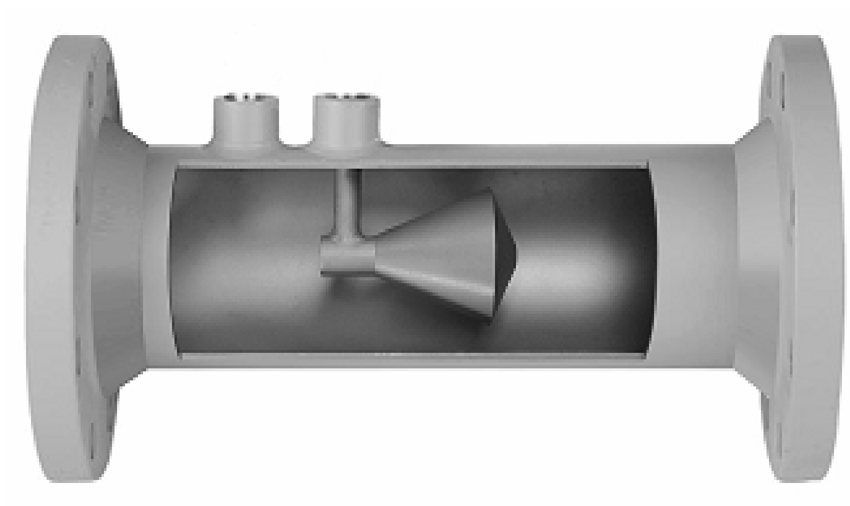
Measurement Systems

NUFLO™

Differential Pressure Cone Meter

User Manual

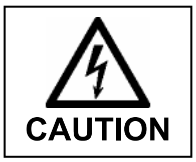


Manual No. 85165000, Rev. 01

Important Safety Information

Symbols used in this manual:

This symbol identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss.



This symbol indicates actions or procedures which if not performed correctly may lead to personal injury or incorrect function of the instrument or connected equipment.

Terms used in this manual:

Note	**Indicates actions or procedures which may affect instrument operation or may lead to an instrument response which is not planned.**

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General Description and Specifications

Introduction

The NuFlo™ Differential Pressure Cone Meter is a process control and multi-fluid meter that uses differential pressure to provide accurate, repeatable and cost-optimized measurement solutions.

The NuFlo Cone Meter produces a differential pressure which is read by a differential pressure or multi-variable transmitter. The NuFlo MVX-II multivariable transmitter and the NuFlo Scanner 2000 microEFM, which feature an integral multi-variable transmitter, are among the devices that are compatible with the Cone Meter. The method used to connect the transmitter to the meter varies, depending on the type of product measured and available space for mounting the meter. This user manual provides installation instructions and piping diagrams for using the Cone Meter in liquid, gas, and steam applications.

Applications

The NuFlo Cone Meter is designed to work in unprocessed and processed applications, and is ideal for upstream, midstream and downstream flow metering applications that present a wide range of measurement challenges. The NuFlo Cone Meter is ideal for low-pressure coalbed methane wellhead and field applications, compressor anti-surge control, and test separator applications.

Meter Components

The meter comprises three primary elements, as shown in Figures 1.1 and 1.2:

- a meter body or tube with or without flanges
- a cone assembly, either fabricated or machined from a solid piece of metal, positioned in the center of the meter tube
- a pair of pressure taps—a wall tap upstream and an integral sensing tap downstream—for reading the differential pressure in the center of the meter tube. (Alternately a downstream tap may be used under certain process measurement conditions.)

The meter can be manufactured from various materials (carbon, stainless, or duplex stainless steel) to meet the specific requirements for metering steam, air, natural gas, digester gas, nitrogen, ethanol, and a host of liquids from crude oil to waste water.

