Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids—Concentric, Square-edged Orifice Meters

Part 1: General Equations and Uncertainty Guidelines

American Gas Association

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Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids—Concentric, Square-edged Orifice Meters
Part 1: General Equations and Uncertainty Guidelines

1 Introduction

1.1 Scope

This standard provides a single reference for engineering equations, uncertainty estimations, construction and installation requirements, and standardized implementation recommendations for the calculation of flow rate through concentric, square-edged, flange-tapped orifice meters. Both U.S. customary (USC), and international system of units (SI) units are included.

1.2 Organization of Standard

The standard is organized into four parts. Parts 1, 2, and 4 apply to the measurement of any Newtonian fluid in the petroleum and chemical industries. Part 3 focuses on the application of Parts 1, 2, and 4 to the measurement of natural gas.

1.2.1 Part 1—General Equations and Uncertainty Guidelines

The mass flow rate and base (or standard) volumetric flow rate equations are discussed, along with the terms required for solution of the flow equation.

The empirical equations for the coefficient of discharge and expansion factor are presented. However, the basis for the empirical equations are contained in other sections of this standard or the appropriate reference document.

In several sections of this revision of Part 1, identified errata have been changed relative to previous editions. In addition, this revision includes a change to the empirical expansion factor (Y) calculation for the flange-tapped orifice meters.

For all existing installations, the decision as to which expansion factor equation to use shall be at the discretion of the parties involved. However, the parties should be cognizant of the following:

1) If the calculated difference between previous revision (1990) Buckingham and Bean expansion factor equation (Annex C or API *MPMS* Ch. 14.3.3/AGA Report No. 3, Part 3, Annex G) and the new revised expansion factor equation is less than or equal to 0.25 %, then the expansion factor values produced by either expansion factor equation will be within the uncertainty of the new expansion factor database and the existence of any flow bias will be uncertain.

2) However, if the calculated difference between expansion factor equations exceeds 0.25 %, then a variable flow bias, which is a function of diameter ratio (β), isentropic exponent (κ), and $\Delta P / P_{f_1}$ ratio (x_1), will be experienced unless the new expansion factor equation is utilized.

For the proper use of this standard, a discussion is presented on the prediction (or determination) of the fluid's properties at flowing conditions. The fluid's physical properties shall be determined by direct measurements, appropriate technical standards, or equations of state.

Uncertainty guidelines are presented for determining the possible error associated with the use of this standard for any fluid application. User-defined uncertainties for the fluid's physical properties and auxiliary (secondary) devices are required to solve the practical working formula for the estimated uncertainty.

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1.2.2 Part 2—Specifications and Installation Requirements

Specifications are presented for orifice meters; in particular, orifice plates, orifice plate holders, sensing taps, meter tubes, and flow conditioners.

Installation requirements for orifice plates, meter tubes, thermometer wells, flow conditioners, and upstream/downstream meter tube lengths are presented.

1.2.3 Part 3—Natural Gas Applications

The application of this standard to natural gas is presented, along with practical guidelines. Mass flow rate and base (or standard) volumetric flow rate methods are presented in conformance with North American industry practices.

1.2.4 Part 4—Background, Development, and Implementation Procedure and Subroutine Documentation

The coefficient of discharge database for flange-tapped orifice meters and its background, development, and limitations are presented.

Implementation procedures for flange-tapped orifice meters are presented, along with a set of example calculations. The examples are designed to aid in checkout procedures for any routines that are developed using the implementation procedures.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *MPMS* Ch. 12.2.1, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors,* Part 1—*Introduction*

API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2/GPA 8185, Part 2, *Concentric, Square-Edged Orifice Meters,* Part 2—*Specification and Installation Requirements* (2000 edition)

API *MPMS* Ch. 14.3.3/AGA Report No. 3, Part 3, *Concentric, Square-Edged Orifice Meters,* Part 3—*Natural Gas Applications*

API *MPMS* Ch. 14.3.4/AGA Report No. 3, Part 4, *Concentric, Square-Edged Orifice Meters,* Part 4—*Background, Development, Implementation Procedures and Subroutine Documentation*

API *MPMS* Ch. 14.6, *Continuous Density Measurement*

API *Technical Data Book—Petroleum Refining*

AGA Report No. 8 [1], *Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases*

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3 Terms, Definitions, and Symbols

3.1 Terms and Definitions

This standard reflects orifice meter application to fluid flow measurement. The definitions are given to emphasize the particular meaning of the terms as used in this standard.

