

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

Part 3: Natural Gas Applications



American Gas Association

AGA Report No. 3
Part 3



AMERICAN PETROLEUM INSTITUTE

Manual of Petroleum
Measurement Standards
Chapter 14.3.3

American Gas Association
400 North Capitol Street, NW
Washington, DC 20001

American Petroleum Institute
1220 L Street, NW
Washington, DC 20005

FOURTH EDITION, NOVEMBER 2013

An American National Standard
ANSI/API MPMS Ch. 14.3.3/AGA Report No. 3, Part 3

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Contents

	Page
1 Scope	1
1.1 General	1
1.2 Definition of Natural Gas	1
1.3 Basis for Equations	1
1.4 Expansion Factor Application	1
2 Normative References	1
3 Symbols, Units, and Terminology	2
3.1 General	2
3.2 Symbols and Units	2
3.3 Terminology	4
4 Flow Measurement Equations	5
4.1 General	5
4.2 Equations for Mass Flow of Natural Gas	5
4.3 Equations for Volume Flow of Natural Gas	6
4.4 Volume Conversion from Reference Base to Base Conditions	8
5 Flow Equation Components Requiring Additional Computation	9
5.1 General	9
5.2 Diameter Ratio (β)	9
5.3 Coefficient of Discharge for Flange-tapped Orifice Meter [$C_d (FT)$]	9
5.4 Velocity of Approach Factor (E_v)	11
5.5 Reynolds Number (ReD)	12
5.6 Expansion Factor (Y)	13
6 Gas Properties	16
6.1 General	16
6.2 Physical Properties	16
6.3 Compressibility	16
6.4 Relative Density	18
6.5 Density of Fluid at Flowing Conditions	20
Annex A (informative) Adjustments for Instrument Calibration	24
Annex B (informative) Factors Approach	30
Annex C (informative) Flow Calculation Examples	33
Annex D (informative) Pipe Tap Orifice Metering	41
Annex E (informative) SI Conversions	42
Annex F (informative) Development of Constants for Flow Equations	44
Annex G (informative) Buckingham and Bean Empirical Expansion Factor (Y) for Flange-tapped Orifice Meters	50
Bibliography	54

Contents

Page

Tables

1	Linear Coefficient of Thermal Expansion	10
A.1	Water Density Based on Patterson and Morris Equation	28
E.1	Volume Reference Conditions for Custody Transfer Operations: Natural Gas Volume	42
E.2	Energy Reference Conditions	42
E.3	Heating Value Reference Conditions	43
G.1	Comparison Between Equation (35) and Equation (G.3)	53

Introduction

API *MPMS* Chapter 14.3.3/AGA Report No. 3, Part 3 is organized as follows: Symbols and units are first defined, the basic flow equation is presented, then key equation components are defined, and finally the gas properties applicable to orifice metering of natural gas are developed. Factors to compensate for meter calibration and location are included in Annex A. The factor approach to orifice measurement is included in Annex B. Annex F covers derivation of constants. The user is cautioned that the symbols may be different from those used in previous orifice metering standards.

Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids— Concentric, Square-edged Orifice Meters Part 3: Natural Gas Applications

1 Scope

1.1 General

This part of API *MPMS* Ch. 14.3/AGA Report No. 3 has been developed as an application guide for the calculation of natural gas flow through a flange-tapped, concentric orifice meter, using the U.S. customary (USC) inch-pound system of units.

For applications involving international system (SI) of units, a conversion factor can be applied to the results (Q_m , Q_v , or Q_b) determined from the equations in 4.3. Intermediate conversion of units will not necessarily produce consistent results. As an alternative, the more universal approach specified in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 can be used. The meter has to be constructed and installed in accordance with API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2.

1.2 Definition of Natural Gas

As used in this document, the term natural gas applies to fluids that for all practical purposes are considered to include both pipeline and production quality gas with single-phase flow and mole percentage ranges of components as given in Table 1 of API *MPMS* Ch. 14.2/AGA Report No. 8. For other hydrocarbon mixtures, the more universal approach specified in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 may be more applicable. Diluents or mixtures other than those stipulated in API *MPMS* Ch. 14.2/AGA Report No. 8 may increase the flow measurement uncertainty.

1.3 Basis for Equations

The computation methods used in this document are consistent with those developed in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 and include the Reader-Harris/Gallagher (RG) equation for flange-tapped orifice meter discharge coefficient. The equation has been modified to reflect the more common units of the USC inch-pound system.