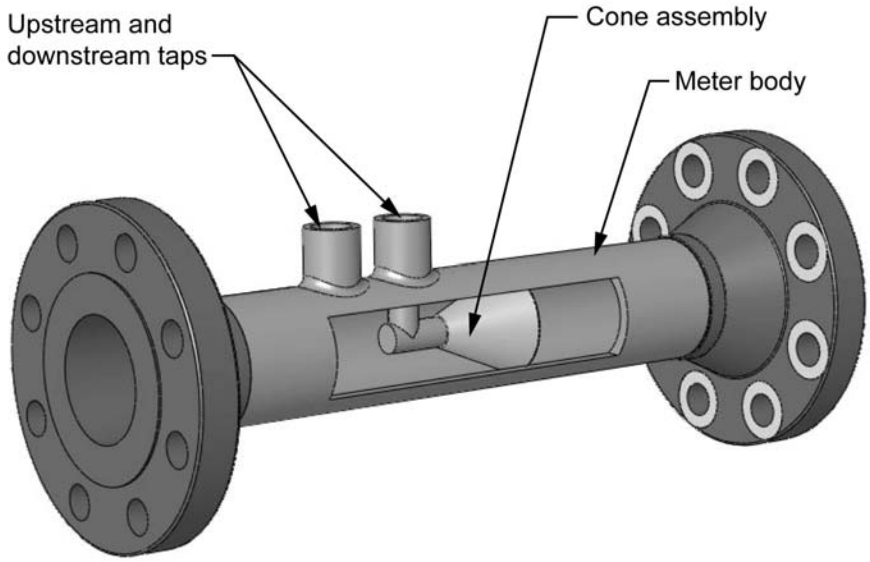


Figure 1.1—Basic components of the NuFlo Cone Meter

The NuFlo Cone Meter has no moving parts, and is designed such that there are no areas of stagnation where trash or fluid particles can lodge. Accordingly it is virtually maintenance-free.

Principles of Operation

The NuFlo Cone Meter generates a differential pressure that can be used to calculate fluid flow rate. A transmitter measures the differential pressure and outputs an integrated electronic signal, typically via Modbus or a 4-20 mA output, to a flow computer or other process controller for interpretation and readout. For compressible fluids, line pressure and temperature measurements are required for accurate flow rate calculations as well as compensation for the adiabatic change in the expansion factor.

As fluid flowing through the pipe flows around the cone, a pressure drop occurs. The static line pressure (P1) is measured via a wall tap located just upstream of the cone (Figure 1.2). Pressure is also measured via a sensing tap that is connected to the cone and measures pressure at a point immediately downstream of the cone (P2). The fluid flow rate is calculated using the difference between the two pressures using variations of the standard differential pressure flow measurement principles.

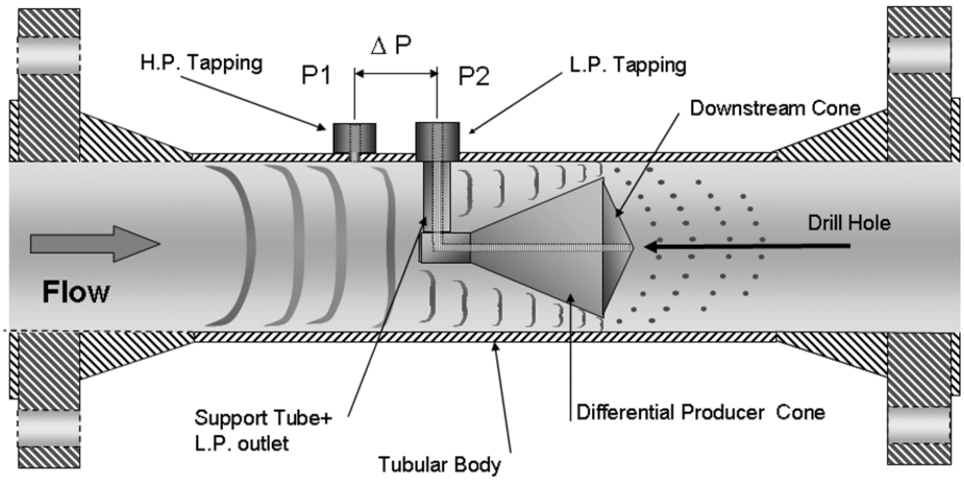


Figure 1.2—NuFlo Cone Meter, cutaway view

The shape of the meter cone reshapes the fluid velocity profile upstream of the meter cone, conditioning flow naturally and eliminating the need for traditional flow conditioners. As a result, the NuFlo Cone Meter can be installed in shorter meter runs than those required by conventional differential pressure meters and a high degree of accuracy is ensured even under extremely disturbed flow conditions.

