**Date of Issue:** January 2019

**Affected Publication:** API *Manual of Petroleum Measurement Standards*, Chapter 14.3.2, *Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids—Concentric, Square-edged Orifice Meters—Part 2: Specification and Installation Requirements*, Fifth Edition

# Errata 2

*Page 32, Section 6.5:*

*The equation (in SI units) should read:*

$$L = \left( \frac{F_m \times 4.38 \times OD \times 10}{S \times V} \sqrt{\frac{E}{\rho}\left(OD^2 + ID^2\right)} \right)^{\frac{1}{2}}$$

where

$L$ is the probe length (mm);

$F_m$ is the virtual mass factor—a constant to take account of the extra mass of the cylinder due to the fluid surrounding it and vibrating with it. For a gas, $F_m = 1.0$ and for water and other liquids, $F_m = 0.9$;

$OD$ is the outside diameter of probe (mm);

$ID$ is the inside diameter of probe (mm);

$S$ is the Strouhal number, dependent on the Reynolds No. and shape of the cylinder, but can be taken as 0.4 for worst case or 0.2 as suggested by API *MPMS* Ch. 8.

$V$ is the velocity of fluid (m/sec);

$E$ is the modulus of elasticity of probe material (kg/cm$^2$);

$\rho$ is the density of probe material (kg/m$^3$).

*The equation (in USC units) should read:*

$$L = \left( \frac{F_m \times 1.205 \times OD}{S \times V} \sqrt{\frac{E}{\rho}\left(OD^2 + ID^2\right)} \right)^{\frac{1}{2}}$$

where

$L$ is the probe length (inches);

$F_m$ is the virtual mass factor—a constant to take account of the extra mass of the cylinder due to the fluid surrounding it and vibrating with it. For a gas, $F_m = 1.0$ and for water and other liquids, $F_m = 0.9$;

$OD$ is the outside diameter of probe (inches);

$ID$ is the inside diameter of probe (inches);

$S$ is the Strouhal number, dependent on the Reynolds No. and shape of the cylinder, but can be taken as 0.4 for worst case or 0.2 as suggested by API *MPMS* Ch. 8.

$V$ is the velocity of fluid (ft/sec);

$E$ is the modulus of elasticity of probe material (psi);

$\rho$ is the density of probe material (g/cc).

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

## Part 2: Specification and Installation Requirements

AGA Report No. 3
Part 2

Manual of Petroleum
Measurement Standards
Chapter 14.3.2

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400 North Capitol Street, NW
Washington, DC 20001

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

FIFTH EDITION, MARCH 2016

An American National Standard

ANSI/API MPMS Ch. 14.3.2/AGA Report No. 3, Part 2

ERRATA 2, JANUARY 2019
ERRATA 1, MARCH 2017

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# Contents

## Contents

# Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids—Concentric, Square-edged Orifice Meters
# Part 2: Specification and Installation Requirements

## 1 Scope

### 1.1 General

This document establishes design and installation parameters for measurement of fluid flow using concentric, square-edged, flanged tapped orifice meters.

### 1.2 Construction and Installation Requirements

This document outlines the various design parameters that shall be considered when designing metering facilities using orifice meters. The mechanical tolerances found in this document encompass a wide range of orifice diameter ratios for which experimental results are available.

For all existing installations, the decision to upgrade to meet the requirements of this standard shall be at the discretion of the parties involved. The parties should be cognizant that if a meter installation is not upgraded to meet this standard, measurement bias errors may exist due to inadequate flow conditioning and upstream straight pipe lengths.

Use of the calculation procedures and techniques shown in the API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1 and API *MPMS* Ch.14.3.3/AGA Report No. 3, Part 3, with existing equipment is recommended, since these represent significant improvements over the previous methods. The uncertainty levels for flow measurement using existing equipment may be different from those quoted in API *MPMS* Chapter 14.3.1/AGA Report No. 3, Part 1.

Use of orifice meters at the extremes of their diameter ratio ($\beta_r$) ranges should be avoided whenever possible. Good metering design and practice tend to be somewhat conservative. This means that the use of the tightest tolerances in the mid-diameter ratio ($\beta_r$) ranges would have the highest probability of producing the best measurement. An indication of this is found in the section on uncertainty in API *MPMS* Chapter 14.3.1/AGA Report No. 3, Part 1.

This standard is based on $\beta_r$ between 0.10 and 0.75. Minimum uncertainty of the orifice plate coefficient of discharge ($C_d$) is achieved with $\beta_r$ between 0.2 and 0.6 and orifice bore diameters greater than or equal to 0.45 inch. Diameter ratios and orifice bore diameters outside of this range may be used; the user should consult the uncertainty section in API *MPMS* Chapter 14.3.1/AGA Report No. 3, Part 1 for limitations.

Achieving the best level of measurement uncertainty begins with, but is not limited to, proper design. Two other aspects of the measurement process have to accompany the design effort; otherwise it is of little value. These aspects are the application of the metering system and the maintenance of the meters, neither of which is considered directly in this standard. These aspects cannot be governed by a single standard as they cover metering applications that can differ widely in flow rate, fluid type, and operational requirements. The user shall determine the best meter selection for the application and the level of maintenance for the measurement system under consideration.

## 2 Normative References

No other document is identified as indispensable or required for the application of this standard.

# 3 Terms, Definitions, and Symbols

## 3.1 Definitions

The definitions are given to emphasize the particular meaning of the terms as used in this standard.

**3.1.1**
**diameter ratio ($\beta$)**
The calculated orifice plate bore diameter ($d$) divided by the calculated meter tube internal diameter ($D$).

**3.1.2**
**diameter ratio ($\beta_m$)**
The measured orifice plate bore diameter ($d_m$) divided by the measured meter tube internal diameter ($D_m$).

**3.1.3**
**diameter ratio ($\beta_r$)**
The reference orifice plate bore diameter ($d_r$) divided by the reference meter tube internal diameter ($D_r$).

**3.1.4**
**differential pressure ($\triangle P$)**
The static pressure difference measured between the upstream and the downstream flange taps.

**3.1.5**
**average differential pressure ($\triangle P_{avg}$)**
A time mean of the static pressure difference measured between the upstream and downstream flange taps.

**3.1.6**
**instantaneous differential pressure ($\triangle P_t$)**
A single measurement of $\triangle P$ at any instance in time.

**3.1.7**
**root mean square differential pressure ($\triangle P_{rms}$)**
The r square root of the sum of squares of the difference between the instantaneous differential pressure ($\triangle P_t$) and time mean differential ($\triangle P_{avg}$).

**3.1.8**
**flange taps**
A pair of tap holes positioned as follows:

a) the upstream tap center is located 1 in. upstream of the nearest plate face;

b) the downstream tap center is located 1 in. downstream of the nearest plate face;

c) the upstream and downstream taps shall be in the same radial position.

**3.1.9**
**flow conditioners**
Flow conditioners can be classified into two categories: flow straighteners or flow conditioners.

Flow straighteners are devices that effectively remove or reduce the swirl component of a flowing stream, but may have limited ability to produce the flow conditions necessary to accurately replicate the orifice plate coefficient of discharge database values. See Table 8a and Table 8b for installation requirements.

Flow conditioners, which have successfully completed the recommended performance test protocol in Annex D, are devices that effectively remove the swirl component from the flowing stream while redistributing the stream to produce a pseudo fully developed flow profile and the flow conditions that accurately replicate the orifice plate coefficient of discharge database values.

**3.1.10**
**meter tube**
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 5.1.

**3.1.11**
**meter tube internal diameter ($D$)**
The inside diameter of the upstream section of the meter tube computed at flowing temperature ($T_f$), as specified in 1.6.3 of API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1. The calculated meter tube internal diameter ($D$) is used in the diameter ratio and Reynolds number equations.

**3.1.12**
**published meter tube internal diameter ($D_i$)**
The inside diameter as published in standard handbooks for engineers. This internal diameter is used for determining the required meter run length in Table 7, Table 8a, and Table 8b.

**3.1.13**
**measured meter tube internal diameter ($D_m$)**
The average inside diameter of the upstream section of the meter tube measured 1 in. upstream of the adjacent face of the orifice plate and at the temperature of the meter tube ($T_m$) at the time of internal diameter measurements, as specified in 5.1.2.

**3.1.14**
**reference meter tube internal diameter ($D_r$)**
The inside diameter of the upstream section of the meter tube calculated at the reference temperature ($T_r$), as specified in 5.1.2. The reference meter tube internal diameter is the certified meter tube internal diameter.

**3.1.15**
**orifice plate**
A thin square-edged plate with a machined circular bore, concentric with the meter tube $ID$, when installed.

**3.1.16**
**orifice plate bore diameter ($d$)**
The internal diameter of the orifice plate measuring aperture (bore) computed at flowing temperature ($T_f$), as specified in 1.6.2 in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1. The calculated orifice plate bore diameter ($d$) is used in the flow equation for the determination of flow rate.

**3.1.17**
**measured orifice plate bore diameter ($d_m$)**
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 4.4.

**3.1.18**
**reference orifice plate bore diameter ($d_r$)**
The internal diameter of the orifice plate measuring aperture at reference temperature ($T_r$), calculated as specified in 4.4. The reference orifice plate bore diameter is the certified or stamped orifice plate bore diameter.

**3.1.19**
**orifice plate holder**
A pressure containing piping element, such as a set of orifice flanges also known as an OFU (orifice flange union) or an orifice fitting, used to contain and position the orifice plate in the piping system.

**3.1.20**
**primary element**
The orifice plate, the orifice plate holder with its associated differential pressure sensing taps, the meter tube, and the flow conditioner, if used.

**3.1.21**
**roughness average ($R_a$)**
The roughness average ($R_a$) used in this standard is that given in ANSI B46.1, and is "the arithmetic average of the absolute values of the measured profile height deviation taken within the sampling length and measured from the graphical centerline" of the surface profile.

**3.1.22**
**tap hole**
A hole drilled radially in the wall of the meter tube or through the orifice fitting and perpendicular to the centerline of the meter tube or orifice plate holder, the inside edge of which is flush and without any burrs.

**3.1.23**
**temperature measurement ($T_f$)**
The flowing fluid temperature measured at the designated location, as specified in 6.5.

In flow measurement, the temperature sensing device is inserted in the flowing stream to obtain the flowing temperature. If the fluid velocity is higher than 25 % of the fluid sound speed at the point of measurement, which rarely occurs, corrections for the increase in temperature due to dynamic effects will need to be applied. Care should be taken to ensure that the temperature sensing elements are coupled to the flowing stream and not to the steel in the meter tube. This practice is recommended for all orifice meter installations. The sensed temperature is assumed to be the static temperature of the flowing fluid.

**3.1.24**
**measured temperature ($T_m$)**
The measured temperature of the orifice plate and/or the meter tube at the time of the diameter measurements, as specified in 4.4 and 5.1.2.

**3.1.25**
**reference temperature ($T_r$)**
The reference temperature used to determine the reference orifice plate bore diameter ($d_r$) and/or the reference internal meter tube diameter ($D_r$), as specified in 4.4 and 5.1.2.

## 3.2 Symbols/Nomenclature

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

| Symbol | Represented Quantity |
|---|---|
| $c$ | Speed of sound |
| $C_d$ | Orifice plate coefficient of discharge |
| $C_d\,(FT)$ | Flange tap orifice plate coefficient of discharge |
| $\triangle C_d\,(FT)/C_d$ | Percent difference between baseline $C_d$ and installation effect $C_d$ |
| $d$ | Orifice plate bore diameter calculated at flowing temperature, $T_f$ |
| $d_m$ | Orifice plate bore diameter measured at temperature, $T_m$ |
| $d_r$ | Orifice plate bore diameter calculated at reference temperature, $T_r$ |
| $D$ | Meter tube internal diameter calculated at flowing temperature, $T_f$ |
| $D_i$ | Published meter tube internal pipe diameter |

| | |
|---|---|
| $DL$ | Meter tube length downstream of orifice plate in multiples of published internal pipe diameters (see Figure 6) |
| $D_m$ | Meter tube internal diameter measured at $T_m$ |
| $D_n$ | Nominal pipe diameter |
| $D_r$ | Meter tube internal diameter calculated at reference temperature, $T_r$ |
| $e$ | Orifice plate bore thickness |
| $E$ | Orifice plate thickness |
| $f$ | Frequency |
| °F | Temperature, in degrees Fahrenheit |
| $l$ | Recommended lengths of gauge line |
| NPS | Nominal Pipe Size |
| $\Delta P$ | Orifice plate differential pressure |
| $\Delta P_{avg}$ | Average orifice plate differential pressure |
| $\Delta P_{rms}$ | Root mean square of the fluctuating differential pressure |
| $\Delta P_t$ | Instantaneous orifice plate differential pressure |
| $P_f$ | Static pressure of the fluid at the pressure tap |
| °R | Temperature, in degrees Rankine |
| $R_a$ | Absolute roughness average |
| Re | Reynolds number |
| $T_f$ | Temperature of fluid at flowing conditions |
| $T_m$ | Temperature of the orifice plate and/or meter tube at time of diameter measurements |
| $T_r$ | Reference temperature (68 °F) of orifice plate bore diameter and/or meter tube internal diameter |
| $UL$ | Meter tube length upstream of orifice plate in multiples of published internal pipe diameters (see Figure 6) |
| $UL1$ | $UL - UL2$ |
| $UL2$ | Meter tube length from flow conditioner exit to orifice plate in multiples of published internal pipe diameters |
| $\alpha$ | Linear coefficient of thermal expansion |
| $\alpha_1$ | Linear coefficient of thermal expansion of the orifice plate material |
| $\alpha_2$ | Linear coefficient of thermal expansion of the meter tube material |
| $\beta$ | Ratio of orifice plate bore diameter to meter tube internal diameter ($d/D$) also known as beta ratio or diameter ratio calculated at flowing temperature, $T_f$ |
| $\beta_m$ | Ratio of orifice plate bore diameter to meter tube internal diameter ($d_m/D_m$) calculated at temperature, $T_m$ |
| $\beta_r$ | Ratio of orifice plate bore diameter to meter tube internal diameter ($d_r/D_r$) calculated at reference temperature, $T_r$ |
| $\varepsilon$ | Orifice plate bore eccentricity |
| $\theta$ | Orifice plate bevel angle |

# 4 Orifice Plate Specifications

## 4.1 General

The symbols for the orifice plate dimensions are shown in Figure 1.

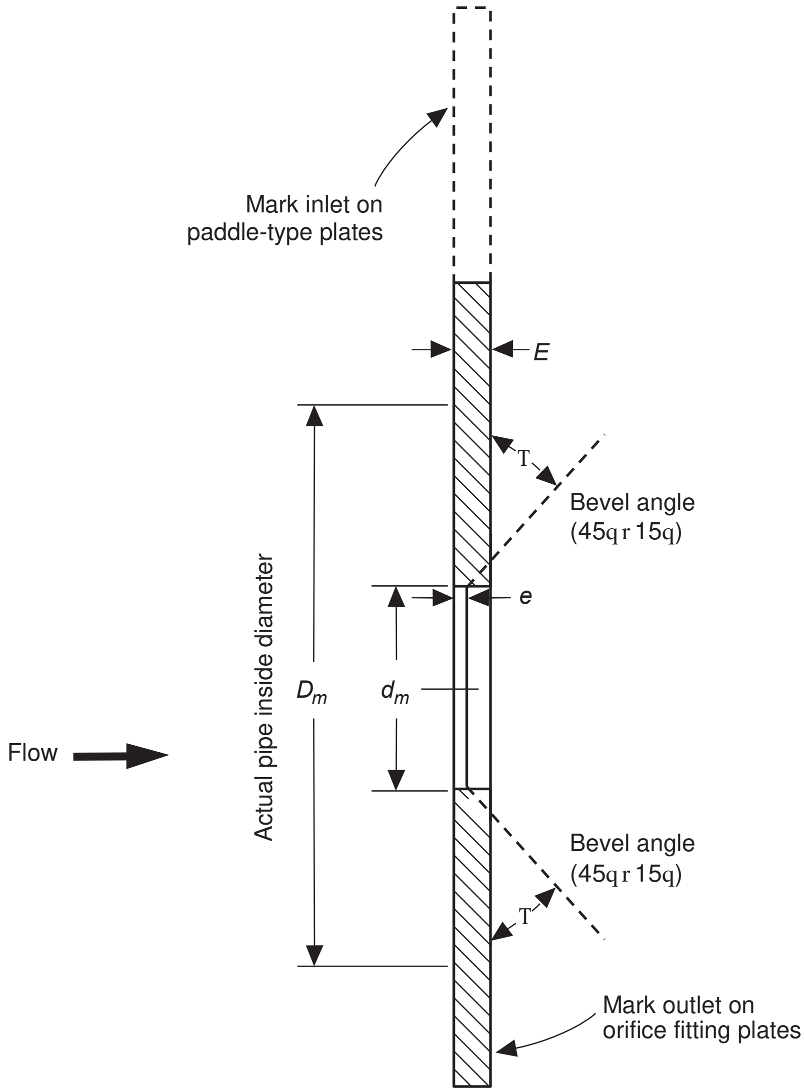



**Figure 1—Symbols for Orifice Plate Dimensions**

## 4.2 Orifice Plate Faces

The upstream and downstream faces of the orifice plate shall be flat. Deviations from flatness on the orifice plate of less than or equal to 1 % of dam height (that is, 0.010 in. per in. of dam height) under non-flowing conditions are allowed. The dam height can be calculated from the formula $(D_m - d_m)/2$. This criterion for flatness applies to any two points on the orifice plate within the dimensions of the inside diameter of the pipe. The departure from flatness is illustrated in Figure 2a, Figure 2b, and Figure 2c.

The surface roughness of the upstream and downstream faces of the orifice plate shall have no abrasions or scratches visible to the naked eye that exceed 50 microinches $R_a$.

