Manual of Petroleum Measurement Standards Chapter 14—Natural Gas Fluids

Section XX— Venturi Metering of Natural Gas and Other Related Hydrocarbon Fluids

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Foreword

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Contents

Figures

Venturi Metering of Natural Gas and Other Related Hydrocarbon Fluids

1 Scope

This standard provides engineering equations, uncertainty estimations, installation requirements, and standardized implementation recommendations for the calculation of flow rate of single-phase fluids, liquid or gas, through concentric differential-pressure-producing Venturi meters.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API *MPMS Ch. 13 all applicable sections*
API *MPMS Ch. 14.3.1/AGA Report No. 3 Part 1, Concentric, Square-Edged Orifice Meters, Part 1-General Equations and Uncertainty Guidelines*
API *MPMS Ch. 14.3.2/AGA Report No. 3 Part 2/GPA 8185 Part 2, Concentric, Square-Edged Orifice Meters, Part 2-Specification and Installation Requirements*
API *MPMS Ch. 21.1, Flow Measurement Using Electronic Metering Systems – Electronic Gas Measurement*
API *MPMS Ch. 21.2, Flow Measurement Using Electronic Metering Systems – Electronic Liquid Volume Measurement Using Positive Displacement and Turbine Meters*
API *MPMS Ch. 22.2, Testing Protocol, Differential Pressure Flow Measurement Devices*
AGA *Report #6, Field Proving of Gas Meters Using Transfer Methods*
ASME *MFC-3M, Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi*
ASME *PTC 19.5, Performance Test Codes, Flow Measurement*
ISO *5167-4, Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full, Part 4: Venturi Tubes*

3 Terms, Definitions, and Symbols

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

3.1
absolute viscosity (μ)
The measure of resistance to shear per unit of time of a fluid's intermolecular cohesive force.

3.2
axial flow velocity (V)
The component of liquid flow velocity at a point in the measurement section that is parallel to the measurement section's axis and in the direction of the flow being measured.

3.3
calibration
A set of operations which establish, under specified conditions, the relationship between the values indicated by a measuring device and the corresponding known values indicated when using a suitable measuring standard.

3.4
custody transfer measurement
Provides quantity and quality information for the physical and fiscal documentation of a change in ownership and/or a change in responsibility for commodities.

3.5
density (*ρ*)
The mass contained in a unit volume.

3.6
diameter ratio (beta) (*β*)
The ratio of the diameter of a circle, that produces the same area as the smallest flow area, to the internal diameter of the meter tube.

3.7
differential pressure (*ΔP*)
The pressure difference between the high and low-pressure taps.

3.8
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.

3.8.1
calibrated discharge coefficient (C_d)
The discharge coefficient determined at specific Reynolds numbers and configurations during a flow calibration of the meter under baseline conditions. The calibrated Cd is typically presented as an equation that curve-fits the individual discharge coefficients determined during flow calibration of the meter or as a fixed value representing the average discharge coefficient determined during flow calibration of the meter.

3.8.2
predicted discharge coefficient
The discharge coefficient determined according to the standard and fabrication method used to construct the differential meter, unless provided by the manufacturer.

3.9
expansion factor (Y)
A factor used to correct the calculated flow rate for the reduction in fluid density that a compressible fluid experiences due to its increased velocity when it passes through a restriction.

3.10
flow conditioner
A device designed to minimize the effect of flow profile distortions on the meter performance.

3.11
flow rate (q_m, q_v, Q_v)
The quotient of a volume or mass of fluid passing a point in a line per unit of time.

3.12
isentropic exponent (κ)
The isentropic exponent (κ) is a thermodynamic state property that establishes the relationship between an expanding fluid's pressure and density.

3.13
meter run
The section of piping which includes the upstream flow conditioning section and the downstream flow section.

3.14
meter tube internal diameter (*D*)
The inside diameter of the upstream section of the meter tube.

3.15
Newtonian fluid
A fluid whose viscosity does not change with rate of flow.

3.16
pulsations
Irregular fluid flow in a piping system resulting from pressure variations.

3.17
pressure loss
The differential pressure in the flowing fluid stream (which will vary with flow rate) between the inlet and the outlet of a meter, flow straightener, valve, strainer, lengths of pipe, etc.

3.18
tap hole
A hole radially drilled in the wall of the meter tube, perpendicular to the centerline of the meter tube, the inside edge of which is flush, without burrs, and as sharp as possible.

3.19
primary element
Any meter run geometry that a change will result in a change to the measured or calculated meter performance.

3.20
Reynolds number (*Re*)
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,

$$\boldsymbol{Re} = \frac{\boldsymbol{VD\rho}}{\mu}$$

, 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.

3.20.1
pipe Reynolds number (Re_D)
The Reynolds number within the meter pipe or meter body. Unless otherwise stated, the term “Reynolds number” refers to the Reynolds number within the meter pipe or meter body.

3.20.2
throat Reynolds number (Re_d)
The Reynolds number within the meter throat.

3.21
secondary devices
Instrumentation used to measure the variable parameters which are used in the determination of reported fluid volumes.

3.22
static pressure (P_f)
Pressure in a fluid or system that is exerted perpendicular to the surface on which it acts. In a moving fluid, the static pressure is measured at right angles to the direction of flow.

3.23
subsonic flow
Flow which occurs at a rate lower than the speed of sound.

3.24
swirl
Swirl is a condition in which the flow has a rotational (tangential) component in addition to the axial velocity component.

3.25
thermowell
Pressure and liquid tight receptacle adapted to receive a temperature sensing element and provided with external threads, flanges or other means for pressure tight attachment to a vessel. A thermowell allows the temperature sensor to be removed and replaced without compromising the process.

3.26
uncertainty
The range or interval within which the true value is expected to lie with a stated degree of confidence.

3.27
Venturi meter
A fluid flow measuring device which produces a differential pressure to infer flow rate. The primary element consists of a cylindrical entrance section, converging section, a concentric cylindrical section called the throat, and a diverging section. The restriction produces a pressure differential measured through tap holes on the upstream section and throat section.

3.27.1
classical (Herschel) Venturi meter
A Venturi meter design specified as a classical (Herschel) Venturi meter in industry standards. The industry standards define the specific geometry, fabrication methods, and tolerances required to produce a specified discharge coefficient.

3.27.2
proprietary Venturi meter
A Venturi meter design specific to a manufacturer. Proprietary Venturi meter designs may differ in geometry compared to the classical (Herschel) Venturi meter.

3.28
Venturi throat diameter (d)
The internal diameter of the throat section of a Venturi meter.

4 General

This standard provides a methodology to define the performance of Venturi meters and is intended specifically for Venturi meters in fiscal applications ranging from custody transfer measurement to fiscal allocation. It may provide useful guidance for Venturi meters used in non-fiscal or operational applications.

For fiscal applications, users are advised to apply testing protocols that prove the uncertainty of each meter's discharge coefficient in comparison to a reference facility or prover.

This standard is not meant to establish strict fabrication tolerances intended to ensure uniformity and geometric similarity between installations, such that a database of empirical data can be generalized and applied to individual Venturi meters without the need for flow calibration. However, if users fabricate Venturi meters with strict conformance to ISO 5167-4 or ASME MFC-3M standards and interested parties agree, users may elect to use the discharge coefficient uncertainty statements as stated in these standards. Users are cautioned that some Venturi meters fabricated according to these standards may not conform to the specified uncertainty. See Annex A for details.

