Manual of Petroleum Measurement Standards
Chapter 22 TESTING PROTOCOLS

Section XX—Testing Protocol for Flow Conditioners for Orifice Meters

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Ave., NW, Washington, DC 20001, standards@api.org.

Contents

Testing Protocol for Flow Conditioners for Orifice Meters

1 Scope

This testing protocol covers any flow conditioner used to create desired flow profiles for Concentric, Square-Edged Orifice Meters as used under API MPMS Chapter 14.3. This testing protocol defines the baseline testing and all influence testing that is necessary to determine the performance of a flow conditioner as well as how the data from the testing is to be reported and analyzed.

2 Normative References

API Manual of Petroleum Measurement Standards (MPMS), Chapter 14.3, Concentric, Square-Edged Orifice Meters, Part 1 – Equations and Uncertainty Guidelines

3 (ANSI 1/API 2530, A.G.A. Report No. 3, GPA 8185) [All sections] ~~This document contains no normative references. A list of documents associated with API MPMS Ch. XX.XX are included in the bibliography.~~

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

~~3.1.1~~3.1

discharge coefficient (C_d)

The ratio of the actual flow rate through a primary device to the theoretical flow rate. The theoretical flow rate corresponds to the flow rate without any loss of energy due to friction.

3.1.1

discharge coefficient R-G (C_{dRG})

The discharge coefficient as determined from the Reader-Harris Gallagher equation from API MPMS Chapter 14.3.1.

3.1.2

discharge coefficient baseline (C_{dbase})

The discharge coefficient as determined from Test 1 (Baseline Test) of this standard.

3.1.3

discharge coefficient test (C_{dtest})

The discharge coefficient as determined from each of Tests 2-5 of this standard.

3.2

disturbance

Any installation upstream of a primary device which significantly alters either the flow profile or the amount of swirl in the pipe.

3.3

flow conditioner

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~~API 14.3, Part 2, for installation requirements.

Commented [KF1]: Not sure if we should reference the tables or just the standard for all installation requirements.

For the purposes of this standard, 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.

3.4
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.

3.5
meter tube internal diameter (D~~i~~)

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.~~The straight sections of pipe, including all segments that are integral to the orifice plate holder, upstream and downstream of the orifice plate.~~

3.6
NIST primary standards

A device or object used as the reference in a calibration that is acknowledged to be of the highest metrological quality and that derives its measurement without reference to some other standard of the same quantity maintained by The National Institute of Standards and Technology (NIST).

3.7
Orifice diameter ratio (β)

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

3.8
published meter tube internal diameter (D_i)

The inside diameter as published in standard handbooks for engineers.-

3.9
Reynolds Number (Re_D)

The Reynolds number is the ratio of the inertial forces to the viscous forces of the fluid flow. This non-dimensional parameter is defined as, $\frac{rVD}{m}$, where V is the average axial velocity, r is the density of the fluid, m is the absolute viscosity of the fluid, and D is a characteristic length, which in most applications is the meter tube diameter for Re_D or bore diameter for Re_d.

3.10
scaling

Testing to determine if the flow conditioner performance changes as a function of the line size of the meter run.

3.11
test facility

A facility capable of performing assessments of flow meters and whose measurements are traceable to

NIST (National Institute of Standards and Technology), other national standards bodies, or applicable regulatory agencies.

3.12

third party

A party that is neither the manufacturer of the device or the user of the device.

3.13

uncertainty

A parameter associated with the result of a measurement that characterizes the dispersion of the values that could be reasonably be attributed to the measurand, often expressed in terms of its variance or standard deviation. (ISO GUM)

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

C_d	Discharge coefficient
C_{dRG}	Discharge coefficient R-G
C_{dbase}	Discharge coefficient baseline
C_{dtest}	Discharge coefficient test
ΔC_d	The change in discharge coefficient from either the R-G equation or the baseline test
D	Measured or calculated meter tube internal diameter
D_i	Published meter tube internal diameter
f	Friction factor
Re_l	The lower Reynolds Number tested during type approval testing
Re_h	The higher Reynolds Number tested during type approval testing
R-G	Reader-Harris Gallagher
R_a	Absolute average roughness of meter tube
TD1	Application Test from Section 6.1
TD2	Type Approval Test from Section 6.1
UL	Meter tube length upstream of orifice plate in multiples of published internal pipe diameters
UL1	Meter tube length from exit of disturbance to upstream edge of flow conditioner
UL2	Meter tube length from flow conditioner exit to upstream edge of orifice plate in multiples of published internal pipe diameters
β	Orifice diameter ratio

4 Field of Application

The application for this testing protocol is limited to devices that are used in the measurement of hydrocarbon fluids in the petroleum, energy, and petrochemical industries. In addition, this protocol is limited to single phase, steady-state, Newtonian fluids.

The application of this testing protocol assumes that the installation of the flow conditioner in the field conforms to the test conditions used in this protocol.

5 Parameter Variations Affecting Device Performance

5.1 Orifice Diameter Ratio or Commonly Referred to as β 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 β-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 β to gauge the installation or flow~~w~~ 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 ΔC_D values for both values of β are negligible, or if ΔC_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~~shall be performed for a complete range of β values between β = 0.20 and β = 0.75.

5.2 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.

6 Mandatory Tests

6.1 Objectives

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 ~~is included~~as in API 14.3.2 Annex C~~(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 (ΔC_d) between the measured discharge coefficient and the baseline discharge coefficient at the same β-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 β-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 1 and ~~2~~3:

$$10^4 \le Re_l \le 10^6 \text{ and } Re_h \ge 10^6 \qquad \text{Equation 1}$$

a) for $\beta = 0.67 \rightarrow f(Re_l) - f\cancel{f}(Re_h) \ge 0.0036$,

or b) for $\beta = 0.75 \rightarrow f(Re_l) - f\cancel{f}(Re_h) \ge 0.0030$

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):

Commented [CC2]: Do we want to use TD1 and TD2 in this document. this is what they are called in 14.3.2 Annex D.