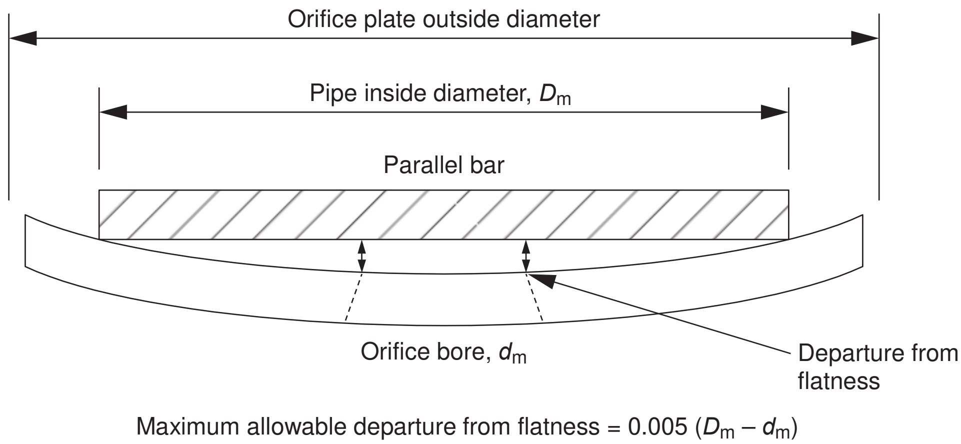



**Figure 2a—Orifice Plate Departure from Flatness (Measured at Edge of Orifice Bore and Within Inside Pipe Diameter)**

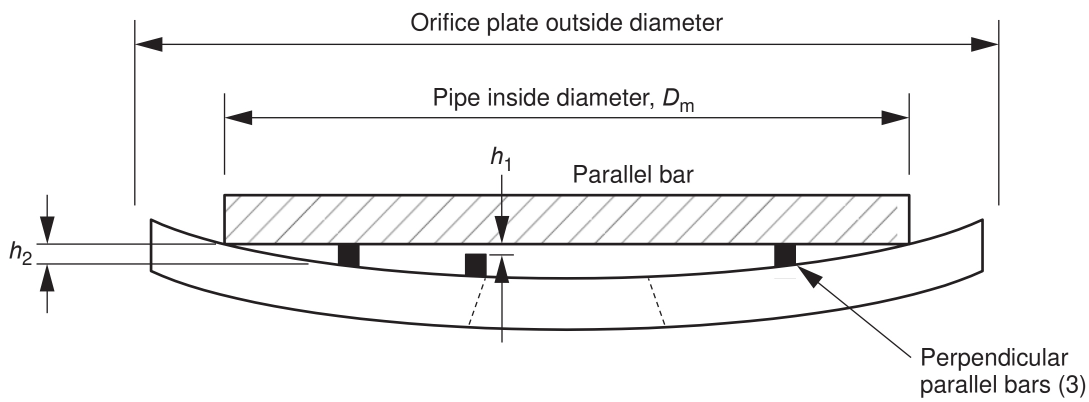
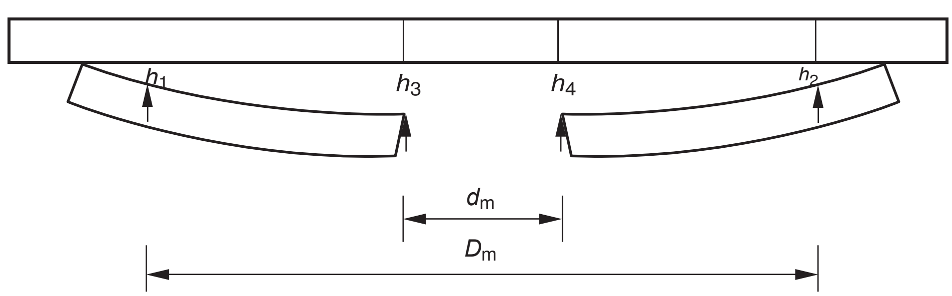



**Figure 2b—Alternative Method for Determination of Orifice Plate Departure from Flatness (Departure from Flatness = h2 – h1)**




$$\text{Maximum departure from flatness} = \frac{[h_3 + h_4] - [h_1 + h_2]}{2}$$

**Figure 2c—Maximum Orifice Plate Departure from Flatness**

The orifice plate surface roughness may be verified by using an electronic-averaging-type surface roughness instrument with a cutoff value of not less than 0.03 inch. Other surface roughness devices (for example, a visual comparator) are acceptable for determining orifice plate surface roughness if the same repeatability and reproducibility as those of the electronic-averaging-type surface roughness instrument can be demonstrated.

Due care shall be exercised to keep the plate clean and free from accumulation of dirt, ice, grit, grease, oil, free liquid, and other extraneous materials by instituting a regular inspection schedule (daily, weekly, monthly, quarterly, etc., depending on the service conditions). Damage and/or accumulation of extraneous materials on the orifice plate may result in a greater uncertainty for the orifice plate coefficient of discharge [$C_d$ $(FT)$]. After any inspection of the plate, it shall be thoroughly cleaned (free from accumulations as stated above) prior to being placed back in service.

## 4.3 Orifice Plate Bore Edge

The upstream edge of the orifice plate bore shall be square and sharp. The orifice plate bore edge is considered too dull for accurate flow measurement if the upstream edge reflects a beam of light when viewed without magnification or if the upstream edge shows a beam of light when checked with an orifice edge gauge.

An estimation of suitable sharpness can be made by comparing the orifice plate bore edge with the bore edge of a properly sharp reference orifice plate of the same nominal diameter. The orifice plate bore edge being evaluated should feel and look the same as the edge of the reference orifice plate.

The upstream and downstream edges of the orifice plate bore shall be free from defects visible to the naked eye, such as flat spots, feathered texture, roughness, burrs, bumps, nicks, and notches.

If there is any doubt about whether the edge has sufficient quality for accurate metering, the orifice plate should be replaced.

## 4.4 Orifice Plate Bore Diameter ($d_m$, $d_r$) and Roundness

The measured orifice bore diameter ($d_m$) is defined as the mean (arithmetic average) of four or more evenly spaced diameter measurements at the inlet edge. None of the four or more diameter measurements may vary from the mean value by more than the tolerances given in Table 1. The orifice plate temperature shall be recorded at the time the bore diameter measurements are made. These measurements shall be made under thermally stable conditions; i.e. during the measurement, the temperature should be constant within ± 1 °F (± 0.5 °C).

The orifice plate bore diameter ($d_r$) is defined as the calculated reference diameter at reference temperature ($T_r$) and can be determined using the following equation:

$$d_r = d_m[1 + \alpha_1(T_r - T_m)] \tag{1}$$

where

$\alpha_1$ is the linear coefficient of thermal expansion for the orifice plate material (see Table 2);

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

$d_m$ is the orifice plate bore diameter measured at $T_m$;

$T_m$ is the temperature of the orifice plate at time of diameter measurements;

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

NOTE $\alpha_1$, $T_m$, 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 ($d_r$) calculated at $T_r$ is the reference diameter used to calculate the bore diameter ($d$) at flowing conditions, as specified in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1.

**Table 1—Roundness Tolerance for Orifice Plate Bore Diameter, $d_m$**

| **Office Bore Diameter, $d_m$** (inches) | **Tolerance** (± inches) |
|---|---|
| ≤0.250 [a] | 0.0003 |
| 0.251 to 0.375 [a] | 0.0004 |
| 0.376 to 0.500 [a] | 0.0005 |
| 0.501 to 0.625 | 0.0005 |
| 0.626 to 0.750 | 0.0005 |
| 0.751 to 0.875 | 0.0005 |
| 0.876 to 1.000 | 0.0005 |
| >1.000 | 0.0005 in. per in. of diameter |

[a] Use of diameters below 0.45 in. are not prohibited, but may result in uncertainties greater than those specified in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1.

**Table 2—Linear Coefficient of Thermal Expansion**

| **Material** | **Linear Coefficient of Thermal Expansion ($\alpha$)** | |
|---|---|---|
| | **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).

## 4.5 Orifice Plate Bore Thickness ($e$)

The inside surface of the orifice plate bore shall be in the form of a constant-diameter cylinder having no defects, such as grooves, ridges, pits, or lumps, visible to the naked eye. The length of the cylinder is the orifice plate bore thickness ($e$).

The minimum allowable orifice plate bore thickness ($e$) is defined by $e \geq 0.01d_r$ or $e > 0.005$ in., whichever is larger.

The maximum allowable value for the orifice plate bore thickness ($e$) is defined by $e \leq 0.02D_r$ or $e \leq 0.125d_r$, whichever is smaller, but e shall not be greater than the maximum allowable orifice plate thickness ($E$).

When the orifice plate thickness ($E$) exceeds the orifice bore thickness ($e$), a bevel (see 4.7) is required on the downstream side of the orifice bore. Use of an unbeveled orifice plate with bore thickness ($e$) that exceeds the limits specified in Table 3 is outside of the scope of this standard.

NOTE Existing orifice plates, whose edge thickness meets the value defined by $e < 0.033D_m$, need not be rebeveled unless reconditioning is required for other reasons.

For ease in machining, the next smaller values of $e$, in multiples of 0.03125 ($^1/_{32}$ in.), may be used.

Orifice plate bores that demonstrate any convergence from inlet to outlet are unacceptable.

Bi-directional flow through an orifice meter tube requires a specially configured meter tube and the use of an unbeveled orifice plate. As a result, bi-directional flow measurement is not covered by this standard.

## 4.6 Orifice Plate Thickness ($E$)

### 4.6.1 General

The minimum, maximum, and recommended values of orifice plate thickness ($E$) for Types 304 and 316 stainless steel orifice plates are given in Table 3.

Maximum allowable differential pressures for the recommended orifice plate thicknesses in Table 3 are for operating temperatures not exceeding 150 °F. For operating conditions, orifice diameter ratios, meter tube sizes, and orifice plate thicknesses not covered in Table 3, see the tables found in Annex E. If a specific application is not covered by Table 3 or Annex E, the orifice plate and/or holding device manufacturer should be contacted for specific information on deflection (see Annex F in the 2000 version of this standard, AGA *Engineering Technical Note—High Differential Pressure Across Orifice Fittings*) for a given diameter ratio, temperature, orifice plate material, orifice plate holder, and differential pressure.

The use of an orifice plate thickness other than the recommended thickness is acceptable in either new or existing orifice plate holding devices as long as the thickness is within the maximum and minimum range shown in Table 3; and the orifice plate eccentricity, bore thickness, differential pressure tap hole, and expansion-factor pressure-ratio tolerances and limits are satisfied.

For incompressible fluids, the maximum differential pressure across the plate is limited by the structural integrity of the fitting design. The maximum differential pressure should be limited to those shown in Table 3 and Annex E. If the maximum differential pressure is to exceed the limits specified, the manufacturer should be consulted for allowable maximum pressure for the fitting design. In addition, the flowing conditions downstream of the orifice plate have to remain above the local vapor pressure of the flowing fluid.

Orifice fitting manufacturers should be consulted to determine the maximum allowable differential pressure during the changing of orifice plates under flowing conditions. The high forces associated with using high differential pressures may make it difficult to remove the plate, and may possibly result in damage to the orifice plate or fitting.

**Table 3—Orifice Plate Thickness and Maximum Allowable Differential Pressure Based on the Structural Limit**

| Nominal Pipe Size (NPS) | Published Inside Pipe Diameter | Orifice Plate Thickness, $E$ (inches) | | | Maximum Allowable $\Delta P$ (in.-$H_2$0) | Maximum Allowable $\Delta P$ (in.-$H_2$0) |
|---|---|---|---|---|---|---|
| (inches) | (inches) | Minimum | Maximum | Recommended | Orifice Fitting | Orifice Flanges |
| 2 | 1.687 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 1.939 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 2.067 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| 3 | 2.300 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 2.624 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 2.900 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 3.068 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| 4 | 3.152 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 3.438 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 3.826 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| | 4.026 | 0.115 | 0.130 | 0.125 | 1000 | 1000 |
| 6 | 4.897 | 0.115 | 0.163 | 0.125 | 345 | 1000 |
| | 5.187 | 0.115 | 0.163 | 0.125 | 345 | 1000 |
| | 5.761 | 0.115 | 0.192 | 0.125 | 345 | 1000 |
| | 6.065 | 0.115 | 0.192 | 0.125 | 345 | 1000 |
| 8 | 7.625 | 0.115 | 0.254 | 0.250 | 1000 | 1000 |
| | 7.981 | 0.115 | 0.319 | 0.250 | 1000 | 1000 |
| | 8.071 | 0.115 | 0.319 | 0.250 | 1000 | 1000 |
| 10 | 9.562 | 0.115 | 0.319 | 0.250 | 570 | 1000 |
| | 10.020 | 0.115 | 0.319 | 0.250 | 570 | 1000 |
| | 10.136 | 0.115 | 0.319 | 0.250 | 570 | 1000 |
| 12 | 11.374 | 0.175 | 0.379 | 0.250 | 285 | 1000 |
| | 11.938 | 0.175 | 0.398 | 0.250 | 285 | 1000 |
| | 12.090 | 0.175 | 0.398 | 0.250 | 285 | 1000 |
| 16 | 14.688 | 0.175 | 0.490 | 0.375 | 465 | 1000 |
| | 15.000 | 0.175 | 0.500 | 0.375 | 465 | 1000 |
| | 15.025 | 0.175 | 0.500 | 0.375 | 465 | 1000 |
| 20 | 18.812 | 0.240 | 0.505 | 0.375 | 235 | 1000 |
| | 19.000 | 0.240 | 0.505 | 0.375 | 235 | 1000 |
| | 19.250 | 0.240 | 0.505 | 0.375 | 235 | 1000 |
| 24 | 22.624 | 0.240 | 0.505 | 0.500 | 360 | 1000 |
| | 23.000 | 0.240 | 0.562 | 0.500 | 360 | 1000 |
| | 23.250 | 0.240 | 0.562 | 0.500 | 360 | 1000 |

**Table 3—Orifice Plate Thickness and Maximum Allowable Differential Pressure Based on the Structural Limit (Continued)**

| Nominal Pipe Size (NPS) | Published Inside Pipe Diameter | Orifice Plate Thickness, $E$ (inches) | | | Maximum Allowable $\Delta P$ (in.-$H_20$) | Maximum Allowable $\Delta P$ (in.-$H_20$) |
|---|---|---|---|---|---|---|
| (inches) | (inches) | Minimum | Maximum | Recommended | Orifice Fitting | Orifice Flanges |
| 30 | 28.750 | 0.370 | 0.562 | 0.500 | 180 | 1000 |
| | 29.000 | 0.370 | 0.578 | 0.500 | 180 | 1000 |
| | 29.250 | 0.370 | 0.578 | 0.500 | 180 | 1000 |

NOTE 1 Maximum allowable differential pressure is limited to 1000 in. of water column, which is the limit of the coefficient of discharge database. For further details on the limit of maximum allowable differential pressure, please refer to the text in 4.6.

NOTE 2 Maximum allowable differential pressure is calculated for worst-case diameter ratio (typically $\beta = 0.55 - 0.65$). Other diameter ratios may be able to go to higher differential pressures (see Annex E).

NOTE 3 The maximum differential pressure applies to stainless steel plates at a maximum temperature of 150 °F, and for the recommended plate thickness.

NOTE 4 Maximum allowable differential pressure for other plate thicknesses refer to Annex E.

NOTE 5 For single- or dual-chamber fittings, the orifice plate seal ring was assumed to deflect under axi-symmetric conditions without plastic deformation. As such, the effect on the seal ring was not investigated.

NOTE 6 Especially at very high differential pressures, the user should carefully consider the associated thermodynamic effects, such as temperature changes resulting from the Joule–Thompson effect as the stream passes through the orifice and the limits on $\Delta P/P_f$, in particular, at low pressures. The sudden reduction of pressure will result in temperature and density changes.

The use of high differential pressures ($\Delta P/P_f > 0.7$ in. of water/psia, where the $\Delta P$ is in inches of water at 60 °F and $P_f$ is in psia) will result in expansion factor uncertainties in excess of 0.1 % (see 12.4.2 of API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1).

Operators should be aware, for a given orifice plate size, that when there is a wide swing from high to low flows, significant measurement errors will occur during the low-flow period if the orifice plate remains unchanged. Generally, operation between 10 % and 90 % of the calibrated differential span is considered good practice. Rangeability can also be increased using today's digital (electronic) transmitters. The effects on the accuracy of transducers and/or transmitters used for wide range should be evaluated versus savings on installation cost.

For the full range of orifice plate thicknesses, the maximum allowable orifice plate differential pressure can be obtained from Annex E.

Higher differential pressures will result in higher meter-run gas velocities and higher permanent pressure losses. It is recommended that the gas velocities be evaluated on an individual installation basis for such things as noise, erosion, and thermowell vibration. The meter run velocity is dependent on several different factors, and each individual user will have different practices and limits on velocity. The allowable maximum differential pressures, shown in Table 3, do not consider meter-run gas velocity.

### 4.6.2 Permanent Pressure Drop

The permanent pressure drop is significant because the energy has been lost to transport the fluid through the pipeline. Several technical books list the permanent pressure loss versus $\beta$ ratio for the concentric, square-edged, flange-tapped orifice meter.

$$\text{The permanent pressure loss} \cong \triangle P(1-\beta^2)$$

| $\beta$ | Losses as a % of $\triangle P$ |
|---|---|
| 0.20 | 96 |
| 0.30 | 91 |
| 0.40 | 84 |
| 0.50 | 75 |
| 0.60 | 64 |
| 0.70 | 51 |
| 0.75 | 44 |

Examples:

a) If the user chooses to use a β of 0.30 at a $\triangle P$ of 400 inches of $H_2O$, then the permanent pressure loss would be approximately 91 % of 400 in. of $H_2O$, which is about 364 in. of $H_2O$ or approximately 13 psi.

b) If the user chooses to use a β of 0.50 at a $\triangle P$ of 100 in. of $H_2O$, then the permanent pressure loss would be approximately 75 % of 100 in. of $H_2O$, which is about 75 in. of $H_2O$ (about 3 psi).

## 4.7 Orifice Plate Bevel ($\theta$)

The plate bevel angle ($\theta$) is defined as the angle between the bevel and the downstream face of the plate. The allowable value for the plate bevel angle ($\theta$) is 45 degrees ± 15 degrees.

The surface of the plate bevel shall have no defects visible to the naked eye, such as grooves, ridges, pits, or lumps.

If a bevel is required, its minimum dimension, ($E$-$e$), measured along the axis of the bore shall not be less than 0.0625 ($^1/_{16}$) inch.

# 5 Meter Tube Specifications

## 5.1 Description

The meter tube consists of the straight upstream pipe of the same diameter length UL of the installation Table 7 and Table 8, (see Figure 6), including the flow straightener/conditioner, if used; the orifice plate holder; and the similar downstream pipe (length DL of the installation Table 7, Table 8a, and Table 8b[see Figure 6]) beyond the orifice plate. The upstream section of the meter tube is defined as the length of straight pipe extending from the upstream face of the orifice plate to the nearest upstream change in cross-sectional area (not including flanged fittings allowed in the standard) or change in the axis of the pipe centerline.

The length of the upstream and downstream pipe sections is addressed in 6.3.1. The tolerances for the diameter and the restrictions for the inside surface of the meter tube are specified in 5.1.1, 5.1.2, and 5.1.3.