This standard is specifically intended to describe the use of Venturi meters in natural gas and other hydrocarbon related fluids. The guidance included in this standard may be applicable to the use of Venturi meters in other process fluids as well.

5 Venturi Meter Principle of Operation

A Venturi meter is a fluid flow measuring device which produces a differential pressure to infer flow rate. The primary element consists of a cylindrical entrance section, converging section, a concentric cylindrical section called the throat, and a diverging section. The restriction produces a pressure differential between the upstream section and throat section. The differential pressure is measured across pressure tap holes located on the inlet and throat sections.

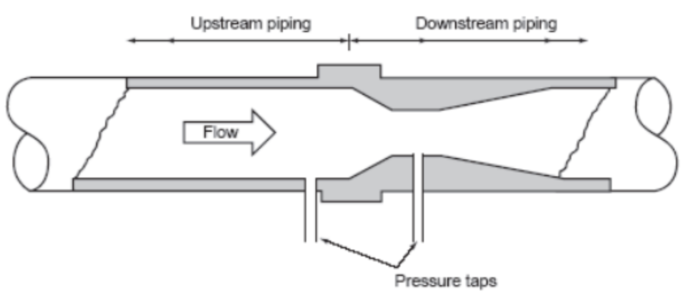

Figure 1 - Venturi Flow Meter

The Venturi meter beta is defined as the ratio of the internal diameter of the throat to the internal diameter of the entrance section.

The design of a Venturi meter is intended to reduce the permanent pressure loss across the device. The gradual changes in diameter and diverging outlet section allow for significant pressure recovery downstream of the throat.

The secondary devices necessary for the precise determination of flow rate are not included in the scope of this standard. These devices are usually instruments that sense the differential and static pressure, fluid temperature, and fluid density and/or relative density (specific gravity).

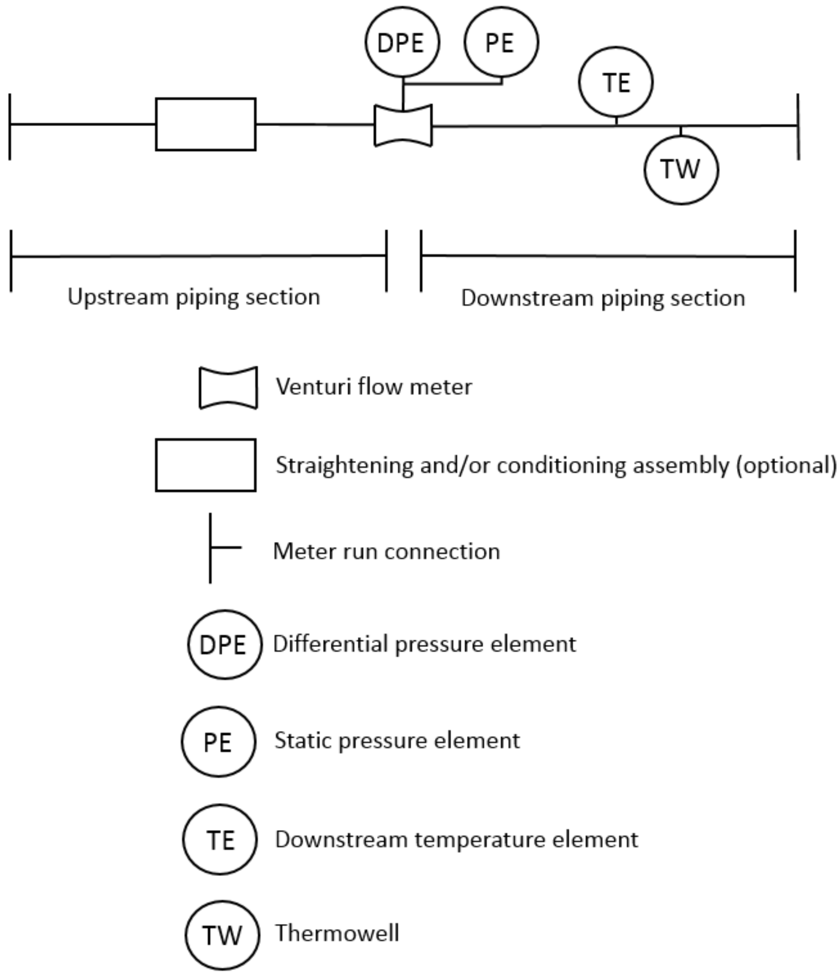

Figure 2 - Venturi Meter Elements

6 Venturi Meter Design

This standard defines the uncertainty of a Venturi meter measurement based upon a defined flow lab calibration and in-situ testing protocol, rather than previously determined empirical data dependent upon the meter design and fabrication tolerances. Venturi meters used in custody transfer and fiscal allocation applications shall be calibrated according to the procedures described in this standard to demonstrate the meter meet the specified uncertainty over the entire operating range. Flow calibration may be useful for Venturi meters used in non-fiscal or operational applications as well.

The most common Venturi meter design is the classical (Herschel) Venturi meter, which is specified in industry standards ASME MFC-3M and ISO 5167-4.

However, many supplier-specific variations to the classical (Herschel) Venturi meter design are possible. A proprietary Venturi meter design is considered within the scope of this standard if it follows the same basic physical geometry as the classical (Herschel) Venturi design described in Section 5.

Venturi meters may be fabricated using various methods including casting, machining, and welding. The method of construction is dependent on the Venturi meter size and metallurgy. The meter shall be fabricated to meet the regulatory or code requirements of the adjacent piping. Venturi meters should be constructed to the tolerances listed in ASME MFC-3M and ISO 5167-4, but meeting these tolerances is less critical when the meter is flow calibrated.

See ASME MFC-3M and ISO 5167-4 for recommendations related to the tap hole size, location, circularity, and edge sharpness. Supplier-specific variations to these criteria are considered within the scope of this standard if calibration of the Venturi meter determines the performance meets the specified uncertainty over the entire operating range.

A differential pressure measurement device shall measure the differential between the upstream and throat tap holes. If the Venturi meter is not flow calibrated, a minimum of two upstream and two throat tap holes are recommended on the Venturi meter. The multiple upstream tap holes are piped together and the multiple throat tap holes are piped together and used as the source for the differential pressure measurement. Typical configurations are referred to as “Triple-T” or piezometer rings. Additional tap holes may be installed if required.

7 Method of Calculation

See API MPMS Chapter 14.3.1 for fundamental equations describing the calculation of flow using a differential pressure measurement device, including the mass flow rate, volumetric flow rate, and volumetric flow at base (standard) conditions. This standard includes equations used to calculate coefficients and terms in the mass flow rate equation.

The equations in API MPMS Chapter 14.3.1 may be applied to Venturi meters. However, the expansion factor equations in API MPMS 14.3.1 are based on empirical data specifically related to orifice plates. ISO 5167-4 includes an expansion factor equation for Venturi meters operating in compressible fluids based on ideal gases which may be used as a reference.

