



Designation: E2515 – 11 (Reapproved 2017)

Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel¹

This standard is issued under the fixed designation E2515; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method is applicable for the determination of particulate matter emissions from solid-fuel-burning appliances including woodstoves, pellet-burning appliances, factory-built fireplaces, masonry fireplaces, masonry heaters, indoor furnaces, and indoor and outdoor hydronic heaters within a laboratory environment.

1.2 Analytes will be a particulate matter (PM) with no CAS number assigned. For data quality objectives, see [Appendix X1](#).

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.4 *This test method does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

¹ This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning Appliances.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[D2986 Practice for Evaluation of Air Assay Media by the Monodisperse DOP \(Diocetyl Phthalate\) Smoke Test \(Withdrawn 2004\)](#)³

[E2558 Test Method for Determining Particulate Matter Emissions from Fires in Wood-Burning Fireplaces](#)

[E2618 Test Method for Measurement of Particulate Emissions and Heating Efficiency of Solid Fuel-Fired Hydronic Heating Appliances](#)

[E2779 Test Method for Determining Particulate Matter Emissions from Pellet Heaters](#)

[E2780 Test Method for Determining Particulate Matter Emissions from Wood Heaters](#)

[E2817 Test Method for Test Fueling Masonry Heaters](#)

2.2 *AISI Document:*⁴

[AISI 316 Stainless Steel](#)

2.3 *NIST Document:*⁵

[NIST Monograph 175 Standard Limits of Error](#)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *laboratory environment*—the area or room that is used for the storage, weighing, assembly, disassembly, and desiccation of filters and related equipment (sample recovery and analysis).

3.1.2 *particulate matter (PM)*—all gas-borne matter resulting from combustion of solid fuel, as specified in the appliance operation test method, that is collected and retained by the specified filter and probe system under the conditions of the test.

3.1.3 *test facility*—the area in which the tested appliance is installed, operated, and sampled for emissions.

³ The last approved version of this historical standard is referenced on www.astm.org.

⁴ Available from American Iron and Steel Institute (AISI), 25 Massachusetts Ave., NW, Suite 800, Washington, DC 20001, <http://www.steel.org>.

⁵ Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, <http://www.nist.gov>.

4. Summary of Test Method

4.1 The total flue-gas exhaust from a solid fuel burning appliance is collected along with ambient dilution air with a collection hood. Duplicate sampling trains are used to extract gas samples from the dilution tunnel for determination of particulate matter concentrations. Each sample train has two glass fiber filters in series. The samples are withdrawn at a consistently proportional rate from sampling points located at the centroid of a sampling tunnel. During sampling, the filters are maintained at a temperature less than 32 °C (90 °F). The mass of the sampled particulate matter is determined gravimetrically after the removal of uncombined water. The total particulate matter mass collected on the filters and in the probe and front filter housing are multiplied by the ratio of the dilution tunnel flow to sample flow to determine the total particulate emissions during a test.

4.2 The sampling system for this test method consists of duplicate dual-filter dry sampling trains. Both of the particulate sampling trains are operated simultaneously at a sample flow rate not to exceed 0.007 m³/min (0.25 cfm/min). The total particulate results obtained from the two sampling trains are averaged to determine the particulate emissions and are compared as a quality control check on the data validity.

4.3 The particulate concentration results for each sampling train is adjusted by the particulate concentration result from a single room air sample blank collected and processed the same as the dilution tunnel particulate sampling trains described in 4.2, except that only one filter is used in the sampling train. A metering system as described in 6.1.1.4 shall be used to determine the volume of room air collected. The sample flow rate shall not exceed 0.007 m³/min (0.25 cfm).

4.4 Appliances tested by this test method are to be fueled and operated as specified in appliance-specific test methods such as, but not limited to, Test Methods E2558, E2618, E2779, E2780, or E2817.

5. Safety

5.1 *Disclaimer*—This test method may involve hazardous materials, operations, and equipment. This test method may not address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

6. Equipment and Supplies

6.1 *Sample Collection*—The following equipment is required for sample collection:

6.1.1 *Particulate Sampling Train*—Two separate, complete particulate sampling trains (also referred to as “sampling trains”) are required for each test run. The filter face velocity shall not exceed 150 mm/sec (30 ft/min) during the test run. The dry gas meter shall be calibrated for the same flow rate range as encountered during the test runs. The sampling train configuration is shown in Fig. 1 and consists of the following components.