1.4 Expansion Factor Application

For all existing installations, the decision as to which expansion factor equation to use is 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 (refer to Annex G) and the new revised expansion factor equation (refer to 5.6) 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 is 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 $\Delta P/P_{f1}$ ratio (x_1), will be experienced unless the new expansion factor equation is utilized.

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. 14.2/AGA Report No. 8, *Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases*

API MPMS Ch. 14.3.1/AGA Report No. 3, Part 1, *Concentric, Square-edged Orifice Meters, Part 1—General Equations and Uncertainty Guidelines*

GPA 2145-09 ¹, *Table of Physical Properties for Hydrocarbons and Other Compounds of Interest to the Natural Gas Industry*

3 Symbols, Units, and Terminology

3.1 General

The symbols and units used are specific to API MPMS Ch. 14.3.3/AGA Report No. 3, Part 3 and were developed based on the USC inch-pound system of units. Regular conversion factors can be used where applicable; however, if SI units are used, the more generic equations in API MPMS Ch. 14.3.1/AGA Report No. 3, Part 1 should be used for consistent results.

3.2 Symbols and Units

C_d	orifice plate coefficient of discharge
$C_d(FT)$	coefficient of discharge at a specified pipe Reynolds number for flange-tapped orifice meter
$C_i(CT)$	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 [Btu/(lbm-°F)]
c_v	specific heat at constant volume [Btu/(lbm-°F)]
D	meter tube internal diameter calculated at flowing temperature, T_f (in.)
D_r	meter tube internal diameter at reference temperature, T_r (in.)
d	orifice plate bore diameter calculated at flowing temperature, T_f (in.)
d_r	orifice plate bore diameter at reference temperature, T_r (in.)
E_v	velocity of approach factor
e	Napierian constant rounded to six significant figures (2.71828)
F_{pv}	supercompressibility factor
G	gas relative density (specific gravity)
G_i	ideal gas relative density
G_r	real gas relative density
h_w	orifice differential pressure (also see ΔP) (inches of water column at 60 °F)
Mr_{air}	molar mass (molecular weight) of air (28.9625 lbm/lb-mol)
Mr_{gas}	molar mass (molecular weight) of gas (lbm/lb-mol)
Mr_i	molar mass (molecular weight) of component (lbm/lb-mol)
m	mass (lbm)
N_4	unit conversion factor (discharge coefficient)
n	number of moles
P	pressure (psia)
P_b	base pressure (psia)

¹ Gas Processors Association, 6526 E. 60th Street, Tulsa, Oklahoma 74145, www.gasprocessors.com.

$P_{b_{\text{air}}}$	base pressure of air (psia)
$P_{b_{\text{gas}}}$	base pressure of gas (psia)
P_f	static pressure of fluid at the pressure tap (psia)
P_{f_1}	absolute static pressure at the orifice upstream differential pressure tap (psia)
P_{f_2}	absolute static pressure at the orifice downstream differential pressure tap (psia)
P_s	reference base pressure (14.73 psia)
Q_b	volume flow rate at base conditions (ft ³ /hr)
Q_m	mass flow rate per hour (lbm/hr)
Q_v	volume flow rate per hour at reference base conditions (ft ³ /hr)
q_m	mass flow rate per second (lbm/s)
R	universal gas constant [1,545.35 (lbf-ft)/(lb-mol-°R)]
Re_D	pipe Reynolds number
T	temperature (°R)
T_b	base temperature (°R)
$T_{b_{\text{air}}}$	base temperature of air (°R)
$T_{b_{\text{gas}}}$	base temperature of gas (°R)
T_f	temperature of fluid at flowing conditions (°R)
T_r	reference temperature of the orifice plate bore diameter and/or meter tube inside diameter (68 °F)
T_s	reference base temperature, set to U.S. standard temperature (519.67 °R)
U_{f_1}	flowing velocity at upstream tap (ft/s)
V	volume (ft ³)
V_b	volume at base conditions (ft ³)
V_{f_1}	flowing volume at upstream tap (ft ³)
w	number of the last component
x	ratio of differential pressure to absolute static pressure
x_1	ratio of differential pressure to absolute static pressure at the upstream pressure tap
x_2	ratio of differential pressure to absolute static pressure at the downstream pressure tap
x/κ	acoustic ratio
Y	expansion factor
Y_1	expansion factor based on upstream absolute static pressure
Y_2	expansion factor based on downstream absolute static pressure
Z	compressibility
Z_b	compressibility at base conditions
$Z_{b_{\text{gas}}}$	compressibility of the gas at base conditions (P_b, T_b)
Z_f	compressibility at flowing conditions (P_f, T_f)
Z_{f_1}	compressibility at upstream flowing conditions
Z_{f_2}	compressibility at downstream flowing conditions
Z_s	compressibility at reference base conditions (P_s, T_s)
$Z_{s_{\text{air}}}$	compressibility of air at 14.73 psia and 60 °F (0.999590)

