Designation: E2515 – 11

Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel[1]

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2986 Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test (Withdrawn 2004)[3]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 Documents:*[4]

AISI 316 Stainless Steel

2.3 *NIST Documents:*[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.

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

---

[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.

Current edition approved Nov. 1, 2011. Published December 2011. Originally approved in 2007. Last previous edition approved in 2010 as E2515 – 10. DOI: 10.1520/E2515-11.

[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.

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

[4] Available from American Iron and Steel Institute (AISI), 1140 Connecticut Ave., NW, Suite 705, Washington, DC 20036, 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.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

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 m^3/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 m^3/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 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*).

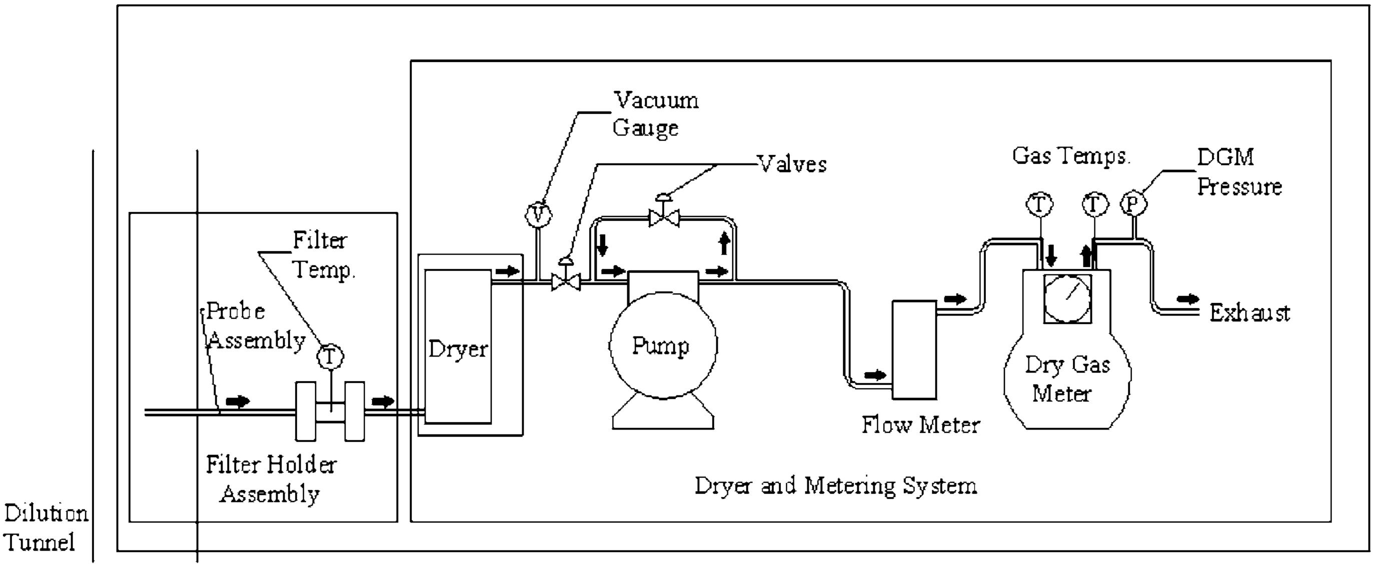

FIG. 1 Particulate Sampling Train

---

[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.