There shall be no pipe connections within the specified upstream and downstream meter tube sections other than the pressure taps specified in 5.4 (and pipe taps as defined in Annex 3-D of API *MPMS* Ch.14.3.3/AGA Report No. 3, Part 3); temperature probes specified in 6.5; flow conditioner attachments (either flanged or in-line); orifice plate holders (welded or flanged on the downstream or upstream end as specified in 5.3.2); and in-line meter tube flanges necessary to connect sections of the meter tube. Any downstream flange connection or weld shall be at least 2 in. away from the downstream face of the orifice plate. Any downstream weld within 0.5$D$ or 2 in. from the downstream face of the orifice plate shall be ground and/or machined to meet the downstream out-of-roundness and the inside surface roughness requirements specified in 5.1.3.2 and 5.1.1, respectively. For any downstream flange connection within 0.5$D$ or 2 in., care has to be taken to avoid any protrusion of the gasket into the line. The closest an in-line meter tube flange can come to the orifice plate, in the upstream meter tube section, should be the designated flow conditioner location, or $10D_i$ for meter tubes without flow conditioner (not including flanged fittings allowed in the standard). All flanges and flange attachments within the designated meter tube lengths shall meet all meter tube requirements contained in 5.1.1, 5.1.2, 5.1.3, and 5.1.4.

### 5.1.1 Inside Surface

The sections of the meter tube to which the orifice plate holder is attached, or the adjacent pipe sections that constitute part of the meter tube, as defined in 5.1, shall comply with 5.1.1.1, 5.1.1.2, and 5.1.1.3. Due to the increased upstream meter tube length requirements of Table 7 and Table 8, and in keeping with the coefficient of discharge database lengths, the upstream meter tube section required to comply with 5.1.1.1, 5.1.1.2, and 5.1.1.3 shall be limited to the lengths shown in Table 7 and Table 8, or 17 published internal pipe diameters, whichever is less. The piping roughness $R_a$ upstream of this length should not be greater than 600 microinches (µin.).

**5.1.1.1** The internal surface roughness of the meter tube should be measured at approximately the same internal axial locations as those used to determine and verify the meter tube internal diameter (see 5.1.2). The $R_a$ values specified in the items below are the arithmetic average roughness obtained using an electronic-averaging-type surface roughness instrument with a cutoff value of not less than 0.03 inch. Other surface roughness devices are acceptable for determining meter-tube surface roughness if the same repeatability and reproducibility as those of the electronic-averaging-type surface roughness instrument can be demonstrated. A minimum of four roughness measurements shall be made.

The mean (arithmetic average) of these four or more roughness measurements is defined as the meter tube internal surface roughness.

For meter runs with nominal diameters of 12 in. or smaller:

a) The maximum meter-tube roughness shall not exceed 300 µin. $R_a$ if the diameter ratios ($\beta_r$) are less than 0.6.

b) The maximum meter-tube roughness shall not exceed 250 µin. $R_a$ if the diameter ratios ($\beta_r$) are greater than or equal to 0.6.

c) The minimum roughness shall not be less than 34 µin. for all diameter ratios.

For meter runs with nominal diameters larger than 12 in.:

a) The maximum meter-tube roughness shall not exceed 600 µin. $R_a$ if the diameter ratios ($\beta_r$) are less than 0.6.

b) The maximum meter-tube roughness shall not exceed 500 µin. $R_a$ if the diameter ratios ($\beta_r$) are greater than or equal to 0.6.

c) The minimum meter-tube roughness shall not be less than 34 µin. for all diameter ratios.

NOTE The use of lower diameter ratios ($\beta_r$) reduces the effect of pipe roughness on uncertainty.

Carefully selected smooth commercial pipe may be used. To improve smoothness within the meter tube, the inside pipe walls may be machined, ground, or coated to meet the required specifications.

**5.1.1.2** Irregularities such as grooves, scoring, or ridges resulting from seams, welding distortion, offsets, and the like, that affect the inside diameter by more than the tolerances in 5.1.3, shall not be permitted. The existence of pits in the surface of the meter tube, although undesirable, is allowed provided their individual measurements do not exceed the surface roughness and/or diameter tolerance requirements of the meter tube and do not compromise the meter tube's pressure integrity. When these tolerances are exceeded, the irregularities shall be corrected.

**5.1.1.3** Due care shall be exercised to keep the meter tube interior clean and free from accumulation of dirt, ice, grit, grease, oil, free liquid and other extraneous materials. Damage and/or accumulation of extraneous materials in the meter tube may result in a greater uncertainty for the orifice plate coefficient of discharge [$C_d(FT)$].

### 5.1.2 Meter Tube Diameter ($D_m$, $D_r$)

The measured internal diameter of the meter tube ($D_m$) shall be determined as specified in 5.1.2.1, 5.1.2.2, 5.1.2.3, 5.1.2.4, and 5.1.2.5.

**5.1.2.1** A minimum of four equally spaced individual internal diameter measurements shall be made in a plane one inch upstream from the upstream face of the orifice plate. The mean (arithmetic average) of these four or more individual measurements is defined as the measured meter tube internal diameter ($D_m$).

**5.1.2.2** Individual check measurements of the internal diameter of the upstream section ($UL$ in Table 7 and Table 8) of the meter tube (excluding the orifice plate gasket or sealing device diameter) shall be made at a minimum of two additional cross-sections. The actual locations of the individual internal diameter check measurements, around the circumference and along the axis of the meter tube, are not specified. These individual checks should be made at points that will indicate the maximum and minimum dimensions of the internal diameter of the meter tube's upstream section.

One of these individual check measurements should be made in a region at least two pipe diameters from the face of the orifice plate, or past the orifice plate holder weld or flange, whichever is the greater distance. Other individual measurements should be made at selected points within the $UL$ dimension.

Individual check measurements are used to verify the uniformity of the internal diameter of the upstream section of the meter tube (see 5.1.3), but do not become a part of the determination of the mean meter tube internal diameter.

**5.1.2.3** Individual check measurements of the meter tube internal diameter ($D_m$) shall be made in the downstream section of the meter tube in a plane 1-inch downstream from the downstream face of the orifice plate (see 5.1.3).

Additional individual check measurements of the internal diameter ($D_m$) (excluding the orifice plate gasket or sealing device diameter), shall be made at a minimum of two other cross-sections in the downstream section of the meter tube (see 5.1.3), similar to the measurements specified in 5.1.2.2.

**5.1.2.4** Meter tube internal diameters are not limited to published nominal inside pipe diameters. All applicable regulations and piping codes shall be followed.

**5.1.2.5** The meter tube temperature to the nearest degree Fahrenheit (0.5 degree Celsius) should be recorded when the internal diameter measurements are made. These measurements shall be made under thermally stable conditions; i.e. during the measurement, temperature should be constant within 5 °F (2.5 °C).

The reference meter tube internal diameter ($D_r$) is defined as the calculated meter tube internal diameter at reference temperature ($T_r$), and can be determined using the following equation:

$$D_r = D_m[1 + \alpha_2(T_r - T_m)] \qquad (2)$$

where

$\alpha_2$ is the linear coefficient of thermal expansion for the meter tube material (see Table 2);

$D_m$ is the meter tube internal diameter measured at temperature ($T_m$);

$D_r$ is the reference meter tube internal diameter calculated at reference temperature ($T_r$);

$T_m$ is the temperature of the meter tube at the time of the diameter measurements;

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

NOTE $\alpha_2$, $T_m$, and $T_r$ have to be in consistent units. For the purpose of this standard, $T_r$ is assumed to be 68 °F (20 °C).

The reference meter tube internal diameter ($D_r$), calculated at reference temperature ($T_r$), is used to calculate the meter tube internal diameter ($D$) at the flowing temperature, as specified in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1.

### 5.1.3 Tolerances and Restrictions

The tolerances for the diameter and the restrictions for the internal surface of the meter tube are specified in 5.1.3.1, 5.1.3.2, and 5.1.3.3.

#### 5.1.3.1 Meter Tube Internal Diameter Roundness Tolerance

##### 5.1.3.1.1 Within the First Mean Meter Tube Diameter ($D_m$) Upstream of the Orifice Plate

The absolute value of the percentage difference between the measured meter tube internal diameter ($D_m$) and any individual diameter measurement within a distance of one meter tube diameter ($D_m$) on the upstream side of the orifice plate shall not exceed 0.25% of $D_m$. The measurement resolution shall be to the nearest thousandth of an inch (0.001 in.) or better.

$$\left| \frac{(\text{Any diameter within one } D_m) - D_m}{D_m} \times 100 \right| \leq 0.25\% \quad (3)$$

An example of this situation is provided in Table 4. All measurements within one meter tube diameter upstream of the orifice plate face are within 0.25 % of the 2.0695 mean.

**Table 4—Example Meter Tube Internal Diameter—Roundness Tolerances Within First Mean Meter Tube Diameter Upstream of Orifice Plate**

Dimensions in inches

| | Meter Tube Internal Diameter Measurements | | | | |
|---|---|---|---|---|---|
| **Position** | **A** | **B** | **C** | **D** | **Mean, $D_m$** |
| 1-in. upstream plate | 2.0696 | 2.0694 | 2.0694 | 2.0696 | 2.0695 |
| Within one $D_m$ | 2.0700 | 2.0676 | 2.0671 | 2.0655 | N/A |
| Percent deviation from mean $D_m$ | 0.024 % | 0.092 % | 0.116 % | 0.193 % | N/A |

##### 5.1.3.1.2 For All Upstream Meter Tube Individual Internal Diameter Measurements, Including Those Within One Meter Tube Diameter Upstream of the Orifice Plate

The percentage difference between the maximum measured individual internal diameter measurement and the minimum measured individual internal diameter measurement of all upstream meter tube individual internal diameter measurements, including those within the first meter tube diameter upstream of the orifice plate, shall not exceed 0.5% of $D_m$:

$$\left| \frac{\text{Maximum diameter} - \text{Minimum diameter}}{D_m} \times 100 \right| \leq 0.5\% \quad (4)$$

An example of this situation is provided in Table 5.

The calculation to verify that the measurements meet the tolerance criterion is as follows:

$$\frac{2.0700 - 2.0655}{2.0695} \times 100 = 0.22\%$$

**Table 5—Example Meter Tube Internal Diameter Roundness Tolerances—
All Upstream Meter Tube Individual Internal Diameter Measurements**

Dimensions in inches

| Position | Meter Tube Internal Diameter Measurements | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | Mean, $D_m$ |
| 1-inch upstream plate | 2.0696 | 2.0694 | 2.0694 | 2.0696 | 2.0695 |
| Within one $D_m$ | 2.0700 | 2.0676 | 2.0671 | 2.0655 | N/A |
| Upstream check measurement | 2.0621 | 2.0620 | 2.0613 | 2.0601 | N/A |

All upstream meter tube individual internal diameter measurements, including those within one meter tube diameter ($D_m$) upstream of the orifice plate are within 0.5 % of $D_m$.

#### 5.1.3.2 Internal Roundness Tolerance for the Downstream Section of Meter Tube

The absolute value of the percentage difference between the measured meter tube diameter ($D_m$) and any individual internal diameter on the downstream side shall not exceed 0.5 % of $D_m$:

$$\left| \frac{(\text{Any downstream diameter}) - D_m}{D_m} \times 100 \right| \leq 0.5\% \tag{5}$$

#### 5.1.3.3 General Meter Tube Restrictions

Abrupt changes of the inside meter tube surface (shoulders, offsets, ridges, welding seams, and the like) shall not exist in meter tubes, with the exception of those allowed in 5.1 and 5.5.

### 5.1.4 Orifice Plate Gasket or Sealing Device Recesses and Protrusions

The orifice plate gasket or sealing device tolerances and restrictions specified in 5.1.4.1 through 5.1.4.5 shall apply at locations immediately upstream and downstream of the orifice plate face.

**5.1.4.1** Protrusions resulting from an orifice plate gasket or sealing device that extend into the pipe bore are not permitted.

**5.1.4.2** A recess resulting from an orifice plate gasket or sealing device, of 0.25 in. or less in length, as measured parallel to the pipe axis, does not require recess depth restriction, diameter ratio ($\beta_r$) limitation, or additional uncertainty.

**5.1.4.3** A recess resulting from an orifice plate gasket or sealing device, of more than 0.25 in. but less than or equal to 0.5 in. in axial length, does not require diameter ratio ($\beta_r$) limitation or additional uncertainty if the depth of the recess is within the limitations of 5.1.3 (0.005 $D_m$).

**5.1.4.4** All orifice plate sealing devices shall be of the same nominal inside pipe diameter (within the limits specified in 5.1.4.1, 5.1.4.2, and 5.1.4.3) as the orifice plate holder in which they are used.

**5.1.4.5** For recesses larger than those described in 5.1.4.2 and 5.1.4.3, additional uncertainty may be required.

## 5.2 Orifice Plate Holders

**5.2.1** Orifice flanges also referred to as Orifice Flange Unions (OFUs) a type of orifice plate holder for orifice meter tube installations should be constructed and attached to the pipe so that all of the mechanical specifications in 5.1.1 and 5.1.4 are met.

Any distortion of the pipe resulting from welding the flange to the pipe shall be removed by machining or grinding to meet the limitations specified in 5.1.3.

**5.2.2** Orifice fittings represent a class of orifice plate holders widely used throughout the industry. With these devices, it is possible to reproduce the orifice coefficients defined by the equation in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1 within the same uncertainty limits as would be found for an orifice plate held between two flanges (the original test devices). To do this, these devices shall be manufactured to the tolerances specified in this standard. With orifice fittings some practical considerations should be recognized; some critical inspections that are unique to these devices should be performed. The following information is based on devices that were commonly known to exist at the time this standard was developed and may not cover innovations that have become commonly known since its publication. Such innovations may be deemed to be in accordance with this standard as long as they meet all tolerances contained herein.

## 5.3 Orifice Fittings Considerations

### 5.3.1 Attachment to Pipe

When an upstream flanged orifice fitting is used, the mean inside diameter of the meter tube connected to the inlet side shall agree with the mean inside diameter of the fitting within the tolerance given in 5.1.3. When the fitting is installed, the inlet side should be connected to the upstream section of the meter tube first, and carefully centered; no sharp edges at this junction are allowed.

To prevent misalignment at this joint when a flanged connection has been used, two diametrically opposed bolt holes may be reamed and snug-fitting bolts installed, or dowel pins may be used. Other alignment methods may be used as long as the same result is obtained.

When the upstream section of the meter tube is attached to the orifice-fitting body by welding (preferred method), any distortion of the pipe resulting from the welding shall be removed by machining or grinding to meet the requirements of 5.1.3.

### 5.3.2 Inspection Considerations

In some instances, the inspection of an orifice fitting may not be as easy as the inspection of a conventional flanged orifice meter. This is true when the fitting in question is of the weld neck design and has already been connected to the meter tube. Unless the meter tube is of a large size, it may be difficult to make measurements in the vicinity of the orifice plate. To make this inspection easier, the fitting should have at least one flanged side (preferably the downstream side). The user should refer to the relevant pressure vessel and pipeline codes to determine whether this particular design may be used in a given system. All measurements of mechanical tolerances should be made after the fitting has been pressure-tested at the maximum required test pressure.

### 5.3.3 Bypass Checks

In orifice fittings, there is the possibility that some fluid may bypass the orifice plate. Tests shall be conducted after the meter run has been pressure-tested in accordance with the relevant code to ensure the following:

a) no differential pressure tap communication or leakage exists;

b) no holding or sealing device fluid bypass exists.

## 5.4 Pressure Taps

### 5.4.1 Flange Taps

#### 5.4.1.1 General

Meter tubes using flange taps shall have the center of the upstream pressure tap hole placed 1 in. from the upstream face of the orifice plate. The center of the downstream pressure tap hole shall be 1 in. from the downstream face of the orifice plate. Each tap hole shall be located at the 1-in. dimension within the tolerances shown in Figure 3. It is recommended that the maximum diameter ratio ($\beta$) of 0.75 allowable pressure tap hole location variation be used in the design of installations. For more information see Annex F.9, found in the 2000 version of this document.

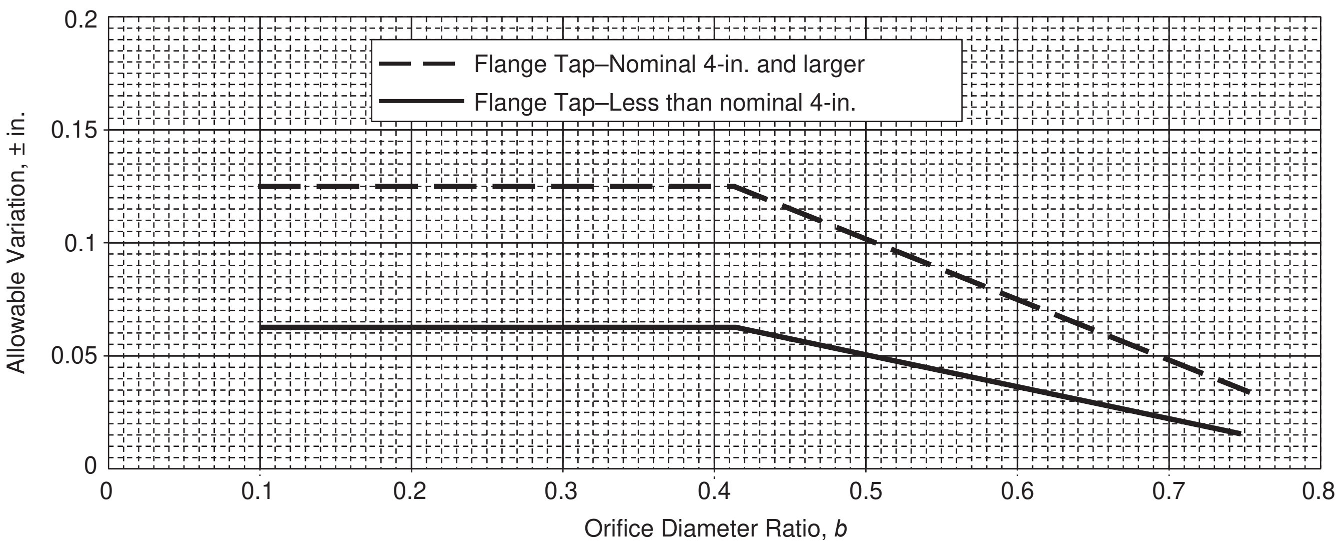



**Figure 3—Allowable Variations in Pressure Tap Hole Location**

Orifice fittings may require different methods of confirming pressure tap hole location than orifice flanges.

Under no circumstances should there be any flow through or out of the flange tap or taps for purposes other than measuring static and/or differential pressure. This includes flows resulting from manufacturing defects that allow for tap communication or the use of the flange taps as a source of fluid for other instruments. For the latter, other taps located outside of the designated meter tube dimensions should be used.

The sharing of metering taps by multiple differential pressure devices may cause increased uncertainty and/or operational problems. If possible, such a practice should be avoided.

#### 5.4.1.2 Orifice Fittings

When an orifice fitting is used, pressure tap hole measurements may be taken prior to final fabrication of the meter tube, especially when a fitting is to be welded to one end of the piping that will become an integral part of the completed meter tube. These measurements may be accomplished by using commercially available micrometers and gauges. Other technically valid techniques for verifying the pressure tap hole location are acceptable.