$^{\circ}\text{F}$	temperature, in degrees Fahrenheit
$^{\circ}\text{R}$	temperature, in degrees Rankine ($459.67 + ^{\circ}\text{F}$)
α	linear coefficient of thermal expansion [$\text{in.}/(\text{in.} \cdot ^{\circ}\text{F})$]
α_1	linear coefficient of thermal expansion of the orifice plate material [$\text{in.}/(\text{in.} \cdot ^{\circ}\text{F})$]
α_2	linear coefficient of thermal expansion of the meter tube material [$\text{in.}/(\text{in.} \cdot ^{\circ}\text{F})$]
β	ratio of orifice plate bore diameter to meter tube internal diameter (d/D) calculated at flowing temperature, T_f
ΔP	orifice differential pressure (see also h_w) (psi)
κ	isentropic exponent (see 5.6)
κ_i	ideal gas isentropic exponent
κ_p	perfect gas isentropic exponent
κ_r	real gas isentropic exponent
μ	absolute viscosity of flowing fluid [$\text{lbm}/(\text{ft} \cdot \text{s})$]
π	universal constant rounded to six significant figures (3.14159)
ρ_b	density of a fluid at base conditions (P_b, T_b) (lbm/ft^3)
$\rho_{b_{\text{air}}}$	density of air at base conditions (P_b, T_b) (lbm/ft^3)
$\rho_{b_{\text{gas}}}$	density of a gas at base conditions (P_b, T_b) (lbm/ft^3)
ρ_s	density of a fluid at reference base conditions (P_s, T_s) (lbm/ft^3)
$\rho_{t,p}$	density of a fluid at flowing conditions (P_f, T_f) (lbm/ft^3)
ρ_{t,p_1}	density of a fluid at flowing conditions at upstream tap position (P_{f_1}, T_f) (lbm/ft^3)
ρ_{t,p_2}	density of a fluid at flowing conditions at downstream tap position (P_{f_2}, T_f) (lbm/ft^3)
ϕ_i	mole fraction of component (mol%/100)

NOTE Factors, ratios, and coefficients are dimensionless.

3.3 Terminology

3.3.1 Pressure

One pound-force (lbf) per square inch (in.^2) pressure is defined as the force a one pound-mass (lbm) exerts when evenly distributed on an area of 1 in.^2 and when acted on by the standard acceleration of free fall, 32.1740 ft/s^2 .

3.3.2 Subscripts

The subscript 1 on the expansion factor (Y_1), the flowing density (ρ_{t,p_1}), the fluid flowing static pressure (P_{f_1}), and the fluid flowing compressibility (Z_{f_1}) indicates that these variables are to be measured, calculated, or otherwise determined relative to the fluid flowing at the conditions of the upstream differential tap. Variables related to the downstream differential pressure tap are identified by the subscript 2, including Y_2 , ρ_{t,p_2} , P_{f_2} , and Z_{f_2} , and can be used in the equations with equal precision of the calculated flow rates (except for Y_2 , which has a separate equation).

The subscript 1 is arbitrarily used in the equations in this part to emphasize the necessity of maintaining the relationship of these four variables to the chosen static pressure reference tap.

3.3.3 Temperature

The temperature of the flowing fluid (T_f) does not have a numerical subscript. This temperature is usually measured downstream of the orifice plate for minimum flow disturbance but may be measured upstream within the locations prescribed in API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2. It is assumed that there is no difference between fluid temperatures at the two differential pressure tap locations and the measurement point, so the subscript is unnecessary.

3.3.4 Reference Base (Standard) Conditions

In this document, reference base conditions are defined as the absolute static pressure, P_s , of 14.73 psia and the absolute temperature, T_s , of 519.67 °R (60 °F). For interstate commerce, the reference base conditions for the flow measurement of natural gases are defined in the United States as a pressure of 14.73 psia (P_s) at a temperature of 60 °F or 519.67 °R (T_s). Although technically incorrect, these reference base conditions are often referred to as standard conditions and designated in symbology by the subscript “s.”