3.1.1 Primary Element

The primary element is defined as the orifice plate, the orifice plate holder with its associated differential pressure sensing taps, and the meter tube.

3.1.1.1
orifice plate
The orifice plate is defined as a thin plate in which a circular concentric aperture (bore) has been machined. The orifice plate is described as a thin plate with a sharp, square edge because the thickness of the plate material is small, compared with the internal diameter of the measuring aperture (bore), and because the upstream edge of the measuring aperture is sharp and square.

3.1.1.2
orifice plate bore diameter (d, d_m, d_r)
The calculated orifice plate bore diameter (d) is the internal diameter of the orifice plate measuring aperture (bore) computed at flowing temperature (T_f), as specified in 6.2. The calculated orifice plate bore diameter (d) is used in the flow equation for the determination of flow rate.

The measured orifice plate bore diameter (d_m) is the measured internal diameter of the orifice plate measuring aperture at the temperature of the orifice plate (T_m) at the time of bore diameter measurements, determined as specified in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2.

The reference orifice plate bore diameter (d_r) is the internal diameter of the orifice plate measuring aperture at reference temperature (T_r), calculated as specified in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2. The reference orifice plate bore diameter is the certified or stamped orifice plate bore diameter.

3.1.1.3
orifice plate holder
The orifice plate holder is defined as a pressure-containing piping element, such as a set of orifice flanges or an orifice fitting, used to contain and position the orifice plate in the piping system.

3.1.1.4
meter tube
The meter tube is defined as the straight sections of pipe, including all segments that are integral to the orifice plate holder, upstream and downstream of the orifice plate, as specified in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2.

3.1.1.5
meter tube internal diameter (D, D_m, D_r)
The calculated meter tube internal diameter (D) is the inside diameter of the upstream section of the meter tube computed at flowing temperature (T_f), as specified in 6.3. The calculated meter tube internal diameter (D) is used in the diameter ratio and Reynolds number equations.

The measured meter tube internal diameter (D_m) is the inside diameter of the upstream section of the meter tube at the temperature of the meter tube (T_m) at the time of internal diameter measurements, determined as specified in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2.

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The reference meter tube internal diameter (D_r) is the inside diameter of the upstream section of the meter tube at the reference temperature (T_r), calculated as specified in API *MPMS* 14.3, Part 2/AGA Report No. 3, Part 2. The reference meter tube internal diameter is the certified or stamped meter tube internal diameter.

3.1.1.6
diameter ratio (β)
The diameter ratio (β) is defined as the calculated orifice plate bore diameter (d) divided by the calculated meter tube internal diameter (D).

3.1.2 Pressure Measurement

3.1.2.1
tap hole
A tap hole is a hole drilled radially in the wall of the meter tube or orifice plate holder, the inside edge of which is flush and without any burrs.

3.1.2.2
flange taps
Flange taps are a pair of tap holes positioned as follows (see Figure 1):

a) the upstream tap center is located 1 in. (25.4 mm) upstream of the nearest plate face,

b) the downstream tap center is located 1 in. (25.4 mm) downstream of the nearest plate face.

3.1.2.3
differential pressure (ΔP)
The differential pressure (ΔP) is the static pressure difference measured between the upstream and downstream flange taps.