6.1.1.1 *Filter Holder Assembly*—The filter holder assembly is shown in Fig. 2 and consists of the following components:

(1) *Filter Holders*—The primary (front) filter holder shall be aluminum or PTFE.⁶ The backup (rear) filter holder may be made of materials such as polycarbonate.⁷ With such plastic materials, it is recommended not to use solvents when cleaning the filter holder parts. Mild soap and distilled water can be used for cleaning plastic filter holder parts. The two filter holders

⁶ The Pall (Gelman) 1235 filter holder has been found suitable for this purpose. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

⁷ The Pall (Gelman) 1119 filter holder has been found suitable for this purpose. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

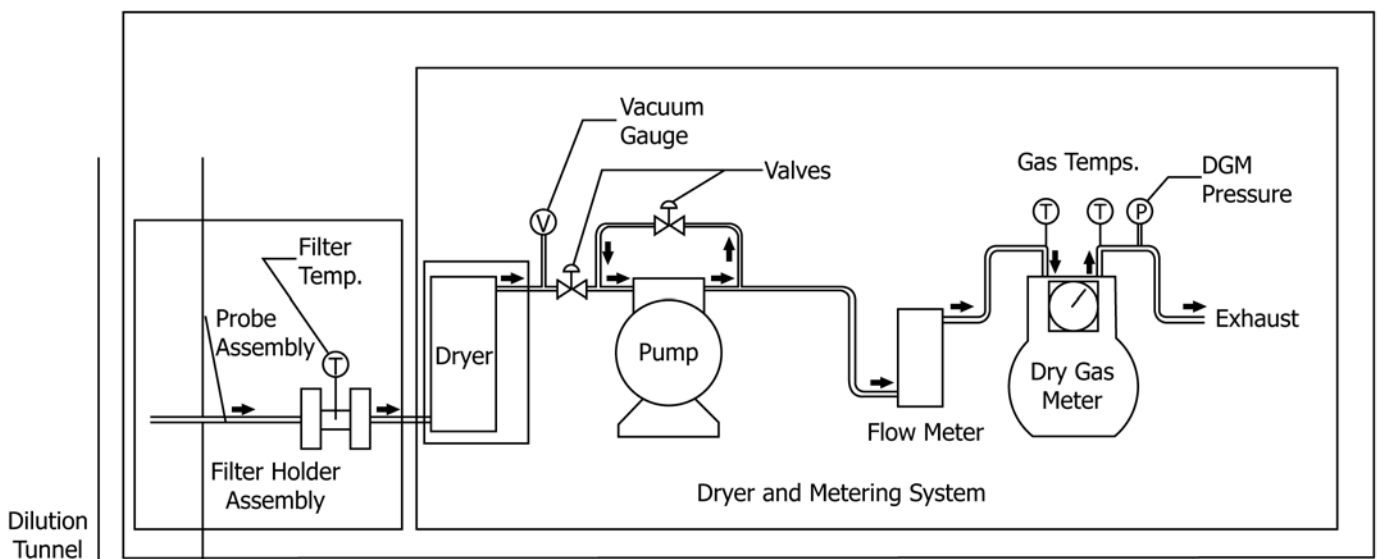


FIG. 1 Particulate Sampling Train

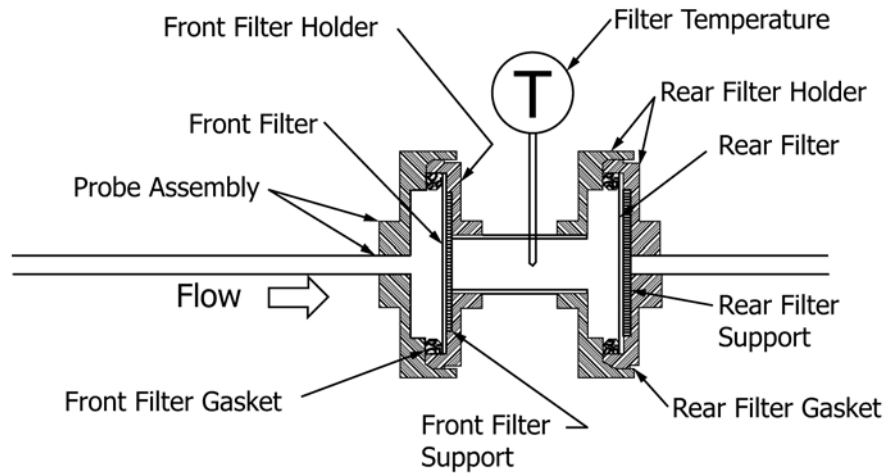


FIG. 2 Filter Holder Assembly

shall be placed in series with the backup filter holder located 25 to 100 mm (1 to 4 in.) downstream from the primary filter holder. The filter holders shall be capable of holding a filter with 47 mm diameter. The holder design shall provide a positive seal against leakage from the outside or around the filters. The use of a porous glass or ceramic frit to support the first (front) filter is not allowed. Any type of filter support is allowed for the second (rear) filter.

(2) *Probe Assemblies*—Probe assemblies shall consist of the following components assembled to provide a leak-tight seal:

(a) Front half of front filter holder as specified in 6.1.1.1(1).

(b) *Probe*—The probe shall be constructed from seamless stainless steel (that is, AISI 316 or grade more corrosion resistant) 6.35 mm (¼ in.) outside diameter (O.D.) and 0.30 to 0.45 m (12 to 18 in.) in length, with a wall thickness such that the total weight of the probe and front filter housing can be weighed to an accuracy of 0.1 mg.

(3) Filters in accordance with 7.1.1.

(4) Filter Gaskets.

6.1.1.2 *Filter Temperature Monitoring System*—A temperature sensor capable of measuring with an accuracy of 2.2 °C (4.0 °F) or 0.75 % of the reading, which ever is greater and meeting the calibration requirements specified in 8.2. The sensor shall be installed at the exit side of the front filter holder so that the sensing tip of the temperature sensor is in direct contact with the sample gas as shown in Fig. 2.