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(i) the Colebrook-White equation

$$\frac{1}{\sqrt{f}} = 1.74 - 2log_{10}\left[6.3\frac{R_a\cancel{R_a}}{D} + \frac{18.7}{Re_D\sqrt{f}}\right]$$ Equation

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

(ii) the Moody diagram;

R_a is the absolute average roughness of meter tube.

$D_i \le 4$ in. and $D_i \ge 8$ in. Equation ~~2~~3

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).~~ Equation 1 and Equation ~~2~~3. The full sequence of *β*-ratio selection is defined in ~~API 14.3.2 Annex D Section D.2~~Section 5.1 ~~.~~.

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)~~Equation ~~2~~3. 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).~~Equation 1. 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 ~~API 14.3.2 Annex D Section D.2~~ Section 5.1.

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)~~Equation 1 is fulfilled for β = 0.67 only; *β* = 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 3×10^6, and the manufacturer or user of the flow conditioner is seeking an approval for applications in the range *Re* >= 3×10^6, 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 ΔC_D of the tested flow conditioner was one-half of the uncertainty limits ± 2σ of Reader-Harris Gallagher (R-G)~~RG~~ equation.

An installation and/or flow conditioner test should be performed for values of upstream meter tube length

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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.

6.2 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).

Commented [CC10]: Also on page 7, what do we want to call these in 22.xx

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 R-G ~~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.

6.3 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.

6.4 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.

6.5 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.

6.6 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.

7 Test and Calibration Facility Requirements

7.1 Test Facility Audit Process

The test facility performing the tests shall provide evidence that the tests are performed in accordance with requirements of this standard. This evidence shall be provided at the request of any user of the facility. Providing documentation that the tests were performed in accordance with the applicable test procedure is responsibility of the test facility. A manufacturer using a third-party test facility can request the system uncertainty of the testing facility to ensure the validity of the tests. The extent of the audit is determined by the user of the facility and shall be consistent with relevant national and/or international standards.

The test facility conducting the tests required in this protocol shall either provide the calculation details or be certified by a third party for the measurement uncertainty of each of the variables monitored and reported in the test results. All references used to establish the measurement uncertainty or performance specifications of the meter shall be traceable to national or internationally recognized standards. The system uncertainty of the calibration facility and each monitored variable included in the test report for establishing the performance of the meter shall include the measurement uncertainty with a 95% confidence interval. If requested by the user of the facility, the test facility shall provide the documentation of the procedure and calculation method used to establish the system uncertainty and frequency of verification, unless the performance uncertainty of the facility is certified and periodically verified by a nationally recognized third party. If the system uncertainty is certified by a third party, a copy of the valid certification would satisfy this requirement.

~~7.2 In-house Calibration Facility Verification Process~~

~~Unlike a test facility, the sole function of a calibration facility is to determine the discharge coefficient of individual field meters under baseline conditions. As such, a calibration facility does not need to meet the same standards that a test facility must meet. Some manufacturers may choose to individually flow-calibrate their meters in a calibration facility that is owned and operated by the manufacturer rather than sending the meters to an independent, unaffiliated facility. While this is an acceptable practice, independent verification of these in-house facilities is required by this protocol to:~~

~~— ensure that the discharge coefficients determined in them are statistically similar (see 8.3) to calibrations performed in an independent calibration facility;~~

~~— quantify the uncertainty of the discharge coefficient determined by the in-house facility; and~~

~~— provide the user of the meter with transparency in the testing process.~~

~~This section does not apply to independent calibration facilities meeting the requirements of 7.1 or to in-house calibration facilities that are accredited under ISO 17025. In-house calibration facilities shall make all calculations regarding the uncertainty of the facility available when requested by the customer.~~

~~In order for a manufacturer to claim that their model, type, or design of meter is compliant with this protocol, the model, type, or design of the meter shall be tested under this section at least every 12 months or anytime there is a change to the equipment or procedures used. When the results of 3 consecutive tests are acceptable, the testing frequency may be reduced to once every 24 months.~~

~~7.2.1 Required Testing at the In-house Calibration Facility~~

~~The calibration facility shall determine the discharge coefficient for one size and area ratio of the meter over the range of Reynolds numbers specified in 6.8.2. All testing shall be done in a baseline configuration as specified in 6.4. The calibrations shall be conducted in exactly the same manner that is used to determine the discharge coefficient for a user of the meter in the field. The serial numbers of the meters tested shall be recorded.~~

~~For each size and area ratio tested, the calibration facility shall report the discharge coefficient determined at each Reynolds number and the uncertainty of the discharge coefficient at each Reynolds number. These data should be shown both graphically and in table form. The uncertainty shall be calculated at a 95% confidence level.~~

~~7.2.2 Required Testing at the Test Facility~~

~~The test facility shall:~~

~~— determine the discharge coefficient of the same meters that were tested under 7.2.1;~~

~~— record the serial numbers of the meters received from the in-house calibration facility;~~

~~— meet the requirements of 7.1; and~~

~~— have a system uncertainty equal or better than the system uncertainty claimed by the calibration facility.~~

~~The testing of each meter shall be done in a baseline configuration (see 6.4) over the range of Reynolds numbers specified in 6.8.2. Testing shall be done using a test fluid that corresponds to the meter's intended use (i.e. if a meter is intended to be used for gas, it shall be tested with gas. If a meter is intended for use with liquid, it shall be tested with liquid).~~

~~For each type, size, and area ratio tested, the independent test facility shall report the discharge coefficient determined at each Reynolds number and the uncertainty of the discharge coefficient at each Reynolds number. These data should be shown both graphically and in table form. The uncertainty shall be calculated at a 95% confidence level.~~

7.~~3~~ 2 Test Facility Qualification

Test facility measurement systems for mass, length, time, temperature, and pressure shall be traceable to the NIST Primary Standards or applicable standards approved by regulatory agencies.