3.1.2.4
static pressure (P_f)
The static pressure (P_f) is the absolute flowing fluid pressure measured at one of the flange tap holes. The absolute pressure may be measured directly or can be obtained by adding local barometric pressure to measured gauge pressure:

$$\text{absolute static pressure} = \text{gauge static pressure} + \text{local barometric pressure}$$

3.1.3 Temperature Measurement (T_f)

The temperature is the flowing fluid temperature (T_f) measured at the designated upstream or downstream location, as specified in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2.

In flow measurement applications where the fluid velocity is well below sonic, it is common practice to insert a temperature sensing device in the middle of the flowing stream to obtain the flowing temperature. For practical applications, the sensed temperature is assumed to be the static temperature of the flowing fluid.

The use of flowing temperature in this part of the standard requires the temperature to be measured in degrees Fahrenheit or degrees Celsius. However, if the flowing temperature is used in an equation of state to determine the density of the flowing fluid, it may require that the Fahrenheit or Celsius values be converted to absolute temperature values of degrees Rankine or Kelvin through the following relationships:

$$°R = °F + 459.67$$

$$K = °C + 273.15$$

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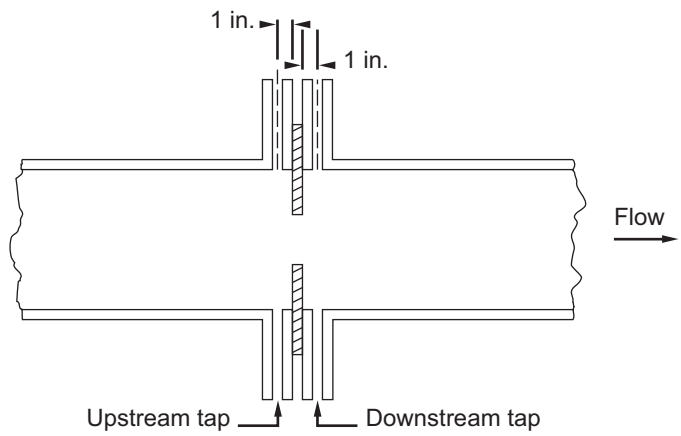

Flange-tapped Orifice Meter

Figure 1—Orifice Tapping Location

3.1.4 Flow Rate Determination

3.1.4.1
orifice flow rate (q_m, q_v, Q_v)
The orifice flow rate is the mass or volume flow through an orifice meter per unit of time.

3.1.4.2
orifice plate coefficient of discharge (C_d)
The orifice plate coefficient of discharge (C_d) is the ratio of the actual flow to the theoretical flow and is applied to the theoretical flow equation to obtain the actual flow.

3.1.4.3
velocity of approach (E_v)
The velocity of approach factor (E_v) is a mathematical expression that relates the velocity of the flowing fluid in the orifice meter approach section (upstream meter tube) to the fluid velocity in the orifice plate bore.

3.1.4.4
expansion factor (Y)
The expansion factor (Y) is an empirical expression used to correct the flow rate for the reduction in fluid density that a compressible fluid experiences when it passes through the orifice plate bore.

3.1.4.5
pipe Reynolds number (Re_D)
The pipe Reynolds number is a dimensionless ratio of forces used to correlate the variations in the orifice plate coefficient of discharge (C_d) with changes in the fluid's properties, flow rate, and orifice meter geometry.

3.1.5 Fluid Physical Properties

3.1.5.1
density ($\rho_{t,p}$, ρ_b)
The flowing fluid density ($\rho_{t,p}$) is the mass per unit volume of the fluid being measured at flowing conditions (T_f, P_f).

The base fluid density (ρ_b) is the mass per unit volume of the fluid being measured at base conditions (T_b, P_b).

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3.1.5.2
absolute viscosity (μ)
The absolute viscosity (μ) is the measure of a fluid's intermolecular cohesive force's resistance to shear per unit of time.

3.1.5.3
compressibility (*Z*)
The compressibility (Z) is an adjustment factor used to account for the deviation from the ideal gas law.