In orifice fittings, the orifice plate is held in place by a carrier mechanism that is intended to correctly position the orifice plate relative to the pressure tap holes. The plate/carrier combination used during pressure tap hole location testing should be of the same type (design) as will be employed in practice. If the internal mechanism of an orifice fitting is replaced, the inspection should be repeated.

For flange-tapped orifice fittings, the location of the flange tap relative to the faces of the orifice plate shall be maintained. The use of either thicker or thinner plates than specified by the original design, is allowed when the thickness is within the maximum and minimum range shown in Table 3, and differential pressure tap hole tolerances and limits as specified in Figure 3 are satisfied, or the fitting has been redrilled. Likewise, the seals or other orifice holding devices should not affect the location of the plate relative to the taps. Seal/plate combinations should be checked to ensure that the tolerance on the location of the flange taps is not exceeded.

#### 5.4.1.3 Orifice Flanges (OFU)

When orifice flanges or OFUs are used, the pressure tap hole placement may be determined by measuring from the face of the flange to the pressure tap hole center. Allowance shall be made for the thickness and compression of gaskets, o-rings, or other plate-sealing mechanisms when the orifice plate is pressed between the two flanges.

### 5.4.2 Pressure Tap Drilling

Pressure tap holes shall be drilled radially to the meter tube; i.e. the centerline of the tap hole shall intersect and form a right angle with the axis of the meter tube.

### 5.4.3 Pressure Tap Diameter

The diameter of the pressure tap holes at the inner surface of the meter tube and along the drilled length of the holes shall be $^{3}/_{8}$ (0.375) in. ± $^{1}/_{64}$ (0.016) in., providing for a maximum diameter of 0.391 in. and a minimum of 0.359 in. for pipe with a nominal diameter of 2 in. or 3 in.; and shall be $^{1}/_{2}$ (0.5) in. ± $^{1}/_{64}$ (0.016) in., providing for a maximum diameter of 0.516 in. and a minimum of 0.484 in. for pipe with a nominal diameter of 4 in. or more.

The pressure tap holes in the orifice plate holder may be drilled out and prepared to receive the desired size of pressure-sensing line connection. The pressure tap hole edge shall be sharp and square.

The diameter of the tap hole shall not be reduced within a length equal to 2.5 times the tap hole diameter, as measured from the inside surface of the meter tube. Reduction of the tap hole diameter while in service, due to the collection of liquids and/or particulate contamination, is unacceptable.

All pressure tap holes shall be round to a tolerance of ± 0.004 in. throughout their length.

Similarly, the inside diameter of the gauge line should remain constant up to the differential pressure sensor and/or manifold.

To avoid any resonance in the gauge line, the length of the gauge line should be as short as possible or should have lengths ($l$) specified according to the highest frequency ($f$) of concern from one of the following formulas.

The length of the gauge line should be as short as possible. To avoid any resonance in the gauge line, for gauge line lengths that exceed the criteria given in Equation 6, lengths ($l$) specified according to the highest frequency ($f$) of concern as specified in Equation 7 through Equation 10 will avoid resonance. For other lengths, testing may be required if gauge line resonance is suspected or anticipated.

$$0 \le l_1 \le 0.25c / (2\pi f) \tag{6}$$

$$l_2 = 2.5c / (2\pi f) \tag{7}$$

$$l_3 = 5.5c / (2\pi f) \tag{8}$$

$$l_4 = 8.5c / (2\pi f) \tag{9}$$

$$l_5 = 11.5c / (2\pi f) \tag{10}$$

where

$c$ is the speed of sound in the flowing fluid at operating conditions;

$f$ is the frequency of pulsation levels;

$\pi$ is the mathematical constant = 3.14159.

The length of the gauge line determined from any of these formulas will ensure that no resonance and/or amplification of pressure pulsation exist in the gauge line. Both gauge lines should be of equal length and have no sudden changes in the internal diameter, especially for low-pressure applications. In some cases, direct-mount manifolds may reduce the effects of pulsation.

See 6.4 for acceptable pulsation environment.

### 5.4.4 Pressure Tap Edges

The edges of the pressure tap holes on the inner surface of the meter tube shall be free from burrs and may be slightly rounded.

## 5.5 Flow Conditioners

### 5.5.1 General

Flow conditioners can be classified into two categories: flow straighteners or flow conditioners.

Flow straighteners are devices that effectively remove or reduce the swirl component of a flowing stream, but may have limited ability to correct a non-fully developed flow profile and produce the flow conditions necessary to accurately replicate the orifice plate coefficient of discharge database values. Flow straighteners should be installed in accordance to Table 8a or Table 8b.

Flow conditioners, which have successfully completed the recommended performance test protocol Annex D, are devices that effectively remove the swirl component from the flowing stream while redistributing the stream to produce a pseudo fully developed flow profile and the flow conditions that accurately replicate the orifice plate coefficient of discharge database values.

It is not the intent of this standard to recommend any particular type of flow conditioner. In an effort to eliminate or reduce the potential for flow measurement bias in existing installations and to provide guidance for improved measurement accuracy in new installations, this standard provides installation recommendation for the 19-tube uniform concentric tube bundle flow straighteners cited in the installation effects research. Due to the significant (outside the designated uncertainty band) coefficient of discharge differences experienced from variations in straightening vane tube bundle construction, only those tube bundle flow straighteners meeting the following criteria are specified to produce “no additional uncertainty” when installed as recommended. All other tube bundles should be considered as “other” flow conditioners.

### 5.5.2 Description of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener

It is necessary for all the tubes, or thin wall pipe, to be of uniform smoothness, outer diameter, and wall thickness and to be arranged in a cylindrical pattern as in Figure 4. The individual tube outer walls shall come in direct contact with each other; they may not be spaced or gapped. To reduce the swirl that can occur between the exterior tubes of the tube bundle flow straightener and the wall of the meter tube, tube outer-diameter sizing shall be based on the resulting tube bundle flow-straightener outside diameter ($OD$) being at maximum equal to $D_i$ and at minimum equal to $0.95D_i$. The length ($LTB$) of the vanes shall be 3 × NPS for NPS of 2 in.; 2.5 × NPS for 2 < NPS ≤ 4 in.; and 2 × NPS for NPS greater than 4 in.

### 5.5.3 Tubing of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener

The individual tube wall thickness of the 1998 Uniform Concentric 19-Tube Bundle Straightener shall be less than or equal to 2.5 % of the $D_i$. All tubes shall be parallel, with an internal chamfer on both ends not less than 50 % of wall thickness by 45 degrees, and shall be mounted axially with the pipe.

### 5.5.4 Fabrication of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener

The 1998 Uniform Concentric 19-Tube Bundle Straighteners shall be sturdily fabricated. Individual tubes should be welded together at the points of tangency at both ends of the tube bundle with welds at each point not exceeding more than 20 degrees around the tube circumference. For tube bundles of 4 in. NPS or less, the F areas (see Figure 4) may be filled with weld. Centering spacers may be provided on the outside of the assembly to assist the installer in centering the device in the meter tube. After being inserted in the meter tube, the tube bundle shall be securely fastened in place, with either a mounting flange or a pinning arrangement, to prevent the device from vibrating or from being dislodged and pushed downstream against the orifice plate. Secure fastening should not distort the tube bundle assembly with respect to symmetry within the meter tube.

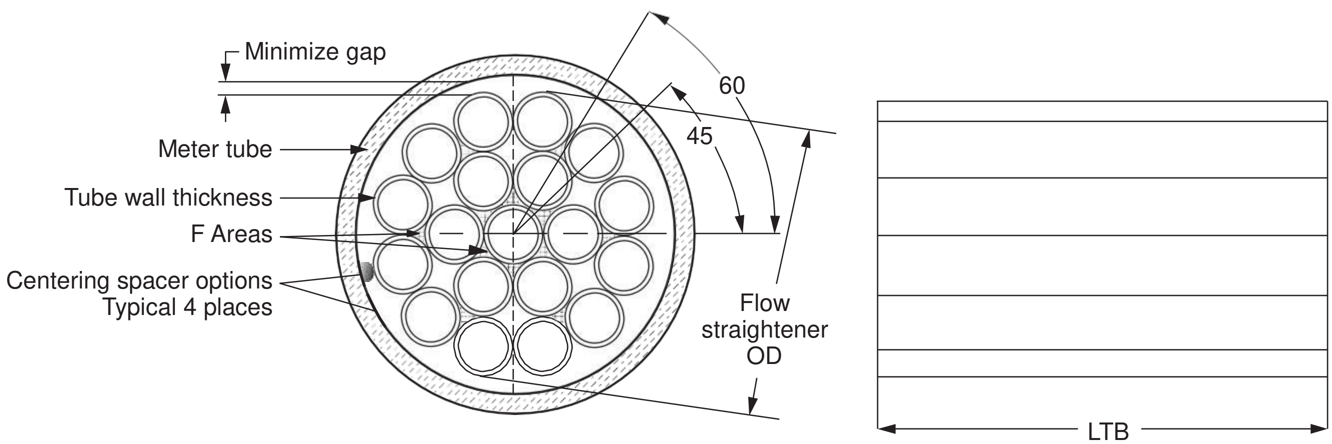



**Figure 4—1998 Uniform Concentric 19-Tube Bundle Flow Straightener**

### 5.5.5 Other Flow Conditioners

Specifications for the description, installation, or uncertainty of other flow conditioners are not presented in this standard.

Flow straighteners not conforming with the description given in 5.5.2, 5.5.3, and 5.5.4 are to be considered as "Other Flow Conditioners" and the installation requirements of Table 8a and Table 8b may not be applicable.

The use of other types of flow conditioners should be based on technical performance data obtained from the performance test(s). This standard provides a uniform criterion for evaluation of installation and/or flow conditioner performance (perturbation) test or tests. This test(s) is required by the standard to confirm the performance level that can be achieved by an orifice meter installation using a flow conditioner. (See Annex C and Annex D for details.) The performance test(s) will confirm the orifice meter diameter ratio ($\beta$) meter tube length, and flow conditioner location for which acceptable performance is obtainable.

#### 5.5.5.1 Performance Criteria

The performance criteria selected [$\triangle C_d$ $(FT)$] are the same ones used to measure the installation influences in meter tubes without flow conditioners and with the 19-tube uniform cylindrical tube bundle flow straightener. The deviation

[$\triangle C_d$ $(FT)$] of the values of the discharge coefficient from reference values determined from separate “baseline” calibrations with the same orifice plates should be used as the measure of the flow conditioner’s performance.

Acceptable performance levels constituting no need for additional measurement uncertainty are defined as $\triangle C_d$ variation equal to or less than 50 % of the stated 2σ uncertainty in the Reader-Harris/Gallagher orifice equation at infinite Reynolds number (see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 12.4).

#### 5.5.5.2 Required Elements of the Installation Performance Test

The types of flow conditions and installation disturbances that form the basis for the installation performance test(s) are as follows.

a) *Good flow conditions.* If a meter tube, with or without a flow conditioner, is installed in a piping configuration in which the axial velocity profile is close to ideal (as produced by 75 or more published inside pipe diameters [$D_i$] of straight pipe), and the amount of swirl is low (less than 2 degree of swirl angle), then the flow conditioner should not introduce a perturbation that causes a significant deviation from the baseline calibration.

b) *Two adjoining (close coupled) out-of-plane 90-degree elbows installed directly upstream of the meter tube.* This configuration is known to produce a swirl velocity component, as well as alter the shape of the axial velocity profile. Swirl angles of up to ± 15 degrees have been measured directly downstream of the second elbow.

c) *A 50 % closed valve installed upstream of, and in line with, the meter tube*. When the valve is a gate or ball valve, this configuration can produce a strongly asymmetric axial velocity profile downstream of the valve.

d) *High swirl*. This test generates a high swirl flow condition that is representative of the flow field downstream of installations such as headers. Research on the effect of a header upstream of a meter tube has shown that swirl angles of up to ± 30 degrees can be measured in the meter tube; and that a header may also cause the axial velocity profile to be asymmetric.

The detailed conditions of the performance test protocol can be found in Annex D.

# 6 Installation Requirements

## 6.1 General

The orifice plate coefficients of discharge [$C_d$ $(FT)$] given in this standard are based on the results of many experiments conducted in the United States and Europe. In all cases, normal flow conditions were obtained by the use of long straight lengths of meter tube, both upstream and downstream from the orifice, or by the use of flow conditioners upstream from the orifice meter (see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 12.4.3). To obtain the uncertainty specified on the coefficient of discharge presented in API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, similar fluid dynamic conditions have to be attained in practice.

## 6.2 Orifice Plate

### 6.2.1 Eccentricity (ε)

The orifice plate bore shall be concentric with both the upstream and the downstream inside bore of the orifice plate holder. Any eccentricity shall be within the following tolerances.

a) *Eccentricity parallel to the axis of the differential pressure taps* ($\varepsilon_x$). For any eccentricity in the x-y plane shown in Figure 5, the component of orifice plate bore eccentricity parallel to the axis of the differential pressure taps, shall be less than or equal to the tolerance defined by the following equation:

$$\varepsilon_x \leq \frac{0.0025 D_m}{0.1 + 2.3\beta_m^4} \tag{11}$$

where

$\varepsilon_x$ is the measurement (X – X')/2 as shown in Figure 5.

Table 6 shows some maximum allowable values of the eccentricity, $\varepsilon_x$.

b) *Eccentricity perpendicular to the axis of the differential pressure taps* ($\varepsilon_y$). For any eccentricity in the x–y plane shown in Figure 5, the component of orifice plate bore eccentricity perpendicular to the axis of the differential pressure taps—measurement (Y – Y')/2 in Figure 5—may be four times the amount calculated using Equation (11).

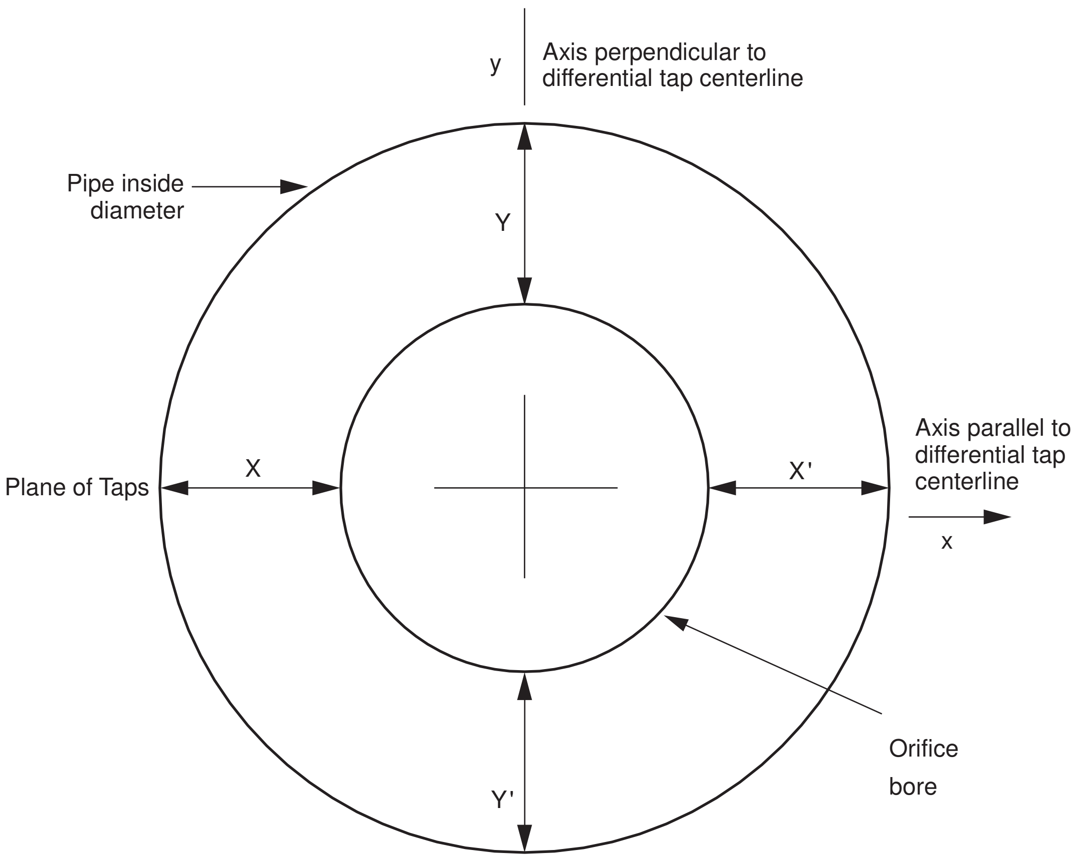



**Figure 5—Eccentricity Measurements (Sample Method)**

The maximum allowable orifice plate bore eccentricity calculated using Equation (11) can be doubled if flange taps 180 degrees apart are connected together to obtain an average pressure. Care should be taken to ensure that equal lengths of tubing of equal diameter (with the nominal diameter being greater than or equal to the tap diameter) are used to connect the taps, and that the connection to the differential pressure ($\Delta P$) device is located midway between the taps. This approach is not recommended if there are concerns about pulsating or fluctuating flow.

When measurement of the eccentricity of an orifice plate installed in orifice flanges or OFUs is not possible, two accurately located alignment pins should be used to support and center the orifice plate while the bolts are tightened. The eccentricity relative to the upstream side is considered the most critical.

**Table 6—Maximum Tolerance of Orifice Plate Bore Eccentricity ($\varepsilon_x$)**

Dimensions in inches

| $\beta_m$ | Meter Tube Inside Diameter | | | | | |
|---|---|---|---|---|---|---|
| | **2.067** | **3.068** | **4.026** | **6.065** | **7.981** | **10.020** |
| 0.20 | 0.050 | 0.074 | 0.097 | 0.146 | 0.192 | 0.242 |
| 0.25 | 0.047 | 0.070 | 0.092 | 0.139 | 0.183 | 0.230 |
| 0.30 | 0.044 | 0.065 | 0.085 | 0.128 | 0.168 | 0.211 |
| 0.35 | 0.038 | 0.057 | 0.075 | 0.113 | 0.148 | 0.186 |
| 0.40 | 0.033 | 0.048 | 0.063 | 0.095 | 0.126 | 0.158 |
| 0.45 | 0.027 | 0.039 | 0.052 | 0.078 | 0.103 | 0.129 |
| 0.50 | 0.021 | 0.032 | 0.041 | 0.062 | 0.082 | 0.103 |
| 0.55 | 0.017 | 0.025 | 0.032 | 0.049 | 0.064 | 0.081 |
| 0.60 | 0.013 | 0.019 | 0.025 | 0.038 | 0.050 | 0.063 |
| 0.65 | 0.010 | 0.015 | 0.020 | 0.030 | 0.039 | 0.049 |
| 0.70 | 0.008 | 0.012 | 0.015 | 0.023 | 0.030 | 0.038 |
| 0.75 | 0.006 | 0.009 | 0.012 | 0.018 | 0.024 | 0.030 |

It is recommended that any alignment pins or other devices used to position the orifice plate be mounted so that the plate is centered relative to the upstream section of the meter tube and pressure tap.

