STANDARD

**ANSI/ASHRAE Standard 41.7-2015 (RA 2018)**
(Reaffirmation of ANSI/ASHRAE Standard 41.7-2015)

# Standard Methods for Gas Flow Measurement

Approved by ASHRAE on April 30, 2018, and by the American National Standards Institute on May 1, 2018.

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ISSN 1041-2336

Approved American National Standard
ANSI
www.ansi.org

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## Standard Methods for Gas Flow Measurement

**NOTE**

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## FOREWORD

*The 1984 edition of Standard 41.7 was limited to square-edged orifice meters. In the 2015 edition, the scope has been expanded to cover the breadth of gas flow measurement devices used for testing heating, ventilating, air-conditioning, and refrigerating systems and components, and to include field gas flow measurements in addition to laboratory gas flow measurements. This standard meets ASHRAE's mandatory language requirements.*

*Selecting an appropriate gas flow flowmeter can be a daunting task given the wide variety of operating principles, measurement precision, and costs of commercial products. Whether gas flow measurements are to be taken in a laboratory or in the field, selecting the appropriate meter should be based on the required measurement accuracy. Once a gas flowmeter has been selected, the user may need to consult with the meter manufacturer regarding installation specifics, operating range limits, calibration limits, and other similar specifics in order to obtain the expected measurement accuracy. Safety is an important consideration for all procedures involving gases, particularly regarding flammability, toxicity, and corrosiveness. Safety glasses and other personal protection equipment should be worn.*

*This is a reaffirmation of Standard 41.7-2015. This standard was prepared under the auspices of ASHRAE. It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interests of obtaining uniform guidelines throughout the industry. This version of the reaffirmation has no changes.*

## 1. PURPOSE

This standard prescribes methods for gas flow measurement.

## 2. SCOPE

This standard applies to laboratory and field gas flow measurement for testing heating, ventilating, air-conditioning, and refrigerating systems and components. This standard is restricted to applications where the entire flow stream of gas enters and exits the gas flowmeter in a gas-only state during data recording with the following exceptions:

a. This standard does not apply to airflow measurements at pressures within this range: –25 kPa to +25kPa (–100 in. $H_2O$ to +100 in. $H_2O$) referenced to ambient pressure. Those measurements are within the scope of ASHRAE Standard 41.2.

b. This standard does not apply to fan performance rating airflow measurements. Those measurements are within the scope of ASHRAE Standard 51.

c. This standard does not apply to gaseous-phase refrigerant mass flow measurements where the gas flow includes circulating lubricant. Those measurements are within the scope of ASHRAE Standard 41.10.

## 3. DEFINITIONS

The following definitions apply to the terms used in this standard.

***accuracy:*** the degree of conformity of an indicated value to the corresponding true value.

***equivalent diameter:*** the diameter of a circle having the same area as a rectangular area.

***error:*** the difference between the test result and its corresponding true value.

***mean,*** $\overline{X}_m$***:*** the arithmetic average of $N$ readings.

***measurement system:*** the instruments, signal conditioning systems (if any), and data acquisition system (if any).

***precision:*** the closeness of agreement among repeated measurements of the same characteristic by the same method under the same conditions.

***random error,*** $\varepsilon$***:*** the portion of total error that varies randomly in repeated measurements throughout a test process.

***sample size,*** $N$***:*** the number of individual values in a sample.

***systematic error,*** $\beta$***:*** the portion of total error that remains constant in repeated measurements throughout a test process.

***test point:*** a specific set of test operating conditions and tolerances for recording data.

***true value:*** the unknown, error-free value of a test result.

***uncertainty:*** a measure of the potential error in a measurement or experimental result that reflects the lack of confidence in the result to a specified level.

***unit under test:*** equipment that is the subject of the gas flow rates measurements using this standard.

## 4. CLASSIFICATIONS

**4.1 Gas Flow Operating State.** Gas flow measurement methods shall be restricted to applications where the entire gas flow stream enters and exits the flowmeter in the vapor-only state during data recording. Trace amounts of liquids shall be less than 1% by mass unless otherwise specified by the flowmeter manufacturer or by the test plan in Section 5.1.