3.1.5.4
isentropic exponent (κ)
The isentropic exponent (κ) is a thermodynamic state property that establishes the relationship between an expanding fluid's pressure and density as the fluid flows through the orifice plate bore. See 10.3 for further information on isentropic exponent as it applies to this standard.

3.1.6 Base Conditions (P_b, T_b)

Historically, the flow measurement of some fluids, such as custody transfer and process control, has been stated in volume units at base conditions of pressure and temperature. Base conditions are reference conditions of pressure and temperature for the calculation of volumes, generally defined by contract or regulation. Often base conditions are set as standard conditions and the terms are sometimes used interchangeably.

The base conditions for the flow measurement of fluids, such as crude petroleum and its liquid products, whose vapor pressure is equal to or less than atmospheric at base temperature are often designated as a pressure of 14.696 psia (101.325 kPa) at a temperature of 60.0 °F (15.56 °C) in the United States (U.S.) and 59.00 °F (15.00 °C) for ISO.

For fluids, such as liquid hydrocarbons, whose vapor pressure is greater than atmospheric pressure at base temperature, the base pressure is customarily designated as the equilibrium vapor pressure at base temperature.

Base conditions are normally defined by contract or government regulation. For interstate commerce, the base conditions for the flow measurement of natural gases are defined in the U.S. as a pressure of 14.73 psia (101.560 kPa) at a temperature of 60.0 °F (15.56 °C). Note, according to ISO, base conditions are defined as a pressure of 14.696 psia (101.325 kPa) at a temperature of 59.00 °F (15.00 °C).

For both liquid and gas applications, these base conditions can change from one country to the next, one state to the next, or one industry to the next. Therefore, it is necessary that the base conditions be identified for standard volumetric flow measurement.

3.1.7 Sensitivity Coefficient (S)

In estimating the uncertainty associated with the metering facility, a number of variables must be combined. The mathematical relationships among the variables establish the sensitivity of the metered quantities to each of these variables. As such, each variable that may influence the flow equation has a specific sensitivity coefficient. The derivation of this coefficient is based on a mathematical relationship or estimated from calculations, tables, or curves.

3.1.8 Meter Factor (MF)

The MF is a number obtained by dividing the quantity of fluid measured by the reference flow system by the quantity indicated by the orifice meter during calibration. See 9.2 for further information on meter factor as it applies to this standard.

3.1.9 In-situ Calibration

An in-situ calibration is defined as a calibration conducted under normal operating conditions, with the actual approach piping configuration, using the actual fluid with the actual orifice plate and recording system in place.

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3.2 Symbols

This standard reflects orifice meter application to fluid flow measurement with symbols in general technical use.

C_d	orifice plate coefficient of discharge
$C_d\,(FT)$	coefficient of discharge at a specified pipe Reynolds number for flange-tapped orifice meter
C_i	coefficient of discharge at infinite pipe Reynolds number
$C_i\,(CT)$	coefficient of discharge at infinite pipe Reynolds number for corner-tapped orifice meter
$C_i\,(FT)$	coefficient of discharge at infinite pipe Reynolds number for flange-tapped orifice meter
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
d	orifice plate bore diameter calculated at flowing temperature, T_f
d_m	orifice plate bore diameter measured at T_m
d_r	orifice plate bore diameter at reference temperature, T_r
D	meter tube internal diameter calculated at flowing temperature, T_f
D_m	meter tube internal diameter measured at T_m
D_r	meter tube internal diameter at reference temperature, T_r
ΔP	orifice differential pressure
°C	temperature, in degrees Celsius
°F	temperature, in degrees Fahrenheit
K	temperature, in Kelvin
°R	temperature, in degrees Rankine
E_v	velocity of approach factor
g_c	dimensional conversion constant
G_i	ideal gas relative density (specific gravity)
κ	isentropic exponent
κ_i	ideal gas isentropic exponent
κ_p	perfect gas isentropic exponent
κ_r	real gas isentropic exponent
MF	calibration meter factor
Mr_{air}	molar mass of air
Mr_{gas}	molar mass of gas
N_1	unit conversion factor (orifice flow)
N_2	unit conversion factor (Reynolds number)
N_3	unit conversion factor (expansion factor)
N_4	unit conversion factor (discharge coefficient)
P	pressure
P_b	base (reference or standard) pressure
P_f	static pressure of fluid at the pressure tap
P_{f_1}	absolute static pressure at the orifice upstream differential pressure tap
P_{f_2}	absolute static pressure at the orifice downstream differential pressure tap