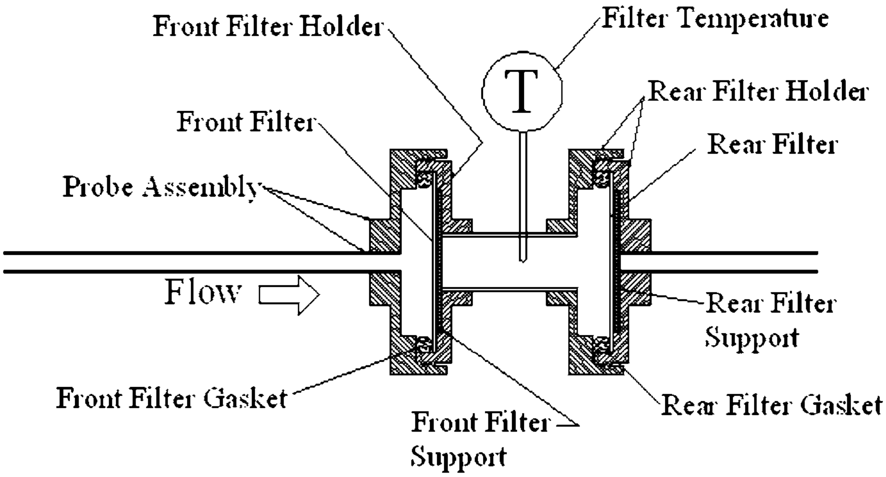

FIG. 2 Filter Holder Assembly

(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

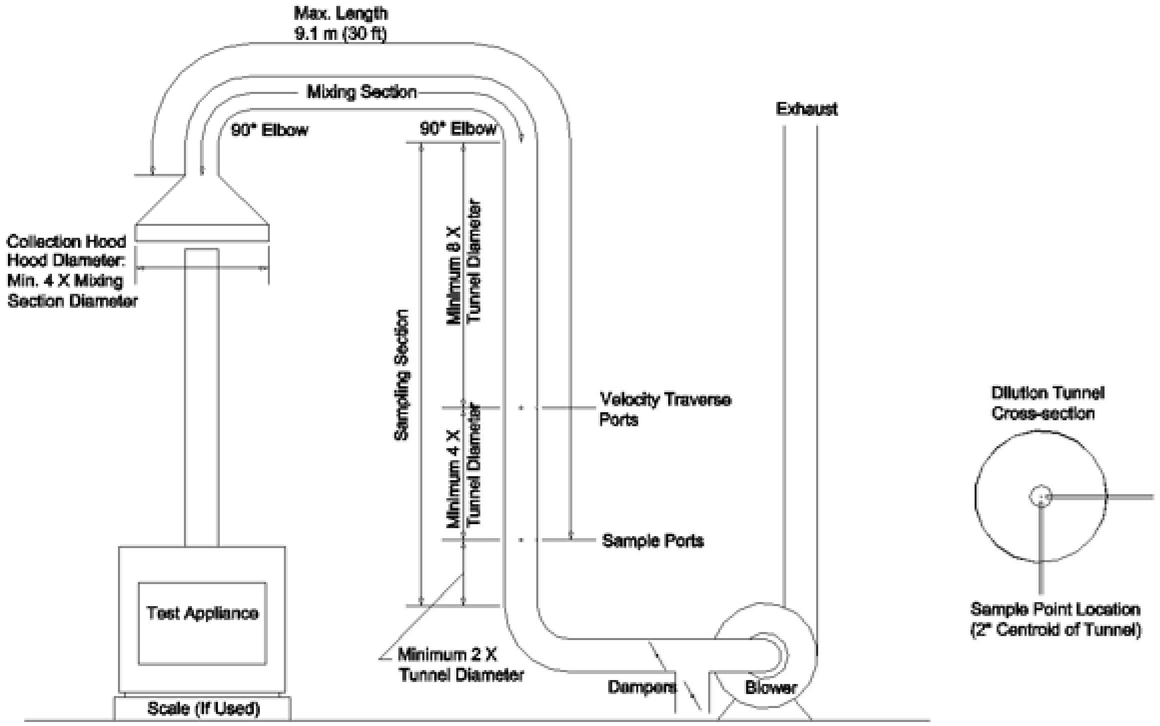

FIG. 3 Steel-Constructed Dilution Tunnel Apparatus

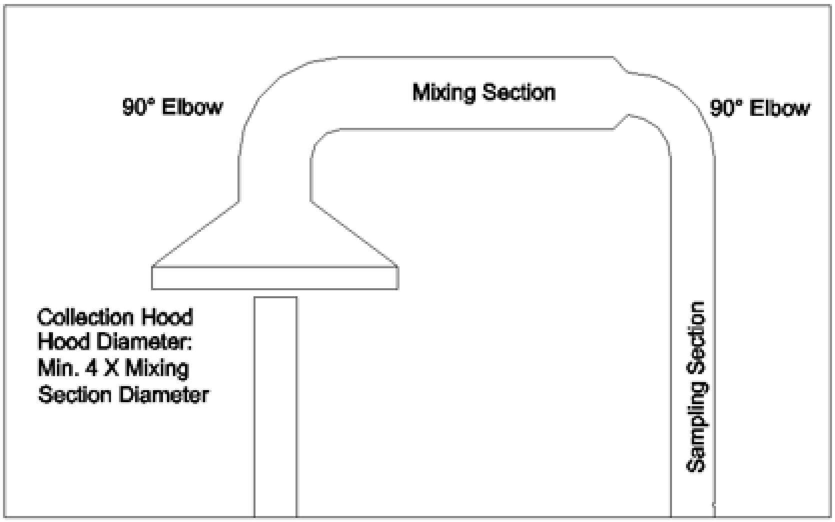

FIG. 4 Mixing Section and Sampling Section with Different Diameters

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 the 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;

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, which ever 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 ($CaSO_4$) 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:*

8.1.1 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 semiannually 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.

---

[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.

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. The filter holder assembly after the front filter need not be desiccated or weighed.

NOTE 4—For the purposes of this section, the term constant weight means a difference of no more than 0.2 mg between two consecutive weighings, with not less than 6 h of desiccation time between weighings.

9.5 *Preparation of the Filter Holder Assemblies*—During preparation and assembly of the filter holder assemblies, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

9.5.1 *Assemble the Filter Holder Assemblies*—Using tweezers or clean disposable surgical gloves, place one labeled and weighed filter in each of the front and back filter holders. Be sure that each filter is properly centered and that the identified filter gasket is properly placed so as to prevent the sample gas

Taverse Point	% of Diameter
1	4.4
2	14.6
3	29.6
Center	50.0
4	70.4
5	85.4
6	95.6

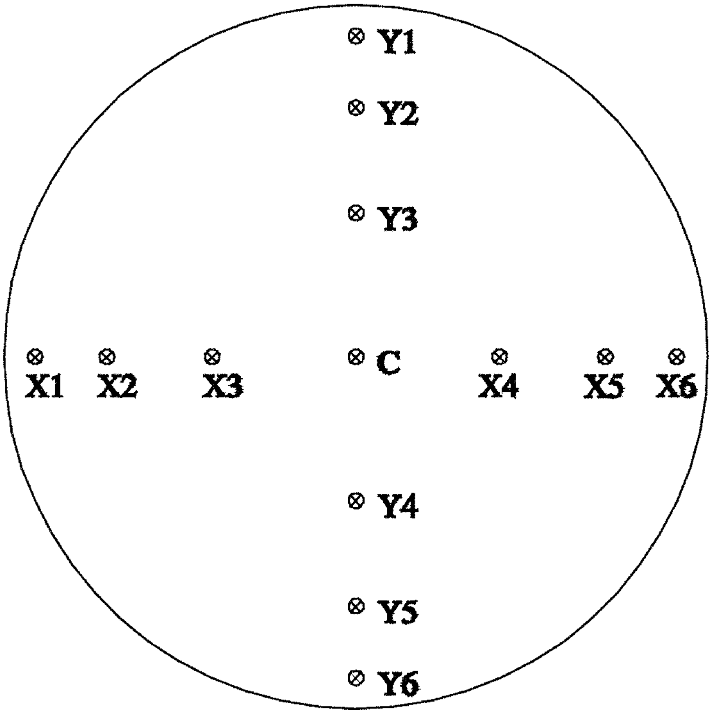

FIG. 5 Dilution Tunnel Diameter Equal To or Greater Than 0.3 m (12 in.) Traverse Point Table

Taverse Point	% of Diameter
1	6.7 *
2	25.0
Center	50.0
3	75.0
4	93.3 *

* No closer than 12.7 mm (0.50 in.) to tunnel wall.

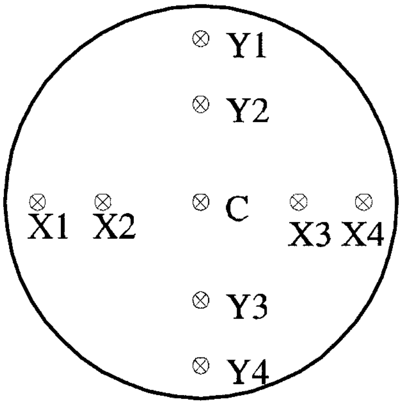

FIG. 6 Dilution Tunnel Diameter Less Than 0.3 m (12 in.) Traverse Point Table

stream from circumventing the filter. Mark the probes by a method that will not affect the tare weight to denote the proper distance for insertion into the tunnel. Set up the filter holder assemblies as shown in Fig. 2 and the sampling trains as shown in Fig. 1.