The fluid’s physical properties may be determined by direct measurements, applicable technical standards, or equations of state. For natural gas applications, refer to API MPMS 14.3.3 for references to standards used for physical property determination. For fiscal measurement of other fluids, refer to an appropriate agreed upon method.

8 Discharge Coefficient

The discharge coefficient of a Venturi meter is generally a function of the meter geometry and the throat Reynolds number. For fiscal applications, the relationship between the throat Reynolds number and discharge coefficient of a Venturi meter shall be determined by laboratory calibration prior to use in this application. See Section 12 of this standard for details regarding acceptable flow calibration procedures.

9 Flow Conditions

Flowing conditions can influence field accuracy; therefore the following operating limitations apply to assure accuracy within the required uncertainty:

a) Fluids shall be clean, single phase, homogeneous, and Newtonian, otherwise the meter uncertainty will be impacted;

b) The fluid shall not undergo any change of phase as it passes through the flow meter;

c) The flow shall be subsonic through the flow meter;

d) The pipe Reynolds number shall be greater than 200,000 unless substantiated by a flow calibration;

e) The beta shall be within the range 0.4 to 0.7 unless substantiated by a flow calibration;

f) The flow shall be free from pulsations as per the definition and equation in API MPMS Chapter 14.3.2.

10 Installation

The installation and orientation of a Venturi meter may affect the performance; therefore the following practices should be followed to minimize these effects.

It is recommended for the diameter and schedule of the adjacent pipe to be the same nominal diameter as the Venturi meter. To avoid installation effects, see Section 11 for the recommended length of straight, interrupted piping upstream and downstream of the meter.

The meter shall also be installed so that gaskets do not protrude inside the pipe.

The meter shall be properly supported to reduce any effects of vibration and pipe stress.

For horizontal piping, the preferred orientation for the Venturi meter is with the tap holes at the horizontal centerline. Other tap hole orientations are possible, however, installations with the tap holes greater than 45 degrees below the meter centerline are not recommended as this increases potential for plugging. In liquid service, the tap holes shall also be oriented to remain liquid-full.

The location of secondary devices such as static pressure, temperature, and density may affect the overall uncertainty of the measurement. See Section 15 for recommended installation of secondary devices.

11 Meter Run

In order to assure a Venturi meter produces a measurement within the specified uncertainty, the fluid should enter the Venturi meter with a fully developed flow profile, free from swirl or vortices. Such a condition is best achieved through the use of adequate lengths of straight pipe preceding and following the Venturi meter or a flow conditioner.

The meter run includes the flow conditioner, if used.

Flow conditioners are devices that effectively remove or reduce the swirl component of a flow stream. Specifications for the description, installation, or uncertainty of flow conditioners are not included in this standard. These devices should be specified as required based on calibration or sufficient performance test data provided by the manufacturer.

It recommended to calibrate a Venturi meter as an assembly including the meter run in order to determine the effect of the upstream and downstream piping configuration on performance. If the Venturi meter and meter run cannot practically be transported for calibration fully assembled, this can be mitigated using alignment techniques such as pinning and match marking. If it is not possible to calibrate the Venturi meter with the meter run, the following straight length requirements apply to achieve the expected uncertainty:

a) For the classical (Herschel) Venturi meter design, refer to the straight length requirements in ASME MFC-3M and ISO 5167-4. The meter run shall meet the requirements for surface roughness and concentricity defined in these standards. If the required straight length is not available, a flow conditioner should be considered.

b) For proprietary Venturi meter designs, the manufacturer's straight length requirements should be consulted and substantiated with sufficient calibration test data to ensure the assembly meets the specified performance criteria. If manufacturer's recommendations are not available, the straight length requirements for the classical (Herschel) Venturi meter design described in ASME MFC-3M and ISO 5167-4 may be used as a reference only. However, proprietary Venturi meter designs might not meet the specified uncertainty if the installation effects are not known or validated with sufficient testing.

12 Flow Calibration

For fiscal applications ranging from custody transfer to allocation where specific performance is required, the relationship between the throat Reynolds number and discharge coefficient of a Venturi meter shall be determined prior to initial installation by calibration. See API MPMS Chapter 22.2 for calibration procedures and requirements, including verification of the flow lab where calibration is performed.

A meter shall be calibrated with a fluid in the same phase (liquid or gas) that corresponds with its intended use. Typically, water, air, or natural gas is utilized as the calibration fluid. Calibration with an alternative fluid is acceptable where transferability to the process fluid has been demonstrated.

To accurately determine the performance of a Venturi meter, it is recommended to perform a baseline calibration in a flow lab with the associated meter run. If it is not practical to calibrate the meter with the meter run, or a meter run is not used, the piping configuration in the flow lab shall be similar to the field installation including pipe lengths upstream and downstream of the meter. See API MPMS Chapter 22.2 for recommended installation effects testing procedures. If it is not practical to reproduce the field piping configuration in the calibration facility, use of the meter will result in measurement error.

Venturi meters shall be calibrated over the full operating Reynolds number range of the application. In some cases, it may not be practical to calibrate a Venturi meter over the entire operating range of Reynolds numbers due to limitations of available calibration facilities such as line size, flow rate, or process fluid conditions. The decision to use the meter beyond the calibrated range may be considered. However, the uncertainty of the measurement can significantly increase depending on the size and condition of the meter, as well as the extent the Reynolds number range is extrapolated past the calibrated range.

Refer to ASME PTC 19.5 for an example procedure to extrapolate meter performance beyond the calibrated range. Using this method, the dependence of the discharge coefficient on the throat Reynolds number is determined within the range the meter was calibrated, and the data is characterized using a linear regression. If the 95% confidence interval of the slope is greater than the absolute value of the slope, the calibration data may be accepted for extrapolation. The uncertainty of the extrapolation is heavily dependent on the calibrated range, so this range should be as large as feasible to reduce the uncertainty.

The calibration data shall be compared to the expected discharge coefficient as described in ASME MFC-3M and ISO 5167-4, or the discharge coefficient specified by the supplier for proprietary Venturi meter designs. A discrepancy beyond three standard deviations between the designed and calibrated discharge coefficient shall be investigated to identify potential sources of error.

Records should be provided which include the method used to individually calibrate each meter, the uncertainty of the calibration facility, the calibration fluid, the procedure used to determine the discharge coefficient, the range of throat Reynolds numbers and other conditions (e.g., temperature, pressure, and density at each flow rate), a description of the installation configuration(s), the serial number of the meter, and the name and location of the calibration facility.

Refer to API MPMS Chapter 22.2 for calibration reporting requirements.

13 Uncertainty of Measurement System

Many factors influence the overall measurement uncertainty associated with a metering application. Major contributors include uncertainty of flow calibration, predictability of and variations in the fluid's physical properties, and uncertainties associated with the secondary devices.

Using the guidelines contained in this standard, API MPMS Ch. 13, and other relevant industry standards in combination with the associated uncertainty tolerances for the fluid's physical properties, the discharge coefficient as determined by calibration, and the appropriate secondary devices, the user can define the overall measurement uncertainty associated with the Venturi meter assembly.

API MPMS Chapter 14.3.1 includes a useful example demonstrating an uncertainty calculation of the complete metering system.