The test facility shall be able to determine values of the orifice discharge coefficient for orifice metering systems that meet the requirements of API MPMS Chapter 14.3.1 (2012), within the 95% confidence interval of the Reader-Harris Gallagher (R-G) equation.~~ The orifice metering system will be tested over the same Reynolds number range that the meter will be tested. The line size of the orifice meter(s) used to verify the facility shall allow these conditions to be met, but may otherwise be of any line size similar to the meters under test. The facility may be verified using historical orifice meter data taken within the previous one year of testing.~~

7.~~4~~ 3 Validity/Precision of Test Facility Results

If the test facility meets all the user requirements and any additional requirements defined in the testing protocol, then the results of the test shall be considered valid.

~~7.5 Test and Calibration Facility Uncertainty~~

~~Total lab uncertainty shall be more accurate than the stated uncertainty of the meter being tested and shall be calculated and reported at each Reynolds number used in the testing of the meter.~~

~~The calculation of uncertainty of the meter under test will include the uncertainty of the test facility.~~

8 Uncertainty and Statistical Significance Analysis and Calculation

~~There are three types of uncertainty and statistical significance calculations required in this protocol: 1) uncertainty of the test facility and the calibration facility, 2) uncertainty of the meter being tested and, 3) a significance determination that is dependent on the uncertainties of the test facility and the meter under test.~~

8.1 Test Facility and Calibration Facility Uncertainty

The uncertainty of the test facility and calibration facility instrumentation including the primary and secondary standard~~ for the specific fluid being tested shall be calculated and recorded~~s shall be verified by the baseline test and the performance of the test facility vs. the R-G equation. The uncertainty of the R-G equation shall be determined per API 14.3.1 Section 12.4.1. ~~From this, the uncertainty of the flow rate determined at a 95 % confidence level shall be determined in accordance with relevant uncertainty calculations (API MPMS Chapter 14.3.1 or ISO GUIDE 98-3). The methodology and formulas used shall be recorded in the test report.~~

~~Reproducibility of the test and calibration facility due to “turn-off, turn-on” and “day to day” considerations should be determined and included over the range of Reynolds numbers tested. These uncertainties are much larger (approximately 10 times) at low flow rates.~~

~~Uncertainty of secondary instrumentation (pressure and differential pressure transmitters) shall be considered. The performance of transmitters used as secondary devices is generally stated in terms of percent of span or percent of full scale. For use in flow measurement uncertainty calculations, the instrument uncertainties expressed as a percent of span shall be converted to percent of reading by the use of the following equation:~~

~~(8.1)~~
~~where~~
~~Urdg =uncertainty in percent of reading,~~
~~Uspan =specified uncertainty in percent of span,~~
~~Vmeas =value in units measured by the instrument,~~
~~Span =calibrated span of the instrument.~~

$$U_{rdg} = U_{span}\left(\frac{Span}{V_{meas}}\right)$$

~~where~~

~~U_{rdg} =uncertainty in percent of reading,~~

~~U_{span} =specified uncertainty in Percent of span,~~
~~V_{meas} =value in units measured by the instrument,~~
~~*Span* =calibrated span of the instrument.~~

~~To minimize the effects of ambient temperature on the secondary instrumentation, flow tests should be performed at a constant ambient temperature. Changes in the ambient temperature during the testing should be measured and recorded in the test report.~~

~~8.2 Meter Uncertainty~~

~~From the test results, the uncertainty of the meter under test during the baseline test (6.4) shall be calculated and reported in the test report (Section 9). A sample calculation methodology is presented in Annex B.4; however, other methods of determining meter uncertainty may also be acceptable. The uncertainty calculation procedure, if different from Annex B.4, shall be clearly described in the test report.~~

~~Regardless of the method used to determine uncertainty, the following guidelines shall be considered.~~

~~1) Test meter uncertainty is the variance (95% confidence) of the mean Cd determined by the test facility compared with the Cd predicted by the manufacturer at each Reynolds number tested. The mean Cd is the arithmetic average of the five or more points taken for each Reynolds number (see 6.8.2). The manufacturers' predicted Cd may be a constant value or an equation that is a function of Reynolds number; however, it shall be consistent with the Cd provided to the user to determine flow rate. The Cd determined by the individual flow calibration of the specific meter being tested shall be used to determine the uncertainty.~~

~~2) The statistical method used to determine the uncertainty should be appropriate for a small data set. Standard deviation is intended to be used with data sets greater than 30 points. Because 6.8.2 requires only 10 points, an alternate method shall be used such as a "Student t-distribution". Other methods may also be acceptable but shall be documented in the test report.~~

~~3) If the statistical analysis shows that the manufacturer's predicted Cd results in a bias greater than the uncertainty of the test facility (determined in 8.1), then the manufacturer shall either offer a new Cd or disclose the bias in the test report.~~

~~4) In no case can the uncertainty of the Cd be less than the uncertainty of the test facility.~~

8.2~~3~~ Determination of Statistical Significance

~~8.3.1 Installation Effects~~

~~The test report shall include a statistical analysis to determine if the Installation Effect Tests are statistically similar to the corresponding Baseline Tests. If the statistical analysis concludes the results are statistically similar, the meter may be used with the upstream and downstream pipe lengths from the worst-case Installation Effect Test with no additional uncertainty or bias. If the results are not similar, the manufacturer has the option of re-running the Installation Effect Tests with longer upstream and/or downstream lengths of meter pipe, or quantifying the additional uncertainty and/or bias associated with the Installation Effect Test configuration.~~For Test 1, the baseline test shall be deemed to be acceptable if the difference between the test discharge coefficient and the discharge coefficient calculated by the R-G equation is within the uncertainty limits of of the R-G equation.

