculation will be halted and a warning will be issued if any net stage or filter weights are negative or zero.

The AGross Gain $\cong$  is calculated as the difference between the initial and final weights for each entry line of entries. Negative and zero values are acceptable in the Gross Gain column. The values in the ABlank Corr(ection) $\cong$  column depend on the user=s selection between the options of Blank Corrections from AManual Entry $\cong$  or from ABlank Stage and Filter. $\cong$  If the former is selected, the user must enter the corrections (if any) individually for each stage. If the latter is selected, the value of the Gross Weight on the Blank Stage entry line is copied automatically into the Blank Correction cells for the impactor stages and the value of the Gross Weight for the Blank Filter is automatically copied into the Filter Blank Correction cell. The net weights for all stages and the filter are then taken as respective Gross Weights less the corresponding Blank Corrections.

If the Net Weights are to be entered manually, that option must be selected in the ANet Weight From... $\cong$  option box so that the automatic calculations will be suppressed.

If the calculations are to be done the Asetup $\cong$  mode preliminary to starting a sampling run or test series, stage weights are not required and can be left blank.

### Providing Blank Corrections:

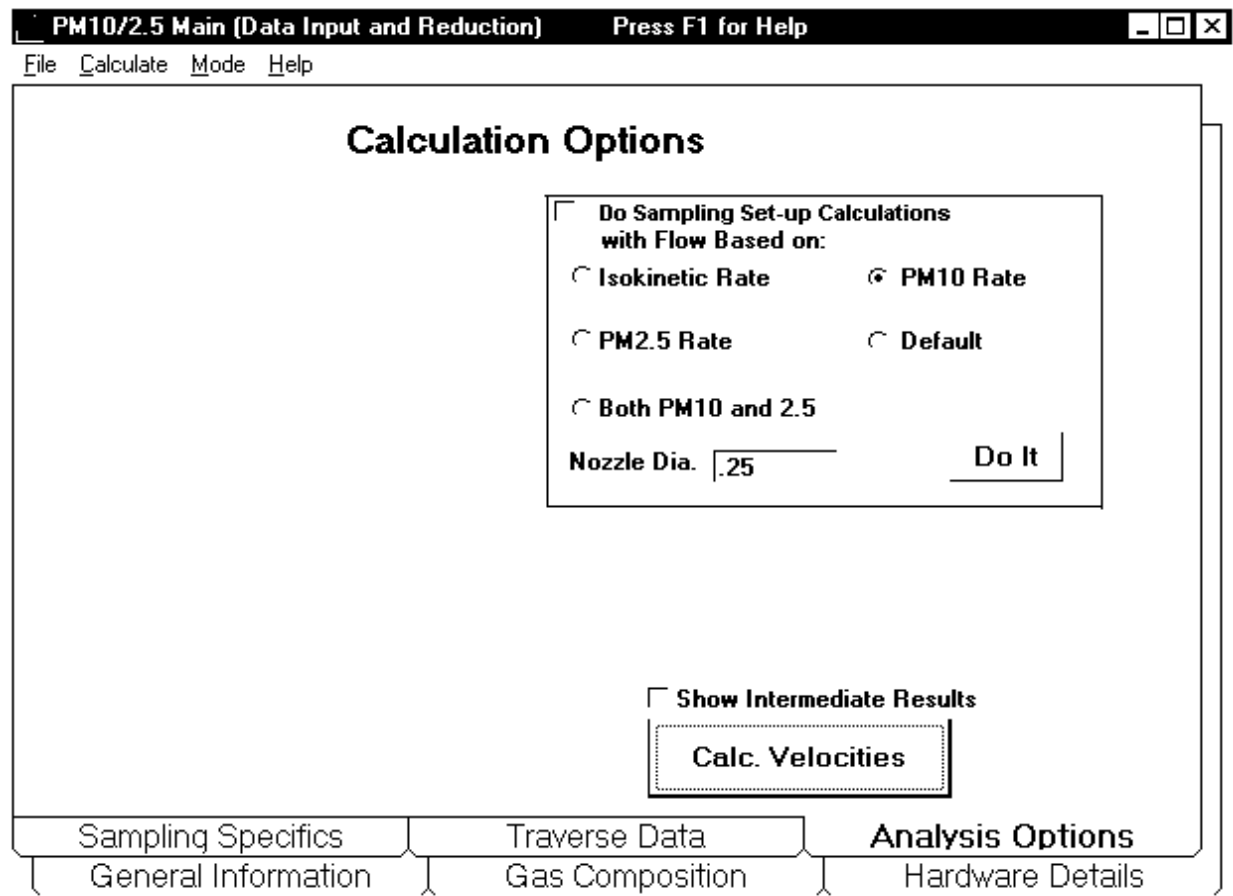
Collection media can undergo weight changes that are the result of things other than adding collected particulate matter to them. Such weight changes can arise from unexpected changes in the moisture content of filter media, chemical reactions with gaseous components of the sampled gas stream (SO<sub>2</sub> for example), or unexpected zero offsets on the balance used to weight the collection media. Any of these changes will bias the results in unknown ways unless steps are taken to account for them. Similar weight changes can occur with filters used for total particulate sampling such as EPA Methods 5 and 17. When measuring total particulate concentrations a reaction that causes a 0.5 mg to 1 mg weight change is of little consequence because the total catch is typically several milligrams to several hundred milligrams. But in the case of PM<sub>10</sub> and/or PM<sub>2.5</sub> sampling the catch weights on some stages may be only a few tenths of a milligram to a few milligrams and an error of a half to one milligram may represent a substantial relative error. The program provides two ways to deal with the problem through the use of Blank Corrections.



For final filter blanks, one way is to simply place a second filter behind the usual final filter. The particulate matter passed by the last stage of the cyclone sampler is collected by the final filter so the filter placed behind it is exposed only to the flue gas. This Ablank filter $\cong$  can thus provide a way to check for any weight changes due to things other than collected particulate matter and any change that occurs to it can be subtracted from the weight change of the real filter. The stage weight data entry table provides entry lines for incorporating such Ablank filters $\cong$  and Ablank stages $\cong$  in the data set and, if such blanks are included in the runs, the program can automatically account for the weight changes that occur on them.