Plate-centering techniques are a function of the design and are only constrained by the maximum allowable eccentricity described above. In most orifice fittings, the orifice plate is held in the flowing stream by a carrier mechanism. Such mechanisms theoretically produce a repeatable eccentricity for the orifice plate; this should be checked for several operations of installing the plate in, and removing it from, the orifice fitting. The carrier used to perform this test shall be the carrier used in the field. If any of the fitting's internal mechanisms are replaced, this inspection should be repeated. It is recommended during factory acceptance testing that for dual-chamber fittings, sizes 2 in. through 8 in. the eccentricity test should be performed in both the horizontal and vertical orientation of the fitting.

#### 6.2.2 Perpendicularity

The orifice plate holder should maintain the plane of the orifice plate at an angle of 90 degrees to the meter tube axis.

## 6.3 Meter Tube

#### 6.3.1 Length

To ensure accurate flow measurement, the fluid should enter the orifice plate with a fully developed, swirl-free flow profile. Such a condition is best achieved through the use of flow conditioners and associated pipe lengths or adequate lengths of straight pipe upstream and downstream from the orifice plate. Any serious distortion of the average (time mean) flow profile or significantly increased flow pulsation level will produce flow measurement errors. Obviously, the best means of eliminating uncertainty or bias due to pulsation is to eliminate it at the source. For further discussion, see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 12.4.3, pulsation reduction measures (see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 7.5) and operation of the orifice meter within flow pulsation limits (see 6.4).

In many piping configurations, the orifice meter may not produce results within the uncertainty of this standard. Some of the more common types of piping installations have been studied with regard to their effect on metering accuracy. Table 7, Table 8a and Table 8b provide the required lengths of meter tube and the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener locations for the installations studied.

For applications that are not explicitly addressed in the installation Table 7, Table 8a, and Table 8b, the required lengths and the 1998 Uniform Concentric 19-Tube Bundle Straightener locations of the “any other configuration” classification from Table 7, Table 8a, and Table 8b should be followed. This includes multiple fittings upstream of the orifice plate where the distance between the fittings is $22D_i$ or less. The majority of the installations were tested so that the upstream piping resulted in a fully developed flow at the inlet to the installation by using a combination of flow conditioners and straight pipe. In some tests, it was found that the interaction between two fittings was negligible if the spacing between the two was greater than $22D_i$, thus suggesting that the flow profile is similar to a fully developed flow. If the characteristics of the inlet profile deviates from that specified above, the specified meter run lengths may be inadequate for optimal orifice-meter performance.

Generally, meter run lengths for installations with or without flow straighteners are not sensitive to variations of Reynolds numbers and roughness within the specified limits in the standard. Exceptions for the case without flow conditioners are two 90 degree elbows in perpendicular planes, separated by a spacer less than or equal to $5D_i$, or any other installation generating swirl such as headers, eccentric expanders, and expanders in combination with elbows. The latter installations fall under the category of “any other configuration” in Table 7.

### 6.3.2 Installation Tables

Installation Table 7 provides the required minimum installation lengths for meter tubes without flow conditioners.

Installation Table 7 indicates that, for meter tubes without flow conditioners, the recommended upstream meter-tube length varies with the diameter ratio ($\beta_r$); and longer lengths of upstream meter tube are required for the higher diameter ratios ($\beta_r$). When the diameter of the orifice bore requires changing to meet different flowing conditions, the recommended length of the installed meter tube should be determined for the maximum diameter ratio ($\beta_r$) that may be used. The design criteria for new installations should be the lengths quoted for diameter ratios ($\beta_r$) equal to 0.75. Upstream meter tubes longer than those shown in Table 7 are desirable.

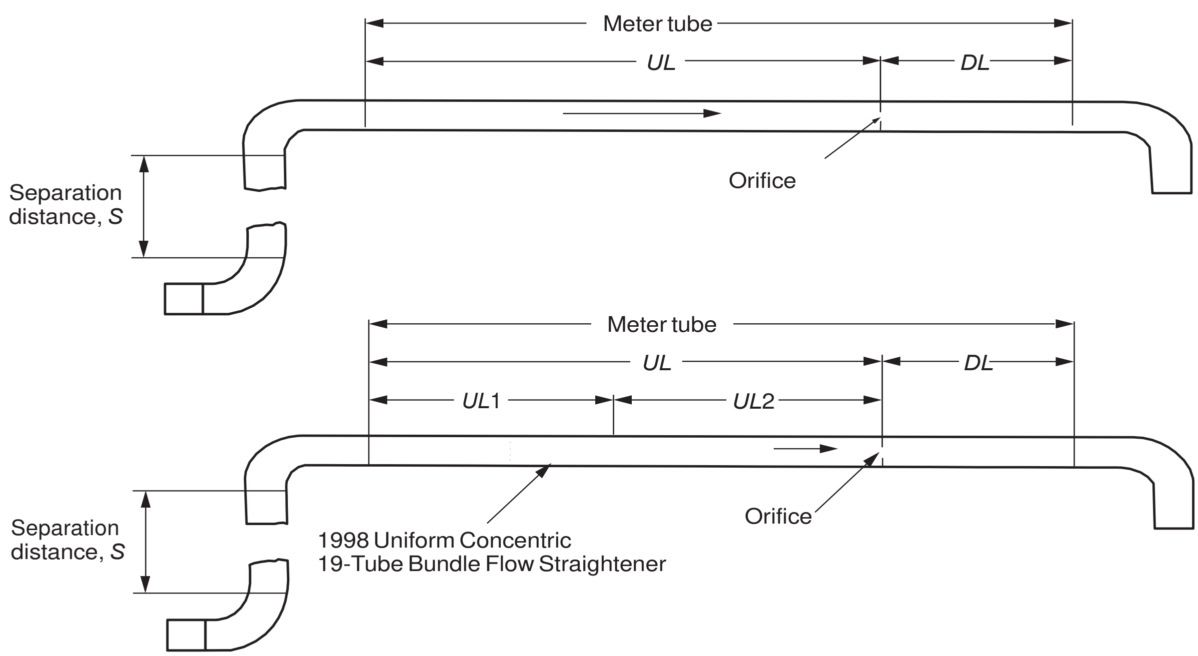



**Figure 6—Orifice Meter Tube Layout for Flanged or Welded Inlet**

Installation Tables 8a and 8b provide the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener allowable location range and the recommended location for two upstream meter-tube length categories, $17D_i \leq UL < 29D_i$, and $UL \geq 29D_i$. The standard does not address upstream meter-tube lengths of less than $17D_i$.

Those installations and/or flow conditioners not explicitly addressed in Table 7, Table 8a, and Table 8b may be flow-tested either in situ or by a flow-testing laboratory with an established base line within the RG coefficient of discharge uncertainty (see Annex C). The flow testing should be performed with calibration devices and methods conforming to nationally and/or internationally approved standard(s). All instruments used to monitor the flow parameters, and/or to calculate the flow rate, shall be traceable to the local, state, or national certifying organization of weights and measures. The primary flow system may be portable or permanently installed. A master meter that has been calibrated with a primary flow standard can also be used for the flow testing. Both the master meter and the proving system shall meet appropriate nationally recognized standards.

NOTE If the flow testing is to be conducted in a flow-testing laboratory, the installation tested should consist of the meter tube or meter station with manifold and appropriate upstream piping configuration, as is necessary to define the flow signature (velocity profile and swirl) entering the meter tube or meter station.

The flow testing should be performed over the normal range of Reynolds numbers experienced during every-day operation. Acceptable performance levels constituting no need for additional measurement uncertainty are defined as $\Delta C_d$ variation equal to or less than 50 % of the stated $2\sigma$ uncertainty in the Reader-Harris/Gallagher orifice equation at infinite Reynolds number (see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 12.4; and API *MPMS* Ch.14.3.2/AGA Report No. 3, Part 2, Annex C).

**Table 7—Orifice Meter Installation Requirements Without a Flow Conditioner**

| Diameter ratio $\beta$ | Minimum Straight Unobstructed Meter Tube Length from the Upstream Side of the Orifice Plate (in multiples of published internal pipe diameter, $D_i$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | a. Single 90° elbow<br>b. Two 90° elbows in the same plane with $S > 30D_i$<br>c. Two 90° elbows in perpendicular planes with $S > 15D_i$ | Two 90° elbows in the same plane "$S$" configuration spacer $S \le 10D_i$ | Two 90° elbows in the same plane, "$S$" configuration $10D_i < S \le 30D_i$ | Two 90° elbows in perpendicular planes, $S < 5D_i$ * | Two 90° elbows in perpendicular planes, $5D_i \le S \le 15D_i$ | Single 90° Tee used as an elbow but not as a header element | a. Single 45° elbow<br>b. Two 45° elbows in the same plane "$S$" configuration $S \ge 22D_i$ | Gate valve at least 50 % open | Concentric reducer | Any other configuration (catch all category) * | Downstream meter tube length |
| | *UL* | *UL* | *UL* | *UL* | *UL* | *UL* | *UL* | *UL* | *UL* | *UL* | *DL* |
| ≤ 0.20 | 6 | 10 | 10 | 50 | 19 | 9 | 30 | 17 | 6 | 70 | 2.8 |
| 0.30 | 11 | 10 | 12 | 50 | 32 | 9 | 30 | 19 | 6 | 108 | 3.0 |
| 0.40 | 16 | 10 | 13 | 50 | 44 | 9 | 30 | 21 | 6 | 145 | 3.2 |
| 0.50 | 30 | 30 | 18 | 95 | 44 | 19 | 30 | 25 | 7 | 145 | 3.5 |
| 0.60 | 44 | 44 | 30 | 95 | 44 | 29 | 30 | 30 | 9 | 145 | 3.9 |
| 0.67 | 44 | 44 | 44 | 95 | 44 | 36 | 44 | 35 | 11 | 145 | 4.2 |
| 0.75 | 44 | 44 | 44 | 95 | 44 | 44 | 44 | 44 | 13 | 145 | 4.5 |
| Recommended length for maximum range $\beta \ge 0.75$ | 44 | 44 | 44 | 95 | 44 | 44 | 44 | 44 | 13 | 145 | 4.5 |

NOTE The tolerance on specified lengths for *UL* and *DL* is ± $0.25D_i$.

*UL* = Minimum meter tube length upstream of the orifice plate in internal pipe diameter ($D_i$) (see Figure 6). Straight length shall be measured from the downstream end of the curved portion of the nearest (or only) elbow or of the tee or the downstream end of the conical portion of reducer or expander.

*DL* = Minimum downstream meter tube length in internal pipe diameters ($D_i$) (see Figure 6).

*S* = Separation distance between piping elements in internal pipe diameter ($D_i$) measured from the downstream end of the curved portion of the upstream elbow to the upstream end of the curved portion of the downstream elbow.

* These installations exhibit the strong effect of Reynolds number and pipe roughness on the recommended length due to the rate of swirl decay. The present recommendations have been developed for high Reynolds numbers and smooth pipes to capture the worst case.

**Table 8a—Orifice Meter Installation Requirements With 1998 Uniform Concentric 19-Tube Bundle Flow Straightener for Meter Tube Upstream Length of $17D_i \leq UL < 29D_i$**

| Diameter Ratio, $\beta$ | Single 90° elbow $R/D_i$ = 1.5 | Two 90° elbows out of plane $S \leq 2D_i$ $R/D_i$ = 1.5 | Single 90° tee used as an elbow but not as a header element | Partially closed valves (at least 50 % open) | High swirl combined with single 90° Tee | Any fitting (catch-all category) | Downstream meter tube length |
|---|---|---|---|---|---|---|---|
| | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *DL* |
| 0.10 | 5 to 14.5 | 5 to 14.5 | 5 to 14.5 | 5 to 11 | 5 to 13 | 5 to 11.5 | 2.8 |
| 0.20 | 5 to 14.5 | 5 to 14.5 | 5 to 14.5 | 5 to 11 | 5 to 13 | 5 to 11.5 | 2.8 |
| 0.30 | 5 to 14.5 | 5 to 14.5 | 5 to 14.5 | 5 to 11 | 5 to 13 | 5 to 11.5 | 3.0 |
| 0.40 | 5 to 14.5 | 5 to 14.5 | 5 to 14.5 | 5 to 11 | 5 to 13 | 5 to 11.5 | 3.2 |
| 0.50 | 11.5 to 14.5 | 9.5 to 14.5 | 11 to 13 | b | 11 to 13 | c | 3.5 |
| 0.60 | 12 to 13 | 13.5 to 14.5 | a | Not allowed | a | Not allowed | 3.9 |
| 0.67 | 13 | 13 to 14.5 | Not allowed | Not allowed | Not allowed | Not allowed | 4.2 |
| 0.75 | 14 | Not allowed | Not allowed | Not allowed | Not allowed | Not allowed | 4.5 |
| Recommended tube bundle location for maximum range of $\beta$ | 13<br>$\beta \leq 0.67$ | 13.5 to 14.5<br>$\beta \leq 0.67$ | 13<br>$\beta \leq 0.54$ | 9.5<br>$\beta \leq 0.47$ | 13<br>$\beta \leq 0.54$ | 9.5<br>$\beta \leq 0.46$ | 4.5 |

NOTE 1 Lengths shown under the *UL*2 column are the dimensions shown in Figure 6, expressed as the number of published internal pipe diameters ($D_i$) between the downstream end of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener and the upstream surface of the orifice plate.

NOTE 2 The tolerance on specified lengths for *UL*, *UL*2, and *DL* is ± $0.25D_i$.

NOTE 3 *Not allowed* means that it is not possible to find an acceptable location for the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener downstream of the particular fitting for all values of *UL*.

$S$ = Separation distance between elbows, measured as defined in Table 7.

$UL1 = UL - UL2$ (see Figure 6).

a $13D_i$ allowed for up to β = 0.54.

b $9.5D_i$ allowed for up to β = 0.47.

c $9.5D_i$ allowed for up to β = 0.46.

**Table 8b—Orifice Meter Installation Requirements With 1998 Uniform Concentric 19-Tube Bundle Flow Straightener for Meter Tube Upstream Length of UL ≥ 29$D_i$**

| Diameter Ratio, $\beta$ | Single 90° elbow $R/D_i$ = 1.5 | Two 90° elbows out of plane $S \le 2D_i$ $R/D_i$ = 1.5 | Single 90° tee used as an elbow but not as a header element | Partially closed valves (at least 50 % open) | High swirl combined with single 90° Tee | Any fitting (catch-all category) | Downstream meter tube length |
|---|---|---|---|---|---|---|---|
| | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *UL*2 | *DL* |
| 0.10 | 5 to 25 | 5 to 25 | 5 to 25 | 5 to 13 | 5 to 23 | 5 to 13 | 2.8 |
| 0.20 | 5 to 25 | 5 to 25 | 5 to 25 | 5 to 13 | 5 to 23 | 5 to 13 | 2.8 |
| 0.30 | 5 to 25 | 5 to 25 | 5 to 25 | 5 to 13 | 5 to 23 | 5 to 13 | 3.0 |
| 0.40 | 5 to 25 | 5 to 25 | 5 to 25 | 5 to 13 | 5 to 23 | 5 to 13 | 3.2 |
| 0.50 | 11.5 to 25 | 9 to 25 | 9 to 23 | 7.5 to 15 | 9 to 19.5 | 11.5 to 14.5 | 3.5 |
| 0.60 | 12 to 25 | 9 to 25 | 11 to 16 | 10 to 17 | 11 to 16 | 12 to 16 | 3.9 |
| 0.67 | 13 to 16.5 | 10 to 16 | 11 to 13 | 10 to 13 | 11 to 13 | 13 | 4.2 |
| 0.75 | 14 to 16.5 | 12 to 12.5 | 12 to 14 | 11 to 12.5 | 14 | Not allowed | 4.5 |
| Recommended tube bundle location for maximum range of $\beta$ | 13 $\beta \le 0.75$ | 12 to 12.5 $\beta \le 0.75$ | 12 to 13 $\beta \le 0.75$ | 11 to 12.5 $\beta \le 0.75$ | 13 $\beta \le 0.75$ | 13 $\beta \le 0.67$ | 4.5 |

NOTE 1 Lengths shown under the *UL*2 column are the dimensions shown in Figure 6 and as defined in Table 8a.

NOTE 2 The tolerance on specified lengths for *UL*, *UL*2, and *DL* is ± 0.25$D_i$.

NOTE 3 *Not allowed* means that it is not possible to find an acceptable location for the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener downstream of the particular fitting for all values of *UL*.

*S* = Separation distance between elbows, measured as defined in Table 7.

*UL*1 = *UL* – *UL*2 (see Figure 6).

### 6.3.3 Requirements for Flow Conditioners

To provide the most comprehensive installation options possible, this standard does not propose to recommend any particular flow conditioner. Rather, the standard provides sufficient installation information to reduce or eliminate any systematic biases resulting from installation considerations. This standard provides minimum required meter tube lengths for meter tubes without flow conditioners. It also provides location ranges and recommended locations for two meter tube length categories ($17D_i \leq UL < 29D_i$ and $UL \geq 29D_i$) for 1998 Uniform Concentric 19-Tube Bundle Flow Straighteners, which meet the construction criteria stipulated in 5.5.2 through 5.5.4. In addition, the standard provides a performance test by which flow conditioners, other flow straighteners, meter tubes without flow conditioners, and meter tube installations can be evaluated against the “no additional” uncertainty requirement. For further information, refer to Annex C and Annex D.

In determining whether or not flow conditioners are required, the governing factor may not always be the nearest piping fitting at the inlet end of the meter tube. For example, the last piping fitting or fittings may give no indication of the presence of swirling flow or degree of velocity profile asymmetry. Each individual station design may have a different set of conditions. It would be impractical to set up specifications that would suit all conditions. The main consideration should be to minimize flow disturbance at the orifice plate from any upstream piping fittings.

The proper installation of flow conditioners may considerably reduce the amount of straight pipe required upstream of an orifice plate. The purpose of the flow conditioner is to reduce or eliminate the effect on the flow measurement of velocity profile asymmetry and/or swirl resulting from the pipe fittings and valves upstream of the meter tube. When flow conditioners are installed, they should be kept clean and free from debris, which may collect against the upstream end.

No flow conditioner can eliminate all possible profile effects unless properly installed and used. Care should be taken to minimize flow disturbances and swirl-generating configurations in the metering system, particularly upstream of the orifice. Thus, when properly located, in properly designed installations, a flow conditioner or 1998 Uniform Concentric 19-Tube Bundle Flow Straightener can eliminate bias in orifice measurement. For further information on proper installation of this flow straightener, refer to Table 8a and Table 8b.