Table 1—Performance Characteristics and Specifications

Accuracy	up to ± 0.5% of rate
Turndown	10:1
Repeatability	± 0.1%
Installation Requirements	0 - 5 pipe diameters upstream (5 diameters if a gate valve is used)
	0 - 3 pipe diameters downstream
Differential Pressure Limit	> 0.1 WC (minimum 1 in. WC preferred but the Reynolds number requirements must be met
Differential Pressure Recommended	50 -200 WC (consult factory for higher DPs)
Reynolds number (Re)	>8000 Re
Y factor (gases only), as installed in various NuFlo computers	see Appendix A for the appropriate expansion factor equations with respect to the meter geometry and process application
Fluids	gases, vapors, or liquids
Meter Orientation	horizontal or vertical
Tap Location	varies with type of product measured (see Figure 2.4, page 15)
Coefficient of discharge (Cd)	Cd is unique to each meter and must be determined by calibration

Beta Range	0.45 to 0.85 standard - (0.05 increments)
End Connections	weld neck flanges
	RTJ flanges
	slip-on connections
	Threaded (fractional inch sizes)
	flangeless (welded in line)
Tube Design	welded construction (1/2-in. and greater diameters)
	carbon, stainless, or duplex stainless steel

The Reynolds number typically ranges from 8500 to above 5 million. With special calibration, the Cd can be calibrated to a lower Reynolds number.

Differential pressures can range from less than 1 in. WC to more than several hundred inches WC to facilitate large turndowns. *(A minimum differential pressure of 1 in. or greater is recommended to ensure a stable and low-noise differential pressure signal, due to transmitter hysteresis.)*

Meter Nameplate

The nameplate affixed to the NuFlo Cone Meter (Figure 1.3) contains specifications for the meter, including the coefficient of discharge (Cd). The calibrated Cd, which is unique to each meter, offers traceability for the accuracy of the meter.

The direction of flow is also indicated on every nameplate for easy reference during installation of the meter.

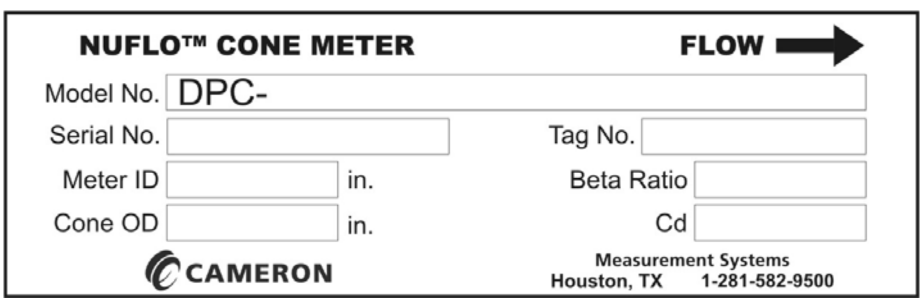


Figure 1.3—Sample nameplate

General Installation Guidelines

Important Safety Information

Installation, inspection, and maintenance of the NuFlo Cone Meter must be performed by authorized and trained personnel who have a working knowledge of piping configurations.

WARNING

Never open a manifold valve or flange unless you have first verified that the system is completely depressurized.

During liquid or wet gas service, open valves very slowly to avoid slugging in the meter run.

Always use proper procedures and equipment for lifting and moving the NuFlo Cone Meter to avoid risk of injury.

Secure all connections properly before starting up a system. Keep a safe distance away from the process upon startup.

Be mindful of static electricity generated by insulated footwear etc., and always ground yourself before touching pipes in the hazardous area where flammable gas is being metered.