14 Uncertainty of Discharge Coefficient

See Section 9 of this standard for limitations placed on the flow conditions. The discharge coefficient uncertainty increases outside these limitations; however, the uncertainty may be acceptable for the application and should be determined by calibration.

The flow calibration data shall be evaluated to determine the discharge coefficient uncertainty, which includes the calibration facility uncertainty and uncertainty associated with the method used to determine the meter discharge coefficient. A statistically significant data set of at least 20 data points shall be collected to determine the uncertainty of the Venturi meter discharge coefficient. The data shall be analyzed to determine the deviation at each point between the meter performance and reference value. See PTC 19.5 for a sample procedure used to evaluate the uncertainty of a flow calibration data set and deviation of the linear regression fit. Other methods of determining meter uncertainty may also be acceptable. The uncertainty calculation procedure, if different from the sample calculation method, shall be clearly described in the test report.

The uncertainty in average of the data set at a 95% confidence interval should not exceed 0.03% for a typical well-constructed meter at a qualified flow laboratory. If this uncertainty in average is not achieved with 20 calibration points, it may be possible to achieve the requirement by collecting additional calibration points.

See Annex A for a sample analysis of Venturi meter calibration data and uncertainty.

15 Secondary Devices

Refer to API MPMS Chapter 21.1 or 21.2 as appropriate for procedures regarding the use of secondary devices to accurately calculate the mass flow rate through the Venturi meter.

A differential pressure device shall be used to measure the differential pressure across the tap holes of the Venturi meter.

Static pressure shall be measured. The preferred location for the static pressure tap is in the upstream inlet meter tube, located 0.5D upstream of the point where the Venturi meter first begins to converge. However, if the meter is calibrated as a complete assembly, the effect of the location of the static pressure tap is accounted for in the calibration of the Venturi meter.

A temperature device should be located to sense the average temperature of the fluid at the Venturi meter. It is recommended to insert the temperature sensing device in the flowing stream within a thermowell. The preferred temperature sensing location is within 5 to 20 pipe diameters downstream of the Venturi meter throat tap hole. The temperature sensing location shall also be at least 2 pipe diameters downstream of the Venturi meter end connection.

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

Insulation of the meter and meter run may be required in the case of extreme temperature differences between the ambient temperature and the temperature of the flowing fluid and/or fluids being metered near their critical point, where small temperature changes may 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.

16 Fluid Density

When an empirical correlation is used to predict a fluid 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. If density is measured directly, the associated uncertainty is that of the device.

17 In-situ Calibration

Reference API MPMS chapter 14.3.1 for an example procedure for in-situ calibration. For in-situ calibration in gas, AGA Report # 6 also includes acceptable procedures.

18 Maintenance

Achieving the specified meter performance requires regular maintenance of the Venturi meter, secondary devices, and other metering system components. Maintenance of the differential pressure transmitter and other system components is not directly covered in this standard.

Due care shall be exercised to keep the Venturi meter internals clean and free from accumulation of coating, build-up, and other extraneous materials to the extent feasible by implementing a regular inspection schedule, as determined by the service conditions. Damage or accumulation of extraneous materials inside the Venturi meter may result in a greater uncertainty for the discharge coefficient. Based upon the inspection, the Venturi meter manufacturer may be contacted to determine the potential effects on performance, and recommended procedure to clean and/or service the meter.

To allow for regular inspection of the Venturi meter internals, it is recommended to install the meter with at least one flanged connection to enable access. If a bypass is installed to enable inspection, to ensure no leakage across the valve it is recommended to use methods to ensure positive closing of the bypass valve (e.g., double block and bleed). Note for custody transfer or regulatory applications bypass piping may not be permitted.

See Annex B for Venturi meter inspection guidelines.

If the Venturi meter is removed for cleaning or other purposes, it should be calibrated or proven in the field as soon as practical. If the Venturi meter does not perform within the specified uncertainty as determined by calibration or proving, it should be reconditioned if possible or replaced.

The secondary devices associated with the Venturi meter should also be verified on regular basis and calibrated, as necessary. Refer to API MPMS 21.1 for recommended verification and calibration procedures.

19 Auditing and Reporting Requirements

The metering system shall conform to the auditing and reporting requirements listed in API MPMS Chapter 21.1 or 21.2 as appropriate.

Annex A
(informative)

Venturi Meter Calibration Data

The ASME PTC 19.5 Committee obtained a representative sample of calibration data reflecting the performance of a Venturi meters in liquid and gas service and this data is shared by permission with API. The calibration data was collected at Colorado Engineering Experiment Station, Inc. (CEESI), Alden Research Laboratory, Inc., and Utah Water Research Laboratory.

The following sections compare Venturi meter measured discharge coefficients to the discharge coefficient predicted by calibration using the method described in this standard. The analysis also compares measured to predicted discharge coefficients for classical (Herschel) Venturi meters constructed according to industry standards ASME MFC-3M and ISO 5167-4.

A.1 Venturi Meter Liquid Calibrations

The calibration data for Venturi meters in liquid service is based on water calibrations from two independent certified flow calibration laboratories. These calibrations represent over 70 Venturi meters ranging in line sizes from 3” to 52”.[1]

The Venturi meters in this study were fabricated according to ASME MFC-3M and ISO 5167-4 standards for classical (Herschel) Venturi meters. These standards define the discharge coefficient for Venturi meters constructed to the specified criteria. Please note, the fabrication method was not recorded for Venturi meters in this study, so the predicted discharge coefficient is based on the assumption the majority of Venturi meters were machined as typical for the size range. Also, the throat diameter was not measured, so there may be minor variations between the as-designed and as-built throat diameter.

Figure 3 compares the measured discharge coefficient to the discharge coefficient predicted by standards. The measured discharge coefficient agrees with the predicted discharge coefficient defined in ASME MFC-3M and ISO 5167-4 within the uncertainty stated in these standards with few exceptions. This discrepancy may be due to assumptions made regarding meter fabrication methods and throat diameter.