For Tests 2-5, the test shall be deemed to be acceptable if the difference between the test discharge coefficient and the discharge coefficient determined during the respective baseline test is within half of the uncertainty limits of of the R-G equation.
~~Annex B.5 presents a methodology for determining statistical significance. Other methods may be used; however, a complete description of the method shall be included in the test report.~~

9 Test Report

9.1 General

The raw data and test condition records of all tests, attested or certified by the test facility, if tests are performed at a third-party facility, shall be retained for future reference by the manufacturer of the device for verification if any of the reported results or computations is questioned at a later date. If a specific test report is not published in the public domain and is not available for verification of any claim, all claims based on that data will be deemed unverifiable.

To facilitate comparison between ~~meters~~flow conditioners, all tests shall be reported in the following set format. ~~Proof of the test facility's compliance with Section 8 shall be presented in the report.~~ The result of the tests should be reported in tabular ~~and graphical~~ form, including results of the baseline tests~~,~~ and all flow conditioner installation tests ~~installation effect tests, gas expansion factor equation tests, and special installation tests, if applicable~~. The test report shall contain the following information.

9.2 Test Facility Information

— Name and location of the test facility

— Date and time of test

— Unique Test Identification Number

— Fluid(s) used

— Type of test installation or API 22.xx Test Number

— Meter tube ID at reference temperature (D_r) (inches)

— Orifice Diameter at reference temperature (d_r) (inches)
~~— Differential pressure, static pressure, and temperature transmitter manufacturer, model number, and uncertainty. Copies of the calibration certificates shall be included for all the transmitters.~~

~~— Surface roughness of the upstream and downstream meter pipes shall be recorded.~~

~~— If a densitometer is used, the model number, uncertainty, and calibration certificates shall be included.~~

~~9.3 Calibration Facility Information~~

~~— Name and location of the facility performing the individual flow calibrations for each meter~~

~~— Date and time of test~~

~~— Fluid(s) used~~

~~— Type of test performed (e.g. weigh tank, flow nozzle, master meter)~~

~~— Description and specifications of all equipment used in the flow calibration (e.g. make, model, uncertainties, calibration certificates)~~

~~— Surface roughness of the upstream and downstream meter pipes shall be recorded.~~

~~— If a densitometer is used the model number, uncertainty, and calibration certificates shall be included.~~

~~— A description of how the data collected is used to establish the discharge coefficient for each meter.~~

9.34 Flow Conditioner~~Meter~~ Information

— Name of the ~~meter~~ flow conditioner manufacturer

— Type/Name/Description of the flow conditioner ~~meter~~

— ~~Meter~~ Flow conditioner serial number and model number

— Nominal size of ~~meter~~ flow conditioner and piping

~~— Meter and piping schedule with pressure rating~~

— ~~Meter~~ Flow conditioner geometry and critical dimensions (drawing of the flow conditioner, may be separate attachment~~meter~~)

~~— Manufacturer's predicted discharge coefficient; this may be a constant value or an equation.~~

~~— All equations required to predict the flow rate for the test meter should be clearly stated in the test report, especially those that are specifically used for that type of meter design. Equations should include the expansion equation (including the limitations for DP/Pf), the discharge coefficient equations and the flow rate equation, when applicable.~~

— ~~Position and type~~Orientation of ~~any required~~ flow conditioner relative to orifice taps

9.4~~5~~ ~~Description of the Full Test Matrix and~~Testing Results

For each test (Tests 1-5), the following information is required at a minimum:

— Mass flowrate as measured by the reference meter (pounds mass per second)

— Temperature measured downstream of orifice plate (°F)

— Static pressure measured at the orifice plate and tap location of static pressure measurement (psia)

— Differential pressure measured across the orifice plate (inches of water at 68°F)

— Beta corrected for flowing temperature (dimensionless)

— Density of fluid (pounds per cubic foot)

— Viscosity of fluid (centipoise)

— Isentropic Exponent (dimensionless)

— Pipe Reynolds Number (ReD) calculated for the test (dimensionless)

— Expansion factor calculated for the test (dimensionless)

— Uncertainty in R-G Equation discharge coefficient calculated for the test (%)

9.4.1 Test 1 (Baseline Test)

Additionally, the following information is required for Test 1 (baseline test):

— Discharge coefficient from test (Cd_{base}) (dimensionless)

— Discharge coefficient from R-G equation (Cd_{RG}) (dimensionless)

— $Cd_{base} – Cd_{RG}$

— Percent difference between Cd_{base} and Cd_{RG}

9.4.2 Test 2-5 (Flow Conditioner Installation Tests)

Additionally, the following information is required for Test 2-5 (Flow Conditioner Installation Tests):

— Statement that all flow conditioner installation testing was performed with the same facility equipment as the corresponding baseline test

— Distance from orifice plate to flow conditioner (UL2) (nominal Pipe Diameters)

— Distance from upstream disturbance to flow conditioner (UL1) (nominal Pipe Diameters)

— Discharge coefficient from test (Cd_{test}) (dimensionless)

— Discharge coefficient from corresponding baseline (Cd_{base}) (dimensionless)

— $Cd_{test} – Cd_{base}$

— Percent difference between Cd_{test} and Cd_{base}

~~— Clear indication of test type (e.g. “baseline” or “installation effect: high swirl”, etc.)~~

