



# Standard Test Method for Average Velocity in a Duct (Pitot Tube Method)<sup>1</sup>

This standard is issued under the fixed designation D3154; 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 reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

## 1. Scope

1.1 This test method describes measurement of the average velocity of a gas stream for the purpose of determining gas flow in a stack, duct, or flue. Although technically complex, it is generally considered the most accurate and often the only practical test method for taking velocity measurements.

1.2 This test method is suitable for measuring gas velocities above 3 m/s (10 ft/s).

1.3 This test method provides procedures for determining stack gas composition and moisture content.

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are for information only.

1.5 This test method is applicable to conditions where steady-state flow occurs, and for constant fluid conditions, where the direction of flow is normal to the face tube opening of the pitot tube employed in the method. The method cannot be used for direct measurement when cyclonic or swirling flow conditions are present.

1.6 *This standard 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:<sup>2</sup>

- D1071 Test Methods for Volumetric Measurement of Gaseous Fuel Samples
- D1193 Specification for Reagent Water
- D1356 Terminology Relating to Sampling and Analysis of Atmospheres

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D3195 Practice for Rotameter Calibration

D3631 Test Methods for Measuring Surface Atmospheric Pressure

D3685/D3685M Test Methods for Sampling and Determination of Particulate Matter in Stack Gases

D3796 Practice for Calibration of Type S Pitot Tubes

D6522 Test Method for Determination of Nitrogen Oxides, Carbon Monoxide, and Oxygen Concentrations in Emissions from Natural Gas-Fired Reciprocating Engines, Combustion Turbines, Boilers, and Process Heaters Using Portable Analyzers

E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

### 2.2 EPA Standards:<sup>3</sup>

EPA-600/9-76-005 Quality Assurance Handbook for Air Pollution Measurement Systems. Vol I. Principles

EPA-600/4-77-027b Quality Assurance Handbook for Air Pollution Measurement Systems. Vol III. Stationary Source Specific Methods