9.5.2 *Assemble the Room Air Blank Filter Holder Assembly*—Using tweezers or clean disposable surgical gloves, place one labeled and weighed filter in the single filter holder. Be sure that the filter is properly centered and that the identified filter gasket is properly placed so as to prevent the sample gas stream from circumventing the filter. Set up the room air blank filter holder assembly as shown in Fig. 7 and the dryer and metering system as shown in Fig. 1. The inlet to the room air blank filter holder assembly shall be located in the same space within the test facility as the test appliance and shall be within 3.1 m (10 ft) of the dilution tunnel hood entrance.

9.6 *Leak-Check Procedures:*

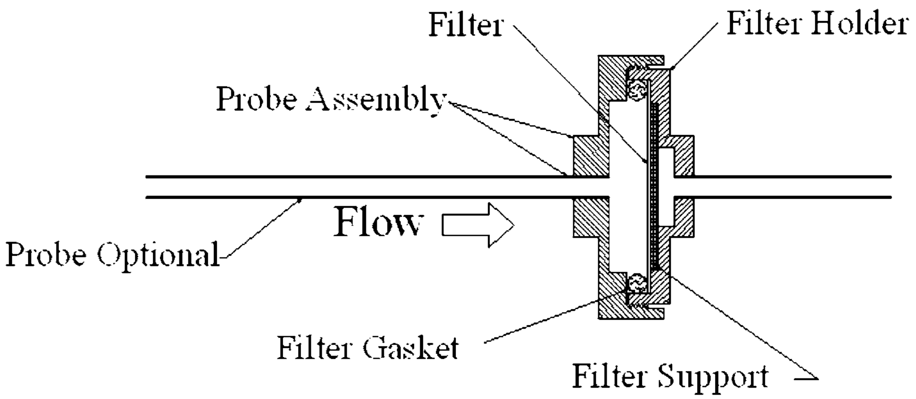

FIG. 7 Room Air Blank Filter Holder Assembly

9.6.1 *Leak-Check of Metering System Shown in Fig. 1*—That portion of the sampling train from the pump to the dry gas meter outlet (or orifice meter, if used) shall be leak-checked prior to initial use and at least semi-annually thereafter. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Fig. 1): Close the main valve before the pump. Attach a rubber tube to the dry gas meter outlet piping, downstream of the dry gas meter pressure gauge. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Read the pressure on the dry gas meter pressure gauge. Pinch off the tubing, and observe the pressure gauge for 1 min.

9.6.2 If using an orifice meter, insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Read the pressure on the orifice manometer. Pinch off the tubing, and observe the manometer for 1 min.

9.6.3 A loss of pressure on the dry gas meter pressure gauge or orifice manometer indicates a leak in the metering system; leaks, if present, must be corrected.

9.6.4 *Pretest Leak-Check:*

9.6.4.1 *Particulate Sampling Trains*—Pretest leak-checks of the sampling trains are required. Leakage in the sampling train results in less tunnel gas sample passing through the filters than is indicated by the metering system. The procedures outlined below should be used.

(1) After each sampling train has been assembled, plug the probe inlet and check for leaks by pulling a 380 mm (15 in.) Hg vacuum.

(2) Leakage rates in excess of 4 % of the average sampling rate or 0.0003 m^3/min (0.01 cfm), whichever is less, are unacceptable.

NOTE 5—A lower vacuum may be used, provided that it is not exceeded during the test. Start the pump with the bypass valve fully open and the coarse adjust valve completely closed. Partially open the coarse adjust valve, and slowly close the bypass valve until the desired vacuum is reached. If the desired vacuum is exceeded, either leak-check at this higher vacuum, or end the leak check and start over.

NOTE 6—If the leakage rate is above acceptable limit, find and repair the leakage source and leak test again. Repeat until the leakage rate is acceptable. When the leak check is completed, first slowly remove the plug from the inlet to the probe, and immediately turn off the vacuum pump.

9.6.4.2 *Pitot Tube Lines:*

(1) A pretest leak-check of Pitot lines using the following procedure is recommended: (*a*) blow through the Pitot impact opening until at least 7.6 cm (3.0 in.) water velocity head registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (*b*) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3.0 in.) water.

9.6.5 *Post-Test Leak Checks:*

9.6.5.1 *Sampling Train*—A leak check of the sampling train is mandatory at the conclusion of each sampling run before sample recovery. The leak check shall be performed in accordance with the procedures outlined in 9.6.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.0003 m_3/min (0.01 cfm) or 4 % of the average sampling rate (whichever is less), the results are acceptable. If, however, a higher leakage rate is obtained, the test shall be considered void unless the total emissions measured by the dual sampling trains agree within the allowable limit as shown in 11.7 and one of the sampling trains is within the specified maximum post-test leakage limit.

9.6.5.2 *Pitot Tube Lines*—A leak test of the Pitot tube lines is mandatory at the conclusion of each sampling run before sample recovery. The leak test shall be conducted in accordance with the procedure outlined in 9.6.4.2. The lines must pass this leak-check in order to validate the velocity head data. The test run is invalid if this leak test is failed.

9.7 *Test Facility*—The test facility shall meet the following requirements during testing:

9.7.1 The test facility temperature shall be maintained between 13 and 32°C (55 and 90°F) during each test run. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the test appliance. Locate the temperature monitor 1 to 2 m (3.3 to 6.6 ft) from the front of the test appliance in the 90° sector in front of the test appliance (See Fig. 8.)