~~— Manufacturer's required upstream and downstream piping and actual installed lengths~~

~~— Meter orientation (i.e. horizontal or vertical)~~

~~— Specific test conditions, including pressures, temperatures, flow rates, differential pressures, and fluid properties~~

~~— Table of results, including estimates of uncertainty in measurement parameters~~

~~— Test summary, including the meter uncertainty determined from the baseline testing, all test conditions for which the stated uncertainty is valid, and the conclusions from the statistical analysis comparing the baseline tests and the installation effect tests.~~

~~— Meter asymmetry with respect to the orientation of the upstream and downstream disturbances (see 5.3)~~

~~— The maximum velocity, DP, and DP/Pf for each set of meter tests~~

~~— The laboratory should record the presence of excessive noise from the meter, if noted during the baseline testing of the meter.~~

~~— The results of any specific installation testing~~

9.5 ~~6~~ Sample Meter Test Reporting Form

Commented [CC11]: THIS SHOULD BE REVISED WITH NEW NUMBERS

The following are example test reporting forms that may be used to report the test results.

9.5.1 Test 1 – Baseline Test

Test Facility Information	
Test Facility:	Date:
Location:	Time:
Fluid:	Test Number:
Meter Tube ID:	API 22.XX Test:
Orifice Diameter:	

Flow Conditioner Information	
Make:	Model:
Serial Number:	

Testing Results - Baseline Test							
Mass Flowrate	Temperature	Pressure	Differential Pressure	Beta @ Tf	Density	Viscosity	Isentropic Exponent

LBMS	°F	psia	"H20 @68	dim	lb/ft3	cP	dim
Expansion Factor	Pipe Reynolds Number	Discharge Coefficent	Discharge Coefficent	Diff	Diff	Uncertainty of R-G	In Tolerance?
dim	dim	From Test	R-G Equation		%	%	

9.5.2 Tests 2-5 (Flow Conditioner Installation Tests)

Test Facility Information	
Test Facility:	Date:
Location:	Time:
Fluid:	Test Number:
Meter Tube ID:	API 22.XX Test:
Orifice Diameter:	

Flow Conditioner Information	
Make:	Model:
Serial Number:	

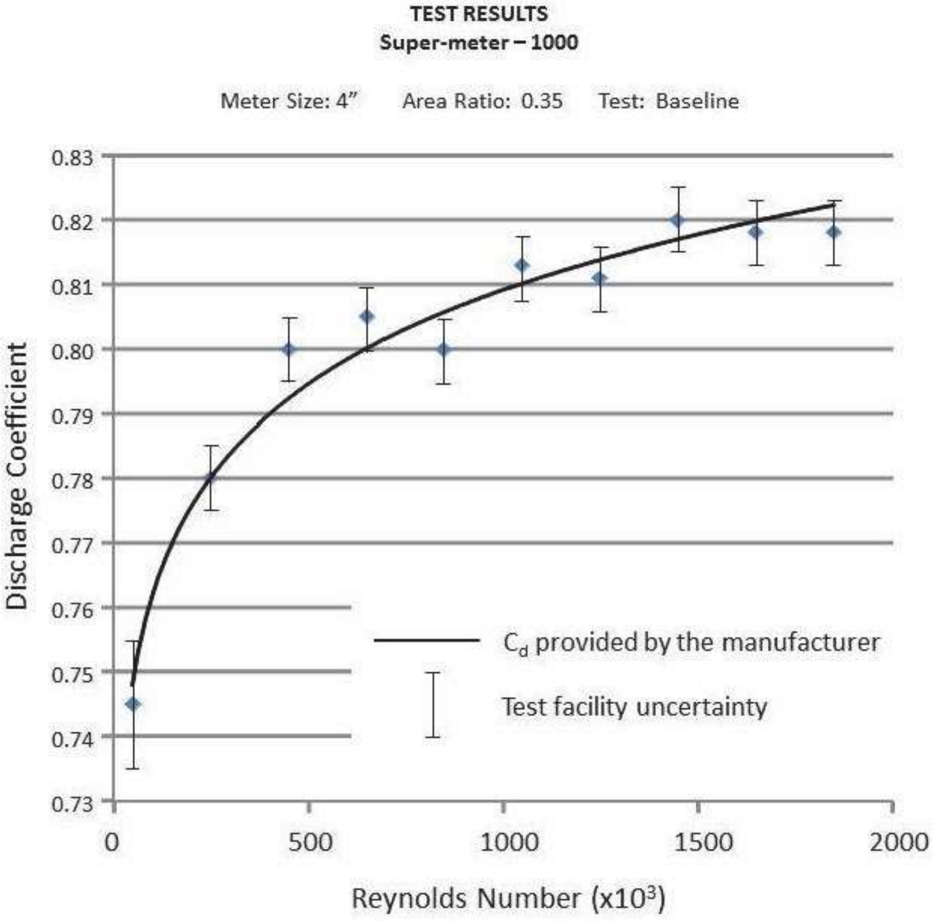
Testing Results - Testing was performed with the same facility equipment as baseline test number:

Mass Flowrate	Temperature	Pressure	Differential Pressure	Beta @ Tf	Density	Viscosity	Isentropic Exponent
LBMS	°F	psia	"H20 @68	dim	lb/ft3	cP	dim
Expansion Factor	Pipe Reynolds Number	Discharge Coefficent	Discharge Coefficent	Diff	Diff	Uncertainty of R-G	In Tolerance?
dim	dim	From Test	Baseline		%	%	
UL2	UL1						
(Nominal Ds)	(Nominal Ds)						