Base conditions, i.e. base pressure (P_b) and base temperature (T_b), are defined by contract or government regulation and may be different from reference base conditions.

3.3.5 Definitions

General definitions are covered in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 and API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2. Definitions specific to API *MPMS* Ch. 14.3.3/AGA Report No. 3, Part 3 are incorporated in the text.

4 Flow Measurement Equations

4.1 General

The following equations express flow in terms of mass and volume per unit time and produce equivalent results. Since this section deals exclusively with the USC inch-pound system of units, the numeric constants defined in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 have been converted to reflect these units.

The numeric constants for the basic flow equations, unit conversion values, density of water, and density of air are given in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 and in Section 6 and Annex F of this document. The tables in this part that list solutions to these equations incorporate these constants and values. Key equation components are developed in Section 5. Other physical properties are given in Section 6.

4.2 Equations for Mass Flow of Natural Gas

The equations for the mass flow of natural gas, in lbm/hr, can be developed from the density of the flowing fluid (see F.3), the ideal gas relative density, or the real gas relative density, using the following equations.

The mass flow developed from the density of the flowing fluid (ρ_{t,p_1}) is expressed as follows:

$$Q_m = 359.072 C_d (FT) E_v Y_1 d^2 \sqrt{\rho_{t,p_1} h_w} \quad (1)$$

Mass flow developed from the ideal gas relative density, G_i , is expressed as follows:

$$Q_m = 589.885 C_d (FT) E_v Y_1 d^2 \sqrt{\frac{G_i P_{f_1} h_w}{Z_{f_1} T_f}} \quad (2)$$

The mass flow equation developed from the real gas relative density, G_r , assumes a pressure of 14.73 psia and a temperature of 519.67 °R (60 °F) as the reference base conditions for the determination of real gas relative density. This assumption allows the base compressibility of air at 14.73 psia and 519.67 °R (60 °F) to be incorporated into the

numeric constant of the flow rate equation. If the assumption about the reference base conditions is not valid, the results obtained from this flow rate equation will have an added increment of uncertainty. The mass flow equation developed from real gas relative density, G_r , is expressed as follows:

$$Q_m = 590.006 C_d(FT) E_v Y_1 d^2 \sqrt{\frac{Z_s G_r P_{f_1} h_w}{Z_{f_1} T_f}} \quad (3)$$

where

$C_d(FT)$ is the coefficient of discharge for flange-tapped orifice meter;

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

E_v is the velocity of approach factor;

G_i is the ideal gas relative density;

G_r is the real gas relative density;

h_w is the orifice differential pressure, in inches of water at 60 °F;

P_{f_1} is the flowing pressure at upstream tap, in psia;

Q_m is the mass flow rate, in lbm/hr;

T_f is the flowing temperature, in °R;

Y_1 is the expansion factor (upstream tap);

Z_s is the compressibility at reference base conditions (P_s, T_s);

Z_{f_1} is the compressibility at upstream flowing conditions (P_{f_1}, T_f);

ρ_{t,p_1} is the density of the fluid at upstream flowing conditions (P_{f_1}, T_f), in lbm/ft³.

4.3 Equations for Volume Flow of Natural Gas

The volume flow rate of natural gas, in ft³/hr at base conditions, can be developed from the densities of the fluid at flowing and base conditions and the ideal gas relative density or real gas relative density using the following equations.

The volume flow rate at base conditions, Q_b , developed from the density of the fluid at flowing conditions (ρ_{t,p_1}) and base conditions (ρ_b) is expressed as follows:

$$Q_b = \frac{359.072 C_d(FT) E_v Y_1 d^2 \sqrt{\rho_{t,p_1} h_w}}{\rho_b} \quad (4)$$

The volume flow rate at base conditions, developed from ideal gas relative density, G_i , is expressed as follows:

$$Q_b = 218.573 C_d(FT) E_v Y_1 d^2 \frac{T_b Z_b}{P_b} \sqrt{\frac{P_{f_1} h_w}{G_i Z_{f_1} T_f}} \quad (5)$$

To correctly apply the real gas relative density to the flow calculation, the reference base conditions for the determination of real gas relative density and the base conditions for the flow calculation have to be the same. Therefore, the volume flow rate at base conditions, developed from real gas relative density, G_r , is expressed as follows:

$$Q_b = 218.573 C_d(FT) E_v Y_1 d^2 \frac{T_b}{P_b} \sqrt{\frac{P_{f1} Z_b Z_{b_{air}} h_w}{G_r Z_{f1} T_f}} \quad (6)$$

If reference base conditions are substituted for base conditions in Equation (4), Equation (5), and Equation (6), then

$$P_b = P_s = 14.73 \text{ psia},$$

$$T_b = T_s = 519.67 \text{ }^\circ\text{R} \text{ (60 }^\circ\text{F)}, \text{ and}$$

$$Z_{b_{air}} = Z_{s_{air}} = 0.999590.$$

The volume flow rate at reference base conditions, Q_v , can then be determined using the following equations.