## 6.4 Acceptable Pulsation Environment

Accurate measurement of flow with an orifice meter operating under pulsating flow conditions can be ensured only when the root mean square (rms) of the fluctuating differential pressure amplitude normalized over differential pressure time mean does not exceed 10 %.

$$\Delta P_{rms} / \Delta P_{avg} \leq 0.10 \tag{12}$$

This limit applies to single frequency flow pulsations with or without several harmonics (e.g. generated by reciprocating compressor or closed relief/blowdown valves) and to broad-band flow pulsations/noise (e.g. generated by throttling valves). Random turbulent pulsations generated by orifice plates in normal pipe flow do not cause additional measurement errors because these effects have been accounted for in the coefficient of discharge regression database (see API *MPMS* Ch.14.3.1/AGA Report No. 3, Part 1, Paragraph 7.1).

The specification for allowable flow pulsation level does not mean that a higher level of normalized pulsations will lead to flow measurement error, although there is no assurance that it will not happen.

Currently, no satisfactory theoretical or empirical adjustment for orifice measurement in pulsating flow applications exists that, when applied to custody transfer measurement, will maintain the measurement accuracy predicted by this standard. Arbitrary application of any correcting formula may even increase the flow measurement error under pulsating flow conditions. The user should make every practical effort to eliminate pulsations at the source to avoid increased uncertainty in measurements.

## 6.5 Thermometer Wells

Thermometer wells (thermowells) should be located to sense the temperature of the fluid at the orifice plate. The thermowells shall be placed on the downstream side of the orifice and neither closer to the plate than dimension $DL$ nor farther than $4DL$, as shown in Table 7, Table 8a, and Table 8b.

Thermowells exposed to the influences of the ambient environment may result in biased measurement.

Care should be taken to ensure that the temperature sensor indicates the flowing fluid temperature and is not thermally coupled to the meter run pipe.

Consideration should be given to insulating or thermally isolating adequate sections of the meter run upstream and downstream of the thermowell location to insure the indicated temperature reflects the temperature of the flowing fluid stream and not the effects of ambient conditions on the pipe surrounding the thermowell. For example, every degree F of incorrect temperature measurement will cause approximately a 0.1 % error in lean natural gas volumetric flow rate measurement, thus evaluating the measurement bias should determine the need for insulation.

Thermowell length shall be no longer than the length determined by the following equation and no shorter than 1/3 the pipe ID and constructed of material providing adequate strength. The probe length is defined as the distance between the probe tip and its point of attachment inside the pipe.

**SI Units**

$$L = \left( \frac{F_m \times 4.38 \times OD \times 10}{S \times V} \sqrt{\frac{E}{\rho}\left(OD^2 + ID^2\right)} \right)^{\frac{1}{2}}$$

where

- $L$ is the probe length (mm);
- $F_m$ is the virtual mass factor—a constant to take account of the extra mass of the cylinder due to the fluid surrounding it and vibrating with it. For a gas, $F_m = 1.0$ and for water and other liquids, $F_m = 0.9$;
- $OD$ is the outside diameter of probe (mm);
- $ID$ is the inside diameter of probe (mm);
- $S$ is the Strouhal number, dependent on the Reynolds No. and shape of the cylinder, but can be taken as 0.4 for worst case or 0.2 as suggested by API *MPMS* Ch. 8.
- $V$ is the velocity of fluid (m/sec);
- $E$ is the modulus of elasticity of probe material (kg/cm$^2$);
- $\rho$ is the density of probe material (kg/m$^3$).

**USC Units**

$$L = \left( \frac{F_m \times 1.205 \times OD}{S \times V} \sqrt{\frac{E}{\rho}\left(OD^2 + ID^2\right)} \right)^{\frac{1}{2}}$$ (adapted from EEMUA Publication No. 138:1988)

where

- $L$ is the probe length (inches);
- $F_m$ is the virtual mass factor—for a gas, $F_m = 1.0$ and for water and other liquids, $F_m = 0.9$;

$OD$ is the outside diameter of probe (inches);

$ID$ is the inside diameter of probe (inches);

$S$ is the Strouhal number, dependent on the Reynolds No. and shape of the cylinder, but can be taken as 0.4 for worst case or 0.2 as suggested by API *MPMS* Ch. 8.

$V$ is the velocity of fluid (ft/sec);

$E$ is the modulus of elasticity of probe material (psi);

$\rho$ is the density of probe material (g/cc).

## 6.6 Insulation

Insulation of the meter tube may be required in the case of temperature differences between the ambient temperature and the temperature of the flowing fluid, and/or for fluids being metered near their critical point, where small temperature changes result in major density changes. This can be critical at low flow rates, where heat transfer effects may cause not only distorted temperature profiles, but also a change in the mixed mean temperature values from the upstream to the downstream side of the meter run, and changes to the mean velocity profile.

# Annex A
(informative)

# Research Projects and Tests Conducted Between 1922 and 1999

NOTE This Annex is not a part of this standard and is included for informational purposes only. Further, the standard is revised solely on the information in the White Papers (maintained by API), which use selected references from those listed in this Annex.

## A.1 Introduction

During the preparation of Chapter 14, Section 3, the committee analyzed the data from research projects and tests conducted between 1922 and 1998. Some of the projects were conducted directly under the supervision of API, Gas Processors Association (GPA), and American Gas Association (AGA) personnel. Other tests were conducted by the Commission of the European Communities. Still other tests, by independent investigators worldwide, made significant contributions to the data base. The references described in A.2 through A.12 are from the original document known as AGA Report No. 2. The references described in A.13 through A.19 were incorporated in the reference list of the document known as AGA Report No. 3. The more recent references listed in A.20 through A.25 were part of an intense review and subsequent white paper developed by the API *MPMS* Ch.14.3.2/AGA Report No. 3, Part 2, working group.

## A.2 Cleveland Holder Tests (1925)

The Cleveland holder tests were conducted by the Gas Measurement Committee using a gas holder owned by the East Ohio Gas Company in Cleveland. These tests were made under the chairmanship of H. C. Cooper and the direct supervision of Professor R. S. Danforth of the Case School of Applied Science. Representatives of the National Bureau of Standards and the U.S. Bureau of Mines were present as observers. The test line consisted of orifice meter runs of 8-, 10-, and 16-in. pipe; 4 in. orifice plates were installed in each of these runs.

## A.3 Buffalo Disturbance Tests (1926)

The Buffalo disturbance tests were conducted by the Gas Measurement Committee at the Daly Station of the Iroquois Gas Corporation, Buffalo, New York. The object of these tests was to determine the effects of disturbances produced in a gas stream by various kinds of pipeline fittings located near an orifice plate on the indications of an orifice meter.

## A.4 Disturbance and Rate-of-Flow Tests (1927)

Disturbance and rate-of-flow tests were conducted by the Gas Measurement Committee at Daly Station of the Iroquois Gas Corporation, Buffalo, New York, under the personal supervision of Howard S. Bean. The first part of these tests was a continuation of the 1926 series described in A.3. The rate-of-flow tests had two objectives:

a) to build up, by means of a series of inter-comparisons, a series of relative orifice coefficient values for orifices in an 8-in. pipe that ranged in diameter from 1 in. to $6^1/2$ inches;

b) to study the effect on orifice coefficients of increasing value of the ratio of differential pressure to static pressure ($h/p$), that is, the ratio of the differential pressure, in inches of water, to the absolute static pressure, in pounds per square inch.

## A.5 Rate-of-Flow, Flange Form, and Supercompressibility Tests (1928)

Rate-of-flow, flange form, and supercompressibility tests were conducted at the Daly Station of the Iroquois Gas Corporation, Buffalo, New York, by the Gas Measurement Committee under the direction of Howard S. Bean. The objects of these tests were as follows:

a) to extend the study of effects on orifice coefficients resulting from changes in the h/p ratio to orifices in 4-in. pipes;

b) to compare the relative indications obtained with recessed and unrecessed orifice ranges;

c) to determine the deviation from Boyle's Law and its effect on measuring gas by orifice meters;

d) to investigate the effect on orifice coefficients for an equal diameter ratio changing from an 8-in. to a 4-in. line.

## A.6 Shop Tests on Effects of Orifice Installation Conditions (1929–1930)

Shop tests on effects of orifice installation conditions were performed by the Bailey Meter Company, the Foxboro Company, the Metric Metal Works, and the Pittsburgh Equitable Meter Company for the Gas Measurement Committee in accordance with an outline prepared by Howard S. Bean. The object of these tests was to determine the effects on orifice meter indications that result from some installation conditions not covered by the disturbance tests described in A.3 and A.4. Additional information was desired about the following conditions:

a) position and size of straightening vanes;

b) position and design of thermometer wells, particularly on the upstream side of the orifice;

c) roughness of pipe adjacent to the orifice;

d) form of flange in which the orifice plate is held;

e) inaccuracy in centering the orifice in the pipe;

f) the condition of the upstream edge of the orifice;

g) the ratio of the width of the orifice edge to the diameter of the orifice.

The results of these tests were reported in the article "Effect of Some Installation and Construction Conditions Upon the Indications of an Orifice Meter," *American Gas Association Monthly*, July–August 1947, Volume 29, pp. 7 and 8.

## A.7 Edgewood Tests (1922–1925)

The Edgewood tests were conducted at Edgewood Arsenal, Maryland, by the National Bureau of Standards with the cooperation of the Chemical Warfare Service, U.S. War Department, under the immediate supervision of Howard S. Bean, with the advice of Edgar Buckingham, and the assistance of Paul S. Murphy. The object of these tests was to obtain original information on the orifice discharge coefficients over as wide a range of pipe sizes, diameter ratios, pressures, and pressure ratios as was permitted by the facilities available. The setup included orifices in 4-, 6-, and 8-in. pipes. Forty-eight orifice plates were used, with orifice-to-pipe diameter ratios ranging from 0.108 to 0.858.

## A.8 Chicago Holder Tests (1923–1924)

The Chicago holder tests were conducted in Chicago by the American Gas Association Committee on the Measurement of Large Volumes of Gas, under the chairmanship of M. E. Benesh. On invitation from Mr. Benesh, the National Bureau of Standards cooperated in these tests, the main object of which was to study the accuracy of several types of meters, including orifice meters used to measure large quantities of gas at pressures near atmospheric.

## A.9 Ohio State University Steam and Water Tests (1929–1931)

Steam and water tests were conducted by the Ohio State University Engineering Experiment Station and the Bailey Meter Company at the Mechanical Engineering Laboratory of Ohio State University, under the supervision of Professors Paul Bucher and Samuel Beitler. The object of the tests was to determine the expansion factor and the coefficients of orifices measuring both steam and water. Both 3- and 6-inch lines were used and a series of orifices were tested, first using water and then steam.

## A.10 Intercomparison of Meter Runs (1932)

An intercomparison of meter runs was conducted by the Peoples Gas Light and Coke Company at its Joliet Measuring Station, Joliet, Illinois, under the supervision of M. E. Benesh.

## A.11 Columbus Tests (1932–1933)

The Columbus tests were conducted by the Joint Orifice Meter Committee at the Hydraulic Laboratory of Ohio State University, Columbus, Ohio, under the immediate supervision of Professor Samuel R. Beitler. Nearly 80 separate orifice plates were used in tests with 1-, 1$^1/_2$-, 2-, 3-, 6-, 10-, and 15-in. pipes; and in many cases, the same orifice was used in two or more different pipe sizes. The orifice pipe diameter ratio ranged from 0.04 to 0.84.

## A.12 South Columbus Flange Form and Pressure Hole Tests (1932)

Flange form and pressure hole tests were conducted by the Joint American Gas Association-American Society of Mechanical Engineers Committee on Orifice Meters at the South Columbus Measuring Station of the Ohio Fuel Gas Company, under the immediate supervision of J. E. Overbeck, with the advice of Professor Samuel R. Beitler. The object of these tests, which were made with natural gas, was to determine more completely than had been done either at Buffalo (A.3 and A.4) or by the shop tests (A.6) the effects of various sizes of internal flange recesses adjacent to the orifice plate. Both the width and the depth of the recesses were varied in the 2-, 4-, and 8-in. pipe sizes that were used in these tests. The orifice-to-pipe diameter ratio ranged from 0.125 to 0.75. In combination with these recesses, various diameters of pressure holes were used.

## A.13 Rockville Tests (1949–1951)

The Rockville tests were conducted by the Joint American Gas Association-American Society of Mechanical Engineers Committee under the direction of Howard S. Bean. Tests with natural gas were performed at the Rockville, Maryland, Measuring Station of the Atlantic Seaboard Corporation to study the following:

a) the effect of plug, globe, and gate valve disturbances on measurement;

b) the effect of elbow placement disturbances (comparison with Buffalo tests);

c) the effect of orifice meter fittings, compared with conventional orifice flanges;

d) the effect of orifice tube roughness;

e) installations of 2- and 8-in. piping.

The results of these tests were published by the American Gas Association in two interim reports, each entitled “Investigation of Orifice Meter Installation Requirements,” and dated March 1951, and January 1954.

## A.14 National Bureau of Standards Hydraulics Laboratory Tests (1950–1951)

The National Bureau of Standards Hydraulics Laboratory tests were conducted by the Joint American Gas Association-American Society of Mechanical Engineers Committee on Orifice Meters at the Hydraulics Laboratory, National Bureau of Standards, Washington, D.C., under the immediate supervision of Howard S. Bean. The object of this project was, in part, to make comparative tests with water for the roughness and orifice fitting installations used in the Rockville tests (A.13) and, in part, to examine the effect of pressure tap location and tap hole size. The results were reported in conjunction with those from the Rockville tests.

## A.15 U.S. Naval Boiler and Turbine Laboratory Tests (1948–1954)

The U.S. Naval Boiler and Turbine Laboratory tests were conducted by the Bureau of Ships, U.S. Department of the Navy, in conjunction with the Joint American Gas Association-American Society of Mechanical Engineers Committee on Orifice Meters, at the U.S. Naval Boiler and Turbine Laboratory in Philadelphia.

This work was conducted under the direction of James W. Murdock. The object of these tests, which were made with steam, was to determine the effect of globe valves and expansion bends on orifice meter indications. Additional tests were performed to check the values of expansion factors to be used in the measurement of steam. The results of these tests were reported in a series of four interim reports published by the U.S. Naval Boiler and Turbine Laboratory. These reports were entitled “Determination of the Minimum Length of Straight Pipe Required Between Various Pipe Fittings,” and “The Orifice Plate for Acceptable Orifice Meter Accuracy,” and were dated January 1950, March 1950, May 1950, and November 1951.

## A.16 Refugio Large-Diameter Orifice Tube Tests (1952–1953)

The Refugio large-diameter orifice tube tests, a PAR Project, were conducted by the Project NX-4 Supervising Committee, under the chairmanship of E. E. Stovall. The primary objective was to determine experimentally whether the basic orifice coefficient data contained in the AGA Gas Measurement Report No. 2 could be extrapolated for use in measuring gas accurately through large-diameter tubes. The test installation was located near Refugio, Texas, on a transmission line of the Tennessee Gas Transmission Company. The results of these tests were published by the American Gas Association in a report, “Large Diameter Orifice Tube Tests,” dated June 1954.

## A.17 Eccentric and Segmental Orifice Tests (1948–1954)

Eccentric and segmental orifice tests were conducted under the supervision of a Subcommittee of the American Society of Mechanical Engineers (ASME) Research Committee on Fluid Meters with the cooperation of the AGA Gas Measurement Committee. The chairman of the ASME subcommittee was L. E. Gess of the Minneapolis Honeywell Company. The objective of the tests was to determine the coefficients of discharge of round orifices mounted with one edge tangent to the pipe wall and of plates with segmental orifices in them. The tests were run at Ohio State University under the supervision of Professor Samuel R. Beitler and were analyzed by Professor E. J. Lindahl of the University of Wyoming. The results of these tests were reported in two ASME papers: “Calibration of Eccentric and Segmental Orifices in 4- and 6-in. Pipelines,” *Transactions of the ASME*, 1949, Volume 71, and “Coefficients of Discharge for Eccentric and Segmental Orifices in 4-inch, 6-inch, 10-inch, and 14-inch Pipes,” presented at the Annual Meeting of the American Society of Mechanical Engineers, New York, November 1954.

## A.18 Pipe Roughness Study (1957–1960)

A pipe roughness study, a PAR Project, was conducted by the Project NW-20 Supervising Committee under the chairmanship of J. W. Murdock. W. B. Ruff, Jr., of the Southern Natural Gas Company, served as the Gas Measurement Committee representative coordinating and supervising the project. The primary purpose of this program was to determine, qualitatively and quantitatively, the effect of the character of the interior surface of orifice tubes on fluid flow measurements by orifice meters. A secondary objective was to correlate any effect on flow measurement with some physical measurement of the tube roughness (such as microinches) to the end that a recommendation could be made about the relative roughness range for satisfactory metering service. The preliminary tests were conducted at the U.S. Naval Boiler and Turbine Laboratory in Philadelphia. The full-scale tests were conducted in Birmingham, Alabama, at Southern Natural Gas Company facilities. Four-in. meter tubes were used in these tests. The results of these tests were published by the American Gas Association in the report, “The Effect of Pipe Roughness on Orifice Meter Accuracy (Catalog No. 33/PR),” dated February 1960.

## A.19 Ohio State University Flow Distortion Tests (1960–1962)

The Ohio State University flow distortion tests constituted PAR Project NY-34. The supervising committee chairman was C. W. Brown, Texas Gas Transmission Corporation. These tests were carried out at Ohio State University to determine the amount of error caused by distortion of the approach velocity profile on the coefficient of orifices. An attempt was made to eliminate swirl, so the report describes the effect of changes in the axial profile only. Six-in. orifice pipes with honed walls (roughness of about 15 microinches) were used, and the inlet profile was distorted by use of special flow disturbances and piping configurations. It was concluded that ordinary disturbances caused by piping configurations, which did not produce swirl, resulted in errors of less than 2 % if there were at least six diameters of straight uniform pipe ahead of the orifice.

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# Annex B
(informative)

# Orifice Meter Inspection Guidelines

NOTE This Annex is not a part of this standard but is included for informational purposes only.

The following outline is intended to provide guidelines for preparing an orifice meter inspection checklist. The outline is provided so that uniformity may be achieved in what is to be inspected. The format of the checklist is left to the user, according to company preference. Although all the items listed may not be required at every inspection, the checklist should provide the pertinent information.

Note that the outline may not include all of a particular user's required information. The minimal information specified in the outline provides a basis for evaluating the quality of the meter run and orifice plate at the time of inspection.