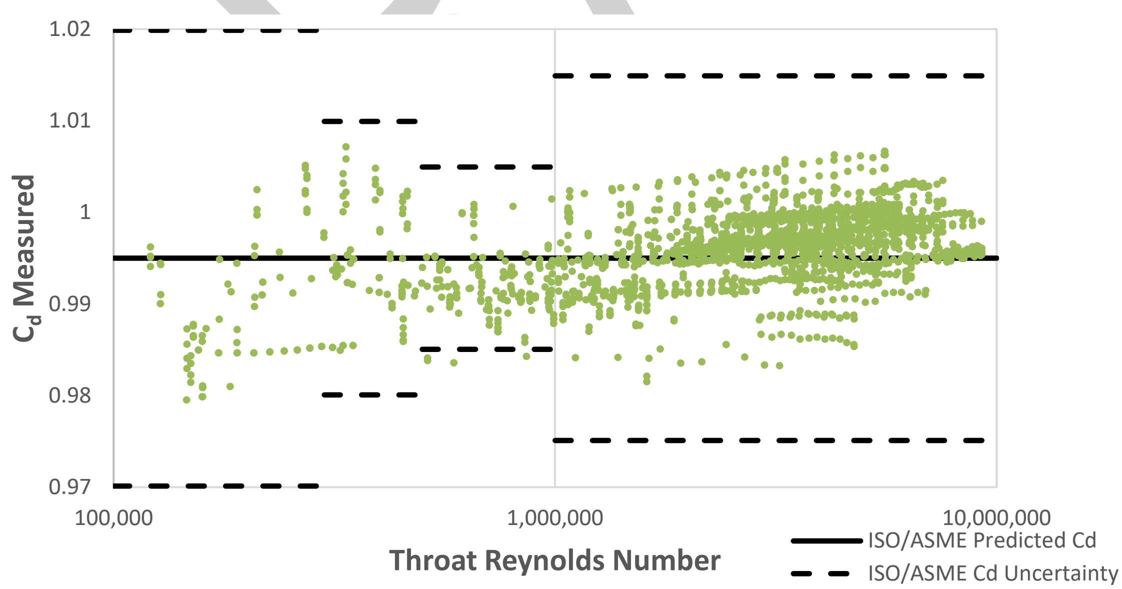

Figure 3 - Venturi Meter Liquid Calibration Data

[1] Water calibration data collected by ASME PTC 19.5 Committee from Alden Research Laboratory, Inc. and Utah Water Research Laboratory

For the Venturi meter liquid calibrations, the relationship between the discharge coefficient and the throat Reynolds number was determined according to the linear regression fit methodology described in ASME PTC 19.5. The data has been analyzed to determine the deviation at each point between the measured discharge coefficient and discharge coefficient determined by the linear regression calibration equation.

Figure 4 indicates the typical percent deviation between the measured discharge coefficient and calibrated discharge coefficient that can be expected for a Venturi meter calibrated in a liquid flow lab with an uncertainty of 0.25%. However, the uncertainty associated with the discharge coefficient for each meter should still be determined based on its individual calibration.

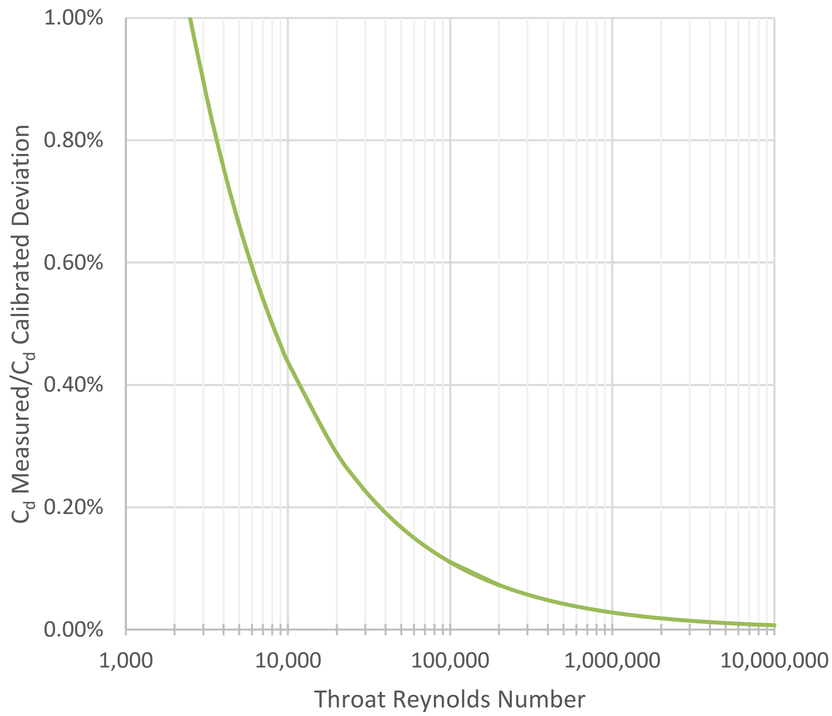

Figure 4 - Venturi Meter Liquid Percent Deviation C_d Measured / C_d Calibrated

A.2 Venturi Meter Gas Calibrations

The calibration data for Venturi meters in gas service is based on over 70 Venturi meter calibrations conducted in air service at CEESI.

The Venturi meters in this study were fabricated according to ASME MFC-3M and ISO 5167-4 standards for classical (Herschel) Venturi meters. These standards define the discharge coefficient for Venturi meters constructed to the specified criteria. Please note, the fabrication method was not recorded for Venturi meters in this study, so the predicted discharge coefficient is based on the assumption the majority of Venturi meters were machined as typical for the size range. Also, the throat diameter was not measured, so there may be minor variations between the as-designed and as-built throat diameter.

Figure 5 compares the measured discharge coefficient to the discharge coefficient predicted by standards.

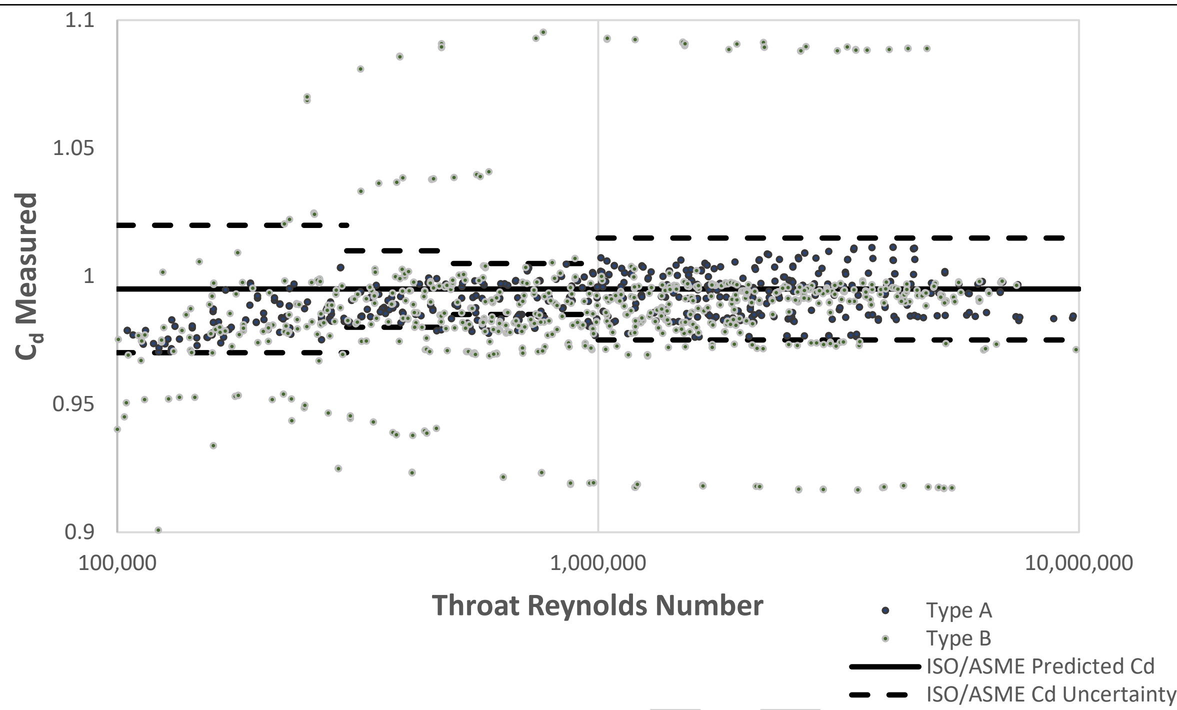

Figure 5 - Venturi Meter Gas Calibration Data Type A & B

In the technical paper describing the CEESI gas calibration findings[2], Venturi meters were divided into four categories based on performance and agreement with the predicted discharge coefficient defined in ASME MFC-3M and ISO 5167-4. Venturi meters categorized as "Type A" agree with the predicted discharge coefficient defined in these standards within the stated uncertainty. For Venturi meters categorized as "Type B", the majority of the measured discharge coefficients agree with the predicted discharge coefficient within the stated uncertainty. For "Type C" and "Type D", the calibrated discharge coefficient does not match the predicted discharge coefficient within the uncertainty defined in these standards.