6.1.1.3 *Dryer*—Any system capable of removing water from the sample gas to less than 1.5 % moisture (volume percent) prior to the metering system. The system shall include a temperature sensor for demonstrating that sample gas temperature exiting the dryer is less than 27 °C (80 °F). See Fig. 1 for location of the dryer.

6.1.1.4 *Metering System*—The metering system shall include a vacuum gauge, leak-free pump, temperature sensors capable of measuring with an accuracy of 2.2 °C (4.0 °F) or 0.75 % of the reading, which ever is greater and meeting the calibration requirements specified in 8.2, gas metering system

capable of measuring the total volume sampled to within ± 2 % of the measured value, and related equipment, as shown in Fig. 1.

6.1.2 *Barometer*—Mercury, aneroid, or other barometer capable of measuring atmospheric pressure with an accuracy of ±2.5 mm Hg (0.1 in.). Must meet calibration requirements specified in 8.3.

NOTE 1—The barometric pressure reading may be obtained from a nearby National Weather Service station. In this case, the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be made at a rate of minus 2.5 mm Hg (0.1 in.) per 30 m (100 ft) elevation increase or plus 2.5 mm Hg (0.1 in.) per 30 m (100 ft) elevation decrease.

6.1.3 *Dilution Tunnel Gas Temperature Measurement*—A temperature sensor capable of measuring with an accuracy of 2.2 °C (4.0 °F) or 0.75 % of the reading, which ever is greater and meeting the calibration requirements specified in 8.2.

6.1.4 *Pitot Tube*—A standard Pitot tube designed according to the criteria given in 6.1.4.1 shall be used to measure flow in the dilution tunnel. Pitot tubes will have an assumed Pitot coefficient of 0.99 and be designed according to these specifications:

6.1.4.1 Standard Pitot design (see Appendix X2 for an example);

6.1.4.2 Hemispherical, ellipsoidal, or conical tip;

6.1.4.3 A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes;

6.1.4.4 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90° bend;

6.1.4.5 Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration; and

6.1.4.6 90° bend, with curved or mitered junction.