I. Header

  A. Company name.

  B. Date of inspection.

  C. Tube location.

  D. Flow direction.

  E. Names of inspector(s) and witness(s).

  F. Any other information required.

II. General Information

  A. Serial number.

  B. Nominal pipe diameter.

  C. Fluid measured: gas or liquid (specify name).

  D. $\beta$-ratio limitations.

III. Meter Tube

  A. Type of orifice holder: flanges or fitting; single- or dual-chamber.

  B. Manufacturer.

  C. Serial number.

  D. Straightening vanes? Yes or no; if yes:

    1. Type of vane.

    2. How fastened? Pinned, welded, or flanged.

3. Dimensions.

4. Dimensional and quality specifications per API *MPMS* Ch. Chapter 14.3.2/AGA Report No. 3 Part 2: pass or fail.

E. Meter run type: single tube or multiple tube.

F. Installation type (see Figure 6 and Table 7, Table 8a, or Table 8b).

G. Dimensional data:

1. Length (see Figure 6 and Table 7, Table 8a, or Table 8b).

2. Upstream and downstream diameters (at least four measurements at each location):

a. Upstream pressure tap (also calculate the average of these values).

b. Downstream pressure tap.

c. First pipe connection.

d. Second pipe connection.

H. Temperature of tube at time of measurement.

I. Meter tube quality: cleanliness and measured roughness upstream and downstream.

J. Average tube inside diameter at 68 °F, as stamped on pipe or nameplate.

K. Inside tube diameter used in flow computer, for calculations and data processing.

IV. Pressure Taps

A. Orientation of primary differential pressure transducer connection (looking from inlet to outlet of meter tube).

B. Location of static pressure transducer connection: upstream, downstream, or none.

C. Number of differential pressure connections.

D. Pressure tap size: 3/8 in., 1/2 in., or other.

E. Measured distance from centerline of tap hole to orifice plate surface, both upstream and downstream.

F. Condition of tap hole edge on inside diameter of meter run.

G. Manifold: manufactured or fabricated on site; full bore or restricted bore; three valves, five valves, or other.

H. Gauge line length.

V. Other Instrumentation

A. Measurement data on other tap connections made to the meter tube: size, location, and orientation.

B. Temperature probe: type and location.

C. Densitometer: manufacturer and type; insertion or sample line; size; inlet or outlet location.

D. Sampler: manufacturer and type; sample line size; inlet or outlet location.

E. Composition/energy analyzers: type; sample line size; inlet or outlet location.

VI. Orifice Plate Centering-Type

A. Flange: plate alignment (pins, male/female, other, or none).

B. Fitting:

1. Measurement from plate edge to pipe wall on primary pressure tap side.
2. Measurement from plate edge to pipe wall on opposite side pressure tap.
3. Half the difference between 1 and 2 above.
4. Measurement from plate edge to pipe wall perpendicular to primary tap.
5. Measurement from plate edge to pipe wall opposite to measurement in 4 above.
6. Half the difference between 4 and 5 above.

VII. Orifice Fitting Leak Test (After Hydrostatic Testing)

A. Measurement of seat width.

B. Measurement of seal width.

C. Difference between A and B above.

D. Results of pressure tap leak test.

E. Results of plate bypass leak test.

F. Type of seal and material of construction.

VIII. Orifice Plate Inspection

A. Type of plate.

B. Material of construction.

C. Manufacturer.

D. Stamped (nominal) diameter at 68 °F.

E. Edge sharpness: sharp or dull.

F. Plate flatness: flat or bent (measured departure from flatness).

G. Measured roughness of plate surface.

H. Any surface film patterning, contamination or debris evident for plates just removed from service?

I. Micrometer measurement of at least four inside diameters of the orifice bore.

J. Average value of the measurements in “I” above.

K. Measured plate thickness.

L. Other data pertinent for identification.

M. Temperature at which plate was measured.

N. Names of inspector(s) and witness(es) and date, if not the same as for meter tube.

O. Is plate beveled or unbeveled? Bevel angle?

P. Is the bevel on the downstream side of the plate?

# Annex C
(normative)

# Specific Installation Calibration Test

NOTE This Annex is an inherent part of this standard.

## C.1 General

Installation calibration tests can be performed for an orifice meter with a specific upstream fitting with or without a specific flow conditioner located at a defined position within the meter.

For the installation tests performed at the actual field installation, if the discharge coefficient values of the test data are within the uncertainty limits ($\pm 2\sigma$) of the 95 % confidence level of the RG equation, the RG equation can be used to calculate the flow rate through the meter. If the test results deviate from the RG equation by more than the uncertainty limits of $\pm 2\sigma$, actual test results as a function of the Reynolds number should be used to calculate the flow rate through the meter.

For an installation test at a test facility different from the actual site, a Baseline Calibration (Section C.2) and the Calibration Test (Section C.3) shall be performed. The Baseline Calibration should be performed with a meter tube that conforms to mechanical tolerances specified in Section 5. Preferably, the baseline test and the calibration test should be performed at the same Reynolds number range, $\beta$-ratio range, and line size as used in the field application. If the calibration test discharge coefficient values deviate from the baseline by more than one-half of the uncertainty limits of the RG equation, the actual calibration data as a function of Reynolds number shall be used to calculate the flow rate through the meter. If the calibration test discharge coefficient values are within one half of the uncertainty limits of the 95 % confidence level of the RG equation, then the RG equation can be used to calculate the flow rate through the meter. If the actual line size and/or the operating Reynolds number range cannot be achieved at the test facility, the test criteria and the setup for the baseline test and the installation calibration tests are described below.

The following are general guidelines and acceptance criteria of the Specific Installation Calibration Test:

a) For line sizes greater than 10 in., a 10-in. meter can be tested to ascertain the installation effect; but the test installation has to maintain geometric similarity to the actual field installation.

b) For line sizes less than or equal to 10 in., it is preferred that the test be performed on the actual line size. For the line sizes 6 in. $\leq D_n \leq$ 10 in., the test may be performed on a line that is one nominal size smaller than the actual line size.

c) For a geometrically similar installation on multiple line sizes, baseline and calibration test results of a 4-in. and an 8-in. line can be used for all line sizes.

d) For a test facility failing to achieve the operating Reynolds number range, tests shall be performed at two different Reynolds numbers. The low Reynolds number test has to be between 104 to 5 × 105; and the high Reynolds number test has to be at 106 or higher. The ratio of the high-to-low Reynolds numbers has to be 5 or greater. In the test with a flow conditioner installed. The range of Reynolds numbers and their ratios has to be determined from the rules specified in the Reynolds number sensitivity test in Annex D. The test results are then valid for any Reynolds number application.

e) If the highest Reynolds number achieved during the test is less than $10^6$, the validity of the test results are limited to the highest Reynolds number of the test.

f) If the same installation is to be used for multiple $\beta$-ratio plates, tests should be performed for the largest and the smallest $\beta$-ratio plates. If the results for the two $\beta$-ratio tests are valid, the whole β-ratio range is valid.

g) If any $\beta$-ratio test results (high or low) of the multiple $\beta$-ratio test fail to meet the performance criteria, then the test results are limited to the results of actual $\beta$-ratio plate tested; or new limits may be established by performing additional tests.

## C.2 Baseline Calibration

A baseline (reference) calibration should be performed using the same orifice plate that will be used in the installation calibration test.

a) The baseline calibration should be performed at approximately the same value of Reynolds number as the installation calibration test.

b) The $\beta$ ratio(s) for the test shall be the same as the orifice plate(s) specific installation test(s).

c) The baseline calibration should be performed using a meter tube with a minimum straight upstream meter-tube length of $70D_i$. The flow at the entrance to the meter tube shall be swirl-free (less than 2-degree swirl angle).

d) Baselines using large pipe diameters (16 in. and 24 in.) may prove to be difficult to perform due to space limitations in most laboratories. An alternative baseline configuration of a minimum of $45D_i$ and an oversized Sprenkle flow conditioner is acceptable. The oversized Sprenkle design has to conform to that specified in NIST Technical Note 1264, or to ISO 5167, and one NPS larger.

e) To prove that the mechanical baseline configuration is valid, the baseline $C_d$ values should lie within the 95 % confidence interval for the RG equation.

f) To minimize the effects of instrumentation bias errors, the same measuring equipment should be used in both the baseline test and the calibration test.

## C.3 Calibration Test

If possible, the test should be performed on the actual installation. If the test is performed on a replicated test setup, the same quality meter tube should be used. The test fixture shall duplicate the pipefitting or installation immediately upstream of the orifice plate, including the location of a flow conditioner, if used, and the piping installations within $5D_i$ downstream of the orifice plate. Any pipefitting or piping change in the field installation, which is within $25D_i$ upstream of the piping installation that is being tested, shall be duplicated for the calibration test. Any piping installation of the test facility upstream of the test setup shall be followed by a flow conditioner, e.g., 1998 Uniform Concentric 19-Tube Bundle Flow Straightener, and shall be at a minimum distance of $30D_i$ from the inlet of the installation test setup being calibrated. The orifice meter has to be calibrated at a minimum of four different pipe Reynolds numbers, of which one shall be at ± 5 % of the minimum, and another at ± 5 % of the maximum of the baseline-test Reynolds-number range of the meter. The meter should be tested for the minimum and maximum $\beta$-ratio plates that are to be used in the field. The diameter ratio $\beta$ in the field installation will be restricted to the maximum and minimum $\beta$-ratio limits of the calibration test. If the deviations ($C_d$) of the discharge coefficient data from the baseline are within the one-half-of-uncertainty limits, $\pm 2\sigma$ of the RG equation, as defined in API *MPMS* Chapter 14.3.1/AGA Report No. 3 Part 1, the actual flow rate can be calculated by using the RG equation. If the $C_d$ data are beyond the one-half-of-uncertainty limits of $\pm 2\sigma$ of the RG equation, the actual calibration data of the discharge coefficient ($C_d$) as a function of Reynolds number, shall be used to calculate the flow rate through the meter.

# Annex D
(normative)

# Flow Conditioner Performance Test

## D.1 General

The objective of performance tests for a flow conditioner is to prove that a tested device meets performance criteria within the specified tolerance limits for any type of piping installation upstream of the orifice meter at one line size and for a narrow range of Reynolds numbers (Test TD1) or for all line sizes and Reynolds numbers (Test TD2). This objective is broader than for a calibration test (Annex C), which deals with a specific type of an upstream installation of interest to the user.

Both types of flow conditioner performance tests contain the following common elements.

— **Test 1**: Baseline Calibration—evaluating performance of the test facility.

— **Test 2**: Good Flow Conditions—test evaluating impact of flow conditioner on fully developed velocity profile.

— **Test 3**: Two 90-degree Elbows in Perpendicular Planes—testing of flow conditioner performance in handling a combination of a modest swirl (up to 15-degree swirl angle) and a nonsymmetrical velocity profile.

— **Test 4**: Gate Valve 50 % Closed—test evaluating flow conditioner performance in a strongly nonsymmetrical velocity profile.

— **Test 5**: High Swirl—test assessing flow conditioner performance in flows with high swirl angle (more than 25 degrees).

The facility baseline has to meet acceptance criteria specified below and the results of Tests 2 through 5 will be evaluated in terms of the normalized deviation ($\Delta C_d$) between the measured discharge coefficient and the baseline discharge coefficient at the same $\beta$-ratio and Reynolds number.

There are two types of flow conditioner performance tests:

— **TD1:** *Application Test*. Approves the use of a flow conditioner for any type of upstream installation; just for the tested line size and a narrow range of Reynolds numbers associated with the tested $\beta$-ratio range and differential pressure range used. For these conditions, the five tests specified have to be performed.

— **TD2:** *Type Approval Test*. Approves use of a tested flow conditioner for any type of upstream installation, any line size, and any Reynolds number. Such a broad approval of the flow conditioner applications requires performance of Tests 1 through 5 within the parameter ranges prescribed in equations D.A and D.B:

Equation D.A.: $10^4 \leq Re_l \leq 10^6$ and $Re_h \geq 10^6$ such that (D.A)

a) for $\beta = 0.67 \rightarrow f(Re_l) - f(Re_h) \geq 0.0036$, or

b) for $\beta = 0.75 \rightarrow f(Re_l) - f(Re_h) \geq 0.0030$

where

$Re_l$ is the low Reynolds number;

$Re_h$ is the high Reynolds number;

$f$ is the pipe friction factor obtained from (i) or (ii):

(i) the Colebrook-White equation

$$1/\sqrt{f} = 1.74 - 2 \log_{10} [6.3\ R_a/D + 18.7 / (Re_D \sqrt{f})]$$

(ii) the Moody diagram;

$R_a$ is the absolute average roughness of meter tube.

Equation D.B: $D_i \leq 4$ in. and $D_i \geq 8$ in. (D.B)

The following selection of tests shall be performed:

Test a) *Disturbance*. Tests 1 through 5 for one Reynolds number range and at one pipe diameter selected from (D.A) and (D.B). The full sequence of $\beta$-ratio selection is defined in Section D.2.

Test b) *Scaling*. Test 1, and one of the Tests 3 through 5, shall be conducted using two pipe sizes (preferably at one pipe size as in **Test a)** selected from two prescribed diameter ranges in (D.B). Each pipe size test shall be conducted at the same Reynolds number (preferably the one as in **Test a)** or at a Reynolds number chosen from the prescribed ranges in (D.A). To demonstrate scalability, the results from the two pipe sizes has to demonstrate that, in both cases, the flow conditioner meets the specified performance criteria for the same meter tube lengths, $UL$ and $UL2$. Selection of β-ratio should follow the procedure described in Section D.2.

Test c) *Reynolds Number Sensitivity*. Test 1, and one of Tests 2 through 5, shall be conducted, preferably at one of the pipe sizes used in Test b), and at two Reynolds numbers selected for a chosen pipe diameter and pipe roughness, in such a way that the condition (D.A) is fulfilled for β = 0.67 only; $\beta = 0.75$ may be used instead, if desired.

EXAMPLE A laboratory decides to use hydraulically smooth pipes, and selects $Re_h = 1.02 \times 10^6$. At the Reynolds number, Moody diagram gives $f\,(Re_h) = 0.0116$. The Reynolds number sensitivity test will be conducted at $\beta = 0.67$; thus, $f\,(Re_l) = f\,(Re_h) + 0.0036 = 0.0116 + 0.0036 = 0.0152$. This value of the friction factor corresponds to $Re_l = 2.31 \times 10^5$ for a smooth pipe at the Moody diagram. The tests can be conducted at the same facility, because $Re_h / Re_l = 4.4$ will not result in excessively high or low pressure differentials across the orifice plate.

The selection of two Reynolds numbers for **Test c)** requires use of an implicit formula or Moody diagram that may result in the ratio of Reynolds number even as low as 4 in facilities operating on liquids, and even higher than 10 in the facilities operating on high-pressure gas.

If the selected Reynolds number in **Test a)** is equal to or larger than $3 \times 10^6$, and the manufacturer or user of the flow conditioner is seeking an approval for applications in the range *Re* $3 \times 10^6$, then the **Test c)** can be skipped.

In both types of performance tests, the use of the flow conditioner is restricted to those locations within the meter run where the $\Delta C_D$ of the tested flow conditioner was one-half of the uncertainty limits ± 2σ of RG equation.

An installation and/or flow conditioner test should be performed for values of upstream meter tube length and/or flow conditioner location that are appropriate for the installation. If desired, a sliding or fixed position flow conditioner test can be performed for a range of flow conditioner locations for one or more upstream meter tube lengths.

## D.2 Orifice Diameter Ratio or Commonly Referred to as $\beta$ Ratio

If it is known that an installation or a flow conditioner is successful in removing swirl from the downstream flow, then it is possible to limit the range of $\beta$-ratios used in the performance test. If swirl is not removed by the installation and/or flow conditioner, it would be misleading and erroneous to rely on a single value of $\beta$ to gauge the installation or flow conditioner's performance. It is recommended that either Test 3 or Test 5 be performed first for β = 0.40 and β = 0.67. If the $\Delta C_D$ values for both values of β are negligible, or if $\Delta C_D$ varies approximately as $\beta^{3.0}$ to $\beta^{4.0}$, then it can be concluded that swirl in the meter tube is not a significant influence. In this case, it is recommended that the other installation or flow conditioner performance tests be performed for a single value of β = 0.67. If the installation or flow conditioner passes the test for *β* = 0.67, experience shows that it will also pass the test for lower values of *β*. If the flow conditioner passes the test for *β* = 0.67, it can also be tested at a higher value of β, if desired.

If swirl effects are not removed by the installation and/or flow conditioner at *β* = 0.40 and *β* = 0.67, Test 3 and Test 5 will have to be performed for a complete range of *β* values between *β* = 0.20 and *β* = 0.75.

## D.3 Meter Tube Length and Flow Conditioner Location

Some flow conditioners that were designed to comply with a particular flow meter standard may be retrofitted into existing meter tubes. In this case, the flow conditioner should be installed at the appropriate location, and its performance evaluated in a meter tube of the appropriate length. If the field meter tube was designed to comply with the API *MPMS* Chapter 14.3.2/AGA Report No. 3, Part 2, 1992 revision, Figure 5—"Partly Closed Valve Upstream of Meter Tube," the flow conditioner performance should be evaluated in a meter tube with an upstream length of $17D_i$, with the flow conditioner located at UL2 = $7.5D_i$ upstream of the orifice plate. If the field meter tube was designed to comply with the ISO 5167 standard, the flow conditioner performance should be evaluated in a meter tube with an upstream length of $45D_i$, with the flow conditioner located at UL2 = $22D_i$ upstream of the orifice plate. Alternatively, if the field meter tube is significantly longer than the minimum recommended length (e.g. some natural gas transmission companies have meter tubes with an upstream length of UL = $25D_i$ to $29D_i$, and install a tube bundle straightening vane at $UL2 = 12D_i$ upstream of the orifice plate), the performance test should be performed with the same installation conditions.

The flow conditioner performance test can be performed for more than one meter tube length, and for more than one flow conditioner location, if desired.

## D.4 Test 1: Baseline Calibration

A baseline (reference) calibration should be performed using the same orifice plates and *β*-ratios that will be used in the application or type approval test(s) (TD1 or TD2).

a) The baseline should be performed using a meter tube with a minimum straight upstream meter tube length of $70D_i$. There shall be swirl-free (less than 2 degree swirl angle) flow at the entrance to the $70D_i$ meter tube.

b) Baselines using large pipe diameters (16 in. and 24 in.) may prove to be difficult to perform because of space limitations in most laboratories. An alternative baseline configuration of a minimum of $45D_i$ and an oversized Sprenkle flow conditioner are acceptable. The oversized Sprenkle design has to conform to that specified in NIST Technical Note 1264, or to ISO 5167, and one NPS larger.

c) To prove that the mechanical baseline configuration is valid, the baseline $C_d$ values should lie within the 95 % confidence interval for the RG equation.

d) To minimize the effects of instrumentation bias errors, the same measuring equipment should be used in both the baseline test and Tests 2 through 5.

## D.5 Test 2: Good Flow Conditions

This test is recommended to show that the installation or flow conditioner does not degrade the measurement performance of a meter tube under good (baseline) flow conditions. The upstream length of the meter tube or the flow conditioner location may be specified as appropriate for a retrofit installation. Otherwise, a sliding or fixed position flow conditioner test may be performed.