This discrepancy may be partially attributed to assumptions made regarding the meter fabrication method and throat diameter. To compensate for the effect of this uncertainty in the actual throat diameter, this study shifted the measured discharge coefficients to align more closely with ISO and ASME standards.

Venturi meters categorized as "Type A" and "Type B" reflect Venturi meters which may be suitable for custody transfer applications, depending on the application requirements. "Type C" and "Type D" represent Venturi meters with higher uncertainty, likely associated with less precise fabrication.

The gas calibration data demonstrates minor deviations in construction, such as pronounced weld beads and weld seams or greater internal surface roughness, have a greater impact on Venturi meter performance in gas than in liquid service. These findings also highlight the importance of calibrating Venturi meters across the entire operating range of Reynolds numbers in order to define Venturi meter performance, especially in gas service.

[2] Kegel, T.M., "The ISO 5167 Compliant Design Venturi – A Further Summary of Calibration Experience", Flowmeko, Taipei, Oct. 13-15 2010.

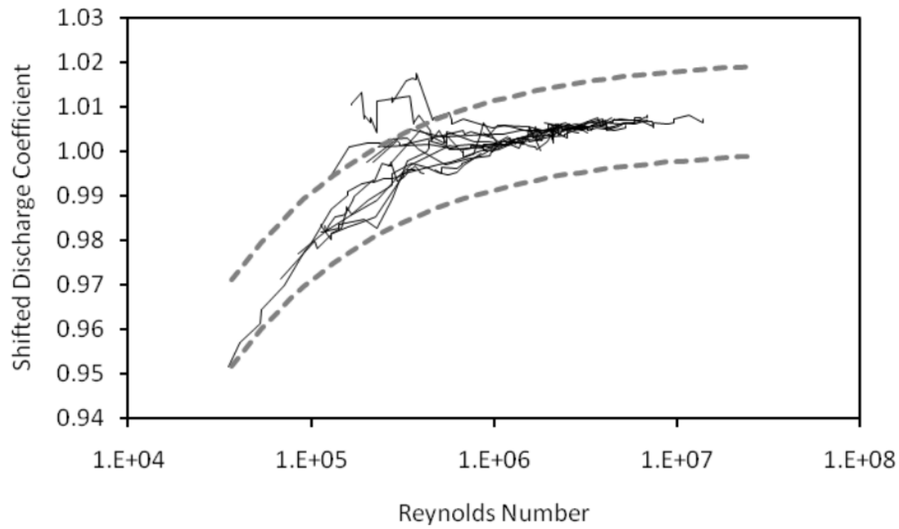

Figure 6 - Venturi Meter Gas Calibrations Classified as Type A

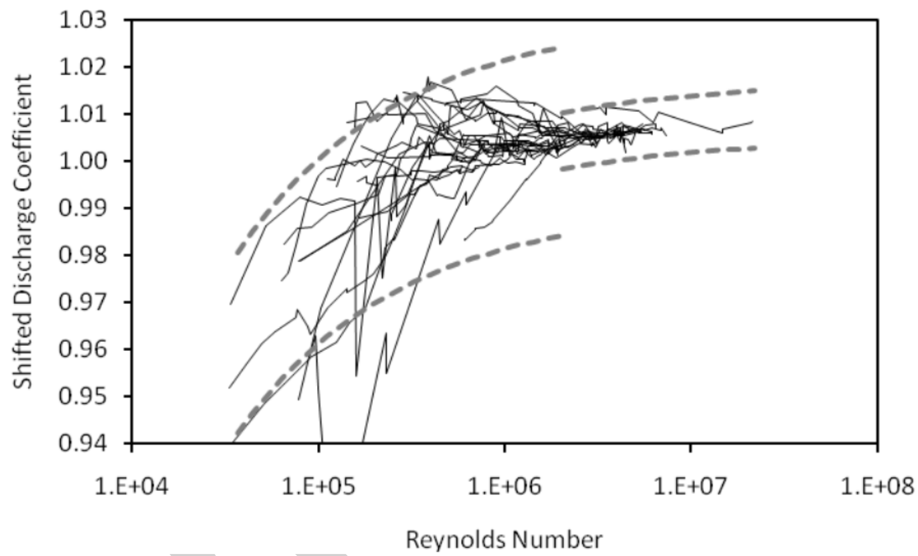

Figure 7 - Venturi Meter Gas Calibrations Classified as Type B

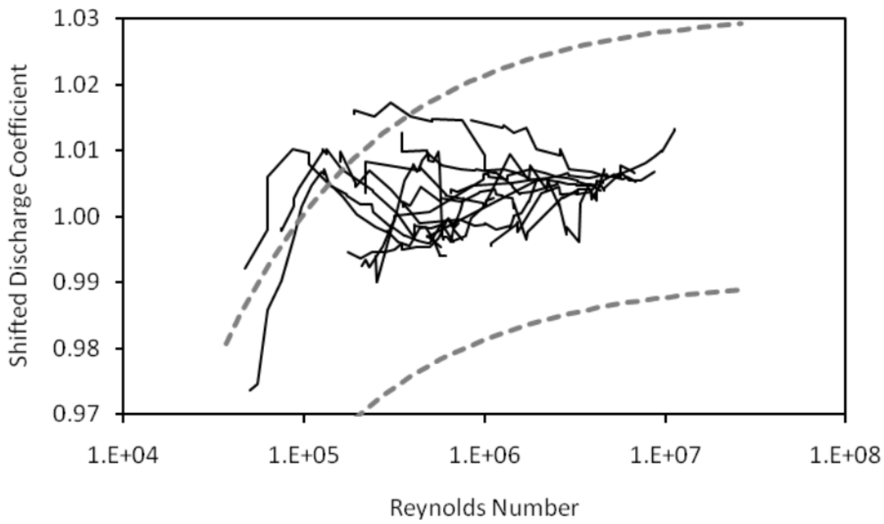

Figure 8 – Venturi Meter Gas Calibrations Classified as Type C

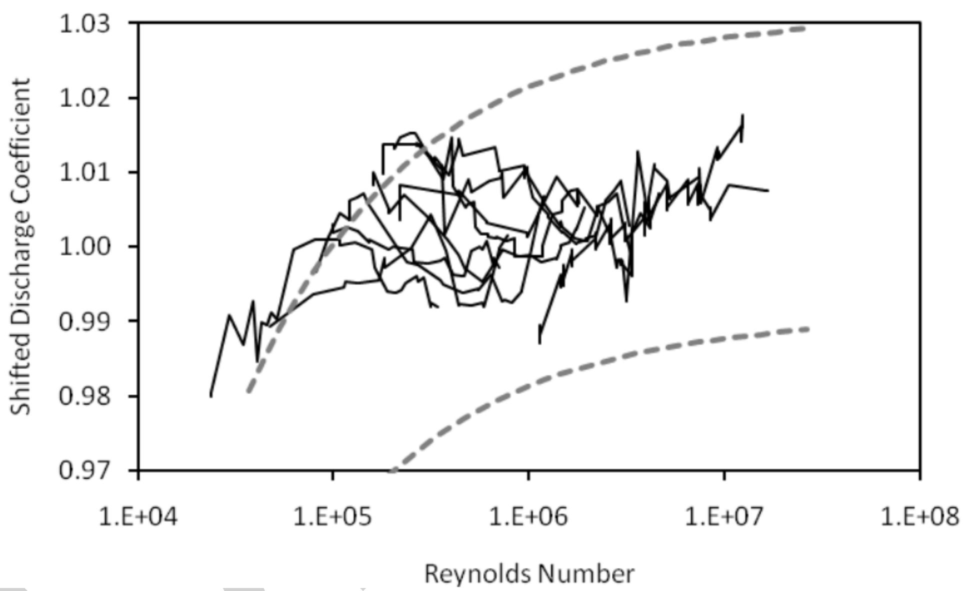

Figure 9 - Venturi Meter Gas Calibrations Classified as Type D