Alternatively, a complete sampling run can be made with a filter mounted ahead of the sampler so that the sampler and its final filter are exposed to the flue gas under the same conditions as those used in the real sampling runs but do not collect any particulate matter. If this is done, select the AManual Blank Correction $\cong$  options and enter any weight changes observed in such a Ablank run $\cong$  in the column labeled Blank Corr(ection) in the stage weights entry table. The program will then apply these values as corrections in calculating the net weights to be used when analyzing the data.

## Analysis Options:



**PM10/2.5 Main (Data Input and Reduction) Press F1 for Help**

File Calculate Mode Help

### Calculation Options

Do Sampling Set-up Calculations with Flow Based on:

Isokinetic Rate       PM10 Rate  
 PM2.5 Rate       Default  
 Both PM10 and 2.5

Nozzle Dia.

Show Intermediate Results

Sampling Specifics      Traverse Data      Analysis Options  
 General Information      Gas Composition      Hardware Details

After completing the entries on the preceding dialog pages, the final step in the process is calculating the appropriate sampling flow rate and traverse point dwell times if preparing for sampling or calculating cyclone cut-diameters and the particulate concentrations in each size fraction if post-test data analysis is being done.

**Do Sampling Set-up Calculations Option:** The choice between processing a real sample and doing a set of preliminary calculations in preparation for performing a run or series of runs is made by means of the Menu **AMode** entry selection. If either the **ASampling Setup** or **AVelocity Traverse. . .** Mode has been selected, a set of preliminary calculations to aid in taking a sample will be made when the **AReduce Run Data** command is executed. If the box is checked, there are five possible ways in which the sampling flow rate to be used can be calculated by the program.

1. If a nozzle size and a gas velocity (or the Pitot information needed to calculate a gas velocity) have been provided by the user, the **Alsokinetic Flow** option will be available.

If this option is taken, the flow rate required for isokinetic sampling will be calculated for that nozzle and gas velocity combination and the stage D50s will be calculated for the selected sampling device at the operating conditions that the user specified. If an orifice meter calibration constant was provided by the user, the program will also calculate the orifice meter pressure drop (Orifice DH) required to obtain the target flow rate.

2. The ADefault≡ option will be available if the information for calculating a flow rate from a set of dry gas meter data or from an orifice meter pressure drop and calibration constant has been provided by the user. The ADefault≡ option will also be available if the user has specified a sampling flow rate on the ASpecific Details≡ data entry page. The latter allows the user to run Awhat-if≡ trials to check on the D50s that a sampling device will provide at user selected flow rates.

3, 4 and 5. Options are also available for calculating the sampling flow rate required to perform PM10 or PM2.5 sampling or combined PM10 and PM2.5 sampling and using that flowrate for calculating the D50s of the selected sampling device(s). Again, the orifice meter pressure drop required to obtain the target flow rate will be calculated if the orifice meter calibration constant has been provided on the ASampling Details≡ page.

Under the ADo Set-up Calculations≡ option the program calculates the stage D50s, pressure drops, etc., but bypasses the size distribution calculations and presentations. Consequently stage weights are not needed nor used in the calculations done under this option. Output from this mode includes the nozzle diameter required for isokinetic sampling at the selected flow rate, the sampling flow rate at actual and standard conditions, and the projected D50's for the two cyclones. The latter is especially useful if combined PM10 and PM2.5 sampling is to be done.

Show Intermediate Results: A number of intermediate results can be viewed as the calculations proceed if this option is elected. These include:

- The wet and dry molecular weights of the sample gas stream
- The gas density of the sample gas stream
- The gas viscosities at the stack temperature and sampler temperature
- The jet velocity and Reynolds Number for each stage of the sampler
- The pressure drops for each stage of the sampler
- The discharge coefficient for each stage of the sampler
- The flow rate at flue gas, sampler, and standard conditions
- The Square Root of Psi50 (the stage Acalibration constant which is actually not a constant at all but depends on Reynolds Number.)

Do Calculations: When all desired options have been selected, clicking the ADo Calculations≡ command button will initiate the calculation sequence. If the AShow

Intermediate Values option was selected, the results will be displayed as the calculations proceed. Otherwise, there will be a short pause while the calculations are carried out and the results are formatted for display on the screen. Upon completion of these actions, the results will be displayed in tabular fashion.

## Velocity Traverses, PM10, and PM2.5 Pre-Sampling Calculations

WinCIDRS and PM10/2.5 contain routines for doing all calculations required for PM10/PM2.5 sampling. Calculation of sampling flow rates is discussed in the section on A Set Up Calculations related to impactor and cyclone operation. The AMode menu item contains an option for performing analysis of velocity traverse data and calculation of Method 201A (PM10 CFR method) sampling dwell times and the velocity/pitot dp limits that must not be exceeded for the results to be valid. If this mode is selected, the input form, shown below, for pitot traverse data is used to enter pitot pressure differentials and flue gas temperatures on a point by point basis over the area to be sampled. If this mode is selected, the calculation command will invoke routines for calculating point by point velocities, PM10/PM2.5 dwell times, and CFR isokinetic ratios for each traverse point. The output in this mode consists of a series of tables containing the velocities, M201 dwell times on a point by point basis, and a table of dwell times

**PM10/2.5 Main (Data Input and Reduction) Press F1 for Help**

File Calculate Mode Help

### Velocity Traverse Data Input

**Traverse Layout**

Ports Across

Ports Down

**Number of Ports and Points**

Across - Ports

Down - Points

**Active Cell Contents:**  Edit contents of active cell in upper box. Press Enter to accept. Use arrow keys to move from cell to cell. Do not use Tab Key.

Port:	Port	1	Port	2	Port	Avg.
Point	DP	T	DP	T	DP	T
1						
2						
Avg.						

Sampling Specifics

**Traverse Data**

Analysis Options

General Information

Gas Composition

Hardware Details

versus pitot dp entries. If a nozzle diameter and sampling flow rate have been entered (or calculated), a table of isokinetic ratios, expressed as percentages, is also generated to allow checking against the prescribed limits set by M201 or the (draft) PM2.5 method together with upper and lower limits to gas velocities and corresponding pitot pressure differentials for the selected nozzle for acceptable sampling.