**4.2 Gas Flow Measurement Applications.** Gas flow measurement applications that are within the scope of this standard shall be classified as one of the following types.

**4.2.1 Laboratory Applications.** Gas flow measurements under laboratory conditions are engineering development tests or tests to determine product ratings.

***Informative Note:*** Laboratory gas flow measurements tend to use more accurate instruments than field measurements do and tend to meet the instrument manufacturer's installation requirements.

**TABLE 5-1 Measurement Values and Units of Measure**

| Quantity | Units of Measure<br>SI | <br>I-P | Note |
|---|---|---|---|
| Mass flow rate and uncertainty | Kilogram per second ($kg/s$) | Pound (avoirdupois) per second ($lb_m/s$) | No notes apply. |
| Volumetric flow rate and uncertainty | Liters per minute (L/min) | Cubic foot per minute (cfm) | Only if specified in the test plan in Section 5.1. |
| Density and uncertainty | Kilograms per cubic meter ($kg/m^3$) | Pound (avoirdupois) per cubic foot ($lb_m/ft^3$) | Only if specified in the test plan in Section 5.1. |

**4.2.2 Field Applications.** Gas flow measurements under field conditions are tests to determine installed system gas flow rates.

*Informative Note:* Field gas flow measurements tend to use less accurate instruments than laboratory measurements do and often do not to meet the instrument manufacturer's installation requirements.

### 4.3 Gas Flowmeters

**4.3.1 Mass Flowmeters**. Gas flowmeters in this category perform direct measurement of gas mass flow rates.

**4.3.2 Volumetric Flowmeters.** Gas flowmeters in this category perform direct measurement of volumetric gas flow rates. If gas mass flow rates are required, each volumetric gas flow measurement shall be multiplied by the inlet gas density at the flow measurement location to obtain the gas mass flow rate measurement.

*Informative Note:* Ultrasonic flowmeters, vortex-shedding flowmeters, and drag-force flowmeters are examples of velocity measuring devices that can be used to determine volumetric flow rates.

**4.4 Gas Flow Measurement Methods.** Gas flow measurement methods that are within the scope of this standard are shown in the following list. Each of these gas flow measurement methods is described in Section 7.5:

a. Coriolis flowmeters
b. Thermal flowmeters
c. Orifice meters
d. Flow nozzles
e. Venturi tubes
f. Turbine flowmeters
g. Variable-area flowmeters
h. Ultrasonic flowmeters
i. Pitot-static tube methods
j. Vortex-shedding flowmeters
k. Drag-force flowmeters

## 5. REQUIREMENTS

**5.1 Test Plan.** A test plan is a requirement. The test plan shall specify the test points and the required measurement system accuracy at each test point. A test plan is a document or other form of communication that specifies the tests to be performed and the required measurement accuracy for each test. Sources of the test plan are (a) the person or the organization that authorized the tests to be performed, (b) a method of test standard, (c) a rating standard, or (d) a regulation or code.

**5.2 Values to be Determined and Reported.** The test values to be determined and reported shall be as shown in Table 5-1. Use the unit of measure in Table 5-1 unless otherwise specified in the test plan in Section 5.1.

### 5.3 Test Requirements

**5.3.1 Accuracy.** A selected gas flowmeter shall meet or exceed the required gas flow measurement system accuracy specified in the test plan in Section 5.1 over the full range of operating conditions.

**5.3.2 Uncertainty.** The uncertainty in each gas flow measurement shall be calculated using the method in Section 8 for each test point. Alternatively, the worst-case uncertainty for all test points shall be estimated and the same value reported for each test point.

**5.3.3 Gas Mass Flow Rate Steady-State Tests.** If the test plan in Section 5.1 requires gas mass flow rate data points to be recorded at steady-state test conditions but does not specify the steady-state criteria, each set of steady-state test conditions shall meet the criteria specified by Equations 5-1 through 5-5.