### 2.3 ASME Performance Test Code Standards:<sup>4</sup>

PTC 19.10-1968 Flue and Exhaust Gas Analysis

PTC 19.10-1981 Part 10, Flue and Exhaust Measurements: Instruments and Apparatus

PTC 38-1980 Determining the Concentration of Particulate Matter in a Gas Stream

### 2.4 Code of Federal Regulation:<sup>3</sup>

40 CFR Part 60 Standards of Performance for Stationary Sources, Appendix A1, Test Methods 1 through 4

## 3. Terminology

### 3.1 Definitions:

3.1.1 For definitions of terms used in this test method, refer to Terminology D1356.

### 3.2 Descriptions of Symbols Specific to This Standard:

<sup>3</sup> Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

<sup>4</sup> Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

|                 |                                                                                                                                                   |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| $A$             | = cross-sectional area of stack, $m^2$ ( $ft^2$ ).                                                                                                |
| $B_{ws}$        | = water vapor in the gas stream, proportion by volume.                                                                                            |
| $C_p$           | = pitot tube coefficient, dimensionless.                                                                                                          |
| $D_s$           | = internal diameter of stack, cm, (in.).                                                                                                          |
| $K_p$           | = pitot tube constant:                                                                                                                            |
|                 | = $128.9 \text{ m/s} \left[ \frac{(g/g - \text{mol})}{(K)} \right]^{1/2}$ (SI),                                                                   |
|                 | = $85.49 \text{ ft/s} \left[ \frac{(\text{lb/lb} - \text{mol})}{(R)} \right]^{1/2}$ (inch-pound).                                                 |
| $m$             | = mean velocity, m/s (ft/s).                                                                                                                      |
| $M_d$           | = molecular weight of stack gas, dry basis, g/g – mol (lb/lb – mol).                                                                              |
| $M_s$           | = molecular weight of stack gas, wet basis, g/g – mol (lb/lb – mol).                                                                              |
| $M_w$           | = molecular weight of water, 18.0 g/g – mol (18.0 lb/lb – mol).                                                                                   |
| $N$             | = number of sampling points across a diameter.                                                                                                    |
| $n$             | = $n$ th sampling point from center of stack.                                                                                                     |
| $\Delta p$      | = velocity head of stack gas, kPa (in. water).                                                                                                    |
| $P_{static}$    | = static pressure of stack gas, kPa (in. water).                                                                                                  |
| $P_{bar}$       | = barometric pressure, kPa (in. Hg).                                                                                                              |
| $P_m$           | = absolute pressure at the dry gas meter (for this test method it equals $P_{bar}$ ), kPa (in. Hg).                                               |
| $P_s$           | = absolute stack gas pressure, kPa (mm Hg).                                                                                                       |
| $P_{std}$       | = standard ambient atmospheric pressure, 101.3 kPa (760 mm Hg).                                                                                   |
| % $CO_2$        | = percent $CO_2$ in the stack gas, by volume, dry basis.                                                                                          |
| %( $N_2 + CO$ ) | = sum of the percents of $N_2$ and $CO$ in the stack gas, by volume, dry basis.                                                                   |
| % $O_2$         | = percent $O_2$ in the stack gas, by volume, dry basis.                                                                                           |
| $Q_{std}$       | = dry volumetric stack gas flow rate corrected to standard conditions, $dm^3/h$ ( $dsft^3/h$ ).                                                   |
| $R$             | = ideal gas constant, 0.08312 (kPa) ( $m^2$ )/g – mol) (K) – (SI system) or 21.85 (in. Hg) ( $ft^2$ )/(lb – mole) ( $^{\circ}R$ ) – (inch-pound). |
| $r_n$           | = radial distance from center of stack to $n$ th sampling point, cm (in.).                                                                        |
| $\rho_w$        | = density of water, 0.9971 g/mL (0.002194 lb/mL) at 25°C (77°F).                                                                                  |
| $S_T$           | = between laboratory bias, m/s (ft/s).                                                                                                            |
| $S_s$           | = among single laboratory bias, m/s (ft/s).                                                                                                       |
| $T_m$           | = absolute average dry gas meter temperature, K ( $^{\circ}R$ ).                                                                                  |
| $T_s$           | = stack gas temperature, K ( $^{\circ}R$ ).                                                                                                       |
| $T_{std}$       | = standard absolute temperature, 298 K (528°R).                                                                                                   |
| $V_i$           | = initial volume of condenser water, mL.                                                                                                          |
| $V_f$           | = final volume of condenser water, mL.                                                                                                            |
| $V_m$           | = volume of gas sample measured by the dry gas meter, $dm^3$ ( $dft^3$ ).                                                                         |
| $v_s$           | = stack gas velocity, m/s (ft/s).                                                                                                                 |
| $V_{m(std)}$    | = volume of gas sample measured by the dry gas meter, corrected to standard conditions, $dm^3$ ( $dft^3$ ).                                       |

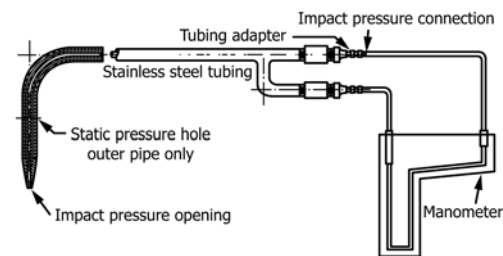


FIG. 1 Pitot Tube

|                |                                                                                                        |
|----------------|--------------------------------------------------------------------------------------------------------|
| $V_{wc(std)}$  | = volume of water vapor condensed, corrected to standard conditions, $sm^3$ ( $sft^3$ ).               |
| $V_{wsg(std)}$ | = volume of water vapor collected in silica gel, corrected to standard conditions, $sm^3$ ( $sft^3$ ). |
| $W_f$          | = final mass of silica gel or silica gel plus impinger, g.                                             |
| $W_i$          | = initial mass of silica gel or silica gel plus impinger, g.                                           |
| $Y$            | = dry gas meter calibration factor.                                                                    |
| 0.28           | = molecular weight of nitrogen or carbon monoxide, divided by 100.                                     |
| 0.32           | = molecular weight of oxygen, divided by 100.                                                          |
| 0.44           | = molecular weight of carbon dioxide, divided by 100.                                                  |
| 3600           | = conversion factor, s/h.                                                                              |

#### 4. Summary of Test Method

4.1 This test method describes the use of instrumentation, equipment, and operational procedures necessary for the measurement and calculation of the average velocity of air or gas flows in flues, ducts, or stacks utilizing the pitot tube principle, with a manometer or draft gauge for pressure measurement. The stack gas composition is determined, using either an Orsat analyzer, a Fyrite analyzer, or automated  $O_2$  and  $CO_2$  analyzers for determining diluent gas ( $O_2$  and  $CO_2$ ) concentrations, and condensation techniques for determining the moisture content.