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q_m	mass flow rate
q_{m_i}	mass flow rate indicated by the orifice meter being calibrated
q_{m_p}	mass flow rate determined by the reference flow system (or master meter)
q_v	volume flow rate at flowing (actual) conditions
q_{v_i}	volume flow rate indicated by the orifice meter being calibrated
Q_v	volume flow rate at base (standard) conditions
R	universal gas constant
R_a	roughness average value from continuously averaging meter readings
Re_D	pipe Reynolds number
T	temperature
T_b	base (reference or standard) temperature
T_f	temperature of fluid at flowing conditions
T_m	temperature of the orifice plate or meter tube at time of diameter measurements
T_r	reference temperature of orifice plate bore diameter and/or meter tube inside diameter
x	ratio of differential pressure to absolute static pressure
x_1	ratio of differential pressure to absolute static pressure at the upstream pressure tap
S	sensitivity coefficient (influence coefficient)
Y	expansion factor
Y_1	expansion factor based on upstream absolute static pressure
Y_2	expansion factor based on downstream absolute static pressure
Z	fluid compressibility
Z_f	fluid compressibility at flowing conditions
Z_{f_1}	compressibility of the fluid flowing at the upstream pressure tap location
Z_{f_2}	compressibility of the fluid flowing at the downstream pressure tap location
α	linear coefficient of thermal expansion
α_1	linear coefficient of thermal expansion of the orifice plate material
α_2	linear coefficient of thermal expansion of the meter tube material
β	ratio of orifice diameter to meter tube diameter calculated at flowing conditions
μ	absolute viscosity of fluid flowing
π	universal constant rounded to six significant figures
ρ	density of the fluid
ρ_b	density of the fluid at base conditions (P_b, T_b)
$\rho_{f,p}$	density of the fluid at flowing conditions (P_f, T_f)

4 Field of Application

4.1 Applicable Fluids

This standard applies to steady-state mass flow conditions for fluids that, for all practical purposes, are considered to be clean, single phase, homogeneous, and Newtonian and have pipe Reynolds numbers of 4,000 or greater. All gases, most liquids, and most dense phase fluids associated with the petroleum, petrochemical, and natural gas industries are usually considered Newtonian fluids.

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4.2 Types of Meters

This standard provides design, construction, and installation specifications for flange-tapped, concentric, square-edged orifice meters of nominal 2-in. Schedule 160 and larger pipe diameters.

An orifice meter is a fluid flow measuring device that produces a differential pressure to infer flow rate. The meter consists of the following elements (see Figure 2):

a) a thin, concentric, square-edged orifice plate;

b) an orifice plate holder consisting of a set of orifice flanges (or an orifice fitting) equipped with the appropriate differential pressure sensing taps;

c) a meter tube consisting of the adjacent piping sections (with or without flow conditioners).

The auxiliary (secondary) devices necessary for the precise determination of flow rate are not included in the scope of this standard. These devices are usually instruments that sense the differential and static pressure, fluid temperature, and fluid density and/or relative density (specific gravity), and either mechanical recording devices or electronic calculators. A review of the publications of AGA, API, GPA, and others that address the specifications and installations of these auxiliary(secondary) devices is encouraged.