$$\frac{\sigma_{\dot{m}}}{\dot{m}} \le 1.0\% \tag{5-1}$$

$$n \ge 10 \tag{5-2}$$

where

$\dot{m}$ = gas mass flow rate, kg/s ($lb_m/h$)
$\sigma$ = standard deviation of measurement samples
$n$ = number of measurement samples

$$\sigma_{\dot{m}} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\dot{m}_i - \bar{\dot{m}})^2} \tag{5-3}$$

$$\bar{\dot{m}} = \frac{1}{n}\sum_{i=1}^{n}\dot{m}_i \tag{5-4}$$

If the test plan in Section 5.1 specifies a target gas mass flow rate for the steady-state test conditions, $\dot{m}_{target}$, then the criterion in Equation 5-5 shall be met unless otherwise specified in the test plan.

$$\left|\frac{\bar{\dot{m}} - \dot{m}_{target}}{\dot{m}}\right| \le 1.0\% \tag{5-5}$$

**5.3.4 Airflow Dynamic Tests.** If required by the test plan in Section 5.1, gas mass flow rate measurements shall be made at the dynamic operating conditions and test condition limits specified in the test plan. Data points shall be recorded at time intervals specified in the test plan.

***Informative Note:*** Dynamic tests need to address the response time of the selected instruments to ensure that the response time is appropriate for the test plan requirements. Take into consideration dampening features that are commonly used in air flowmeter electronics and signal conditioning. Dynamic measurements of velocity would be needed if quantities like turbulence intensity were to be measured.

## 6. INSTRUMENTS

### 6.1 Instrumentation Requirements for All Measurements

**6.1.1** Instruments and data acquisition systems shall be selected to meet the measurement system accuracy specified in the test plan.

**6.1.2** Measurements from the instruments shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST) or to the Bureau International des Poids et Mesures (BIPM) if a National Metrology Institute (NMI) other than NIST is used. In either case, the indicated corrections shall be applied to meet the uncertainty stated in subsequent sections. Instruments shall be recalibrated on regular intervals that do not exceed the intervals prescribed by the instrument manufacturer and calibration records shall be maintained. Instruments shall be installed in accordance with the instrument manufacturer's requirements, or the manufacturer's accuracy does not apply.

**6.1.3** Instruments shall be applied and used in accordance with the following standards:

a. **Temperature.** ASHRAE Standard 41.1[1] if temperature measurements are required.
b. **Pressure.** ASHRAE Standard 41.3[2] if pressure measurements are required.

**6.2 Temperature Measurements.** If temperature measurements are required by the test plan in Section 5.1, the measurement system accuracy shall be within the following limits unless otherwise specified in the test plan:

a. Temperature sensors within ±0.2[illegible]°C (±0.5°F)
b. Temperature difference sensors within ±l.0% of the reading

### 6.3 Pressure Measurements

#### 6.3.1 Laboratory Pressure Measurements

**6.3.1.1** If pressure measurements are required by the test plan in Section 5.1, the measurement system accuracy shall be within ±1.0% of reading unless otherwise specified in the test plan. If absolute pressure sensors are not used, the barometric pressure shall be added to obtain absolute pressure values prior to performing uncertainty calculations.

**6.3.1.2** If differential pressure measurements are required by the test plan, the measurement system accuracy shall be within ±1.0% of reading unless otherwise specified in the test plan. Pressure shall be measured in close proximity to the flowmeter in accordance with the flowmeter manufacturer's specifications.

#### 6.3.2 Field Pressure Measurements

**6.3.2.1** If pressure measurements are required by the test plan in Section 5.1, the measurement system accuracy shall be within ±3.0% of reading unless otherwise specified in the test plan. If absolute pressure sensors are not used, the barometric pressure shall be added to obtain absolute pressure values prior to performing uncertainty calculations.

**6.3.2.2** If differential pressure measurements are required by the test plan, the measurement system accuracy shall be within ±3.0% of reading unless otherwise specified in the test plan. Pressure shall be measured in close proximity to the flowmeter in accordance with the flowmeter manufacturer's specifications.

**6.4 Time Measurements.** Time measurement system accuracy shall be within ±0.5% of the elapsed time measured, including any uncertainty associated with starting and stopping the time measurement unless (a) otherwise specified in the test plan in Section 5.1 or (b) a different value for time measurement system accuracy is required to be consistent with the gas flow rate measurement system accuracy specified in the test plan.

## 7. GAS FLOW RATE MEASUREMENT METHODS

**7.1 Gas Properties.** If not specified in the test plan in Section 5.1, the source of the gas property data shall be recorded in the test report.