Data entry is performed in a manner like that used for entering stage catch weights. The data entry table can be set up for the ports to go across the table and the points for each port to go down the form or vice-versa. The default (ports across) layout is probably best, but if the number of ports is larger than the number of points per port, the APoints Across layout will be better in terms of output formatting. The default form size is for a 2 port by 2 points/port layout. However, the form can be adjusted to accommodate a single point (1 point in 1 port) up to 12 ports by 12 points/port. Changes in the number entry lines and columns (actually column pairs, one for pitot dp and one for temperature) is made by adjusting the values in the ANumber of Ports and Points, AAcross and ADown values. These are changed by clicking either the upward (increase) or downward (decrease) triangles adjacent to the cells containing the current values. The traverse data are entered as pitot pressure differentials and flue gas temperatures for each point in the traverse. Pitot dp's and flue gas temperatures are entered in inches of water and degrees Fahrenheit respectively if English units are used and cm of water and degrees Celsius if Metric units are used. The pitot and temperature entries data are entered in a tabular form similar to that used for stage catch weights. Average temperatures and pitot dp's are calculated for the overall traverse and for all points for each port and all points having a common depth (that is, row and column averages are calculated as well as the overall average). The Average pitot dp's are actually the squares of the averages of the square roots of the dp's, as needed for correctly calculating average velocities, etc. The overall effective average pitot dp (from the averages square root to the dp's) and average gas temperature are carried over automatically to the corresponding data entry cells in the ASampling Details data entry page for use in doing setup calculations for particle sizing runs.

It is suggested that if PM10 or PM2.5 sampling is to be done, the user should first enter the preliminary velocity traverse data. The average gas temperature and effective average pitot DP are calculated as the velocity traverse data entries are made. After entering the data from the preliminary velocity traverse, enter a trial nozzle diameter and set the flow rate via the PM10, PM2.5, or Both PM10 & PM2.5 ASetup options. If the percent isokinetic result is in the 90% to 110% range, proceed with the velocity calculations. Otherwise select a new nozzle size and repeat the flow rate/percent isokinetic calculation until a suitable nozzle has been identified then do the velocity calculations. At this time the program will calculate the isokinetic ratio at each point based on the prescribed sampling flowrate and the selected nozzle size. If the isokinetic ratios do not fall within the allowable limits for all sampling points (with one allowable exception), the calculations can be repeated with another nozzle size to see if one is available that does meet the specifications of the method for all sampling points. In the event that no nozzle can be found which is suitable for all points on the traverse, the sampling area must be broken down into two or more zones with a nozzle suitable for each zone being selected for use with the nozzles being changed as

necessary during the traverse. The velocity traverse data can be saved as a data file to be reloaded for use at a later time and the results can be posted via the Windows Clipboard for use in a spreadsheet or inclusion in a report, etc.

## Tabular Presentation of Results:

The results from the analysis of a PM10 and/or PM2.5 sampling run are presented on a stage by stage basis in a text window. All or part of these tabulated results can be selected and copied to the Windows Clipboard from which they can be *A*past<sup>e</sup>d into a Windows spreadsheet or word processor immediately.

The stage by stage results include the calculated stage D50s, the Cunningham Correction for each stage, the percentage of the total catch that was passed by each stage, the stage Reynolds Number, the pressure drop of each stage, and the particulate concentration for each stage.

Results from velocity traverse calculations including point by point velocities, average velocity and temperature, Method 201a dwell times for each traverse point, and dwell times *versus* pitot dp are all provided in a series of tables that will appear in a text window upon completion of the calculations.

## Printing Results

The tables of results can be printed directly from PM10/2.5 by selecting the part of the tabular display to be printed and invoking Print under *A*File<sup>e</sup> in the PM10/2.5 Menu. To select a block of text, position the cursor at the start of the desired segment and then drag it over the segment while holding the mouse button down. This can also be done, perhaps more easily, by positioning the cursor at the desired starting point and then running the cursor over the desired text with the arrow keys while holding the shift key down. Printing in this manner does not permit selection of fonts, nor does it allow any reformatting of the text.

A copy of the results text is automatically placed on the Windows *A*Clipboard<sup>e</sup> at the same time the results are displayed on the screen. Alternatively, the text can be selected as described above, which places it on the Windows *A*Clipboard.<sup>e</sup> If a Windows based word processor is running at the time or is then started, the selected text can be *A*Past<sup>e</sup>d into the current (or a new) word processor document where it can be edited and formatted as the user wishes. (The text used in the screen displays is CourierXa mono-spaced font which simplifies the alignment of the text in each column when assembling the screen displays.



## File System and Directory Structure

PM10/2.5 is installed with a main directory, WINCIDRS, and three subdirectories: WINCIDRS/RUNDATA, WINCIDRS/RESULTS, and WINCIDRS/SAMPLERS. The PM10/2.5 program and help files are located in the main directory, individual run data files are stored in RUNDATA, individual run results are stored in RESULTS, and particle sizing sampler configurations are stored in SAMPLERS.

File names in the RUNDATA files are comprised of an alphanumeric Test-Designation character string of up to six characters plus a two digit numeric Run Number. The file extension is used as a key for identifying three additional pieces of information. The first character after the dot (A.≡) is a AD,≡ identifying the file as a Adata≡ file. The second character is a AC≡ to identify the type sampler that was used in doing the run (cyclone). Velocity and stage weight data are stored in a common file. The third character in all cases is either an AI,≡ an AO,≡ or an AS≡ to identify the run type; I(nlet), O(utlet), or S(tack).

# Drop-Down Menus

The data entry portion of the program provides four drop-down menu entries:

File  
Calculate  
Mode

and

Help.

All of these contain several sub-menu selections as described below. (Menu items that are not currently available at any given time are grayed out. For instance, results cannot be saved (under File) until they have been calculated.)

## **File:**

There are five menu options under File:

New - Clears all data entries and sets up the program for the entry of a new data set.

Open - Provides a choice of opening (loading) either a data file. Selection of this menu item opens a standard Windows File-Open Dialog Box which will list all available data files of the appropriate type.

Save - Provides a means of saving either raw data.

Print - Prints the results of a set of calculations in tabular form. An option to print the raw data as well is given during the print setup process.