#### 5. Significance and Use

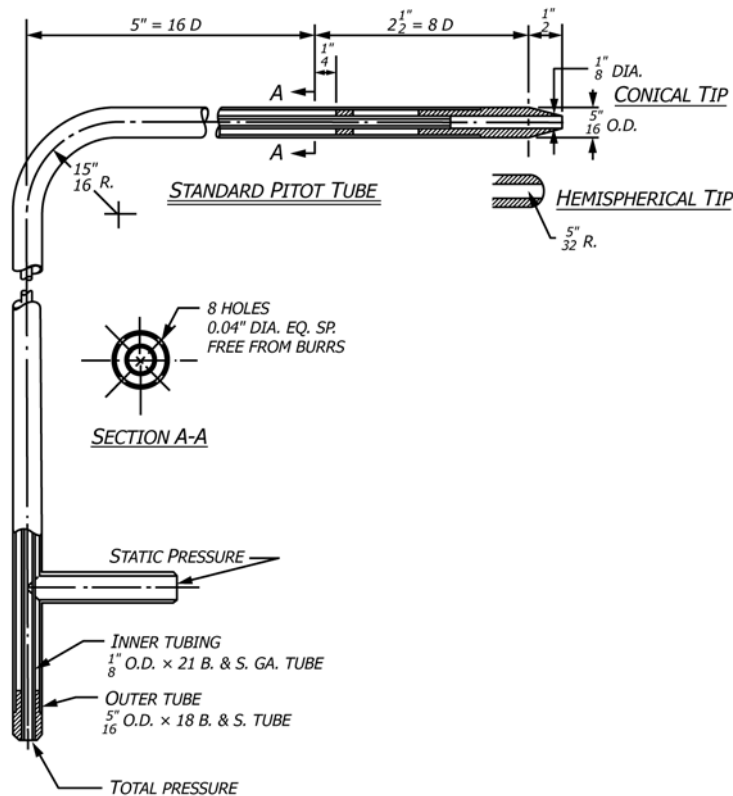
5.1 The procedures presented in this test method are available, in part, in Test Methods D3685/D3685M, as well as the ASME Methods (PTC 19.10-1968, PTC 19.10-1981, and PTC 38-1980) given in 2.3 and Footnote 5,<sup>5</sup> the 40 CFR Part 60 given in 2.4, and the publication given in Footnote 6.<sup>6</sup>

#### 6. Apparatus

6.1 *Pitot Tube*, used in conjunction with a suitable manometer, provides the method for determining the velocity in a duct. The construction of a standard pitot tube and the method of connecting it to a draft gauge are shown in Fig. 1. Details are shown in Fig. 2.

<sup>5</sup> Colen, P., Corey, R. C., and Meyers, J. W., "Methods and Instrumentation for Furnace Heat Absorption Studies; Temperature and Composition of Gases at Furnace Outlets," *Transaction of the American Society of Mechanical Engineers*, Vol 71, pp. 965–78, 1949.

<sup>6</sup> Bulletin WP-50, Western Precipitation Division, Joy Manufacturing Co., "Methods for Determination of Velocity, Dust, and Mist Content of Gases."



| Metric Equivalents |     |       |      |
|--------------------|-----|-------|------|
| in.                | mm  | in.   | mm   |
| 1/8                | 3.2 | 1/2   | 12.7 |
| 5/32               | 4.0 | 15/16 | 23.8 |
| 1/4                | 6.4 | 2 1/2 | 63.5 |
| 5/16               | 7.9 | 5     | 127  |