***Informative Note:*** Informative Annex A, Section A1, identifies one potential source of gas refrigerant properties.

**7.2 Operating Limits.** Operating conditions during gas flow rate data measurements shall not exceed limits for pressure, pressure differential, temperature, gas velocity, or pressure pulsations specified in the test plan or by the gas flowmeter manufacturer to achieve the measurement system accuracy required by the test plan.

**7.3 Leakage Requirement.** Unless otherwise specified in the test plan in Section 5.1, measured gas leakage out of the test apparatus shall be not be greater than 0.25% of the gas flow at the greatest pressure tested under laboratory conditions, or not greater than 1% of the gas flow at the greatest pressure tested under field conditions.

***Informative Note:*** Account for the leakage in the uncertainty analysis.

**7.4 Gas Flowmeter Installation.** The selected gas flowmeter shall be installed in accordance with instructions from the manufacturer, or the uncertainty calculations shall include estimated uncertainties for installations that are not in accordance with the manufacturer's instructions.

### 7.5 Gas Flowmeter Descriptions

**7.5.1 Coriolis Flowmeters.** Coriolis gas flowmeters provide direct measurement of gas mass flow rates. In a Coriolis flowmeter, the gas flows through a vibrating sensor tube within the meter. An electromagnetic coil located on the sensor tube vibrates the tube in a cantilever motion at a known frequency. The gas enters a vibrating tube and is given the vertical momentum of the tube. The gas in the entry portion of the sensor tube resists in the downward direction when the tube is moving upward during half of the vibration cycle.