~~**Test Type:** Baseline~~	~~**Nominal Size:** 4~~	~~**Nominal Area Ratio:** 0.35~~
~~**Actual Piping:** 40D upstream, with flow conditioner at 10D; 10D downstream~~		
~~**Minimum Piping per Manufacturer:** 10D upstream, 2D downstream; No flow conditioner required~~		
~~**Orientation:** Horizontal~~	~~**Test Fluid:** Air~~	~~**Serial No.:** 02181982~~
~~**Meter type:** Super-meter 1000~~	~~**Actual ID:** 4.026~~	~~**Actual Area Ratio:** 0.3502~~

~~#~~	~~Q (scf/hr)~~	~~DP (in H2O)~~	~~P (psia)~~	~~T (°F)~~	~~DP/P~~	~~Reynolds Number~~	~~C_d~~				
							~~From Testing~~	~~Predicted (Equation)~~	~~Δ~~	~~Δ%~~	~~Uncertainty (95%)~~
~~1~~	~~4,249~~	~~0.19~~	~~402~~	~~66~~	~~0.00002~~	~~50,251~~	~~0.7451~~	~~0.7481~~	~~-0.0030~~	~~-0.3993~~	~~±1.1411~~
~~2~~	~~21,244~~	~~4.26~~	~~411~~	~~66~~	~~0.00037~~	~~250,574~~	~~0.7803~~	~~0.7803~~	~~0.0000~~	~~0.0007~~	~~±0.6050~~
~~3~~	~~38,239~~	~~13.50~~	~~398~~	~~64~~	~~0.00122~~	~~449,533~~	~~0.7998~~	~~0.7924~~	~~0.0074~~	~~0.9247~~	~~±0.5855~~
~~4~~	~~55,234~~	~~28.12~~	~~396~~	~~67~~	~~0.00256~~	~~651,015~~	~~0.8052~~	~~0.8001~~	~~0.0051~~	~~0.6365~~	~~±0.5850~~
~~5~~	~~72,229~~	~~47.64~~	~~404~~	~~66~~	~~0.00426~~	~~852,998~~	~~0.8001~~	~~0.8057~~	~~-0.0056~~	~~-0.7022~~	~~±0.5845~~
~~6~~	~~89,224~~	~~69.33~~	~~411~~	~~67~~	~~0.00609~~	~~1,047,562~~	~~0.8129~~	~~0.8102~~	~~0.0027~~	~~0.3332~~	~~±0.5839~~
~~7~~	~~106,220~~	~~102.54~~	~~395~~	~~66~~	~~0.00937~~	~~1,248,841~~	~~0.8110~~	~~0.8139~~	~~-0.0029~~	~~-0.3577~~	~~±0.5837~~
~~8~~	~~123,215~~	~~132.44~~	~~401~~	~~64~~	~~0.01192~~	~~1,453,680~~	~~0.8204~~	~~0.8171~~	~~0.0033~~	~~0.4057~~	~~±0.5831~~
~~9~~	~~140,210~~	~~169.80~~	~~407~~	~~64~~	~~0.01506~~	~~1,651,487~~	~~0.8178~~	~~0.8198~~	~~-0.0020~~	~~-0.2498~~	~~±0.5822~~
~~10~~	~~157,205~~	~~218.28~~	~~398~~	~~64~~	~~0.01979~~	~~1,850,006~~	~~0.8176~~	~~0.8223~~	~~-0.0047~~	~~-0.5753~~	~~±0.58~~

Commented [KF12]: Should we show examples or the reports (TD1 and TD2) with data?


TEST RESULTS
Super-meter – 1000
Meter Size: 4"
Area Ratio: 0.35
Test: Baseline
Discharge Coefficient
0.83
0.82
0.81
0.80
0.79
0.78
0.77
0.76
0.75
0.74
0.73
0
500
1000
1500
2000
Reynolds Number (x10³)
Cd provided by the manufacturer
Test facility uncertainty

~~Annex A~~

~~(informative)~~

~~Uncertainty Estimate~~

~~The most important assumption in the analysis and reporting of meter performance is that the random and systematic biases of the laboratory or test facility instruments are randomized within the data base. This means that the variations due to the biases of different equipment of the calibration laboratory are reported as the total uncertainty of the meter. Additionally the database is limited; hence evaluation of the meter uncertainty is likely to be more conservative than the true or actual uncertainty of the meter. This allows the use of results from reported data as a qualitative and quantitative representation of the performance of the meter. When the meter is tested at a facility whose performance and random and systematic biases are known with respect to other internationally recognized calibration facilities, a better assessment of the meter uncertainty is possible.~~

~~A.1 General Consideration~~

~~Many factors associated with differential-pressure flowmeter installations influence the overall error in flow measurement. These errors are due to uncertainties of the following:~~

- ~~representation of the actual flow rate by the mass flow-rate equation defined for the meter;~~
- ~~uncertainty in defining the actual physical properties of the fluid being measured;~~
- ~~measurement uncertainty associated with the measured physical dimensions of the metering device and the conduit that the flow equation is a function of.~~

~~Examples of the calculation of overall uncertainty based on the major parameters affecting uncertainty are given below.~~

~~A.2 Uncertainty Over a Flow Range~~

~~One of the primary contributors to the inaccuracy of a differential pressure meter is the uncertainty of the differential pressure sensing device (transmitter). Transmitter uncertainty is dependent on the quality of the transmitter and is normally a function of where the differential pressure reads as a percent of the transmitter's span. Typically, the lower the differential pressure, the higher the uncertainty of the differential pressure reading. Transmitter uncertainty is also a function of ambient temperature effects, static pressure effects, long term drift, hysteresis, linearity, repeatability, and the uncertainty of the calibration or verification standards.~~