Exit - Close and exit the PM10/2.5 application. This command should always be used to close and exit the program. Otherwise, some parts of the system may needlessly remain in the computer's memory (RAM), reducing the amount of memory available to other applications that are used subsequently.

## **Calculate:**

There are three possible options available under Calculate:

Reduce Run Data - Initiates calculations of results for current data set.

Setup Calc=s - Initiates calculations when using the program to do setup calculations prior to performing a sampling run.

Traverse Points - Invokes routine for calculating the locations of standard traverse points in round and rectangular ducts and the distances from the sampling nozzle to the needed index marks on a sampling probe to position the nozzle at the traverse points.

Velocities and Dwell Times - Sets up data forms for entering and reducing velocity traverse data.

### **Mode:**

Particle Sizing Data Analysis - Configures WinCIDRS for entry and analysis of particle sizing data.

Velocities, PM10/PM2.5 Dwell Times - Configures WinCIDRS for entry and analysis of velocity traverse data and calculation of PM10/PM2.5 sampling dwell times.

Sampling Setup Calculations - Configures WinCIDRS for doing sampling flowrate and orifice meter dp calculations in preparation for taking a sample.

### **Help:**

Contents - Displays the Table of Contents for the Help System.

Search for Help on... - Provides search capabilities for topics and keywords for which WinCIDRS can provide help.

Index - Provides an index of topics and keywords contained in the WinCIDRS Help Files.

Obtaining Technical Support - Provides information on how to obtain technical support on PM10/2.5 and consulting services on particle sizing in general.

About PM10/2.5 - Provides copyright and version information regarding the program.

## Glossary:

**Aerodynamic Diameter** - Diameter of a spherical particle with a density of 1 g/cc that has the same behavior in air as the particle in question (same settling velocity....)

**Available Files** - Files in a directory that meet a given file specification. For instance files of run results that were done at outlet locations and were calculated on the basis of aerodynamic diameters would be available under the file specification: \*.?AO.

**Barometric Pressure** - Local barometric pressure at the meter box location at the time sampling is done. Expressed in inches of mercury in English units and millimeters of mercury in Metric units.

**Blank Corrections** - corrections to made to the apparent weights of material collected on impactor stages and filters to account for weight changes resulting from factors other than the collected particulate matter.

**Blank Filter** - Filter that is exposed to the gas stream being sampled for the same time duration and under the same conditions as the final filter in a particle sizing device. It serves as a control and is used to provide a value for any blank correction that might be needed to obtain an unbiased catch weight for a backup filter.

**Blank Stage** - Impactor collection substrate that is exposed to the gas stream being sampled for the same time duration and under the same conditions as the substrates used to collect the impacted particles at each stage of a particle sizing device. Or, in the case of cyclone samplers, this might be the weight of any residue left from drying a like quantity of solvent used in recovering material collected in a cyclone. It serves as a control and is used to provide a value for any blank correction that might be needed to obtain unbiased catch weights for the impactor and/or cyclonestages.

**Bulk Gas Composition** - The composition of the sampled gas in terms of those components that contribute significantly to the mass of the gas, gas viscosity, molecular weight, etc. For combustion sources these components are typically nitrogen, oxygen, carbon dioxide, and carbon monoxide in some cases. Water vapor may be treated as one of the bulk gas constituents, in which case the bulk gas composition is said to be on a *Awet* basis, or it may be treated separately from the others in which case the bulk gas composition is said to be on a *dry* basis. The bulk gas composition totals 100% in either case. Trace constituents with concentrations below about 0.5% are generally ignored so far as the bulk gas composition is concerned.

**Calculate** - Menu item which provides access to the major calculation options available in WinCIDRS (Single Run Analysis, Velocity Traverse Data Analysis, Traverse Point Locations...).

Cascade Impactors - Multistage inertial particle separators which operate by forcing a gas stream to make an abrupt turn, usually 90 degrees. Particles whose inertia is great enough will cross the flow stream and impact on a collection surface. If the particles contacting the collecting surface adhere to it, they will be removed while particles with less inertia will be carried on with the gas. By using sequential stages with each having a greater approach velocity and/or a shorter turning radius (smaller jet diameter) smaller particles can be removed at each successive stage, thus providing a mechanism for classifying and separating particles by size.

Clipboard - A temporary cache that the Windows operating system uses to hold text and graphics during cutting, copying and pasting operations. The material in the cache is available for pasting into any Windows application until it is deleted from the clipboard or is replaced by another operation that uses the clipboard.

Coefficient of Discharge - A function of Reynolds Number and other parameters that relates the pressure drop across head-type flow meters, flow nozzles, orifice plates, etc. to the volume or mass flow through them. This is used in WinCIDRS in calculations of stage pressure drops for impactors and cyclones.

Collection Substrate - The surface on which particles impact and accumulate in each stage of a cascade impactor.

Condensed H<sub>2</sub>O - The volume of water collected in impingers, condensers, or drying agents (silica gel, etc.) that was in the vapor phase in the sampled gas stream. If the quantity of condensed water is provided as input data together with a dry gas volume from a gas meter, WinCIDRS will calculate a moisture content, the value of which will override any value entered on the gas composition data page.

Consulting - Consulting services with regard to data analysis, sampling methods and programs, development of special purpose samplers, and field measurement services related to the measurement of particle size distributions, PM<sub>10</sub> and PM<sub>2.5</sub> are available by the developer of WinCIDRS and/or his coworkers. Call for current rates and services.

Copy & Paste - The text in the tabular presentations of results in WinCIDRS can be selected and copied to the Windows Clipboard for transfer to spreadsheets or word processors. Use the mouse or arrow keys to position the cursor at the start of the desired section of text and then, while holding the <Shift> key down, drag the cursor over the text using the mouse or move it through the text with the arrow keys until the end of the desired section is reached. When the desired text has been highlighted in this fashion, press <Ctrl-C> (that is, press the AC≡ character key while holding the AControl≡ key down) to copy the selected text to the clipboard. If the application in

which the text is to be copied is then entered, the text can be pasted into it either through the use of an Edit-Paste command in the second application's menu (or in some cases simply by pressing <Ctrl-V> at the desired insertion point).

To select the entire text of the results, click in the results text box, press <Ctrl-Home> and then press <Shift-Ctrl-End> (Shift, Control and End keys simultaneously). This will highlight the complete results text which can then be copied to the clipboard by pressing <Ctrl-C>.