6.1.5 *Differential Pressure Gauge*—An inclined manometer or equivalent shall be readable to the nearest 0.127 mm (0.005 in.) water for Δp values greater than 2.54 mm (0.10 in.) water,

and to the nearest 0.025 mm (0.001 in.) water for Δp values less than 2.54 mm (0.10 in.) water.

6.1.6 *Dilution Tunnel*—The dilution tunnel apparatus is shown in Fig. 3 and Fig. 4 and consists of the following components:

6.1.6.1 *Hood*—Constructed of steel. Hood shall be large enough to capture all of the flue-gas flow exiting the top of the appliance chimney. The dilution tunnel hood shall be conical with a minimum diameter at the entrance of at least four times the tunnel diameter. The height of the conical section shall be at least three tunnel diameters. A skirt can be used around the inlet to the conical section to insure capture of the flue-gas exhaust as shown in 9.2.4 as long as the requirements of 9.2.3 are met. The outlet of the conical section shall be sized to mate with the mixing section of the dilution tunnel. (See Fig. 3 and Fig. 4.)

6.1.6.2 *90° Elbows*—Steel 90° elbows should be used for connecting mixing section, the sampling section, and the optional damper assembly. There shall be at least two 90° elbows upstream of the sampling section. (See Fig. 3 and Fig. 4.) The last elbow before the sampling section begins shall be of the same diameter as the sampling section straight ducting.

6.1.6.3 *Straight Duct*—Straight sections of steel ducting shall be used to construct both the mixing section and sampling section of the dilution tunnel apparatus. The mixing section is considered to be the ducting that is upstream of the last elbow before the sampling section begins. The mixing section and sampling section may be different diameters, but the sampling section shall have a consistent diameter over its full length. (See Fig. 4.) Two velocity traverse ports shall be located at least eight tunnel diameters downstream of the last flow disturbance (for example, a 90° elbow) and positioned at 90° to

each other in the dilution tunnel sampling section. These velocity traverse points shall be of sufficient size to allow entry of the standard Pitot tube but shall not exceed 12.7 mm (0.5 in.) diameter. Two particulate sample extraction ports shall be located at least four tunnel diameters downstream of the velocity traverse ports and at least two tunnel diameters upstream from the next downstream flow disturbance. These sample extraction ports shall be of sufficient size to allow entry of the sampling probes. The total length of duct from the center of the outlet of the hood to the sampling ports shall not exceed 9.1 m (30 ft). (See Fig. 3.)

6.1.6.4 *Blower*—Squirrel cage or other type of fan capable of gathering and moving all flue-gases and entrained dilution air from the dilution tunnel extraction hood to the dilution tunnel exhaust having sufficient flow to maintain dilution rate specifications in Section 9. (See 9.2.)

6.1.7 *Test Facility Temperature Monitor*—A thermocouple capable of measuring with an accuracy of 2.2 °C (4.0 °F) or 0.75 % of the reading, which ever is greater, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends. Must meet the calibration requirements specified in 8.2.

6.1.8 *Anemometer*—Device capable of detecting air velocities less than 0.10 m/sec (20 ft/min) and used for measuring air velocities in the test facility near the test appliance.

6.2 *Sample Analysis*—The following items are required for sample analysis:

6.2.1 *Desiccator*—Any airtight cabinet or other container containing desiccant to remove moisture from the probes, front filter housings, filters, and filter gaskets prior to and after testing;