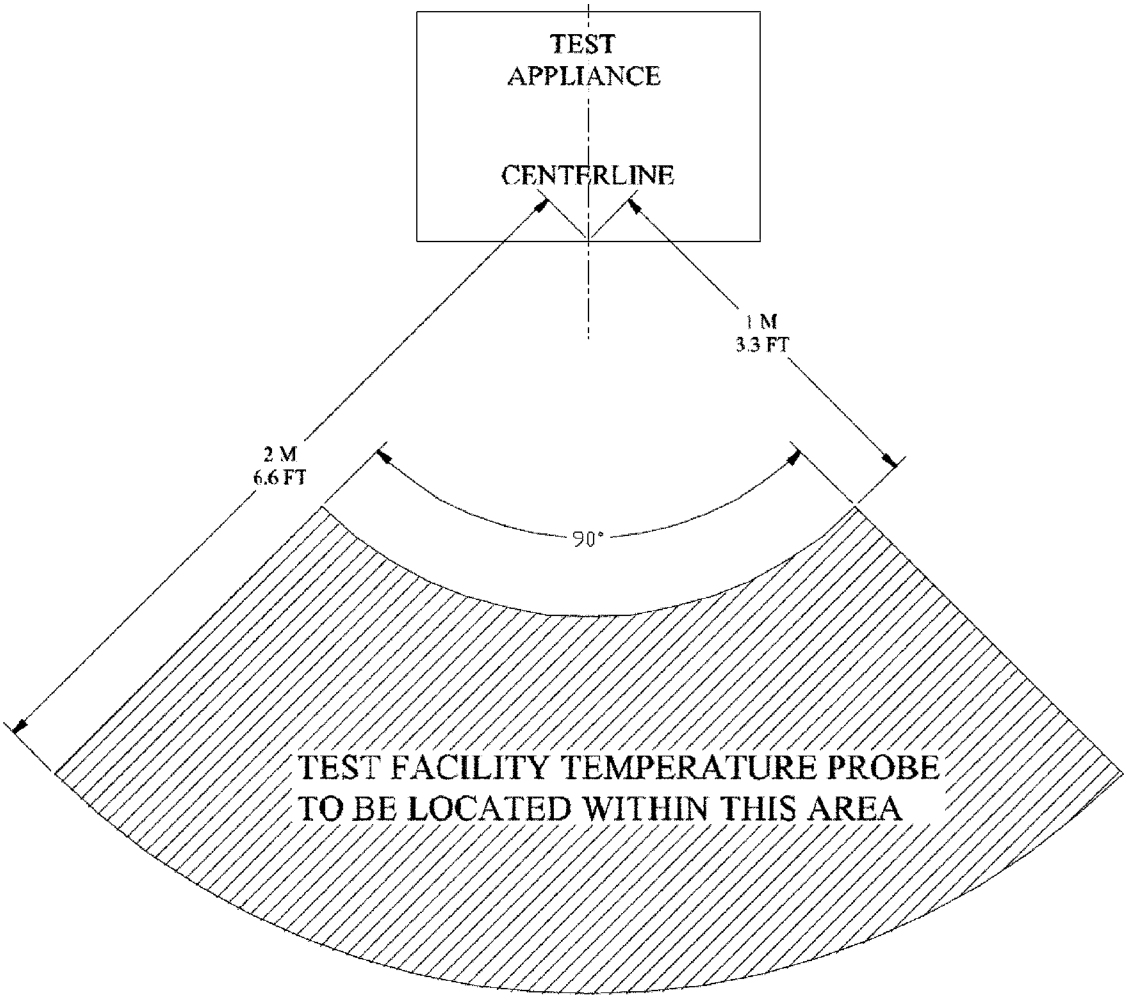

FIG. 8 Test Facility Temperature Monitor

9.7.2 Air velocities within 0.6 m (2 ft) of the test appliance shall be less than 0.25 m/sec (50 ft/min) without fire in the unit. Use an anemometer to measure the air velocity. Measure and record the room air velocity before starting a fire in the test appliance and once immediately following the test run completion.

9.7.3 Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run.

9.8 *Sampling Train Operation*—Locate the probe inlets within the 50 mm (2 in.) diameter centroidal area of the dilution tunnel (see Fig. 3), no closer than 25 mm (1 in.) apart, and block off the openings around the probes to prevent unrepresentative dilution of the gas stream. Be careful not to bump the probes into the stack wall when removing or inserting the probe through the porthole; this minimizes the chance of extracting deposited material.

9.8.1 Begin sampling at the start of the test run as defined in the applicable test method. During the test run, maintain the sample flow rates for both tunnel particulate sampling trains proportional to the dilution tunnel flow rate (within 10 % of the initial proportionality ratio) and a filter holder temperature of no greater than 32°C (90°F). Begin room air sampling (background) at the same time as the tunnel particulate trains and maintain the room air sample flow rate with 20 % of the initial room air sample flow rate.

9.8.2 For each test run, record the required data. Be sure to record the starting dry gas meter readings for both tunnel particulate sampling trains and for the room air sampling train. Refer to Fig. 1 for a graphic description of the sampling trains. Record the dry gas meter readings for both tunnel particulate sampling trains at the beginning and end of each sampling time increment. It is not necessary to record dry gas meter readings for each sampling time increment for the room air sampling train. Recording flow meter readings is acceptable for the room air sampling train. Record the dry gas meter readings for both tunnel particulate sampling trains and the room air sampling train when sampling is halted. Take other needed readings at least once each 10 min during the test run. Since the manometer level and zero may drift because of vibrations and temperature changes, make periodic checks during the test run. Record tunnel gas static pressure at the beginning and end of each test run.

9.8.3 For the purposes of proportional sampling rate determinations, data from calibrated flow rate devices, such as glass rotameters, may be used in lieu of incremental dry gas meter readings. Proportional rate calculation procedures must be revised, but acceptability limits remain the same.

9.8.4 During the test run, make periodic adjustments to keep the temperature between the filters at the proper level. The probes may be cooled to help maintain filter temperature. Do not change sampling trains during the test run.

9.8.5 At the end of the test run as defined in the applicable test method, stop tunnel particulate sampling using the following procedure. Turn off both tunnel sampling train coarse adjust valves, remove the probe and filter assemblies from the dilution tunnel, turn off the sampling pumps, record the final dry gas meter readings, and conduct post-test leak-checks, as outlined in 9.6.5. Turn off the room air (background) sampling system at the same time as the tunnel particulate sampling trains. Record the final dry gas meter reading and conduct a post-test leak check as outlined in 9.6.5.

9.9 *Calculation of Proportional Sampling Rate*—Calculate percent proportionality (see Section 11) to determine whether the run was valid or another test run should be made.

9.10 *Sample Recovery*—After post test leak checking, disconnect the filter holder assembly from the dryer and metering system and carefully clean the outside of the probe with acetone, cap the ends of the filter holder assembly, identify (label) it, and transfer to the laboratory sample recovery area. Carefully disassemble the filter holder and remove the filters and the filter gaskets from the filter holders, and place them in identified containers. Use a pair of tweezers or clean disposable surgical gloves, or both, to handle the filters and filter gaskets. Reassemble the empty filter holder assemblies, cap the ends, identify (label), and transfer all the samples to the laboratory weighing area. Disassemble the filter holder assembly and remove the cap from the probe inlet. The probe assembly shall be weighed without sample recovery (use no solvents) in order to determine the sample weight gain. Requirements for filter holder reassembly, capping, and transport of sample containers are not applicable if sample recovery and weighing occur in the same laboratory environment.