Unpacking the Meter

All NuFlo Cone Meters are securely packed to help prevent damage during shipment. Inspect the packing list on receipt of the device and report any discrepancies immediately.

Assembling the System

The NuFlo Cone Meter alone cannot measure flow. It is intended for use with instrumentation such as a transmitter or flow computer.

The installation usually comprises a manifold system for isolating the process fluid and allowing maintenance and calibration of the transmitter.

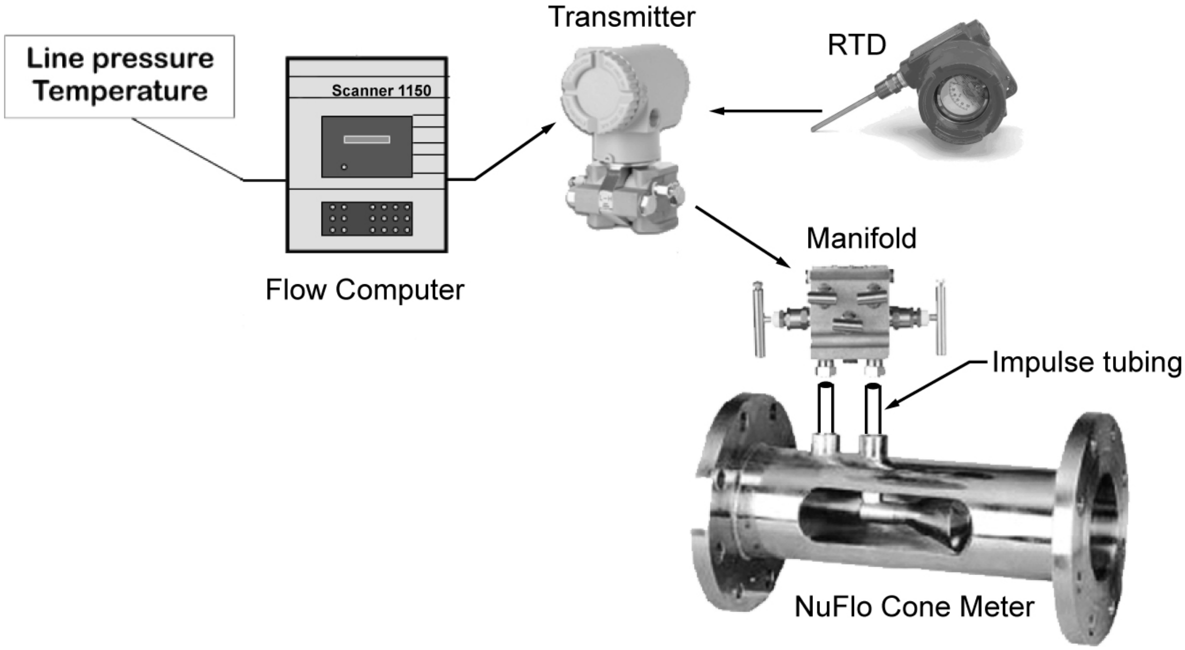


Figure 2.1—Typical components of a NuFlo Cone Meter system

System Components

A transmitter, valve manifold, shut-off valves, and impulse tubing are typically required for the operation of a NuFlo Cone Meter. If the meter is used to measure steam, a condensate pot may also be required.

Before installing a NuFlo Cone Meter, review the following installation tips:

- Make sure the piping, tubing, or manifold installed between the NuFlo Cone Meter and the transmitter complies with national and local standards, regulations, and codes of practice to ensure safe containment of fluid.
- A hydrostatic or pneumatic test may be required for piping systems to prove the integrity of the pressure-containing components.
- In installations that are prone to plugging, a rod or other device may be used to remove materials blocking the impulse tubing.

WARNING

Never use a rod to clean out process lines in high-pressure applications or where high temperatures (e.g. steam) or dangerous fluids are being measured. The meter run should be isolated and completely depressurized before inserting a rod into an impulse tube.