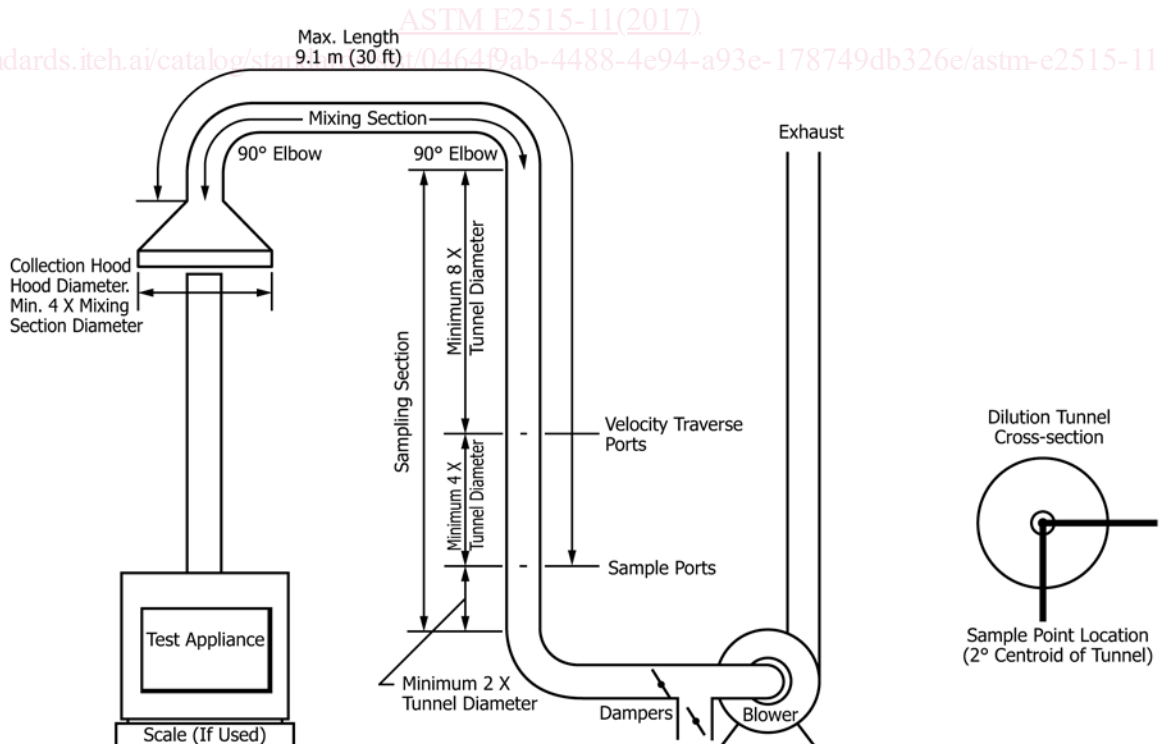


FIG. 3 Steel-Constructed Dilution Tunnel Apparatus

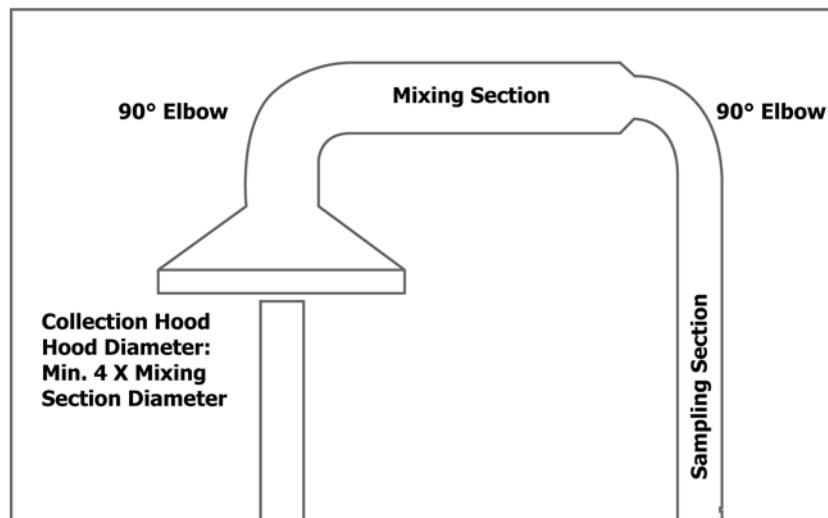


FIG. 4 Mixing Section and Sampling Section with Different Diameters

6.2.2 *Analytical Balance*—With a resolution 0.1 mg or better. Must meet the calibration requirements specified in 8.4;

6.2.3 *Hygrometer or Sling Psychrometer*—To measure the relative humidity of the laboratory environment with a resolution of 2 % RH or better; and

6.2.4 *Temperature Sensor*—To measure the temperature of the laboratory environment with an accuracy of 2.2 °C (4.0 °F) or 0.75 % of the reading, whichever is greater, and meeting the calibration requirements specified in 8.2.