10. Analytical Procedure

10.1 *Record the Data Required*—Use the same analytical balance for determining tare weights and final sample weights.

10.2 *Sample Weight Determination:*

10.2.1 Desiccate the filters and filter gaskets at 20 ± 5.6°C (68 ± 10°F) and ambient pressure for at least 24 h. Weigh each component at intervals of at least 6 h until a constant weight is achieved. Report the results to the nearest 0.1 mg. Filters and filter gaskets may be weighed directly without a Petri dish. They may be weighed in pairs (front and back filters and front and back filter gaskets from same filter train) to reduce handling and weighing errors. During each weighing, the components shall not be exposed to the laboratory atmosphere for longer than 2 min. For the room air background sample filter and filter gasket, treat negative particulate catch weights as "zero" when determining total room air particulate weight in accordance with 10.2.

10.2.2 Remove the probe assemblies from the filter holder assemblies and uncap the probe assemblies. Desiccate the probe assemblies at 20 ± 5.6°C (68 ± 10°F) and ambient pressure for at least 24 h. Weigh each probe assembly at intervals of at least 6 h until a constant weight is achieved. Report the results to the nearest 0.1 mg. During each weighing, the components shall not be exposed to the laboratory atmosphere for longer than 2 min. If the probe assemblies have reached constant weight and result in a negative particulate catch weight in the probe assembly:

10.2.2.1 Treat the negative sample probe catch as "zero" when determining total particulate catch weight in accordance with 10.2 if the negative value is equal to or less than 5 % of the total particulate catch (excluding the probe).

10.2.2.2 Treat the test run as invalid if the negative value is greater than 5 % of the total particulate catch weight (excluding the probe).

10.2.2.3 For the room air sample probe assembly, treat negative particulate catch weights as "zero" when determining total room air particulate weight in accordance with 10.2.

NOTE 7—For the purposes of 10.2, the term constant weight means a difference of no more than 0.2 mg or 1 % of total weight less tare weight (particulate catch), whichever is greater, between two consecutive weighings, with intervals of not less than 6 h of desiccation time between weighings.

11. Data Analysis and Calculations

11.1 Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

11.2 *Nomenclature:*

A = Cross-sectional area of tunnel m^2 (ft^2).
B_{ws} = Water vapor in the gas stream, proportion by volume (assumed to be 0.02 (2.0 %)).
C_p = Pitot tube coefficient, dimensionless (assigned a value of 0.99).
c_r = Concentration of particulate matter room air, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
c_s = Concentration of particulate matter in tunnel gas, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
E_T = Total particulate emissions, g.
F_p = Adjustment factor for center of tunnel pitot tube placement.

$$F_p = \frac{V_{strav}}{V_{scent}} \tag{1}$$

$$K_p = \text{Pitot Tube Constant, } 34.97 \frac{\text{m}}{\text{sec}} \left[\frac{(\text{g/g}\bullet\text{mole})(\text{mm Hg})}{(\text{K})\ (\text{mm water})} \right]^{\frac{1}{2}} \tag{2}$$

or

$$K_p = \text{Pitot Tube Constant, } 85.49 \frac{\text{ft}}{\text{sec}} \left[\frac{(\text{lb/lb} - \text{mole})(\text{in. Hg})}{(\text{R})(\text{in. H}_2\text{0})} \right]^{\frac{1}{2}}$$

L_a = Maximum acceptable leakage rate for either a pretest or post-test leak- check, equal to 0.0003 m^3/min (0.010 cfm) or 4 % of the average sampling rate, whichever is less.

L_p = Leakage rate observed during the post-test leak-check, m^3/min (cfm).
m_p = mass of particulate from probe, mg.
m_f = mass of particulate from filters, mg.
m_g = mass of particulate from filter gaskets, mg.
m_r = mass of particulate from the filter, filter gasket, and probe assembly from the room air blank filter holder assembly, mg.
m_n = Total amount of particulate matter collected, mg.
M_s = the dilution tunnel dry gas molecular weight (may be assumed to be 29 g/g mole (lb/lb mole).
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_g = Static Pressure in the tunnel (in. water).
PR = Percent of proportional sampling rate.
P_s = Absolute average gas static pressure in dilution tunnel, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
Q_{std} = Average gas flow rate in dilution tunnel.

$$Q_{std} = 60\left(1 - B_{ws}\right) v_s A \left[\frac{T_{std} P_s}{T_s P_{std}}\right] \tag{3}$$

dscm/min (dscf/min).

T_m = Absolute average dry gas meter temperature, K (R).
T_{mi} = Absolute average dry gas meter temperature during each 10-min interval, *i*, of the test run.

$$T_{mi} = \frac{\left(T_{mi(b)} + T_{mi(e)}\right)}{2} \tag{4}$$

K (R).

where:

$T_{mi(b)}$ = Absolute dry gas meter temperature at the beginning of each 10-min test interval, *i*, of the test run, K (R), and
$T_{mi(e)}$ = Absolute dry gas meter temperature at the end of each 10-min test interval, *i*, of the test run, K (R).

T_s = Absolute average gas temperature in the dilution tunnel, K (R).
T_{si} = Absolute average gas temperature in the dilution tunnel during each 10-min interval, *i*, of the test run, K (R).

$$T_{si} = \frac{\left(T_{si(b)} + T_{m=si(e)}\right)}{2} \tag{5}$$

K (R).

where:

$T_{si(b)}$ = Absolute gas temperature in the dilution tunnel at the beginning of each 10-min test interval, *i*, of the test run, K (R), and
$T_{si(e)}$ = Absolute gas temperature in the dilution tunnel at the end of each 10-min test interval, *i*, of the test run, K (R).

T_{std} = Standard absolute temperature, 293K (528R).
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
V_{mc} = Volume of gas sampled corrected for the post test leak rate, dcm (dcf).
V_{mi} = Volume of gas sample as measured by dry gas meter during each 10-min interval, *i*, of the test run, dcm.
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions.

$$V_{m(std)} = K_1 V_m Y \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{T_m} \tag{6}$$

dscm (dscf).

where:

K_1 = 0.3855 K/mm Hg for SI units and = 17.64 R/in. Hg for inch-pound units.