The calibration data also demonstrates a phenomena specific to certain Venturi meter designs operating in gas service. For many Venturi meters, the relationship between the throat Reynolds number and discharge coefficient is linear across the entire calibrated range of Reynolds numbers. However, some Venturi meter calibration data shows a noticeable "transition hump" between the linear, transition, and turbulent flow ranges. In these cases, the relationship between the throat Reynolds number and discharge coefficient may be described by a different linear regression equation in each flow regime. The presence of a "transition hump" is thought to be caused by the formation of a boundary layer at the Venturi meter throat which affects certain Venturi meter designs.

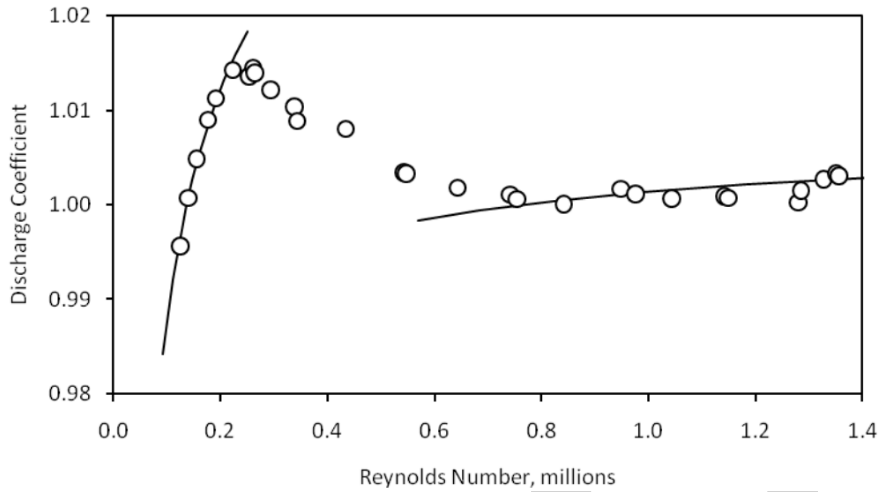

Figure 8 - Venturi Meter Gas Calibration with a Large Transition Hump

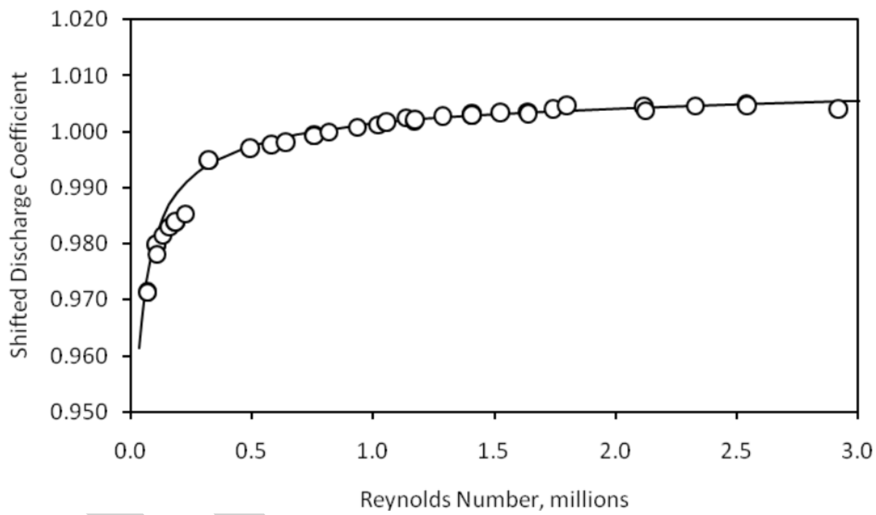

Figure 9 - Venturi Meter Gas Calibration without a Large Transition Hump

For the Venturi meter gas calibrations, the relationship between the discharge coefficient and the throat Reynolds number has been determined according to the linear regression fit methodology described in ASME PTC 19.5. The data has been analyzed to determine the deviation at each point between the measured discharge coefficient and discharge coefficient determined by the linear regression calibration equation.

Figure 12 indicates the typical percent deviation between the measured discharge coefficient and calibrated discharge coefficient that can be expected for a Venturi meter calibrated in a gas flow lab with an uncertainty of 0.5%. However, the uncertainty associated with the discharge coefficient for each meter should still be determined based on its individual calibration.