The volume flow rate at reference base conditions, developed from the density of the fluid at flowing conditions ($\rho_{t,p1}$) and reference base conditions (ρ_s), is expressed as follows:

$$Q_v = \frac{359.072 C_d(FT) E_v Y_1 d^2 \sqrt{\rho_{t,p1} h_w}}{\rho_s} \quad (7)$$

The volume flow rate at reference base conditions, developed from ideal gas relative density, G_i , is expressed as follows:

$$Q_v = 7711.19 C_d(FT) E_v Y_1 d^2 Z_s \sqrt{\frac{P_{f1} h_w}{G_i Z_{f1} T_f}} \quad (8)$$

The volume flow rate equation at reference base conditions, Q_v , developed from the real gas relative density, requires the reference base conditions for G_r and incorporates $Z_{b_{air}}$ at reference base conditions of 14.73 psia and 519.67 °R (60 °F) in its numeric constant. Therefore, the volume flow rate at reference base conditions, developed from real gas relative density, G_r , is expressed as follows:

$$Q_v = 7709.61 C_d(FT) E_v Y_1 d^2 \sqrt{\frac{P_{f1} Z_s h_w}{G_r Z_{f1} T_f}} \quad (9)$$

where

$C_d(FT)$ is the coefficient of discharge for flange-tapped orifice meter;

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

E_v is the velocity of approach factor;

G_i is the ideal gas relative density;

G_r is the real gas relative density;

h_w is the orifice differential pressure, in inches of water at 60 °F;

P_b is the base pressure, in psia;

- P_{f_1} is the flowing pressure (upstream tap), in psia;
 P_s is the reference base pressure = 14.73 psia;
 Q_b is the volume flow rate per hour at base conditions, in ft³/hr;
 Q_v is the volume flow rate per hour at reference base conditions, in ft³/hr;
 T_b is the base temperature, in °R;
 T_f is the flowing temperature, in °R;
 T_s is the reference base temperature = 519.67 °R (60 °F);
 Y_1 is the expansion factor (upstream tap);
 Z_b is the compressibility at base conditions (P_b, T_b);
 $Z_{b_{air}}$ is the compressibility of air at base conditions (P_b, T_b);
 Z_{f_1} is the compressibility at upstream flowing conditions (P_{f_1}, T_f);
 Z_s is the compressibility at reference base conditions (P_s, T_s);
 $Z_{s_{air}}$ is the compressibility of air at reference base conditions (P_s, T_s);
 ρ_b is the density of the flowing fluid at base conditions (P_b, T_b), in lbm/ft³;
 ρ_s is the density of the flowing fluid at reference base conditions (P_s, T_s), in lbm/ft³;
 ρ_{t, P_1} is the density of the fluid at upstream flowing conditions (P_{f_1}, T_f), in lbm/ft³.

4.4 Volume Conversion from Reference Base to Base Conditions

For the purposes of this document, reference base and base conditions are assumed to be the same. However, if base conditions are different from reference base conditions, the volume flow rate calculated at reference base conditions can be converted to the volume flow rate at base conditions through the following relationship:

$$Q_b = Q_v \left(\frac{P_s}{P_b} \right) \left(\frac{T_b}{T_s} \right) \left(\frac{Z_b}{Z_s} \right) \quad (10)$$

where

- P_b is the base pressure, in psia;
 P_s is the reference base pressure, in psia;
 Q_b is the base volume flow rate, in ft³/hr;
 Q_v is the reference base volume flow rate, in ft³/hr;
 T_b is the base temperature, in °R;
 T_s is the reference base temperature, in °R;
 Z_b is the compressibility at base conditions (P_b, T_b);
 Z_s is the compressibility at reference base conditions (P_s, T_s).

5 Flow Equation Components Requiring Additional Computation

5.1 General

Some of the terms in Equation (1) through Equation (9) require additional computation and are developed in this section.