NOTE 8—Eq 6 can be used as written unless the leakage rate observed during the mandatory post test leak check exceeds L_a. If L_p exceeds L_a but the other requirements in accordance with 9.6.5.1 are met, Eq 6 must be modified as follows:

$$V_{m(std)} = K_1 V_{mc} Y \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{T_m} \tag{7}$$

where:

V_{mc} = $V_m - (L_p - L_a)\theta$
V_{mr} = Volume of room air sample as measured by dry gas meter, dcm (dcf), and
$V_{mr(std)}$ = Volume of room air sample measured by the dry gas meter, corrected to standard conditions.

$$V_{mr(std)} = K_1 V_{mr} Y \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{T_m} \tag{8}$$

dscm (dscf).

where:

K_1 = 0.3855 K/mm Hg for SI units and = 17.64 R/in. Hg for inch-pound units, and
V_s = Average gas velocity in the dilution tunnel.

$$v_s = F_p K_p C_p \sqrt{\Delta p_{avg}} \sqrt{\frac{T_s}{P_s M_s}} \tag{9}$$

m/sec (ft/sec).

V_{si} = Average gas velocity in dilution tunnel during each 10-min interval, *i*, of the test run.

$$v_{si} = F_p K_p C_p \sqrt{\Delta p_i} \sqrt{\frac{T_{si}}{P_s M_s}} \tag{10}$$

m/sec (ft/sec).

V_{scent} = Average gas velocity at the center of the dilution tunnel calculated after the Pitot tube traverse.
V_{strav} = Average gas velocity calculated after the multi-point Pitot traverse.
Y = Dry gas meter calibration factor.
ΔH = Average pressure at the outlet of the dry gas meter or the average differential pressure across the orifice meter, if used, mm water (in. water).

Δp_{avg} = Average velocity pressure in the dilution tunnel, mm water (in. water).

Δp_i = Velocity pressure in the dilution tunnel as measured with the Pitot tube during each 10-min interval, *i*, of the test run.

$$\Delta p_i = \frac{\left(\Delta p_{i(b)} + \Delta p_{i(e)}\right)}{2} \qquad (11)$$

mm water (in. water).

where:

$\Delta p_{i(b)}$ = Velocity pressure in the dilution tunnel as measured with the Pitot tube at the beginning of each 10-min interval, *i*, of the test run, mm water (in. water), and

$\Delta p_{i(e)}$ = Velocity pressure in the dilution tunnel as measured with the Pitot tube at the end of each 10-min interval, i, of the test run, mm water (in. water).

θ = Total sampling time, min.

10 = ten min, length of first sampling period.

13.6 = Specific gravity of mercury.

100 = Conversion to percent.

11.3 *Total Particulate Weight*—Determine the total particulate catch, mn, from the sum of the catches obtained from the filters, probe and filter housing and filter gaskets (O-rings).

$$m_n = m_p + m_f + m_g \qquad (12)$$

grams.

11.4 *Particulate Concentration:*

11.4.1 *Particulate Concentration-Sample:*

$$c_s = K_2 \frac{m_n}{V_{m(std)}} \qquad (13)$$

g/dscm (g/dscf).

where:

K_2 = 0.001 g/mg.

11.4.2 *Particulate Concentration-Room Air:*

$$c_r = K_2 \frac{m_r}{Vm_{r(std)}} \qquad (14)$$

g/dscm (g/dscf).

where:

K_2 = 0.001 g/mg.

11.5 *Total Particulate Emissions:*

$$E_T = (c_s - c_r)\, Qstd\, \theta \qquad (15)$$

(total emissions in grams.)

NOTE 9—See specific appliance operation and test procedures for appropriate emissions rate or factor for calculations for the appliance type. This involves dividing the total emissions determined by this test method by operational parameters such as total fuel load weight, heat output rate, test duration, or other factors.

11.6 *Proportional Rate Variation*—Calculate PR for each 10-min interval, *i*, of the test run.

reported as percentage.

11.6.1 Alternate calculation procedures for proportional rate variation may be used if other sample flow rate data (for example, orifice flow meters or rotameters) are monitored to maintain proportional sampling rates. The proportional rate variations shall be calculated for each 10-min interval by comparing the dilution tunnel to sample probe nozzle velocity ratio for each 10-min interval to the average dilution tunnel to sample probe nozzle velocity ratio for the entire test run. Proportional rate variation may be calculated for intervals shorter than 10 min with appropriate revisions to Eq 16. The results are acceptable if 90 % of the PR values calculated for all the sampling intervals are between 90 % and 110 % and if no PR value falls outside the range of 80 % to 120 %. If the PR values for the test run are determined to be unacceptable, repeat the test run.

11.7 *Dual Train Comparison*—Calculate the total emissions from each sampling train as shown in 11.5 separately and determine the average total emissions from the two values. Calculate the emissions factors for each sample train by dividing the total emissions by the weight of dry fuel burned. The total emissions values calculated for each sampling train shall not differ by more than 7.5 % from the average total emissions value or the difference between the emissions factors for the two trains shall not be greater than 0.5 grams per kilogram of dry fuel. If this specification is not met, the results are unacceptable.

12. Precision and Bias

12.1 *Precision*—It is not possible to specify the precision of the procedure in this test method for measuring solid fuel burning appliance emissions because the appliance operation and fueling protocols and the appliances themselves produce variable amounts of emissions and therefore the results cannot be used to determine reproducibility or repeatability of this measurement method.

12.2 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring solid fuel burning appliance emissions because no material having an accepted reference value is available.

APPENDIXES

(Nonmandatory Information)

X1. MEASUREMENT UNCERTAINTY

X1.1 Total Emissions Measurement Uncertainty

X1.2 *Introduction* —Solid fuel burning appliance particulate emissions measured by this test method are subject to both measurement uncertainty and variation due to uncontrolled random factors. The combustion process with wood fuels in particular results in variation in emissions measurements due to a large number of variables that cannot be precisely controlled. Fuel density, moisture content, piece size and placement, turbulent combustion air flow patterns and a number of other variables are known to have some effect on the total particulate emissions produced. There is insufficient data to determine just how significant the variation in results might be for particular appliances or appliance types. However, it is the consensus of experienced testers that these factors alone can account for variation in apparently identical test runs of at least ±10 % in total particulate emissions.