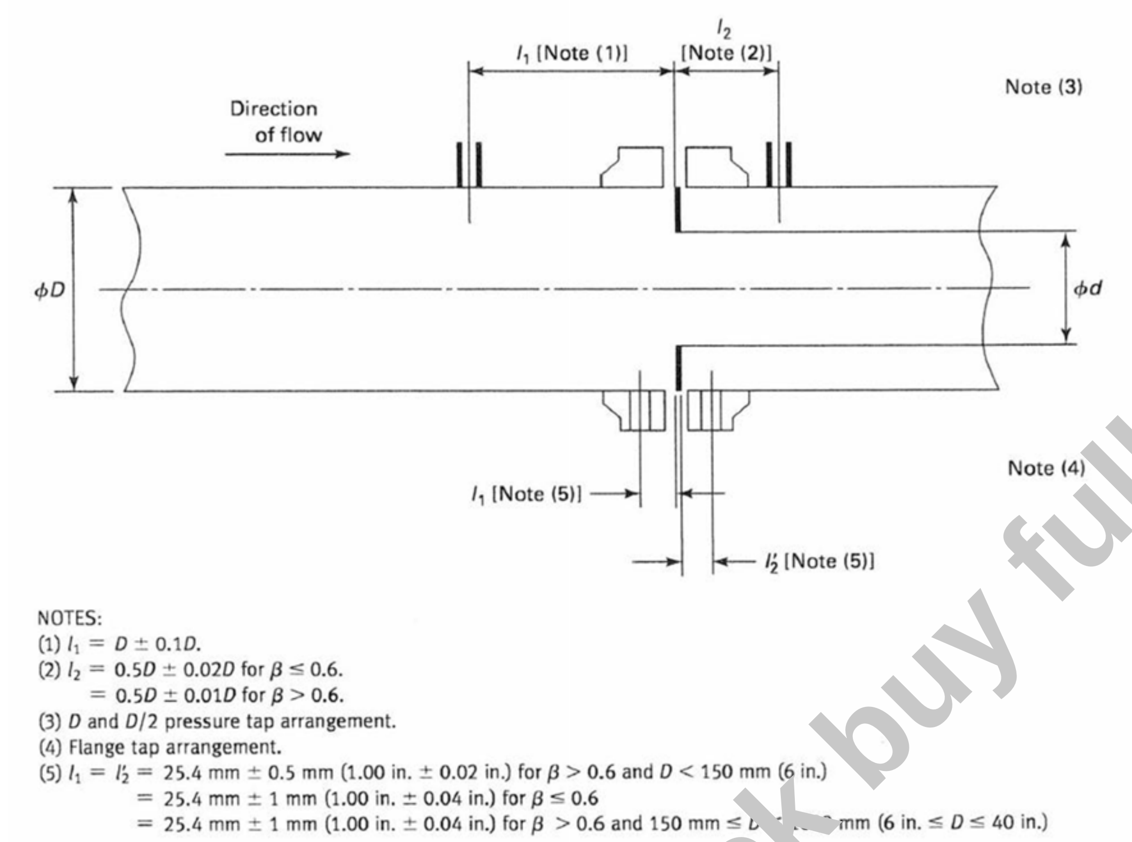


**FIGURE 7-1 Orifice flowmeter geometric profile.** (Reprinted with permission of ASME.)

Conversely, when the tube is moving downward during half of the vibration cycle, the gas in the exit portion of the sensor tube resists in the upward direction. Combined, these effects create a symmetrical twist angle. According to Newton's Second Law of Motion, the amount of sensor tube twist angle is directly proportional to the mass flow rate of gas flowing through the tube. Electromagnetic velocity sensors located on opposing sides of the sensor tube measure the velocity of the vibrating tube. Mass flow rate is determined by measuring the time difference in the velocity measurements: the greater the time difference, the greater the mass flow rate.

***Informative Note:*** For further reading, see Informative Annex A, Section A2.

**7.5.2 Thermal Flowmeters.** Thermal flowmeters provide direct measurement of gas mass flow rates. The basic elements of the constant heat input thermal mass flowmeters are two temperature sensors that are positioned on opposite sides of an electric heater. The gas mass flow rate shall be obtained from Equation 7-1.

***Informative Note:*** For further reading, see Informative Annex A, Section A3.

$$\dot{m} = \frac{K_q}{C_p(T_2 - T_1)} \tag{7-1}$$

where

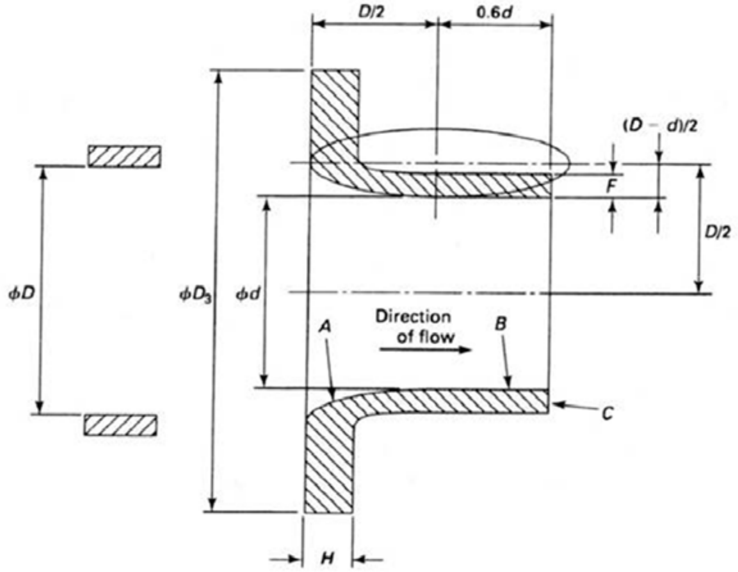
$\dot{m}$ = gas mass flow rate, kg/s (lb$_m$/s)
$K$ = dimensionless meter coefficient
$q$ = electric heat flux rate, kJ/s (Btu/s)
$C_p$ = specific heat of the gas, kJ/kg·K (Btu/lb·°F)
$T_1$ = incoming gas temperature, °C (°F)
$T_2$ = outgoing gas temperature, °C (°F)

**7.5.3 Orifices, Flow Nozzles, and Venturi Tube Flowmeters.** Orifices, flow nozzles, and venturi tubes are mass flowmeters. ASME PTC 19.5[3] and ASME MFC-3M[4,5] describe measurement of fluid flow in pipes using orifices, flow nozzles, and venturi tubes, including construction proportions and port locations.