~~For installations that measure a wide range of flow rates, "stacked" differential pressure transmitters can be used. With stacked transmitters a high range transmitter and a low range transmitter are both connected to a single set of pressure taps. At low flow rates (low differential pressure) the flow computer is programmed to use the reading from the low range transmitter to calculate flow rate. As the flow rate increases, the flow computer switches to read the high range transmitter at some set threshold. This allows the differential pressure reading to remain at a higher percent of the active transmitter's span over a wide range of flow rates, thereby reducing the uncertainty in measured differential pressure. The same affect can be achieved by using parallel meter runs.~~

~~A.3 Uncertainty of Flow Rate~~

~~The overall uncertainty is the root-sum-square of the uncertainty associated with the pertinent variables. For practical considerations, the pertinent variables are assumed to be independent to provide simpler uncertainty calculations. Generally, dependence of any of the variables on another that affects the flow rate calculation is negligible and has no discernible uncertainty contribution. Hence the assumption of independence of each variable is acceptable for the differential pressure devices.~~

~~The basic equation for determining flow rate is typically expressed as:~~

~~$q_m = N \frac{C_d Y A_r D^2}{\sqrt{1 - A_r^2}} \sqrt{\rho \Delta P}$~~

~~(A.1)~~

~~where~~

~~q_m =the mass flowrate,~~

~~N =a numeric conversion factor, including the acceleration due to gravity, g,~~

~~C_d =the coefficient of discharge for the meter, which may be a function of Reynolds number (Reynolds number is a function of D, r, q_m, and viscosity, μ),~~

~~A_r =the area ratio,~~

~~Y =the gas expansion factor (for incompressible fluid = 1),~~

~~D =the pipe diameter (assume circular cross section),~~

~~ρ =the density of the flowing fluid, and~~

~~ΔP =the differential pressure generated by the primary device.~~

~~It can be observed that the mass flow rate from the above equation is a function of the dimensions of the flow element, the fluid properties at the operating conditions, and differential pressure.~~

~~The uncertainty of each of the parameters listed above is specific to each design and size of the meter. In some meters the uncertainty of one or more of the parameters listed above may be highly sensitive to influences such as edge sharpness or dimensional tolerances, while other meters may be less sensitive to those influences. The meter manufacturer should specify which influences are the primary impacts to the meter performance. This will allow the user to estimate and minimize the uncertainty of the measurement of a specific meter design by following uncertainty calculation procedures accepted in the industry.~~

~~A.4 Typical Uncertainty~~

~~For precise measurement, such as custody transfer application, the flowmeter and meter piping should meet the minimum requirements specified for the device by the manufacturer. The typical uncertainties expressed in the following sections can be obtained only through compliance with the requirements specified by the manufacturer.~~

~~A.4.1 Empirical Coefficient of Discharge~~

~~The estimated uncertainty of the empirical coefficient of discharge for a differential pressure device is generally a function of the Reynolds number and the meter geometry. With many meter designs, the effect of Reynolds number on the coefficient of discharge diminishes as Reynolds number increases. The uncertainty of the discharge coefficient and the limits of the Reynolds number for the defined precision of measurement by the meter are to be specified by the manufacturer.~~

~~A.4.2 Empirical Gas Expansion Factor, Y, for Compressible Fluids~~

~~The value of Y computed by the empirical gas expansion factor equations are subject to an uncertainty varying from zero, when the differential pressure ratio (X = DP/P$_f$) is zero, to some larger value at the maximum allowable differential pressure ratio limit specified by the manufacturer. The manufacturer shall specify the uncertainty values of the gas expansion factor for their device as a function of the differential pressure ratio, X.~~

~~A.4.3 Installation Conditions~~

~~To assure accurate flow measurement, the fluid should enter the meter with a fully developed flow profile, free from swirl, asymmetries, or vortices. Such a condition is often achieved through the use of a flow conditioner and/or adequate length of straight pipe preceding and following the meter. Sensitivity to swirl, asymmetry, or vortices varies based on meter design, size, and area ratio. For various technical reasons the uncertainty associated with installation conditions is difficult to quantify. The combined practical uncertainty levels are generally contributed by the following:~~

- ~~empirical coefficient of discharge,~~
- ~~installation condition, velocity profile, and swirl; and~~
- ~~mechanical specifications of the dimensional parameters of the meter.~~

~~This testing protocol is designed to determine the sensitivity of a meter design, size, and area ratio to "worst case" flow profiles with the understanding that most real-world installations will result in flow profiles that are less distorted. The manufacturer should mitigate flow profile sensitivity by increasing the length of upstream and downstream meter pipe lengths, or by providing other means of flow conditioning, in order to ensure that the discharge coefficient is statistically similar to baseline conditions.~~

~~The intention of this protocol is to provide the user with data to allow the evaluation of relative performance of different meter designs based on how they perform under the same test conditions. The discharge coefficient uncertainty and the sensitivity of the discharge coefficient to installation effects may not be the same for all meters of the same design, size, and area ratio. This is due to the limited test database and random and systematic uncertainty of the flow facility that is embedded in the reported data.~~

~~A.4.4 Meter Pipe Internal Diameter, D_m~~

~~The uncertainty of the pipe diameter can be determined from the measured values of the pipe internal diameter. If the five measured pipe internal diameters are 20.006, 19.996, 19.998, 20.003, and 19.997, then the average is 20.000 and the differences are 0.006, -0.004, -0.002, 0.003, and -0.003. The uncertainty of the meter pipe internal diameter is the root-sum-square of the differences, which equals ±0.009 in. or ±0.04 %.~~

~~A.4.5 Secondary Instrumentation~~

~~Performance specifications for the differential pressure transmitter shall be provided by the manufacturer. The user selects a device based on its performance specifications and the desired uncertainty associated with the application.~~