X1.2.1 One component of the variability in results is the Measurement Uncertainty (MU) of the actual particulate emissions measurement. This component of variability can be analyzed and estimated by standard MU analysis techniques. The purpose of Appendix X1 is to provide an outline of the process for determining MU with an example of the needed calculations for its application. However, performing this calculation is not a requirement of the test method.

X1.2.2 For the purposes of this appendix, uncertainties will be stated at a 95 % confidence level meaning that there is a 5 % or less probability that any measurement would deviate from the true value by more than the stated MU. To simplify the analysis it will be assumed that all uncertainties of individual measurements have the same distribution and coverage factor so that standard uncertainties do not need to be derived or stated.

X1.3 Measurement Uncertainty Analysis

X1.3.1 Every numerical physical measurement process is subject to a quantifiable level of uncertainty. This uncertainty is determined in the process of calibrating the measurement instrument. Therefore, the measurement uncertainty for each direct measurement required in a test method can be determined. When multiple measurements of specific quantities are combined into a final numerical measurement result, the combined uncertainty can be calculated by application of well defined and accepted procedures. These procedures are outlined fully in ISO "Guide to the Expression of Uncertainty in Measurement."

X1.3.2 Analysis of the MU for the total particulate emissions in this test method requires combining the uncertainty of the following individual measurements.

X1.3.2.1 Dilution tunnel volumetric flow rate.

X1.3.2.2 Sampling system volumetric flow rate.

X1.3.2.3 Filter and sample probe particulate gravimetric catch.

X1.3.2.4 Ambient particulate background concentration.

X1.3.3 *Component Measurement Uncertainties:*

X1.3.3.1 *Dilution Tunnel Flow Rate*—The dilution tunnel flow is measured by a standard Pitot tube and a differential pressure gauge. The direct measurement is of flow velocity at the operating temperature and pressure. Pitot tube measurements are considered a primary reference method and therefore the primary component of uncertainty in the velocity measurement is that of the differential pressure gauge. Conversion of the velocity measurement to flow rate at standard temperature and pressure conditions requires additional measurements of the tunnel cross sectional area, the temperature and the absolute pressure. An analysis of the overall uncertainty of the tunnel flow rate indicates that the measurements of tunnel cross sectional area, temperature and pressure have a relatively minor affect. The procedure in this standard has been specified such that the overall uncertainty of this parameter is about ±2 % of the flow rate.

X1.3.3.2 *Sampling Volumetric Flow Rate*—The equipment available to measure the sample flow rate has a high precision and can be calibrated such that the measurement uncertainty is ±1 % or better of the actual flow rate. For the purposes of this appendix a ±1 % uncertainty will be assumed. However, laboratories should use the actual MU of the metering equipment they use to estimate the MU of their test results.

X1.3.3.3 *Filter and Probe Particulate Catch*—The analytical balance specified has a measurement uncertainty of ±0.0001g (0.1 mg). A total of 4 to 6 weighings may be needed to determine the net catch depending on whether filters, o-rings and probes are weighed together or separately. Since each weighing is subject to the same uncertainty, the overall uncertainty of the weighing is:

$$MU_{weighing} = \sqrt{0.1^2 \cdot X} \qquad (X1.1)$$

where:

X = The total number of weight values actually used to calculate emissions. This does not include weighings during pretest or post-test drying.

= For a process that involves three pretest and three post-test weighings, this uncertainty is ±0.245 mg.

An additional component of the filter catch weight uncertainty is the potential for incomplete recovery of the filter material. There is no objective data to determine the magnitude of this factor, but laboratories familiar with the procedures report that they believe it to be less than 0.1 mg. Combining an additional ±0.1 mg with the weighing uncertainty results in an overall weighing uncertainty of ±0.27 mg.

X1.3.3.4 *Ambient Particulate Background Concentration* —This measurement uses the same measurement equipment and procedures as the sample system and is subject to a similar measurement uncertainty.

X1.3.4 *Combined Measurement Uncertainty*—This section shows an example calculation.

X1.3.4.1 Combined uncertainties are calculated by taking the square root of the sum of squares of the component uncertainties multiplied by a "sensitivity coefficient". The sensitivity coefficient is the partial derivative of the function used to calculate the result with respect to the specific measurement parameter. The general formula (law of propagation of uncertainty) is:

$$uY = \sqrt{((\delta Y/\delta\, x_1) \times u_1)^2 + \ldots + ((\delta Y/x_n) \times u_n)^2} \tag{X1.2}$$

where:

$\delta Y/\delta x_i$ = Partial derivative of the combining formula with respect to individual measurement x_i, and
u_i = is the uncertainty associated with that measurement.

The formula to calculate total particulate emissions is:

$$E_T = (c_s - c_r)\, Q_{std}\, \theta \tag{X1.3}$$

where:

c_s = sample filter catch/(sample flow rate x test duration), g/dscf,
c_r = room background filter catch/(sample flow x sampling time), g/dscf,
Q_{std} = average dilution tunnel flow rate, dscf/min, and
θ = sampling time, minutes.

X1.3.4.2 For the sake of example the following values will be used in an MU analysis of E_T.

Measurement	Measured Value	MU	Units
Sample Filter Catch (F_c)	0.025	±0.00027	g
Sample Flow Rate (Q_{sample})	0.25	±0.0025	dscfm
Sampling Duration (θ)	180	±0.1	minutes
Background Filter Catch (BG_c)	0.002	±0.00027	g
Background Filter Flow Rate (Q_{BG})	0.15	±0.0015	dscfm
Tunnel Flow Rate (Q_{std})	150	±3.0	dscfm

(1) Calculate the MU of c_s:

$$c_s = F_c/(Q_{sample}\, x\ \theta\,) = 0.025/(0.25 \times 180) = 0.0005555 \tag{X1.4}$$

$$\frac{\delta c_s}{\delta F_c} = \frac{1}{Q_{sample} \bullet \Theta} = \frac{1}{0.25 \bullet 180} = 0.0222 \tag{X1.5}$$

$$\frac{\delta c_s}{\delta Q_{sample}} = \frac{-F_c}{Q^2_{sample} \bullet \Theta} = \frac{-0.025}{0.25^2 \bullet 180} = -0.00222 \tag{X1.6}$$

$$\frac{\delta c_s}{\delta \Theta} = \frac{-F_c}{Q_{sample} \bullet \Theta^2} = \frac{-0.025}{0.25 \bullet 180^2} = -0.000003 \tag{X1.7}$$

$$MUc_s = \sqrt{(0.00027 \bullet 0.0222)^2 + (0.0025 \bullet -0.00222)^2} \tag{X1.8}$$

$$\sqrt{+(0.1 \bullet -0.000003)^2} = 0.0000081 g$$

Thus, c_s would be 0.555 mg/dscf ± 0.0081 mg/dscf at 95 % confidence level.