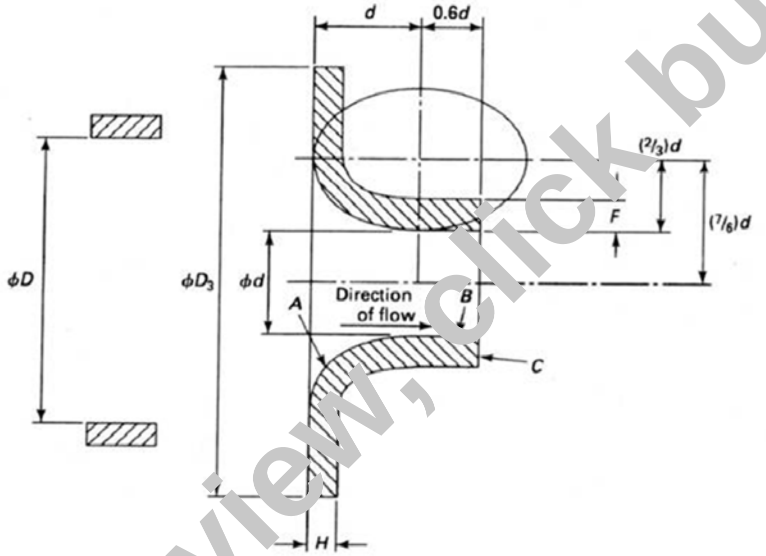
**7.5.3.1 Orifices, Flow Nozzles, and Venturi Tube Flowmeter Geometric Profiles.** Figure 7-1 illustrates the geometric profile of an orifice metering section. Figure 7-2 illustrates the geometric profile of a long-radius nozzle, and Figure 7-3 shows the geometric profile of a venturi tube.

**7.5.3.2 Gas Mass Flow Rate Equations and Procedures.** This section provides the equation procedures for calculating gas mass flow rates using long-radius nozzles and provides reference information for calculating gas mass flow rates using orifices.

Calculating a gas mass flow rate using these methods requires iteration because (a) the discharge coefficient, *C*, is a function of the Reynolds number and the Reynolds number is a function of the average gas flow velocity; and (b) the average gas flow velocity is not known until the gas mass flow rate has been determined. ASME PTC 19.5[3] includes an example of this iterative procedure on page 25, and ASME MFC-3M[4,5] provides the limits of use, discharge coefficient



(a) High Ratio 0.25 ≤ β ≤ 0.8



(b) Low Ratio 0.2 ≤ β ≤ 0.5

**FIGURE 7-2 Long-radius nozzle geometric profile.** (Reprinted with Permission of ASME)

equations, and expansibility factor equations for orifices, long-radius nozzles, ISA 1932 nozzles, venturi nozzles, and venturi tube flowmeters.

Measurements required for this section shall be as follows:

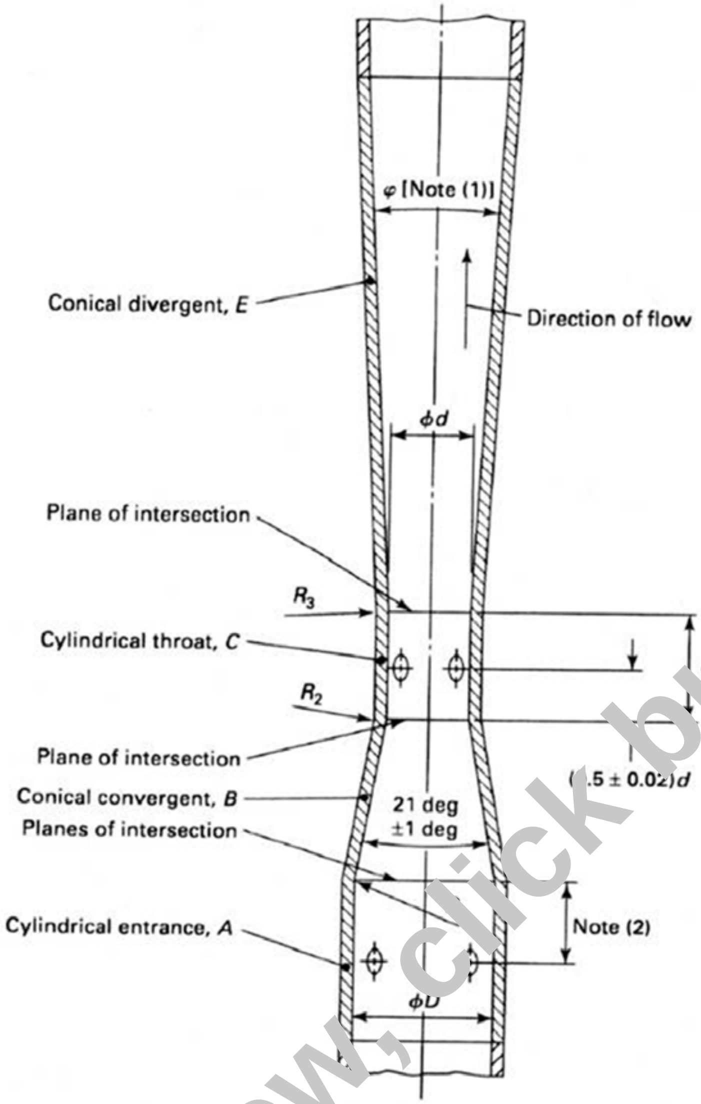
a. Nozzle inlet pipe diameter, $D$, m (ft)
b. Nozzle throat diameter, $d$, m (ft)
c. Nozzle inlet absolute pressure, $p_1$, Pa (psia)
d. Nozzle inlet absolute pressure, $p_2$, Pa (psia)
e. Nozzle differential pressure, $\Delta p = (p_1 - p_2)$, Pa (psia)
f. Nozzle inlet temperature, $t_1$, °C (°F)