**Cumulative Mass Concentration** - Total mass concentration of particulate matter contained in particles smaller than a stated diameter. Concentration units in WinCIDRS are milligrams per dry normal cubic meter (mg/dncm)

**Cumulative Number Concentration** - Total concentration of particulate matter in terms of numbers of particles larger than a stated diameter. Concentration units in WinCIDRS are number of particles per dry normal cubic meter (number/dncm)

**Cumulative Weight Percent** - Percentage by mass (or weight) of total particulate concentration that is in the form of particles smaller than a stated diameter.

**Cunningham Correction** - Correction which accounts for change in effective particle drag (aerodynamic resistance) from a simple viscous flow model when the particle diameter is comparable to or smaller than the mean free path of the gas molecules. Accounts for a breakdown in Stokes law for calculating particle motion in fluids when the particle size is small as compared to the mean free path.

**Custom Services** - Data analysis, custom data analysis software, sampling program planning, operator training, and other services are available on a fee basis. Call for details.

**Cut Diameter** - The particle diameter that is assumed to be the effective cutoff diameter for particle collection by a cyclone or a stage of an impactor. If the collection efficiency of a cyclone or impactor stage were a step function from zero to one-hundred percent, this would be the diameter at which the step took place. In the case of real cyclones and impactors, the cut diameter is usually defined to be the diameter at which the collection efficiency is 50%. The latter diameter is also termed the AD50" of the cyclone or impactor stage. Provided the cut diameters, or D50s, of successive stages are spaced far enough apart. The excess mass collected on a stage from material contained in particles smaller than the D50 is offset reasonably well by the failure to collect some of the particles larger than the D50. Thus the mass collected on the second of two stages in sequence can be considered to be a close approximation to the true mass of particles having sizes between its D50 and D50 of the preceding stage. This approximation breaks down if the two stage efficiency curves have significant overlap.

The D50 of a stage is calculated from the equation:

$$D50 = \sqrt{18 * \Psi_{50} * \text{GasViscosity} * \text{JetDiameter} / (\text{CunninghamCorrection} * \text{JetVelocity} * \text{RhoP})}$$

where

$$\text{Sqrt}(x) = \text{square root of } x$$

and

$$\text{RhoP} = \text{density of the particle.}$$

In the case of cyclones, the jet diameter and jet velocity become inlet throat diameter and inlet throat velocity.

Copy/Cut & Paste - Standard means provided by most Windows applications for editing text and graphics by placing copies of the desired material on the Windows Clipboard from which it can be inserted by Apasting into another location in the same application or into another application altogether.

Cyclones - WinCIDRS was written to handle cut diameter and size distribution measurement calculations for any sampling cyclone for which the cut diameter can be related to the cyclone geometry, sampling conditions (temperatures, pressures, cyclone flow rate, etc.) through a the relationship:

$$D50 = \sqrt{18 * \Psi_{50} * \text{GasViscosity} * \text{InletDiameter} / (\text{CunninghamCorr} * \text{InletVelocity} * \text{RhoP})}$$

where

$$\text{Sqrt}(x) = \text{square root of } x$$

and

$$\text{RhoP} = \text{density of the particle.}$$

and

$$\text{Ln}(\text{Sqrt}(\Psi_{50})) = A * \text{Ln}(\text{Re}) + B * \text{Sqrt}(\text{Ln}(\text{Re})) + C.$$

Cyclone Inlet Diameter - The diameter of the tangential inlet throat of a cyclone. Assumes cyclone inlet is round, not rectangular.

Cyclone Outlet Diameter - The diameter of the exit tube of the cyclone. Assumes exit tube is cylindrical and located on the cyclone axis.

Cyclone Reynolds Number - Reynolds number of flow at cyclone inlet based on gas flow rate and conditions at the inlet to the cyclone and the diameter of the cyclone inlet throat.

Data Entry - Entry of field data, etc., to the data analysis program.

D50s - See ACut Diameters $\cong$

DH@ - Metering orifice calibration constant. Defined in the same way as is standard for US EPA Method 5 sample metering systems. The value of the constant represents the orifice meter pressure differential required to obtain a flow rate of 0.75 cubic feet per minute at an inlet pressure of one atmosphere and a temperature of 68 degrees Fahrenheit when metering dry air of normal atmospheric composition.

dncm - dry normal cubic meter. A cubic meter of gas at a pressure of one atmosphere and a temperature of 20 degrees Celsius.

Dry Basis - Gas composition totals 100% without consideration of moisture (eg. composition of gas downstream of a moisture trap). Also, the composition of combustion gases that is provided directly by Orsat analysis.

Duct Pressure - The static pressure differential between the interior of the duct (or stack) from which a sample is obtained and the local ambient pressure at the altitude of the duct.

Edit Cell - The cell in which data entries are made or editing is done in WinCIDRS.

Editing - Changing the contents of a data entry or results table.

English Units - Use English engineering units of measurement of temperatures, pressures, gas volumes, etc.

Entry Restrictions - Some entry cells are restricted as to the number of characters and/or the types characters they will accept as input. For instance, a temperature entry cell will be restricted to entry of numeric values, decimal, and minus-sign only.

Exit - Menu command which closes the PM10/2.5 application.



File Directories - The disk directories in which WinCIDRS files are stored

File Names - Names up to eight characters in length that are used to identify disk files. The three character extension to a file name is often considered as being part of the file name, but that is not the case in discussions of file names in WinCIDRS.

File Name Extensions - File Name Extensions, that three character part of the full file specification beyond the dot ( AEXE,≡ ABAT,≡ and ADLL≡ being common examples) are used in WinCIDRS as key identifiers to certain specific pieces of information regarding the WinCIDRS data and results files. For a full explanation of these keys, please see the **AFile System and Directory Structure**≡ section of **AHow to Use PM10/2.5**≡ under Help.

File Nomenclature - Please see the **AFile System and Directory Structure**≡ section of **AHow to Use PM10/2.5**≡ under Help.

File Selection - File selections in the program are made either through a **AFile Open**≡ or **AFile Save**≡ dialog box or through a combination of three list boxes, one for selecting the drive to use, one for selecting directories and subdirectories on that drive and one containing a listing of files available in the chosen directory or subdirectory.