FIG. 2 Standard Pitot Tube Details

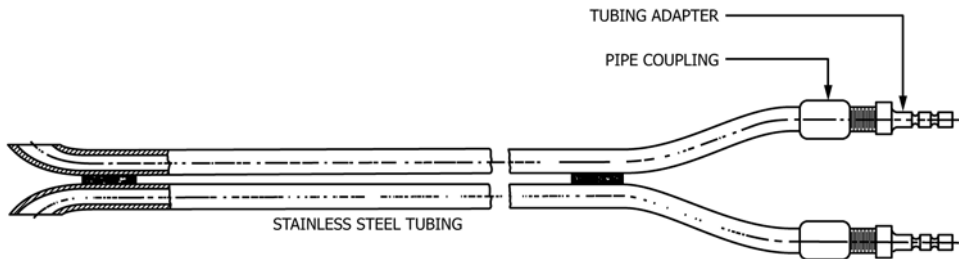


FIG. 3 Type 3 Pitot Tube (Special)

6.1.1 To minimize the stem effect when the physical dimensions of the pitot tube are too large with respect to the flow scale, the diameter of the pitot tube barrel shall not exceed  $\frac{1}{30}$  the size of the duct diameter.

6.1.2 At locations where the standard pitot tube cannot be used in accordance with the sampling plan (see 8.1), or where dust or moisture or both are present that may clog the small holes in this instrument, a calibrated Staubscheibe pitot tube, commonly called a Type “S” pitot tube, shown in Fig. 3, shall be used.

6.1.3 The Type “S” pitot tube may be used in all applications, provided that it has been calibrated. See Practice

D3796. However, use of the standard pitot tube, where feasible, will give additional accuracy.

6.2 *Differential Pressure Gauge*—A liquid-filled inclined manometer or an equivalent device used to measure the velocity head. See Fig. 1. It is equipped with a 250 mm (10 in.) water column inclined manometer that has 0.25 mm (0.01 in.) divisions on the 0-to-25 mm (1 in.) inclined scale, and 2.5 mm (0.1 in.) divisions on the 25 to 250-mm (1 to 10-in.) vertical scale. This type manometer (or other gauge of equivalent sensitivity) is satisfactory for measurements of  $\Delta p$  values as low as 12.5 Pa (0.05 in.  $H_2O$ ).

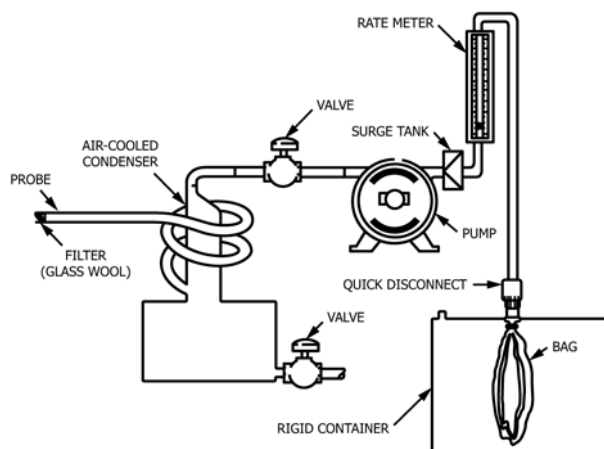


FIG. 4 Integrated Gas Sampling Train

6.3 *Manometer*—An electronic manometer or a water filled U-tube manometer capable of measuring the stack or duct static pressures to within 0.33 kPa (2.5 mm Hg).

6.4 *Thermocouple*—A bimetallic device for measuring temperature utilizing the fact that a small voltage is generated whenever two junctions of two dissimilar metals in an electric circuit are at different temperature levels.

6.4.1 *Potentiometer*—An instrument for measuring small voltages, or for comparing small voltages with a known voltage, used in conjuncture with the thermocouple. Alternative thermocouple read-out devices capable of accurately measuring the effluent gas temperature to within 2°C may be used.

6.4.2 *Thermometer*—A precision digital thermometer based on resistance temperature detectors (RTDs), thermistors, thermocouples, or organic liquid-in-glass thermometers (such as Thermometer S18C in Specification E2251) meeting the requirements of this application may be used.

6.5 *Barometer*—An instrument capable of measuring ambient atmospheric pressure to 0.5 kPa. See Test Methods D3631.

6.6 *Gas Density Determination Equipment*—See Fig. 4.

6.6.1 *Probe*—A stainless steel or borosilicate glass tube, equipped with an in-stack or out-of-stack filter to remove particulate matter.