7. Reagents and Standards

7.1 *Sample Collection*—The following reagents are required for sample collection:

7.1.1 *Filters*—Glass fiber filters with a diameter of 47 mm without organic binder, exhibiting at least 99.95 % efficiency (<0.05 % penetration) on 0.3-micron dioctyl phthalate smoke particles in accordance with Practice D2986. Manufacturer’s quality control test data are sufficient for validation of efficiency.⁸

7.2 *Sample Analysis*—One reagent is required for the sample analysis:

7.2.1 *Desiccant*—Desiccant shall be capable of drying air to a moisture content of 0.005 g/L or less. Calcium sulfate (CaSO₄) and molecular sieve desiccants are suitable.

7.3 *Probe Assembly Cleaning*—Acetone is used to clean and remove moisture from the probe assembly before pretest desiccation and to remove particulate material that has accumulated on the outside of the probe during the test run prior to post-test desiccation.

8. Calibration and Standardization

NOTE 2—Maintain a laboratory record of all calibrations.

8.1 Volume Metering System:

⁸ Gelman A/E 61631 and Whatman 1841-047 filters have been found acceptable for this purpose. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

8.1.1 Sampling system volume metering equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibration shall be traceable to NIST and demonstrate a maximum uncertainty of ±1.0 % of measured volume at the operating conditions (flow rate and total volume) used in the test.

8.2 *Temperature Sensors*—Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with NIST Monograph 175.

8.3 *Barometer*—Calibrate against a mercury barometer before the first certification test and at least semi-annually, thereafter. If a mercury barometer is used, no calibration is necessary. Follow the manufacturer’s instructions for operation. Barometers shall have an uncertainty of ±1.27 mm (0.05 in.) of mercury or better.

8.4 *Analytical Balance*—Perform a multipoint NIST traceable calibration (at least five points spanning the operational range) of the analytical balance before the first test and semiannually, thereafter. Before each test, audit the balance by weighing at least one calibration weight that corresponds to 50 to 150 % of the weight of one filter. If the scale cannot reproduce the value of the calibration weight to within 0.1 mg, conduct the multipoint calibration before use.

9. Procedures

9.1 *Dilution Tunnel Assembly and Cleaning*—A schematic of a dilution tunnel is shown in Fig. 3. The dilution tunnel requirements and other features are described in 6.1.6. Assemble the dilution tunnel, sealing joints, and seams to prevent air leakage. Clean the dilution tunnel with an appropriately sized wire chimney brush before each test run.

9.2 Dilution Tunnel:

9.2.1 *Size*—The dilution tunnel diameter shall be sized such that the flow velocity as measured as shown in 9.3 and as established in 9.2.2 shall result in a minimum of 4.1 m/sec (800 ft/min) when the velocity pressure is measured to an accuracy

of ± 0.025 mm (0.001 in.) water or a minimum of 7.6 m/sec (1500 ft/min) when the velocity pressure is measured to an accuracy of ± 0.127 mm (0.005 in.) water.

9.2.2 Flow Rate—The dilution tunnel flow rate shall be selected to provide sufficient flow to collect and fully entrain all flue products during the test and provide sufficient velocity for accurate flow measurement. For closed combustion appliances tunnel flow rates in the range of 0.07 to 0.24 scm/sec (150 to 500 SCFM) have been found to be acceptable. For open combustion appliances, such as fireplaces, tunnel flow rates in the range of 0.24 to 0.71 scm/sec (500 to 1500 SCFM) have been found to be acceptable. The maximum tunnel flow rate shall not exceed five times the minimum flow rate determined as shown in 9.2.4.

NOTE 3—Optimum accuracy is achieved when the dilution tunnel flow rate is set so that the ratio of sample flow to tunnel flow is maximized.

9.2.3 Induced Draft Determination—Prepare the test appliance in accordance with appropriate test method. Locate the dilution tunnel collection hood over the appliance chimney exhaust. Operate the dilution tunnel blower at the flow rate to be used during the test run. Measure the static pressure imposed on the appliance by the dilution tunnel (that is, the difference in static pressure measured with and without the dilution tunnel operating) at a location no greater than 0.3 m (1 ft) above the flue connector. Adjust the distance between the top of the test appliance chimney and the dilution tunnel hood so that the dilution tunnel induced static pressure is less than 1.25 Pa (0.005 in. water). Have no fire in the appliance, open and close any doors, and open fully the flue damper if applicable during this check and adjustment.