(2) Calculate the MU of c_r:

$$c_r = BGc/(QBG \times \theta) = 0.002/(0.15 \times 180) = 0.000074 \tag{X1.9}$$

$$\frac{\delta\, c_r}{\delta BG_c} = \frac{1}{Q_{BG} \bullet \Theta} = \frac{1}{0.15 \bullet 180} = 0.03704 \tag{X1.10}$$

$$\frac{\delta c_r}{\delta Q_{BG}} = \frac{-BG_c}{Q^2_{BG} \bullet \Theta} = \frac{-0.002}{0.15^2 \bullet 180} = -0.0004938 \tag{X1.11}$$

$$\frac{\delta c_r}{\delta \Theta} = \frac{-BG_c}{Q_{BG} \bullet \Theta^2} = \frac{-0.002}{0.15 \bullet 180^2} = -0.0000004 \tag{X1.12}$$

$$MUc_r = \sqrt{(0.00027 \bullet 0.03704)^2 + (0.0015 \bullet -0.0004938)^2} \tag{X1.13}$$

$$\sqrt{+(0.1 \bullet -0.0000004)^2} = 0.00001 g$$

Thus, c_r would be 0.074 mg/dscf ± 0.01 mg/dscf at 95 % confidence level.

(3) Calculate E_T and MU_{ET}

$$E_T = (c_s - c_r)\, Q_{sd}\, \theta = (0.000555 - 0.000074) \times 150 \times 180 = 13.00\, g \tag{X1.14}$$

$$\frac{\delta\, E_T}{\delta c_s} = Q_{std} \bullet \Theta = 150 \bullet 180 = 27{,}000 \tag{X1.15}$$

$$\frac{\delta E_T}{\delta c_r} = Q_{std} \bullet \Theta = 150 \bullet 180 = 27{,}000 \tag{X1.16}$$

$$\frac{\delta E_T}{\delta Q_{std}} = c_s \bullet \Theta - c_r \bullet \Theta = 0.000555 \bullet 180 - 0.000074 \bullet 180 = 0.08667 \tag{X1.17}$$

$$\frac{\delta E_T}{\delta \Theta} = c_s \bullet Q_{std} - c_r \bullet Q_{std} = 0.000555 \bullet 150 - 0.000074 \bullet 150 = 0.07222 \tag{X1.18}$$

$$MU_{ET} = \sqrt{(27{,}000 \bullet 0.0000081)^2 + (27{,}000 \bullet 0.00001)^2\ (0.08667 \bullet 3)^2} \tag{X1.19}$$

$$\sqrt{+(0.07222 \bullet 0.1)^2} = 0.436$$

Thus the result in this example would be:
ET = 13.00 g ± 0.44 g at a 95 % confidence level.

X1.3.5 *Conclusion*—This example, which is representative of the measurement method as it is currently applied to woodstoves under the EPA NSPS, indicates that the uncertainty related to the dilution tunnel flow rate measurement and filter catch weights are the primary components of the overall uncertainty of the result. Tunnel flow rates may be much higher than necessary to capture all emissions. This can influence the uncertainty of the test method. For example, increasing the tunnel flow rate from 150 to 600 scfm in the above example increases the MU of the result to ±1.3 g or about ±10 % of the measured emissions. Therefore, keeping tunnel flow rates near the minimum necessary to reliably capture the exhaust stream, while keeping the tunnel velocity at a level that can be accurately measured during tests will minimize the uncertainty of the measurement.

X2. STANDARD PITOT TUBE

X2.1 See Fig. X2.1.

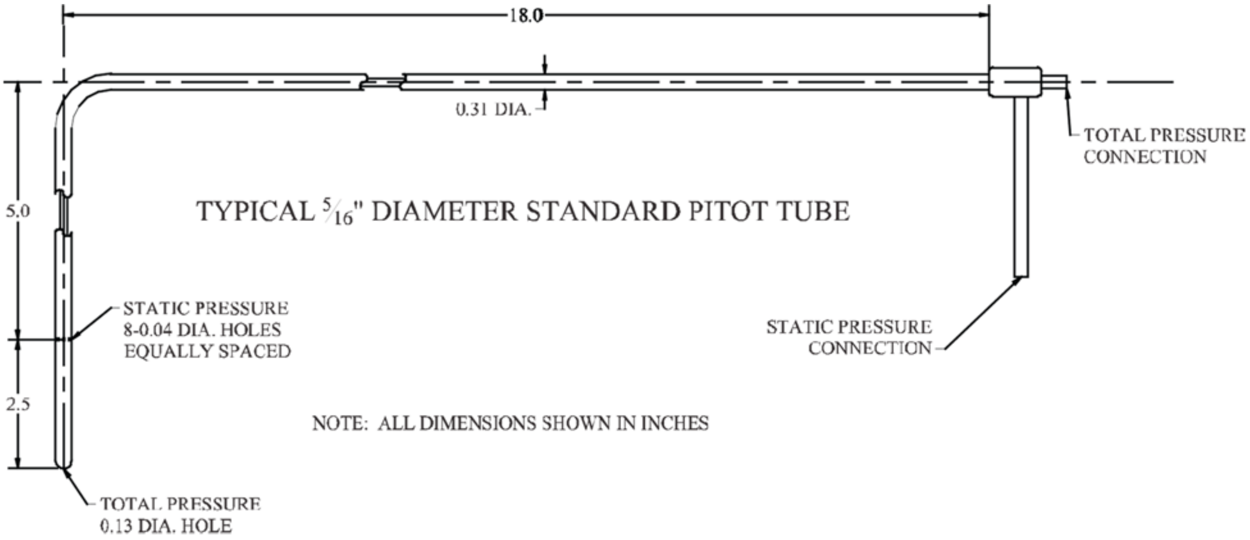

FIG. X2.1 Standard Pitot Tube

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the ASTM website (www.astm.org/COPYRIGHT/).