Filter - An element of the particulate sampling system that collects all particles arriving at the element regardless of particle size. In principle, for impactor and cyclone samplers it collects those particles which were too small to be collected by the last size fractionating stage in the device.

Filter Blank - See Blank Filter

Final Stage Weight - The weight (or mass) of the material caught by an impactor stage or cyclone and the container or substrate it is in or on. The weight (or mass) of the container or substrate after the sampling run has been made and the sample has been stabilized in a desiccator.

Flow From - Heading of a box in WinCIDRS that provides the user with the available choices that can be used to obtain the sampling flow rate through the impactor or cyclone train given the sampling details provided by the user.

Flow Rates - The flow rate of the sampled gas through the sizing device. The conditions in the duct are used for calculating the flow rate at the sampling nozzle. The conditions in the impactor or cyclones are used for calculating the flow rate through each impactor stage or cyclone in a series cyclone sampler. And the flow rate at **Anormal**≡ (standard) conditions are used for calculating particulate concentrations. The Flow rate must be held constant when sampling with inertial particle sizing devices because changes in flow rate will result in changes in the stage cut diameters.

Flow Metering System or Device - The means by which the sample flow is set, maintained, and measured during a sampling run.

Fonts - Type styles and sizes used in screen displays and printing of text.

Gamma - EPA Method 5 term for factor used to correct the reading of a dry gas meter from apparent volume sampled at meter conditions to true volume sampled at meter conditions.

Gas Composition - the make up of the major constituents of the sampled gas stream expressed in percentages by volume

Gas Meter - A device used for measuring gas flows and sample volumes. This may be a rotameter, an orifice meter, a bellows-type integrating dry gas meter or any other device for measuring sampling rates and volumes. However, it is most commonly used as meaning an integrating bellows-type dry gas meter.

Gas Meter Calibration Constant - see  $A\Gamma_{\cong}$

Gas Velocity - the velocity of the gas stream in the duct or stack from which the sample is withdrawn.

General Information - One of seven data entry forms used in the program. The General Information form contains information related to the run that has no direct bearing on the calculation of particle size distributions for a sampling run, but provides descriptive information related to the run.

GM Corr. Factor - See  $A\Gamma_{\cong}$

GM End - The indicated integrated gas volume on a dry gas meter at the conclusion of a sampling run.

GM Net - The net (or total) gas volume sampled during a sampling run as indicated by a dry gas meter from its initial and final readings for the run.

GM Start - The indicated reading from an integrating dry gas meter at the start of a sampling run.

GM Temp. - The average temperature of the sampled gas at meter conditions through a sampling run.

GM Volume - The indicated reading from a dry gas meter. Also sometimes used to mean the uncorrected net volume sampled as indicated by a dry gas meter.

Gross Stage Weight - The total weight (or mass) of the material collected by a cyclone, impactor stage, or filter before any blank correction is applied to it.

Hardware Details - The data entry page in the program on which the sampling system type and the file containing the impactor configuration information for run are specified when reducing data from a sampling run.

Help - Menu item that invokes the program's help system.

Impactors - Particle size fractionating devices that operate by forcing a particle laden sample stream to make an abrupt turn immediately above a collection surface. Particle with inertias greater than some critical value will contact, or impact, the surface and, if conditions are right, will adhere to it. The critical value of inertia required for impaction and collection to take place depends on the geometry of the impaction jet, the distance between the jet exit and the collection surface, the local gas conditions, and the jet diameter and velocity.

Cyclone Pressure Drop - The total pressure drop that takes place through a cyclone as a result of accelerations of the gas stream as it passes through the successive stages of the device. If measured by the user, the measured value can be entered and will be used in calculating jet velocities, etc., that go into the stage D50 calculations. Otherwise, the program will calculate the latter using pressure drops estimated by means of standard orifice equations.

Cyclone Temperature - The temperature of the sampled gas when it passes through the cyclone(s). This may be equal to, higher than, or lower than the flue gas temperature. For instance, the sampling head may be heated to temperatures above that of the gas stream being sampled in order to avoid condensation, Or it may be run at a temperature below that of the sampled gas stream in situations in which the sampled gas stream is too high for the hardware and/or sample collection media to withstand.

Initial Stage Weight - The weight (or mass) of a sample container or impaction substrate prior to use.

Inlet - Sampling location at the inlet to a particulate control device.

Inlet Runs - Sampling runs made at a control device inlet.

Isokinetic Ratio - The ratio between the velocity of the sampled gas stream in the inlet nozzle of the sampling device to the local free stream gas velocity in the duct or stack from which the sample is taken. The isokinetic error ratio represents the maximum possible ratio which the measured particulate concentration and emission rate can have relative to the true concentration and emission rate.

Isokinetic Sampling Rate - The sampling rate at which the gas velocity in the sampling nozzle matches the local free stream gas velocity in the duct. At this sampling rate the isokinetic ration is unity and the measured concentration and emission rate is equal to the true concentration and emission rate.

Jet Reynolds Number - The Reynolds Number of the flow through the jet of an impactor stage or cyclone. This value is a determining factor in calculating the stage constant (Psi50) from which the D50 of the stage is calculated.

Jet Velocity - The plug flow velocity of the gas exiting the jet of an impactor stage (or the inlet throat velocity in the case of a cyclone).

Load Run - Command to load a set of run data from disk for some specified run that had been entered and saved previously.

Loading Files - The act of loading files from disk (Displayed as a message while runs are being loaded for averaging).

Log-Normal Distributions - distributions which are Gaussian in form if the logarithm of particle diameter is used as the independent variable.

Manual Flow Entry - The sampling flow rate (at nozzle entry conditions) can be entered directly by the user. This will be necessary if the user has not provided information from which it can be calculated unless WinCIDRS is being used to do preliminary calculations to set up to do a sampling run.

Manual Velocity Entry - The free stream gas velocity in the duct or stack from which the sample is taken. Required if pitot information from which the velocity can be calculated is not provided by the user and the isokinetic ratio is to be calculated or isokinetic sampling rates are to be calculated when doing sampling setup calculations.

Mass Size Distribution - Particle size distributions in which the distribution function or curve is based on particle mass (or weight).