9.2.4 Smoke Capture—Prior to any test run, burn the appliance at a high burn rate using a kindling fuel load and specified test load, operate the dilution tunnel, and visually monitor the appliance chimney exhaust. Determine the minimum dilution tunnel flow rate needed to insure that 100 % of the chimney effluent is collected by the dilution tunnel collection hood. If the appliance has doors, operate the appliance with the doors in all positions specified in the appliance owner's manual. It may be necessary to artificially inject smoke (using smoke pellets or smoke generator) into the area around dilution tunnel collection hood to provide a better visual check that no exhaust gases are escaping. If less than 100 % of the chimney effluent is collected, adjust the distance between the test appliance chimney outlet and the dilution tunnel hood or increase the dilution tunnel flow rate just to the point where no visible effluent is escaping, or both. With the Pitot tube located at the center of the dilution tunnel, record this dilution tunnel velocity head (D_p), temperature and static pressure.

9.3 Velocity Measurements—Prior to ignition, conduct a velocity traverse in the dilution tunnel to determine the Pitot Factor (F_p). The Pitot tube shall be placed at the center of the tunnel during the test run.

9.3.1 Velocity Traverse—Measure the diameter of the dilution tunnel at the velocity traverse port location through both ports. Calculate the dilution tunnel area using the average of the two diameters. Place the standard Pitot tube at the center of the dilution tunnel in either of the velocity traverse ports. Seal

any gap between the velocity traverse port in the dilution tunnel and the Pitot tube and seal the unused velocity traverse port to prevent any air leakage into the dilution tunnel. Adjust the damper or similar device on the blower inlet until the velocity indicated by the Pitot tube indicates that a dilution tunnel flow rate within the allowable range as shown in 9.2 has been achieved. Continue to read the velocity head (D_p) and temperature until the velocity has remained constant (less than 5 % change) for 1 min. Once a constant velocity is obtained at the center of the dilution tunnel, perform a velocity traverse as specified in 9.3.2. Seal any gap between the velocity traverse port in the dilution tunnel and the Pitot tube and seal the unused velocity traverse port to prevent any air leakage into the dilution tunnel.

9.3.1.1 Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 6.1.5). If it is necessary to change to a more sensitive gauge, do so, and re-measure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in 9.6.5, to validate the traverse. Measure the Δp and tunnel temperature at each traverse point and record the readings.

9.3.1.2 Calculate the total gas flow rate using calculations contained in Section 11, using the velocity traverse points in accordance with 9.3.2, excluding the center readings. Verify that the flow rate is equal to the target flow; if not, readjust the damper, and repeat the velocity traverse.

9.3.2 Velocity Traverse Measurements—Measure and record the velocity head and temperature at the traverse points specified as follows:

9.3.2.1 For dilution tunnel diameters equal to or greater than 0.3 m (12 in.) locate the traverse points on two perpendicular diameters according to the table in and the example shown in Fig. 5. For dilution tunnel diameters less than 0.3 m (12 in.) locate the traverse points on two perpendicular diameters according to the table and example shown in Fig. 6.

9.3.2.2 For dilution tunnel diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the tunnel walls.

9.4 Pretest Preparation—The sampling equipment should be maintained according to good laboratory practices and manufacturer's instructions where applicable.

9.4.1 Check filters visually against light for irregularities, flaws, or pinhole leaks. Label the filters on the back side near the edge using numbering machine ink.

9.4.2 Rinse the probe assemblies with acetone to clean and remove moisture before desiccating.

9.4.3 Mark the probe assemblies in such a way that each can be identified during use.

9.4.4 Desiccate the filters, filter gaskets, and the probe assemblies at 20 ± 5.6 °C (68 ± 10 °F) and ambient pressure for at least 24 h. Weigh each component at intervals of not less than 6 h until a constant weight is achieved. Record results to the nearest 0.1 mg. During each weighing, the period for which the components are exposed to the laboratory environment shall be less than 2 min. The filter gaskets can be weighed in sets to be used in each filter holder and kept in an identified container at all times except during sampling and weighing.