6.6.2 *Condenser*—A water-cooled condenser that will not remove O<sub>2</sub>, CO<sub>2</sub>, CO, and N<sub>2</sub>, to remove excess moisture if the gas stream contains over 2 % moisture by volume. The main consideration is that the condenser volume be kept to the minimum size because it will be more difficult to purge the sample train before collecting a sample if the condenser is too large. A 63-mm (0.25-in.) stainless steel coil, or equivalent, connected to a water collection chamber with a capacity of about 40 mL is sufficient.

6.6.3 *Valve*—A needle valve to adjust the sample gas flow rate.

6.6.4 *Pump*—A leak-free diaphragm pump, to transport the sample gas to the flexible bag. A small surge tank shall be installed between the pump and the rate meter to eliminate the pulsation effect of the pump on the rate meter. Leak-test the pump, surge tank and rate meter (see 6.6.5), as described in 9.4.3.

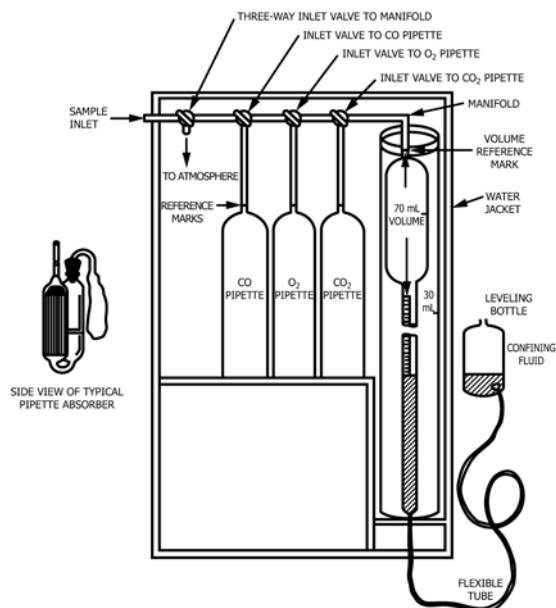


FIG. 5 Orsat Apparatus

6.6.5 *Rate Meter*—A rotameter or equivalent rate meter, capable of measuring flow rates to within  $\pm 2$  % of the selected flow rate.

6.6.6 *Flexible Bag*—A leak-free inert plastic bag, having the capacity adequate for the selected flow rate and length of time of the test. A capacity of 90 L (3.2 ft<sup>3</sup>) is usually sufficient. The bag shall be leak-tested before each test, as described in 9.4.4.

6.6.7 *Vacuum Gauge*—An electronic manometer, or equivalent of 101.3 kPa (760 mm Hg) capacity, to be used for the sample train leak test. Test the gauge as described in 9.4.6.

6.6.8 *Diluent Gas Analyzer(s)*—Automated gas analyzers or an Orsat gas analyzer or Fyrite analyzer are used to analyze the gas sample for CO<sub>2</sub>, and O<sub>2</sub>, stack gas concentrations. The Orsat analyzer (see Fig. 5) is operated by successively passing the gas through adsorbents that remove the specific gaseous components. The difference in gas volumes before and after the absorptions represents the amount of constituent gas in the sample. Separate Fyrite analyzers for measurement of CO<sub>2</sub> and O<sub>2</sub> concentrations may be used to determine diluent gas concentrations for some sources. Each Fyrite analyzer determines the difference in sample volume resulting from the absorption of the respective constituent gas in an appropriate absorbing solution. Do not use CO<sub>2</sub> Fyrite analyzers at sources where effluent CO<sub>2</sub> concentrations exceed 20 % such as mineral calciners.

6.6.8.1 The analyzer shown in Fig. 5 includes a glass buret to measure the gas volume of the sample, a water jacket to maintain constant temperature, a manifold to control the gas flow, two or three absorption pipets (to remove CO<sub>2</sub>, and O<sub>2</sub>, as well as CO at the option of the user), rubber expansion bags, and a liquid-filled leveling bottle to move the gas sample within the analyzer.

6.6.8.2 For CO<sub>2</sub> values  $>4$  %, a standard Orsat gas analyzer with a buret with 0.2 mL divisions and spacings divisions of about 1 mm (0.14 in.) is satisfactory. For values  $<4$  %, a