## D.6 Test 3: Two 90-Degree Elbows in Perpendicular Planes

This test ensures that the installation or flow conditioner can remove normal amounts of swirl and provide good performance in a double out-of-plane elbow installation. The spacing between the exit plane of the first elbow and the entry plane of the second elbow should not exceed two pipe diameters. Since the out-of-plane elbows will produce swirl in the meter tube, the flow entering the first elbow should be swirl-free.

## D.7 Test 4: Gate Valve 50 % Closed

This test ensures that the installation or flow conditioner can accept a highly asymmetric profile of axial velocity without degradation of measurement performance. The 50 % closed valve should be the primary source of the velocity profile asymmetry. The velocity profile of the flow approaching the valve should be symmetric and swirl-free. In the flow conditioner performance tests, a full-bore gate valve was used. The gate was modified so that 50 % of the flow area was blocked when the gate was lowered. The gate had to be raised to allow a sliding flow conditioner to enter the meter tube downstream of the valve.

For an evaluation of the performance of a flow conditioner at a fixed location, it is possible to substitute a segmented orifice plate mounted between two flanges for the gate valve. The segmented plate should block 50 % of the flow through the meter tube. A segmented plate is employed in the high-level perturbation test described in the ISO/DIS 9951 standard for gas turbine meter installations. The open area of the plate should be adjacent to one of the orifice pressure tap pairs. The closed area of the plate should be adjacent to the pressure tap pairs on the opposite side of the orifice fitting.

## D.8 Test 5: High Swirl

This test is recommended when the meter tube will be installed downstream of a header that may produce large axial swirl angles. The objective of the test is to prove that the flow conditioner is effective in high-swirl environments. The Chevron axial vane swirler is effective in generating a solid body type of rotation, with a linear distribution of swirl angle from near zero on the pipe centerline to a maximum value of 30 degrees near the pipe wall. The design of the Chevron swirler is as follows.

The basic design consists of a hub of 1.5 in. (38 mm) in diameter and 6 in. (152 mm) in length. The hub has a streamlined parabolic nose facing upstream and a blunt base [corner radius approximately 0.1 in. (2.5 mm)] facing downstream. The hub is supported and centered by struts from the stainless steel housing wall.

Ten vanes or blades are attached to the hub by shafts that pass through the housing wall and allow individual adjustment of each blade's angle. Outside the housing, a protractor is fitted to each shaft. The vanes can be rotated by turning the shaft from outside the housing. The degree of rotation is read from the affixed vernier. The thickness of each blade 0.2 in. (5 mm) is milled to a tapered profile to streamline the flow when the blades are aligned in the axial direction.

The Chevron swirler used in the installation and/or flow conditioner performance tests verification has a nominal diameter of 6 inches. With reducer fittings attached to front and back, it performed well in tests with $D_i$ = 4-in. pipe. For larger diameter pipe (8-in., 10-in., or 16-in.) it will be necessary to design and fabricate a larger diameter device. If another swirl-generating device is used in place of the Chevron swirler, the swirl-generator device should produce a swirl angle of at least ± 24 degrees at a distance of $17D_i$. Confirmation of the swirl angle is to be obtained by measurement using an appropriate technique; for example, a multi-hole Pitot tube. The setting of the vane angle on the swirler is not considered to be a measure of the swirl angle at the location of the meter.

# Annex E
(normative)

# Maximum Allowable Orifice Plate Differential Pressure

Table E-1 (in four segments) provides the calculated maximum allowable differential pressure limits for orifice plate thickness.

**Table E-1—Maximum Allowable Calculated Differential Pressure Across 304/316SS Orifice Plate at 150 °F**

| | 2 in. | | 3 in. | | 4 in. | | 6 in. | | | | 8 in. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.125 plate | | 0.125 plate | | 0.125 plate | | 0.125 plate | | 0.1875 plate | | 0.125 plate | | 0.250 plate | | 0.3125 plate | | |
| | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | |
| β-Ratio | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | β-Ratio |
| 0.20 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 480 | 1000[a] | 1000[a] | 1000[a] | 205 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.20 |
| 0.25 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 440 | 1000[a] | 1000[a] | 1000[a] | 190 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.25 |
| 0.30 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 405 | 1000[a] | 1000[a] | 1000[a] | 175 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.30 |
| 0.35 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 385 | 1000[a] | 1000[a] | 1000[a] | 165 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.35 |
| 0.40 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 365 | 1000[a] | 1000[a] | 1000[a] | 160 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.40 |
| 0.45 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 350 | 1000[a] | 1000[a] | 1000[a] | 155 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.45 |
| 0.50 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 345 | 1000[a] | 1000[a] | 1000[a] | 150 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.50 |
| 0.55 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 345 | 1000[a] | 1000[a] | 1000[a] | 150 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.55 |
| 0.60 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 345 | 1000[a] | 1000[a] | 1000[a] | 150 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.60 |
| 0.65 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 355 | 1000[a] | 1000[a] | 1000[a] | 155 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.65 |
| 0.70 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 375 | 1000[a] | 1000[a] | 1000[a] | 165 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.70 |
| 0.75 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 395 | 1000[a] | 1000[a] | 1000[a] | 180 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 0.75 |

NOTE Measurement uncertainty is increased if the ratio of the differential to static pressure (both expressed in psia) exceeds 0.2 or 20 %. Care should be taken to not violate the recommendations or tolerances stated in Table 3 and Annex E.

[a] Although the structural integrity of the flange mounting will allow calculated values for the maximum orifice plate differential pressures in excess of 1000 in. of water, the coefficient of discharge database is limited to 1000 in. of water.

Assumptions for determining maximum differential pressures across orifice plates in orifice fittings:

1) Support diameter ($D_s$) is 0.2 in. less than outside orifice plate diameter.
2) Internal diameter ($D$) is the largest diameter in Table 4 of API *MPMS* Chapter 14.3.2/AGA Report No. 3 Part 2.
3) Maximum differential values are for orifice plates at a flowing temperature less than or equal to 150 °F ($T_f \leq 150$ °F).

**Table E-1—Maximum Allowable Calculated Differential Pressure Across 304/316SS Orifice Plate at 150 °F (continued)**

| | 10 in. | | | | | | | | 12 in. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.125 plate | | 0.1875 plate | | 0.250 plate | | 0.3125 plate | | 0.1875 plate | | 0.250 plate | | 0.3125 plate | | 0.375 plate | | |
| | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | |
| β-Ratio | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | β-Ratio |
| 0.20 | 100 | 545 | 335 | 1000[a] | 800 | 1000[a] | 1000[a] | 1000[a] | 175 | 1000[a] | 420 | 1000[a] | 820 | 1000[a] | 1000[a] | 1000[a] | 0.20 |
| 0.25 | 90 | 555 | 310 | 1000[a] | 735 | 1000[a] | 1000[a] | 1000[a] | 160 | 1000[a] | 385 | 1000[a] | 755 | 1000[a] | 1000[a] | 1000[a] | 0.25 |
| 0.30 | 85 | 585 | 285 | 1000[a] | 680 | 1000[a] | 1000[a] | 1000[a] | 150 | 1000[a] | 355 | 1000[a] | 700 | 1000[a] | 1000[a] | 1000[a] | 0.30 |
| 0.35 | 80 | 640 | 270 | 1000[a] | 640 | 1000[a] | 1000[a] | 1000[a] | 140 | 1000[a] | 335 | 1000[a] | 655 | 1000[a] | 1000[a] | 1000[a] | 0.35 |
| 0.40 | 75 | 725 | 255 | 1000[a] | 610 | 1000[a] | 1000[a] | 1000[a] | 130 | 1000[a] | 315 | 1000[a] | 620 | 1000[a] | 1000[a] | 1000[a] | 0.40 |
| 0.45 | 70 | 850 | 245 | 1000[a] | 590 | 1000[a] | 1000[a] | 1000[a] | 125 | 1000[a] | 300 | 1000[a] | 595 | 1000[a] | 1000[a] | 1000[a] | 0.45 |
| 0.50 | 70 | 1000[a] | 240 | 1000[a] | 575 | 1000[a] | 1000[a] | 1000[a] | 120 | 1000[a] | 295 | 1000[a] | 575 | 1000[a] | 995 | 1000[a] | 0.50 |
| 0.55 | 70 | 1000[a] | 240 | 1000[a] | 570 | 1000[a] | 1000[a] | 1000[a] | 120 | 1000[a] | 290 | 1000[a] | 565 | 1000[a] | 980 | 1000[a] | 0.55 |
| 0.60 | 70 | 1000[a] | 240 | 1000[a] | 575 | 1000[a] | 1000[a] | 1000[a] | 120 | 1000[a] | 285 | 1000[a] | 560 | 1000[a] | 970 | 1000[a] | 0.60 |
| 0.65 | 70 | 1000[a] | 245 | 1000[a] | 590 | 1000[a] | 1000[a] | 1000[a] | 120 | 1000[a] | 290 | 1000[a] | 565 | 1000[a] | 980 | 1000[a] | 0.65 |
| 0.70 | 75 | 1000[a] | 255 | 1000[a] | 615 | 1000[a] | 1000[a] | 1000[a] | 125 | 1000[a] | 295 | 1000[a] | 575 | 1000[a] | 1000[a] | 1000[a] | 0.70 |
| 0.75 | 80 | 1000[a] | 275 | 1000[a] | 655 | 1000[a] | 1000[a] | 1000[a] | 125 | 1000[a] | 305 | 1000[a] | 595 | 1000[a] | 1000[a] | 1000[a] | 0.75 |

NOTE Measurement uncertainty is increased if the ratio of the differential to static pressure (both expressed in psia) exceeds 0.2 or 20 %. Care should be taken to not violate the recommendations or tolerances stated in Table 3 and Annex E.

[a] Although the structural integrity of the flange mounting will allow calculated values for the maximum orifice plate differential pressures in excess of 1000 in. of water, the coefficient of discharge database is limited to 1000 in. of water.
Assumptions for determining maximum differential pressures across orifice plates in orifice fittings:

1) Support diameter ($D_s$) is 0.2 in. less than outside orifice plate diameter.

2) Internal diameter ($D$) is the largest diameter in Table 4 of API *MPMS* Chapter 14.3.2/AGA Report No. 3 Part 2.

3) Maximum differential values are for orifice plates at a flowing temperature less than or equal to 150 °F ($T_f \leq 150$ °F).

**Table E-1—Maximum Allowable Calculated Differential Pressure Across 304/316SS Orifice Plate at 150 °F (continued)**

| | 16 in. | | | | | | | | 20 in. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.250 plate | | 0.375 plate | | 0.4375 plate | | 0.500 plate | | 0.250 plate | | 0.3125 plate | | 0.375 plate | | 0.4375 plate | | 0.500 plate | | |
| | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | |
| β-Ratio | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | β-Ratio |
| 0.20 | 200 | 1000[a] | 690 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 100 | 640 | 200 | 1000[a] | 345 | 1000[a] | 550 | 1000[a] | 825 | 1000[a] | 0.20 |
| 0.25 | 185 | 1000[a] | 630 | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 1000[a] | 90 | 650 | 185 | 1000[a] | 320 | 1000[a] | 505 | 1000[a] | 755 | 1000[a] | 0.25 |
| 0.30 | 170 | 1000[a] | 585 | 1000[a] | 930 | 1000[a] | 1000[a] | 1000[a] | 85 | 685 | 170 | 1000[a] | 295 | 1000[a] | 470 | 1000[a] | 700 | 1000[a] | 0.30 |
| 0.35 | 160 | 1000[a] | 545 | 1000[a] | 870 | 1000[a] | 1000[a] | 1000[a] | 80 | 750 | 160 | 1000[a] | 275 | 1000[a] | 440 | 1000[a] | 655 | 1000[a] | 0.35 |
| 0.40 | 150 | 1000[a] | 515 | 1000[a] | 820 | 1000[a] | 1000[a] | 1000[a] | 75 | 850 | 150 | 1000[a] | 260 | 1000[a] | 415 | 1000[a] | 620 | 1000[a] | 0.40 |
| 0.45 | 145 | 1000[a] | 495 | 1000[a] | 785 | 1000[a] | 1000[a] | 1000[a] | 70 | 995 | 145 | 1000[a] | 250 | 1000[a] | 395 | 1000[a] | 595 | 1000[a] | 0.45 |
| 0.50 | 140 | 1000[a] | 480 | 1000[a] | 760 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 140 | 1000[a] | 240 | 1000[a] | 385 | 1000[a] | 575 | 1000[a] | 0.50 |
| 0.55 | 135 | 1000[a] | 470 | 1000[a] | 745 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 135 | 1000[a] | 235 | 1000[a] | 380 | 1000[a] | 565 | 1000[a] | 0.55 |
| 0.60 | 135 | 1000[a] | 465 | 1000[a] | 740 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 135 | 1000[a] | 235 | 1000[a] | 375 | 1000[a] | 560 | 1000[a] | 0.60 |
| 0.65 | 135 | 1000[a] | 465 | 1000[a] | 740 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 135 | 1000[a] | 235 | 1000[a] | 375 | 1000[a] | 565 | 1000[a] | 0.65 |
| 0.70 | 140 | 1000[a] | 475 | 1000[a] | 755 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 140 | 1000[a] | 240 | 1000[a] | 385 | 1000[a] | 575 | 1000[a] | 0.70 |
| 0.75 | 140 | 1000[a] | 485 | 1000[a] | 775 | 1000[a] | 1000[a] | 1000[a] | 70 | 1000[a] | 145 | 1000[a] | 250 | 1000[a] | 395 | 1000[a] | 595 | 1000[a] | 0.75 |

NOTE Measurement uncertainty is increased if the ratio of the differential to static pressure (both expressed in psia) exceeds 0.2 or 20 %. Care should be taken to not violate the recommendations or tolerances stated in Table 3 and Annex E.

[a] Although the structural integrity of the flange mounting will allow calculated values for the maximum orifice plate differential pressures in excess of 1000 in. of water, the coefficient of discharge database is limited to 1000 in. of water.
Assumptions for determining maximum differential pressures across orifice plates in orifice fittings:

1) Support diameter ($D_s$) is 0.2 in. less than outside orifice plate diameter.

2) Internal diameter ($D$) is the largest diameter in Table 4 of API *MPMS* Chapter 14.3.2/AGA Report No. 3 Part 2.

3) Maximum differential values are for orifice plates at a flowing temperature less than or equal to 150 °F ($T_f \leq 150$ °F).

**Table E-1—Maximum Allowable Calculated Differential Pressure Across 304/316SS Orifice Plate at 150 °F (continued)**

| | 24 in. | | | | | | | | | | 30 in. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.250 plate | | 0.375 plate | | 0.4375 plate | | 0.500 plate | | 0.5625 plate | | 0.375 plate | | 0.4375 plate | | 0.500 plate | | 0.5625 plate | | |
| | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | Fitting | Flange | |
| β-Ratio | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | in. $H_2O$ | β-Ratio |
| 0.20 | 60 | 360 | 215 | 1000[a] | 340 | 1000[a] | 510 | 1000[a] | 725 | 1000[a] | 105 | 610 | 170 | 965 | 255 | 1000[a] | 365 | 1000[a] | 0.20 |
| 0.25 | 55 | 365 | 195 | 1000[a] | 310 | 1000[a] | 465 | 1000[a] | 665 | 1000[a] | 95 | 615 | 155 | 980 | 235 | 1000[a] | 335 | 1000[a] | 0.25 |
| 0.30 | 50 | 385 | 180 | 1000[a] | 290 | 1000[a] | 435 | 1000[a] | 615 | 1000[a] | 90 | 650 | 145 | 1000[a] | 215 | 1000[a] | 310 | 1000[a] | 0.30 |
| 0.35 | 50 | 420 | 170 | 1000[a] | 270 | 1000[a] | 405 | 1000[a] | 580 | 1000[a] | 85 | 710 | 135 | 1000[a] | 205 | 1000[a] | 290 | 1000[a] | 0.35 |
| 0.40 | 45 | 480 | 160 | 1000[a] | 260 | 1000[a] | 385 | 1000[a] | 550 | 1000[a] | 80 | 805 | 130 | 1000[a] | 195 | 1000[a] | 275 | 1000[a] | 0.40 |
| 0.45 | 45 | 560 | 155 | 1000[a] | 250 | 1000[a] | 370 | 1000[a] | 530 | 1000[a] | 75 | 945 | 125 | 1000[a] | 185 | 1000[a] | 265 | 1000[a] | 0.45 |
| 0.50 | 45 | 690 | 150 | 1000[a] | 240 | 1000[a] | 360 | 1000[a] | 515 | 1000[a] | 75 | 1000[a] | 120 | 1000[a] | 180 | 1000[a] | 260 | 1000[a] | 0.50 |
| 0.55 | 45 | 880 | 150 | 1000[a] | 240 | 1000[a] | 360 | 1000[a] | 510 | 1000[a] | 75 | 1000[a] | 120 | 1000[a] | 180 | 1000[a] | 255 | 1000[a] | 0.55 |
| 0.60 | 45 | 1000[a] | 150 | 1000[a] | 240 | 1000[a] | 360 | 1000[a] | 510 | 1000[a] | 75 | 1000[a] | 120 | 1000[a] | 180 | 1000[a] | 255 | 1000[a] | 0.60 |
| 0.65 | 45 | 1000[a] | 155 | 1000[a] | 245 | 1000[a] | 365 | 1000[a] | 520 | 1000[a] | 75 | 1000[a] | 120 | 1000[a] | 185 | 1000[a] | 265 | 1000[a] | 0.65 |
| 0.70 | 45 | 1000[a] | 160 | 1000[a] | 250 | 1000[a] | 385 | 1000[a] | 540 | 1000[a] | 80 | 1000[a] | 125 | 1000[a] | 190 | 1000[a] | 270 | 1000[a] | 0.70 |
| 0.75 | 50 | 1000[a] | 165 | 1000[a] | 265 | 1000[a] | 400 | 1000[a] | 570 | 1000[a] | 85 | 1000[a] | 135 | 1000[a] | 200 | 1000[a] | 285 | 1000[a] | 0.75 |

NOTE Measurement uncertainty is increased if the ratio of the differential to static pressure (both expressed in psia) exceeds 0.2 or 20 %. Care should be taken to not violate the recommendations or tolerances stated in Table 3 and Annex E.

[a] Although the structural integrity of the flange mounting will allow calculated values for the maximum orifice plate differential pressures in excess of 1000 in. of water, the coefficient of discharge database is limited to 1000 in. of water.
Assumptions for determining maximum differential pressures across orifice plates in orifice fittings:

1) Support diameter ($D_s$) is 0.2 in. less than outside orifice plate diameter.

2) Internal diameter ($D$) is the largest diameter in Table 4 of API *MPMS* Chapter 14.3.2/AGA Report No. 3 Part 2.

3) Maximum differential values are for orifice plates at a flowing temperature less than or equal to 150 °F ($T_f \leq 150$ °F).

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