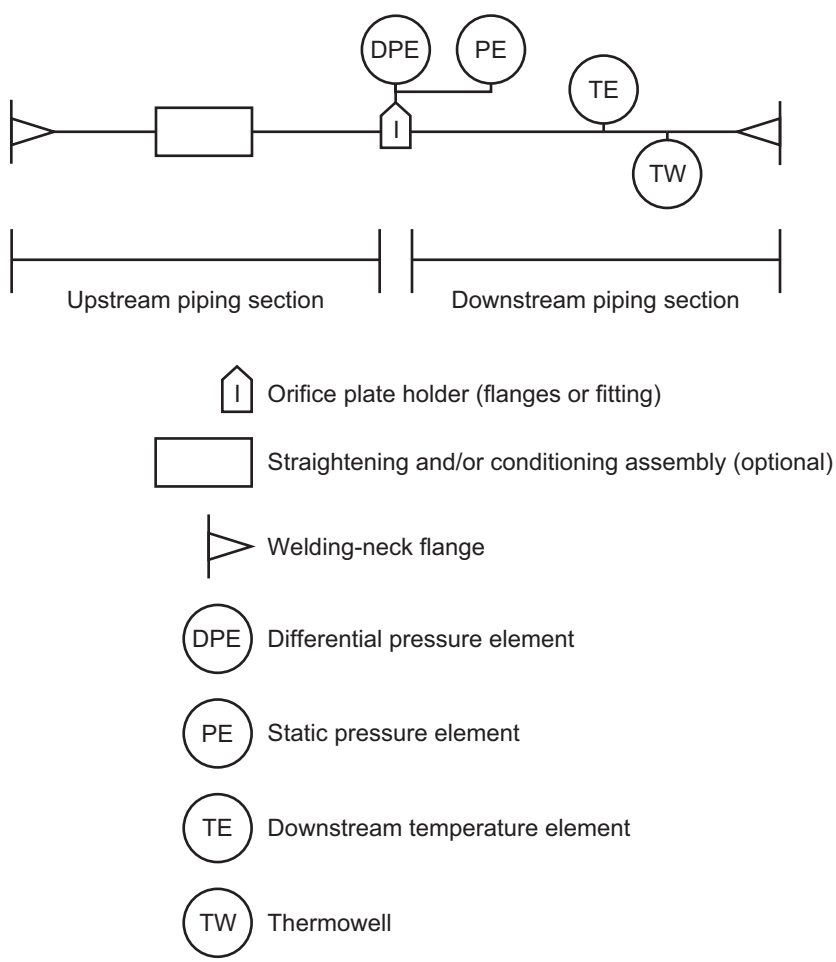

Figure 2—Orifice Meter Elements

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4.3 Uncertainty of Measurement

Many factors influence the overall measurement uncertainty associated with a metering application. Major contributors include construction tolerances in the meter components, tolerances of empirical coefficient of discharge databases or in-situ flow calibrations, predictability of and variations in the fluid's physical properties, and uncertainties associated with the auxiliary (secondary and tertiary) devices.

Using the guidelines contained in this standard and other relevant industry standards in combination with the associated uncertainty tolerances for the fluid's physical properties, in-situ calibrations, or coefficient of discharge databases, and the appropriate auxiliary (secondary and tertiary) devices, the user can estimate the overall measurement uncertainty associated with a properly designed, installed, and maintained thin plate, concentric, square-edged orifice metering application.

5 Method of Calculation

This standard provides recommended standardized calculation implementation methods for the quantification of fluid flow under defined conditions, regardless of the point of origin or destination or the units of measure required by governmental customs or statute. The recommended implementation procedures provided in API *MPMS* Ch. 14.3, Part 4/AGA Report No. 3, Part 4 allow different entities using various computer languages on different computing hardware to arrive at nearly identical results using the same standardized input data.

The following two recommended implementation procedures have been prepared to illustrate the standardized set of mathematical expressions and sequencing, including iteration/rounding techniques:

a) mass flow rate,

b) standard volumetric flow rate.