Gas mass flow rates shall be calculated from Equation 7-2 (SI) or Equation 7-3 (I-P).

$$\dot{m} = C\varepsilon\left(\frac{\pi}{4}\right)d^2\sqrt{\frac{2\rho_1(\Delta p)}{(1-\beta^4)}} \qquad (7\text{-}2)$$

where

$\dot{m}$ = gas mass flow rate, kg/s
$C$ = discharge coefficient, dimensionless
$\varepsilon$ = expansibility factor, dimensionless
$d$ = nozzle throat diameter, m
$\rho_1$ = nozzle inlet gas density, kg/m$^3$
$p_1$ = nozzle inlet absolute pressure, Pa
$\Delta p$ = nozzle differential pressure, Pa
$\beta$ = $d/D$, dimensionless



NOTES:
(1) 7 deg ≤ φ ≤ 15 deg.
(2) See para. 4-[illegible]7.

**FIGURE 7-3 Venturi tube flowmeter geometric profile.** (Reprinted with Permission of ASME)

$$\dot{m} = C\varepsilon\left(\frac{\pi}{4}\right)d^2\sqrt{\frac{2g_c\rho_1(\Delta p)}{(1-\beta^4)}} \tag{7-3}$$

where

$\dot{m}$ = gas mass flow rate, $lb_m$/min
$C$ = discharge coefficient, dimensionless
$\varepsilon$ = expansibility factor, dimensionless
$g_c$ = gravitational constant, 32.174 $(lb_m \cdot ft)/(lb_f \cdot s^2)$
$d$ = nozzle throat diameter, ft
$\rho_1$ = nozzle inlet gas density, $lb_m/ft^3$
$p_1$ = nozzle inlet absolute pressure, psia
$\Delta p$ = nozzle differential pressure, psia
$\beta$ = $d/D$, dimensionless

The inlet gas density, $\rho_1$, shall be obtained from the gas property data as a function of the nozzle inlet temperature, $t_1$, and pressure, $p_1$, at each data point.

The nozzle diameter ratio, $\beta = d/D$, shall be calculated. If gas flow operating temperatures are not the same as the gas flow operating temperatures during calibration, parameters $d$, $D$, and $\beta$ shall be corrected to account for thermal expansion in accordance with ASME PTC 19.5 [3], Section 3-10.

Limits for the use for long-radius nozzle are as follows:

a. 50 mm (2 in.) $\le D \le$ 630 mm (25 in.).
b. $R_a/D \le (3.2 \times 10^{-4})$, where $R_a$ is the mean of the surface roughness in the upstream duct.
c. $(1 \times 10^4) \le Re_D \le (1000 \times 10^7)$ where $Re_D$ is defined in Equation 7-4.