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.

Designation: E2029 – 11 (Reapproved 2019)

Standard Test Method for Volumetric and Mass Flow Rate Measurement in a Duct Using Tracer Gas Dilution[1]

This standard is issued under the fixed designation E2029; 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 describes the measurement of the volumetric and mass flow rate of a gas stream within a duct, stack, pipe, mine tunnel, or flue using a tracer gas dilution technique. For editorial convenience all references in the text will be to a duct, but it should be understood that this could refer equally well to a stack, pipe, mine tunnel, or flue. This test method is limited to those applications where the gas stream and the tracer gas can be treated as ideal gases at the conditions of the measurement. In this test method, the gas stream will be referred as air, though it could be any another gas that exhibits ideal gas law behavior.

1.2 This test method is not restricted to any particular tracer gas although experimental experience has shown that certain gases are used more readily than others as suitable tracer gases. It is preferable that the tracer gas not be a natural component of the gas stream.

1.3 Use of this test method requires a knowledge of the principles of gas analysis and instrumentation. Correct use of the formulas presented here requires consistent use of units.

1.4 *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, health, and environmental practices and to determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 7.

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 Standard:*[2]

E631 Terminology of Building Constructions

2.2 *ANSI/ASME Standard:*[3]

ANSI/ASME TC 19.1–1985 (1994) Measurement Uncertainty: Instrument Apparatus

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method, refer to Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *ideal gas, n*—a gas or gas mixture for which the ratio of the pressure divided by product of the density and temperature is a constant.

3.2.2 *mass flow, n*—the total mass of air passing the sampling point per unit time (kg/s, lb/min).

3.2.3 *tracer gas, n*—a gas that can be mixed with air and measured in very low concentrations.

3.2.4 *tracer gas analyzer, n*—a device that measures the concentration of tracer gas in an air sample.

3.2.5 *tracer gas mass concentration, n*—the ratio of the mass of tracer gas in air to the total mass of the air-tracer mixture. For an ideal gas, the mass concentration is independent of temperature and pressure.

3.2.6 *tracer gas molar concentration, n*—the ratio of the number of moles of tracer gas in air to the total number of moles of the air-tracer mixture.

3.2.7 *tracer gas volume concentration, n*—the ratio of the volume of tracer gas in air to the total volume of the air-tracer mixture. For an ideal gas, the volume concentration is independent of temperature and pressure and is equal to the molar concentration.

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation Performance.

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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.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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3.2.8 *volumetric flow, n*—the total volume of air passing the sampling point per unit time (m^3/s, ft^3/min).

3.3 *Symbols:*

C = mass concentration[4] of tracer gas (ppb-mass, ppm-mass, ppt-mass)
C_U = upstream mass concentration[4] of tracer gas (ppb-mass, ppm-mass, ppt-mass)
C_D = downstream mass concentration[4] of tracer gas (ppb-mass, ppm-mass, ppt-mass)
C_I = injection stream mass concentration[4] of tracer gas (ppb-mass, ppm-mass, ppt-mass)
c = volume concentration[4] of tracer gas (ppb, ppm, ppt)
c_U = upstream volume concentration[4] of tracer gas (ppb, ppm, ppt)
c_D = downstream volume concentration[4] of tracer gas (ppb, ppm, ppt)
c_I = injection volume concentration[4] of tracer gas (ppb, ppm, ppt)
F = mass flow rate[5] (kg/s, g/min, lb/min)
F_I = injection mass flow rate[5] (kg/s, g/min, lb/min)
F_U = upstream mass flow rate[5] (kg/s, g/min, lb/min)
F_D = downstream mass flow rate[5] (kg/s, g/min, lb/min)
f = volumetric flow rate[5] (m^3/s, L/min, cfm)
f^{std} = volumetric flow rate at standard conditions[5] (m^3/s, L/min, cfm)
f_I = injection volumetric flow rate[5] (m^3/s, L/min, cfm)
f_U = upstream volumetric flow rate[5] (m^3/s, L/min, cfm)
f_D = downstream volumetric flow rate[5] (m^3/s, L/min, cfm)
f_I^{std} = injection volumetric flow rate[5] at standard conditions (m^3/s, L/min, cfm)
f_U^{std} = upstream volumetric flow rate[5] at standard conditions (m^3/s, L/min, cfm)
f_D^{std} = downstream volumetric flow rate[5] at standard conditions (m^3/s, L/min, cfm)
ρ = density[6] (kg/m^3, g/L, lb/ft^3)
ρ_a = density[6] of gas stream without any tracer (kg/m^3, g/L, lb/ft^3)
ρ_t = density[6] of the tracer gas (kg/m^3, g/L, lb/ft^3)
ρ_I = density[6] of the injection gas mixture (kg/m^3, g/L, lb/ft^3)
ρ_U = density[6] of the upstream gas mixture (kg/m^3, g/L, lb/ft^3)
ρ_D = density[6] of the downstream gas mixture (kg/m^3, g/L, lb/ft^3)
$\rho^t{}_U$ = density[6] of the tracer gas at upstream conditions (kg/m^3, g/L, lb/ft^3)
$\rho^t{}_D$ = density[6] of the tracer gas at downstream conditions (kg/m^3, g/L, lb/ft^3)