~~When considering the uncertainty, care shall be taken to account for the effects of the ambient temperature, pressure, humidity, driving mechanism, and response time on the user selected device.~~

~~For gas flow measurement, the performance specifications for the static pressure transmitter and temperature transmitter shall also be considered.~~

~~A.4.6 Fluid Density~~

~~When an empirical correlation is used to predict a liquid density, the uncertainty should be estimated based on the stated uncertainty of the correlation and the estimated uncertainty of the variables required to calculate the density. The uncertainty calculation depends on the rate of change of density of the fluid due to changes in temperature and pressure at the operating conditions of the fluid.~~

~~A.4.7 Fluid Viscosity~~

~~Fluid viscosity affects the Reynolds number, which in turn affects the shape of the velocity profile and the discharge coefficient.~~

~~A.5 Significance Determination~~

~~The purpose of this section is to provide an objective methodology to compare two data sets to determine whether or not they are statistically similar. This statistical method of significance determination is required if no other acceptable method is provided. If another method is used, it shall be thoroughly explained, documented, and acceptable to all parties. This, or another acceptable method, is used to comply with 8.3 when comparing:~~

- ~~installation effects tests with baseline testing;~~
- ~~baseline tests at a low DP/P~~$_f$ ~~ratio with baseline tests at a high DP/P~~$_f$ ~~ratio; and~~
- ~~discharge coefficients determined at an in-house calibration facility with discharge coefficients determined in an independent test facility.~~

~~For each Reynolds number tested, this method establishes a significance threshold for the difference in discharge coefficients at that Reynolds number. If the difference in discharge coefficients is less than the significance threshold for all Reynolds numbers tested, the two data sets are considered to be statistically similar. If the difference in discharge coefficients for any Reynolds number tested exceeds the significance threshold for that Reynolds number, the two data sets are not statistically similar.~~

~~The significance threshold is defined as:~~

$$S_i = \sqrt{U^2_{fac1,i} + U^2_{fac2,i}}$$

~~(A.2)~~

~~where~~

S_i ~~= significance threshold for the discharge coefficient at Reynolds number~~ i, ~~±%~~

~~$U_{fac1,i}$ = uncertainty of discharge coefficient at Reynolds number i, from one test facility, ±% (see 8.1.1 for determining lab uncertainty)~~

~~$U_{fac2,i}$ = uncertainty of discharge coefficient at Reynolds number i, from a second test facility, ±% (see 8.1.1 for determining lab uncertainty)~~

~~When comparing test results determined in the same facility, the equation for significance threshold reduces to:~~

$$S_i = U_{fac,i}\sqrt{2}$$

~~(A.3)~~

~~where~~

~~$U_{fac,i}$ = uncertainty of discharge coefficient at Reynolds number i, from the facility performing the tests~~

~~EXAMPLE~~

~~The following table shows the results of a baseline test and a specific installation effect test done in the same test facility:~~

~~**Run Number**~~	~~**Reynolds Number**~~	~~**Baseline Test C_d**~~	~~**Installation Effect Test C_d**~~	~~**Deviation C_d (%)**~~	~~**Lab Uncertainty +/- (%)**~~	~~**Significance Threshold +/- (%)**~~
~~1~~	~~10,000~~	~~0.6870~~	~~0.6861~~	~~0.1310~~	~~0.468~~	~~0.6619~~
~~2~~	~~50,000~~	~~0.6895~~	~~0.6870~~	~~0.3626~~	~~0.441~~	~~0.6237~~
~~3~~	~~90,000~~	~~0.6901~~	~~0.6877~~	~~0.3478~~	~~0.430~~	~~0.6081~~
~~4~~	~~130,000~~	~~0.6907~~	~~0.6871~~	~~0.5212~~	~~0.422~~	~~0.5968~~
~~5~~	~~170,000~~	~~0.6910~~	~~0.6875~~	~~0.5065~~	~~0.418~~	~~0.5911~~
~~6~~	~~210,000~~	~~0.6913~~	~~0.6880~~	~~0.4774~~	~~0.413~~	~~0.5524~~
~~7~~	~~250,000~~	~~0.6912~~	~~0.6880~~	~~0.4630~~	~~0.410~~	~~0.5798~~
~~8~~	~~290,000~~	~~0.6915~~	~~0.6877~~	~~0.5495~~	~~0.407~~	~~0.5756~~
~~9~~	~~330,000~~	~~0.6913~~	~~0.6870~~	~~0.6220~~	~~0.406~~	~~0.5742~~
~~10~~	~~370,000~~	~~0.6910~~	~~0.6865~~	~~0.6512~~	~~0.406~~	~~0.5742~~

~~The tests were conducted in the same facility, therefore, the significance threshold in the right hand column is determined from Equation A.3. Because the difference in discharge coefficients between the baseline and installation effects test in run numbers 9 and 10 are greater than the significance threshold, the installation effects test is not statistically similar to the baseline test at those Reynolds numbers.~~

Bibliography

The following documents are directly referenced in this recommended practice.

ISO 5167:2022 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements ~~American Petroleum Institute, ANSI/API Standard 521/ISO 23251 Sixth Edition, *Pressure-relieving and Depressuring Systems*.~~

ISO 9951:1993 Measurement of gas flow in closed conduits — Turbine meters ~~CSA Z260: 2019 *Pipeline System Safety Metrics*[1]~~

NIST Technical Note 1264 : Measurements of Coefficients of Discharge for Concentric Fiange-Tapped Square-Edged Orifice Meters in Water Over the Reynolds Number Range 600 to 2,700,000 - 1989

~~[1] Canada Standards Association Group, 178 Rexdale Blvd. Toronto,ON M9W 1R3, Canada https://www.csagroup.org/standards/~~