The procedures presented address only the solution of the flow rate equation and require specific inputs (fixed and variable). Typical fixed inputs include meter tube internal diameter, orifice plate bore diameter, and linear coefficient of expansion for steels (pipe and orifice plate). Typical variable inputs may include differential and static pressure, temperature, fluid density, isentropic exponent for compressible fluids, and fluid viscosity.

The fluid's physical properties shall be determined by direct measurements, appropriate technical standards, or equations of state. If multiple parties are involved in the measurement, the appropriate technical method selected for determining the fluid's physical properties shall be mutually agreed upon.

6 Orifice Flow Equation

The accepted one-dimensional equation for mass flow through a concentric, square-edged orifice meter is stated in Equation (1) or Equation (2). The derivation is based on conservation of mass and energy, one-dimensional fluid dynamics, and empirical functions such as equations of state and thermodynamic process statements. Any derivation is accurate when all the assumptions used to develop it are valid. As a result, an empirical orifice plate coefficient of discharge is applied to the theoretical equation to adjust for multidimensional viscous fluid dynamic effects. In addition, an empirical expansion factor is applied to the theoretical equation to adjust for the reduction in fluid density that a compressible fluid experiences when it passes through an orifice plate.

The fundamental orifice meter mass flow equation is as follows:

$$q_m = C_d E_v Y(\pi/4)d^2\sqrt{2g_c\rho_{t,p}\Delta P} \quad (1)$$

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where

C_d is the orifice plate coefficient of discharge;

d is the orifice plate bore diameter calculated at flowing temperature (T_f);

ΔP is the orifice differential pressure;

E_v is the velocity of approach factor;

g_c is the dimensional conversion constant;

π is the universal constant = 3.14159;

q_m is the mass flow rate;

$\rho_{t,p}$ is the density of the fluid at flowing conditions (P_f, T_f);

Y is the expansion factor.

The practical orifice meter flow equation used in this standard is a simplified form that combines the numerical constants and unit conversion constants in a unit conversion factor (N_1):

$$q_m = N_1 C_d E_v Y d^2 \sqrt{\rho_{t,p} \Delta P} \tag{2}$$

where

C_d is the orifice plate coefficient of discharge;

d is the orifice plate bore diameter calculated at flowing temperature (T_f);

ΔP is the orifice differential pressure;

E_v is the velocity of approach factor;

N_1 is the unit conversion factor;

q_m is the mass flow rate;

$\rho_{t,p}$ is the density of the fluid at flowing conditions (P_f, T_f);

Y is the expansion factor.

The expansion factor, Y, is included in Equation (1) and Equation (2) because it is applicable to all single-phase, homogeneous Newtonian fluids. For incompressible fluids, such as water at 60 °F (15.56 °C) and atmospheric pressure, the empirical expansion factor is defined as 1.0000.

The orifice plate coefficient of discharge, C_d, and the expansion factor, Y, are empirical functions derived from experimental data.

The orifice meter is a mass meter from which a differential pressure signal is developed as a function of the velocity of the fluid as it passes through the orifice plate bore. Manipulation of the density variable in the equation permits calculation of flow rate in either mass or volume units. The volumetric flow rate at flowing (actual) conditions can be calculated using the following equation:

$$q_v = q_m / \rho_{t,p} \tag{3}$$

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The volumetric flow rate at base (standard) conditions can be calculated using the following equation:

$$Q_v = q_m / \rho_b \tag{4}$$

The mass flow rate (q_m) can be converted to a volumetric flow rate at base (standard) conditions (Q_v) if the fluid density at the base conditions (ρ_b) can be determined or is specified.

The unit conversion factor (N_1), is defined and presented in 11.1.

6.1 Velocity of Approach Factor (E_v)

The velocity of approach factor (E_v), is calculated as follows:

$$E_v = \frac{1}{\sqrt{1-\beta^4}} \tag{5}$$

and

$$\beta = d/D \tag{6}$$

where

d is the orifice plate bore diameter calculated at flowing temperature (T_f);

D is the meter tube internal diameter calculated at flowing temperature (T_f).