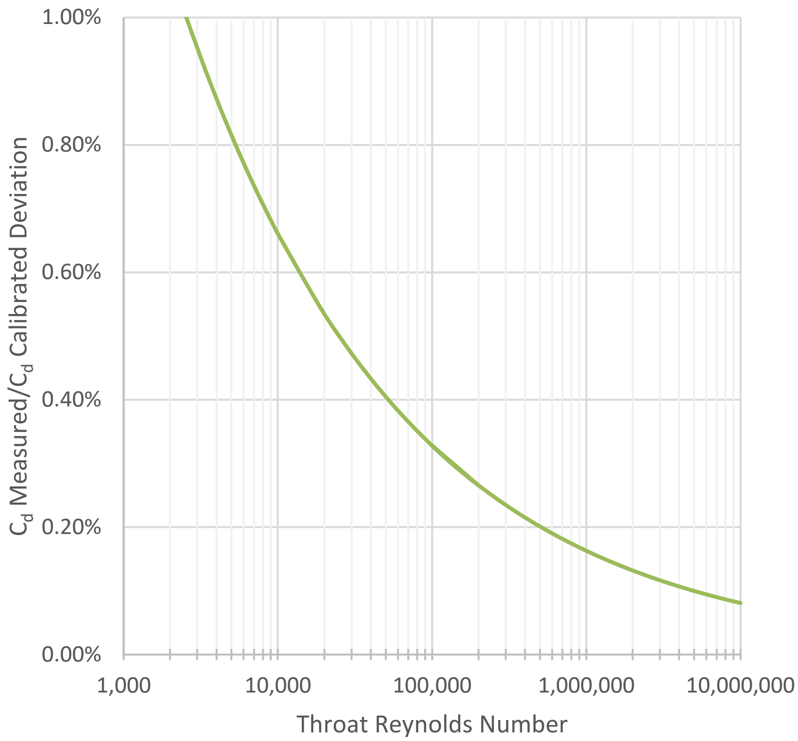

Figure 12 - Venturi Meter Gas Percent Deviation Cd Measured / Cd Calibrated

A.3 Conclusions

The collected calibration data highlights the importance of calibrating Venturi meters across the entire operating range of throat Reynolds numbers to verify performance and measurement uncertainty, rather than relying on predicted performance according to industry standards. The data also demonstrates the majority of well-constructed Venturi meters calibrated at an accredited flow calibration laboratory according to the process defined in this standard are capable of producing flow measurement within an acceptable uncertainty.

Figure 13 compares selected Venturi meter liquid and gas calibration data (Type A and B) with discharge coefficients compensated for unknowns regarding the actual throat diameter. This analysis demonstrates Venturi meters operating in both liquid and gas service are typically linear for pipe Reynolds numbers above 200,000. Venturi meter uncertainty increases significantly below pipe Reynolds number below 200,000 based on the collected data, as well as ASME MFC-3M and ISO 5167-4 industry standards. In order to meet the requirements of this standard, it is recommended to operate above a pipe Reynolds number of 200,000. Venturi meters may be operated at lower Reynolds numbers only if calibration determines the meter meets the required uncertainty in this range.

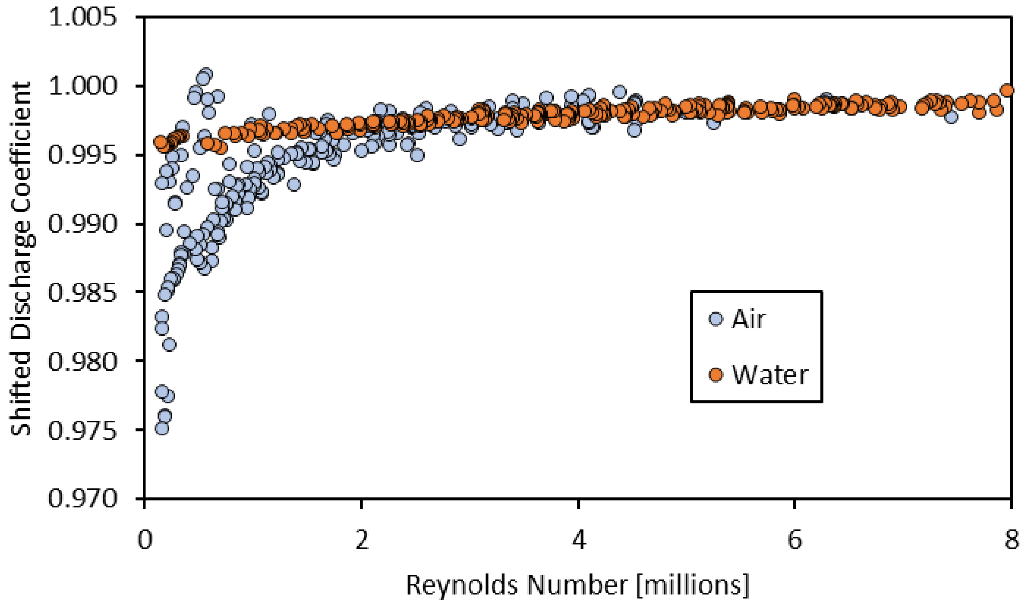

Figure 10 - Venturi Meter Liquid and Gas Comparison

Using the calibration methods outlined in this standard, a Venturi meter's performance can be defined within the calibrated range and may be suitable for custody transfer of liquid or gas, depending on the application requirements. Venturi meter performance should only be extrapolated beyond the calibrated range with caution, as the uncertainty may increase significantly depending on the size and condition of the meter, as well as the Reynolds number range.

Annex B
(informative)

Venturi Meter Inspection Guidelines

The following outline is intended to provide guidelines for preparing a Venturi 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 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 Venturi meter at the time of inspection.

a) Header
    1) Company name
    2) Date of inspection
    3) Meter location
    4) Flow direction
    5) Names of inspector(s) and witness(s)
    6) Any other information required

b) General Information
    1) Serial number
    2) Nominal pipe diameter
    3) Fluid measured: gas or liquid (specify name)
    4) Beta limitations

c) Meter Run
    1) Manufacturer
    2) Serial number
    3) Straightening vanes? Yes or no; if yes:
        a. Type of vane
        b. How fastened? Pinned, welded, or flanged
        c. Dimensions
    4) Nearest upstream disturbance
    5) Dimensional data:
        a. Length
        b. Upstream and downstream diameters (at least four measurements at each location):
            i. Upstream pressure tap hole (also calculate the average of these values)
            ii. Downstream pressure tap hole
            iii. First pipe connection
            iv. Second pipe connection
    6) Temperature of meter at time of measurement
    7) Meter run quality: cleanliness and roughness upstream and downstream
    8) Average tube inside diameter at 68°F, as stamped on pipe or nameplate
    9) Inside tube diameter used in flow computer, for calculations and data processing

d) Pressure Tap Holes
    1) Orientation of primary differential pressure transducer connection (looking from inlet to outlet of meter tube)
    2) Location of static pressure transducer connection: upstream, downstream, or none
    3) Number of differential pressure connections
    4) Pressure tap hole size

5) Manifold: manufactured or fabricated on site; full bore or restricted bore; three valves, five valves, or other
6) Gauge line length

e) Other Instrumentation
1) Measurement data on other tap connections made to the meter tube: size, location, and orientation
2) Temperature sensor: type and location
3) Densitometer: manufacturer and type; insertion or sample line; size; inlet or outlet location
4) Sampler: manufacturer and type; sample line size; inlet or outlet location
5) Composition/energy analyzers: type; sample line size; inlet or outlet location

f) Venturi Fitting Leak Test (After Hydrostatic Testing)
1) Measurement of seat width
2) Measurement of seal width
3) Difference between a and b above
4) Results of pressure tap leak test
5) Results of plate bypass leak test
6) Type of seal and material of construction

g) Venturi Meter Inspection
1) Material of construction
2) Manufacturer
3) Any surface film patterning?
4) Micrometer measurement of at least four inside diameters of the meter bore
5) Average value of the measurements in d above
6) Other data pertinent for identification
7) Temperature at which meter was measured
8) Names of inspector(s) and witness(es) and date, if not the same as for meter run

Bibliography

Venturi Meter Calibration Studies

[1] Water calibration data collected by ASME PTC 19.5 Committee from Alden Research Laboratory, Inc. and Utah Water Research Laboratory

[2] Kegel, T.M., “The ISO 5167 Compliant Design Venturi – A Further Summary of Calibration Experience”, Flowmeko, Taipei, Oct. 13-15 2010.