5.2 Diameter Ratio (β)

The diameter ratio (β), also known as beta ratio, which is used in determining the orifice plate coefficient of discharge (C_d), the velocity of approach factor (E_v), and the expansion factor (Y), is the ratio of the orifice bore diameter (d) to the internal diameter of the meter tube (D). For the most precise results, the actual dimensions should be used, as determined in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 and/or API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2.

$$\beta = d/D \quad (11)$$

where

$$d = d_r [1 + \alpha_1 (T_f - T_r)] \quad (12)$$

and

$$D = D_r [1 + \alpha_2 (T_f - T_r)] \quad (13)$$

where

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

D_r is the reference meter tube internal diameter calculated at reference temperature, T_r ;

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

d_r is the reference orifice plate bore diameter calculated at reference temperature, T_r ;

T_f is the temperature of the fluid at flowing conditions;

T_r is the reference temperature for the orifice plate bore diameter and/or the meter tube internal diameter;

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

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

β is the diameter ratio.

NOTE α , T_f , and T_r have to be in consistent units. For the purpose of this standard, T_r is assumed to be 68 °F.

The orifice plate bore diameter, d_r , and the meter tube internal diameter, D_r , calculated at T_r are the diameters determined in accordance with API *MPMS* Ch. 14.3.2/AGA Report No. 3, Part 2.

5.3 Coefficient of Discharge for Flange-tapped Orifice Meter [C_d (FT)]

The coefficient of discharge for a flange-tapped orifice meter (C_d) has been determined from test data. It has been correlated as a function of diameter ratio (β), tube diameter, and pipe Reynolds number. In this document, the equation for the flange-tapped orifice meter coefficient of discharge developed in API *MPMS* Ch. 14.3.1/AGA Report No. 3, Part 1 has been adapted to the USC inch-pound system of units.

Table 1—Linear Coefficient of Thermal Expansion

Material	Linear Coefficient of Thermal Expansion (α)	
	USC (in./in.-°F)	SI (mm/mm-°C)
Type 304 stainless steel ^a	0.00000961	0.0000173
Type 316 stainless steel ^a	0.00000889	0.0000160
Type 304/316 stainless steel ^c	0.00000925	0.0000167
Monel 400 ^a	0.00000772	0.0000139
Carbon steel ^b	0.00000620	0.0000112
NOTE For flowing temperature limits or other materials, refer to ASM International's <i>Metals Handbook</i> , <i>Engineering Properties of Steel</i> and <i>Handbook of Stainless Steels</i> .		
^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 and is recommended when the orifice plate is stainless steel but the grade is unknown.		
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).		

The equation for the concentric, square-edged flange-tapped orifice meter coefficient of discharge, $C_d(FT)$, developed by RG, is structured into distinct linkage terms. The equation is applicable to nominal pipe sizes of 2 in. and larger; diameter ratios (β) of 0.1 to 0.75, provided the orifice plate bore diameter, d_p , is greater than 0.45 in.; and pipe Reynolds numbers (Re_D) greater than or equal to 4,000. For orifice diameters, diameter ratios, and pipe Reynolds numbers outside the stated limits, the uncertainty statement increases. For guidance, refer to API MPMS Ch. 14.3.1/ AGA Report No. 3, Part 1, Section 12.4.1 (September 2012).

The RG equation is defined as follows:

$$C_d(FT) = C_i(FT) + 0.000511 \left(\frac{10^6 \beta}{Re_D} \right)^{0.7} + (0.0210 + 0.0049 A) \beta^4 C \quad (14)$$

$$C_i(FT) = C_i(CT) + \text{tap term} \quad (15)$$

$$C_i(CT) = 0.5961 + 0.0291 \beta^2 - 0.2290 \beta^8 + 0.003(1 - \beta) M_1 \quad (16)$$

$$\text{tap term} = \text{upstrm} + \text{dnstrm} \quad (17)$$

$$\text{upstrm} = (0.0433 + 0.0712 e^{-8.5 L_1} - 0.1145 e^{-6.0 L_1})(1 - 0.23 A) B \quad (18)$$

$$\text{dnstrm} = -0.0116(M_2 - 0.52 M_2^{1.3}) \beta^{1.1} (1 - 0.14 A) \quad (19)$$

also

$$B = \frac{\beta^4}{1 - \beta^4} \quad (20)$$

$$M_1 = \max\left(2.8 - \frac{D}{N_4}, 0.0\right) \quad (21)$$