Meter Volumes - The gas volumes obtained directly from gas meters.

Metering System - The system used to set, control and meter the sampling rate and gas volume sampled.

Method 5 Sampling System - A standard EPA Method 5 sampling system comprised of a series of impingers or condensers for removing moisture, a drying agent to remove uncondensed moisture, a leakless pump with flow control metering valves, an integrating dry gas meter for measuring the total gas volume sampled and an orifice meter for measuring the instantaneous sample flow rate.

Metric Units - WinCIDRS offers the user a choice of entering sampling data for a particle sizing run using either English or Metric Units. The choice is made by clicking the desired option in an entry box on the General Info page of data entry.

mg - milligrams

Moisture Content - the concentration of water vapor in the gas stream sampled.

Multiple Runs - A series of sampling runs made under a common test condition.

Net Stage Weight - The weight (or mass) of particulate matter collected by a stage of a particle sizing device after any blank correction to be made has been applied. (Gross stage weight minus blank correction.)

New File - command to reset all data entries to the program startup values. Used to clear current entries if one wishes to ensure that no current entries are accidentally retained when a new set of data is to be input.

Nozzles - The sampling nozzles used at the inlet of the sampling device or precollector. The diameter of the nozzle is usually chosen so that isokinetic sampling conditions will be obtained at the target flow rate for a sampling run. The sampling nozzle diameter and flow rate usually determine the maximum particle size for which valid size distribution data are obtained. (For instance, a Method 5 or similar 90 degree bend nozzle will affect the sample at all sizes larger than about 2 micrometers, rendering the results questionable for all sizes larger than that. WinCIDRS permits a Method 5 or similar nozzle to be treated as the first stage in an impactor configuration file, permitting the user to determine the possible extent to which such a nozzle might affect the results obtained. As a general rule, the use of such nozzles should be avoided completely.)

Number Distribution - Particle size distribution based on particle concentrations on a number rather than mass basis,

Number Size Distribution - See Number distribution.

Open File - Command to Open (load) a previously stored set of run data from a collection of data files on disk.

Optional Information - Information that is not required by WinCIDRS for its internal calculations that the user may wish to enter as part of the record for a sample run.

Orifice Meter - Orifice type flow meter used primarily to control the instantaneous flow rate while sampling. However, the sampled gas volume can easily be calculated from the orifice meter when working with inertial sizing devices because of their requirement that sampling rates be held constant. The use of orifice meters for the latter purpose is especially valuable when using a very low flow rate device such as the Brink impactor, for which the flow rate is too low for conventional dry gas meters to operate.

Orifice Meter DH - The pressure drop at which an orifice meter is operated during a sampling run.

Orifice Meter Constants - The calibration constants for orifice meters (see DH@ under Help).

Other Flow Meters - Flow rate and/or sampled gas volume data measured with flow meters and metering devices other than dry gas meters and orifice meters must be entered manually.

Outlet - Designates sample taken at the outlet of a particulate control device (or at the outlet of the first of pair of control devices operated in series).

Outlet Runs - Sampling runs made at the outlet of a particulate control device (or at the outlet of the first of pair of control devices operated in series).

Page Tabs - The Atabs= at the bottom of the screen display in the PM10/2.5 program that are used to switch data entry pages.

Particle Density - the value of mass per unit volume of the particle itself, expressed in grams per cubic centimeter. (Density of a water drop is 1 g/cc. The density of coal fly ash is typically about 2.4 g/cc.) If the approximate composition of the particles is known, the density can be estimated from that. The density can be measured directly with a bulk sample of the particulate matter using a helium picnometer. Finally, the particle density is not needed if only aerodynamic diameters are to be calculated. The density is 1 g/cc for the latter by definition.

Particle Diameter - The diameter of a particle can be defined in a number of ways. Obviously, for homogeneous spheres, the most readily apparent definition is the actual physical diameter. However, a number of Aequivalent diameters≡ are also used in the aerosol sciences, even for spherical particles, and more especially for non-spherical

and irregular particles. The two diameters most commonly used when dealing with inertial particle size fractionating devices are the aerodynamic diameter and Stokes diameter. The aerodynamic diameter is the diameter of a unit density sphere with the same settling velocity in air as the particle in question and the Stokes diameter is the diameter of a sphere with the same density as the particle in question that has the same settling velocity as the particle in question. Other diameter definitions include the volume equivalent diameter (the diameter of a sphere that has the same total included volume as that of the particle in question), the diameter of a sphere having the same cross-sectional area as the particle in question, and many others. However, the latter are not often directly relatable to the size fractions produced by an inertial particle sizing device.

Particle Shape - Particles can have any number of shapes and the shape of a particle will have a distinct impact on its collection characteristics in a cyclone or impactor. Shape factors can be found in the literature which relate the aerodynamic behavior of certain non-spherical particles to their volume. These relations are available only for a few regular solids (for instance: cubes, prolate and oblate ellipsoids, cylinders, and a few other special cases), the treatment of which is beyond the scope of WinCIDRS.

Percent Isokinetic - The ratio of the gas velocity in the sampling nozzle of a particulate sampling system to the gas velocity of the stream from which the sample is taken, expressed as a percentage. EPA Method 5 requires that a run be within 90 percent of isokinetic to 110 percent of isokinetic to be considered acceptable without question in this regard. This plus-or-minus ten percent limit is usually relaxed to plus-or-minus twenty percent (80% to 120%) for particle sizing runs in general because of the difficulties in maintaining near isokinetic conditions while holding the sampling flow rate constant. In the cases of PM<sub>10</sub> and PM<sub>2.5</sub> sampling, the limits are related to the specific circumstances of each individual run such that the maximum error at 10 micrometers or 2.5 micrometers respectively is held to an acceptable value.

Physical Diameter - The actual diameter for a spherical particle or, as frequently used in inertial particle sizing, the particle Stokes diameter as an estimated equivalent diameter for such purposes as predicting light scattering properties for predicting opacity or particle charging and drag properties for predicting particle collection in an electrostatic precipitator.

Pitot Constant - The ratio of the square root of the pressure drop of a standard pitot tube to that obtained with any other type. For the AS-type pitots commonly used in particulate source testing, the pitot constant,  $C_p$ , is typically about 0.84.