4. Summary of Test Method

4.1 This test method describes the use of a tracer gas dilution technique to infer the volumetric flow rate through a duct. In practice, tracer gas is injected into a duct at a known mass or volumetric flow rate. Downstream of the injection point gas samples are taken and are analyzed for the resulting tracer concentration. The ratio of the injection flow rate and the downstream concentration represents the dilution volume per unit time or volumetric flow rate in the duct.

5. Significance and Use

5.1 The method presented here is a field method that may be used to determine mass and volume flow rates in ducts where flow conditions may be irregular and nonuniform. The gas flowing in the duct is considered to be an ideal gas. The method may be especially useful in those locations where conventional pitot tube or thermal anemometer velocity measurements are difficult or inappropriate due either to very low average flow velocity or the lack of a suitable run of duct upstream and downstream of the measurement location.

5.2 This test method can produce the volumetric flow rate at standard conditions without the need to determine gas stream composition, temperature, and water vapor content.

5.3 This test method is useful for determining mass or volumetric flow rates in HVAC ducts, fume hoods, vent stacks, and mine tunnels, as well as in performing model studies of pollution control devices.

5.4 This test method is based on first principles (conservation of mass) and does not require engineering assumptions.

5.5 This test method does not require the measurement of the area of the duct or stack.

5.6 The test method does not require flow straightening.

5.7 The test method is independent of flow conditions, such as angle, swirl, turbulence, reversals, and hence, does not require flow straightening.

5.8 The dry volumetric airflow can be determined by drying the air samples without measuring the water vapor concentration.

6. Apparatus

6.1 The apparatus includes a source of tracer gas, means for distributing the tracer gas in the duct, means for obtaining air samples from the duct, and a gas analyzer to measure tracer gas concentrations in the air samples.

6.2 *Tracer Gas*—See Appendix X1 for information on tracer gases and equipment used to measure their concentrations. Appendix X1 also contains tracer gas target concentrations and safety information.

6.3 *Tracer Gas Injection Source*—This normally is a cylinder of compressed tracer gas either pure or diluted in a carrier such as air or nitrogen. Tracer release from the cylinder is controlled by a critical orifice or nozzle, a metering valve, an electronic mass flow meter or mass flow controller, or other gas flow rate measurement and control device. A rotameter is not recommended for this measurement unless of special design, calibration, and a corresponding decrease in measurement accuracy is acceptable.

6.4 *Tracer Gas Distribution*—A single tube or a tubing network is inserted into the duct to dispense tracer gas. The

[4] Equations in this test method assume that all mass or volume concentrations are in the same units.

[5] Equations in this test method assume that all mass or volume flow rates are in the same units.

[6] Equations in this test method assume that all densities are in the same units.

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tube or tubes may have either a single or multiple release points for tracer gas. For large cross-section ducts a network that distributes tracer gas over a wide area will facilitate measurement.