6.2 Orifice Plate Bore Diameter (d)

The orifice plate bore diameter (d) is defined as the diameter at flowing conditions and can be calculated using the following equation:

$$d = d_r\,[1 + \alpha_1\,(T_f - T_r)] \tag{7}$$

where

α_1 is the linear coefficient of thermal expansion for the orifice plate material (see Table 1);

d is the orifice plate bore diameter calculated at flowing temperature (T_f);

d_r is the reference orifice plate bore diameter at reference temperature (T_r);

T_f is the temperature of the fluid at flowing conditions;

T_r is the reference temperature of the orifice plate bore diameter.

NOTE α, T_f, and T_r must be in consistent units. For the purpose of this standard, T_r is assumed to be 68 °F (20 °C).

The orifice plate bore diameter (d_r) calculated at T_r is the diameter determined in accordance with the requirements contained in API *MPMS* Ch. 14.3, Part 2/AGA Report No. 3, Part 2.

6.3 Meter Tube Internal Diameter (D)

The meter tube internal diameter (D) is defined as the diameter at flowing conditions and can be calculated using the following equation:

$$D = D_r[1 + \alpha_2(T_f - T_r)] \tag{8}$$

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where

α_2 is the linear coefficient of thermal expansion for the meter tube material (see Table 1);

D is the meter tube internal diameter calculated at flowing temperature (T_f);

D_r is the reference meter tube internal diameter at T_r;

T_f is the temperature of the fluid at flowing conditions;

T_r is the reference temperature of the meter tube internal diameter.

NOTE α, T_f, and T_r must be in consistent units. For the purpose of this standard, T_r is assumed to be 68 °F (20 °C).

The meter tube internal diameter (D_r) calculated at T_r is the diameter determined in accordance with the requirements contained in API *MPMS* 14.3, Part 2/AGA Report No. 3, Part 2.

Table 1—Linear Coefficient of Thermal Expansion

Material	Linear Coefficient of Thermal Expansion (α)	
	USC (in./in. °F)	Metric Units (mm/mm °C)
Type 304/316 stainless steel [c]	0.00000925	0.0000167
Type 304 stainless steel [a]	0.00000961	0.0000173
Type 316 stainless steel [a]	0.00000889	0.0000160
Monel 400 [a]	0.00000772	0.0000139
Carbon steel [b]	0.00000620	0.0000112

NOTE For flowing temperature limits or other materials, refer to the American Society for Metals (ASM) *Metals Handbook*, *Engineering Properties of Steel,* and *Handbook of Stainless Steels*.

[a] For flowing conditions between +32 °F and +212 °F for stainless steels and +68 °F and +212 °F for Monel.

[b] For flowing conditions between –7 °F and +154 °F, refer to API *MPMS* Ch. 12.2.1.

[c] Type 304/316 stainless steel linear coefficient of thermal expansion is the average of the type 304 and type 316 stainless steel coefficients.

NOTE Over a temperature range from 32 °F to 130 °F the maximum difference in calculated flow between use of the 304/316 average coefficient and either the 304 or 316 coefficient is less than 0.005 % (50 ppm).

7 Empirical Coefficient of Discharge

Empirical coefficients of discharge for flange-tapped orifice meters have been determined from experimental data by comparing the measured and theoretical flow rates. A major factor in the definition of the experimental patterns for this orifice research was dynamic similarity. Using Reynolds' Law of Similarity, experimental correlations can be applied to dynamically similar meters.

To accurately predict the coefficient of discharge, $C_d\ (FT)$, for a flange-tapped orifice meter manufactured to the specifications of this standard, certain parameters concerning the orifice meter and the fluid must be known. The relationships between these functions can be simplified for application to commercial use. In fact, the coefficient of discharge can be shown to depend on a number of parameters, the major ones being the Reynolds number (Re_D), sensing tap location, meter tube diameter (D), and β ratio:

$$C_d = f\,(Re_D,\ \text{Sensing tap location},\ D,\ \beta)$$

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