Pitot Data - Velocity pressures obtained by making a pitot traverse over a sampling area.

Pitot DP - The pressure differential between the velocity pressure port and static pressure port (high pressure leg and low pressure leg) of a pitot tube.

PM10 - The concentration of particles having aerodynamic diameters smaller than ten micrometers as measured with a size fractionating device having a collection efficiency curve with respect to particle size that falls within a certain tolerance of that provided by EPA's official PM10 cyclone specification.

PM10 Sampling Rate - The flow rate required to produce a D50 of ten micrometers. This term is generally used in reference to the use of the EPA PM10 cyclone.

PM2.5 - The concentration of particles having aerodynamic diameters smaller than two-and-a-half micrometers as measured with a size fractionating device having a collection efficiency curve with respect to particle size that falls within a certain tolerance of that provided by EPA's official PM2.5 cyclone specification.

PM2.5 Sampling Rate - The flow rate required to produce a D50 of 2.5 micrometers. This term is generally used in reference to the use of the EPA PM2.5 cyclone.

Pressure Drops - Differential pressures across metering orifices, impactor stages, cyclones, etc.

Pressures - Absolute gas pressures.

Pretest Calculations - Preliminary calculations done prior to sampling for the purpose of selecting optimum impactor configurations, sampling flow rates and sampling nozzle sizes.

Psi50 - Parameter which fixes the relationship between jet dimensions, gas viscosities, sampling flow rates, etc., and the D50 of an impaction stage or cyclone. For a cyclone the value of Psi50 depends on the Reynolds number of the flow in the cyclone throat. For an impactor stage it depends on the Reynolds number of the flow in the jet and the jet-to-plate spacing.

Raw Data - Unprocessed information supplied by the user from which the program does its calculations.

References - Listing or literature that the user may find helpful concerning sampling and data analysis related to particle sizing.

Required Data - Data that is required by the program for doing its calculations.

Results - The results of calculations done by the - the program output product.



Reynolds Numbers - Dimensionless number related to properties of the flow field in a gas stream. ( $\text{GasDensity} * \text{GasVelocity} * \text{JetDiameter}/\text{GasViscosity}$ ). The Reynolds number is a determining factor in the value of Psi50 which in turns defines the relationship between the D50 of a stage, the stage hardware configuration, the properties of the gas being sampled and the sample flow rate. It also is a determining factor in the value of the discharge coefficient of an orifice which in turn is a factor in calculating the pressure drop across an impactor stage.

Run Number - An arbitrary sequence number between zero (0) and ninety-nine (99) that the user enters to distinguish each of a set of multiple runs made at a common location and test condition from one another.

Run Results - The output particle size distribution and concentrations by particle that are the output product of program.

Sample Type - A key to the location within a source and any associated particulate control devices regarding the point at which samples are taken. Sampling runs made at the input side of a control device are designated as being Inlet runs. Samples taken at the output of a control device are designated as Outlet runs. And samples taken at the stack are designated Stack runs.

Sample Volume - The total volume of gas drawn through the particle sizing device while obtaining a sample.

Saving Raw Data - Storing the unprocessed information concerning a sampling run to disk for later reuse.

Selecting Text - High-lighting text with the cursor to mark it for copying or cut-and-paste operations.

Series Cyclones - Two or more cyclones with successively smaller D50s used in series as a device to obtain particle size distribution information.

Setup Calculations - Pretest calculations used to select flow rates and sampling nozzles and/or calculations to aid in configuring an impactor or cyclone train to produce optimal results.

Show Intermediate Results - Provide a screen display of the results of intermediate calculations for each stage as data reduction proceeds. This provides the user with access to some values that are not in the tables of results that the program generates upon completing all calculations.

Single Run - An individual sampling run.

Sizing Devices - Devices which provide information on a particle size specific basis. Cyclones and impactors are among these, but they are not the only sizing devices available.

Stack Diff. Pressure - The difference in static pressures between the inside of a duct or stack and the local ambient barometric pressure outside of it.

Stack Runs - Sampling runs made at a stack location.

Stack DP to Ambient - See Stack Diff. Pressure

Stack Temperature - The gas temperature within the duct of stack from which a sample is taken.

Stage Weights - the raw weights (or masses) of the sample containers or substrates either before or after use.

Stokes Diameter - The diameter of a homogenous sphere having the same density and settling velocity in air as the particle in question.

Stokes50 - The value of the Stokes number of a particle for which the collection efficiency of a cyclone or impactor stage is 50%.  $Stokes50 = \Psi_{50} * \sqrt{2}$ .

Sub-directories - Directories contained within the WinCIDRS main directory

Tabbed Entry Page - Data entry pages used in the program in which tabs at the bottoms of the pages are used to move from one page to another.

Tab, tabbing - Pressing the tab key will shift the focus (advance the active entry cell or option choice) to the next entry field on the page displayed. Shift-tab will move the active cell or entry field back one cell.

Tabular Output - The results table that WinCIDRS displays upon concluding its calculations.

Technical Assistance - Technical assistance is available by phone at (205) 822 5703 or by e-mail at [jmccain@compuserve.com](mailto:jmccain@compuserve.com). There is a charge for assistance beyond answering direct questions regarding the operation of the WinCIDRS software package.

Temperatures - Temperatures are to be entered in degrees Fahrenheit if English units were selected for data entry or in degrees Celsius if metric units were selected. The stack temperature (temperature of the gas being sampled) and impactor temperature (temperature of the sampled gas as it passed through the impactor) are required. The gas meter temperature is also required if the gas volume sampled and sample flow rate are to be calculated from a gas meter volume or orifice meter pressure drop.

Test Designation - An alphanumeric string of up to six characters that is combined with the Run Number to form the file name for run data files and individual run results files.

Trial Setups - Mock sampling data sets that are used to do preliminary calculations before obtaining a sample. Such a trial setup can be saved for use as a starting point when the data from the run are to be reduced. This can be a time saver in many instances.

Unimodal Distributions - distributions which have only a single peak in the differential form of the particle size distribution.

Windows Help File - The file used by the Windows Help System to provide the information when Help is invoked. PM10\_2p5.HLP in the case of this program.

Word Processors - Applications like Word for Windows or Word Perfect that might be used for writing reports.