6.5 *Tracer Sampling*—This is performed using tubing inserted into the duct downstream of the injection point. A single tube is inserted into the duct. Air samples are removed from the duct by means of a sampling pump to distribute tracer laden air to the analyzer either directly or by means of syringe samples.

6.6 *Gas Analyzer*—This device must be suited for the tracer gas used and the concentrations expected in the duct being measured. It should be calibrated properly and exhibit a accuracy of better than ±3 % at concentrations employed in the measurement.

7. Hazards

7.1 Safety is the responsibility of the user of this test method. Tracer gases have safe maximum concentration limits due to health and, in some cases, explosive potential. Table 1 presents, as a guide, the maximum allowable concentration in air for some tracer gasses that can be used for airflow measurements. The tracer gas supplier must provide a Material Safety Data Sheet (MSDS) that will provide information about health, fire, and explosion hazards.

7.2 *Health Limitations*—Use current OSHA information on the permissible exposure limit (PEL), or the ACGIH threshold limit value (TLV) if the particular tracer is not listed with a PEL, to determine the safe concentration for the gas chosen for the test. Never exceed the maximum safe concentration. It is good practice to use a concentration that is at most one tenth of the maximum safe concentration. Avoid using tracer gases for which no PEL or TLV exists.

7.3 *Compressed Gas Equipment*—Observe the supplier's safety information and CGA information on the transportation, use, and storage of compressed gas cylinders, regulators, and related equipment.

8. Procedure for Measuring Mass and Volumetric Flowrate

8.1 Inject tracer of known concentration, $C_I(c_I)$, and at a known rate, $F_I(f_I)$, into a flowing duct using procedures provided in Section 9.

8.1.1 If the tracer gas analyzer is field calibrated using a single point method, the injection rate, or injection concentration, or a combination thereof, should be adjusted to produce a concentration at the sample location that is the same as the calibration concentration to within ±20 %.

TABLE 1 Tracer Gases and Safety Issues

Tracer Gas	TLV[A]	Toxicity	Chemical Reactivity	Comments
Hydrogen	Asphyxiant	Nontoxic	Highly reactive in presence of heat, flame, of O_2	Fire and explosion hazard when exposer to heat, flame, or O_2
Helium	Asphyxiant	Nontoxic	Inert	
Carbon Monoxide	25 ppm	Combines with hemoglobin to cause anoxia	Highly reactive with O_2	Fire and explosion hazard when exposed to heat or flame
Carbon Dioxide	5000 ppm	Can be an eye irritant	Reacts vigorously with some metals; soluble in water	
Sulfur Hexafluoride	1000 ppm	Nontoxic	Inert	Thermal decomposition yields highly toxic compounds
Nitrous Oxide	25 ppm	Moderately toxic	Violent reaction with aluminum; water soluble	Can form explosive mixture with air; ignites at high temperature
Ethane	Asphyxiant	Nontoxic	Flammable	Incompatible with chlorine and oxidizing materials
Methane	Asphyxiant	Nontoxic	Flammable	Incompatible with chlorine and oxidizing materials
Octofluorocyclobutane (Halocarbon C-318	1000 ppm	Low toxicity	Nonflammable	Thermal decomposition yields highly toxic compounds
Bromotrifluoromethane (Halocarbon 13B1)	500 ppm	Moderately toxid by inhalation	Incompatible with aluminum	Dangerous in a fire
Dichlorodifluoromethane (Halocarbon 12)	1000 ppm	Central nervous system and eye irritant; can be narcotic at high levels	Nonflammable; can react violently with aluminum	Thermal decomposition yields highly toxic compounds
Dichlorotetrafluoromethane (Halocarbon 116)	1000 ppm	Can be asphyxiant, mildly irritating, narcotic at high levels	Can react violently with aluminum	Thermal decomposition yields highly toxic compounds

[A] *Threshold Limit Values for Chemical Substances in the Work Environment*, American Conference of Governmental Industrial Hygienists (ACGIH), 1997.

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