Differential Pressure Transmitter

A differential pressure transmitter records the differential pressure signal generated by the cone meter and provides an analog or serial output to a flow computer or data control system.

The transmitter(s) selected for an installation must be appropriate for operating conditions of the process in terms of both accuracy and safety.

DP devices must be zeroed following installation. The procedure varies somewhat for liquid, gas, and steam applications. Procedures are provided for each application in Sections 3, 4, and 5, respectively.

Shut-Off Valves

Choose a block valve that is rated for the operating pressure of the pipe in which it will be installed. Where dangerous or corrosive fluids or gases like oxygen are likely, the block valve and packing must provide ample protection. The valves must not affect the transmission of the differential pressure signal.

Install block valves next to the NuFlo Cone Meter pressure taps. Never use a globe valve for differential pressure transmission lines.

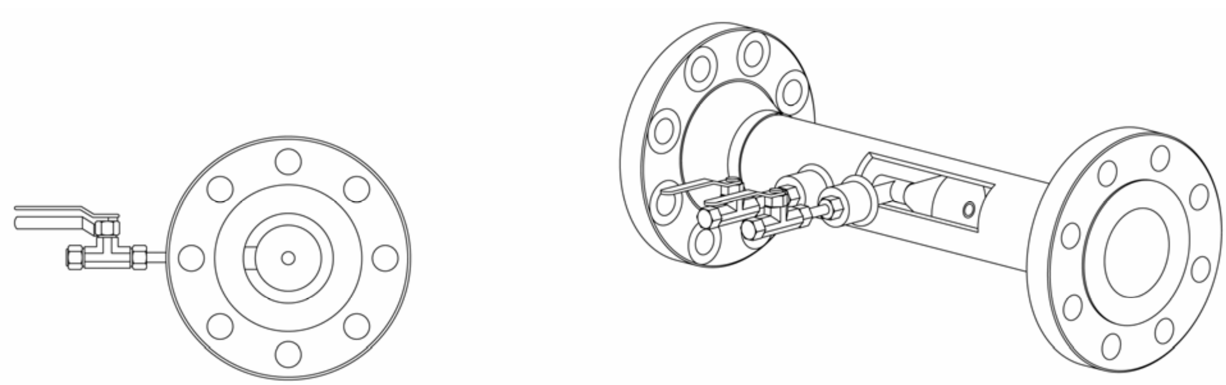


Figure 2.2—Block valves

Valve Manifolds

A 3-way or 5-way valve manifold isolates the transmitter from the process lines (5-valve manifolds recommended). They allow the operator to calibrate the transmitter without removing it from the impulse tubing, drain the transmitter and impulse tubing or vent it to atmosphere. Valve manifolds must be oriented according to the manufacturer’s instructions to prevent trapping of air or liquid.

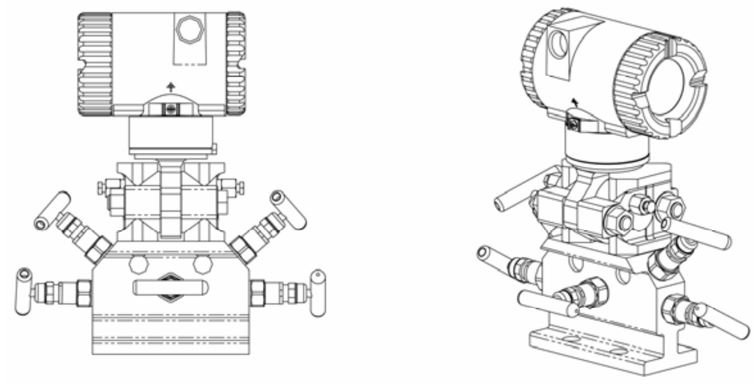


Figure 2.3—A 5-way manifold block mounted with a multi-variable transmitter

Thermowell or Thermocouple

Flow measurement calculations for differential pressure devices require temperature and pressure measurement. Generally, a thermowell with an RTD installed is mounted downstream of the meter within 3 pipe diameters of the meter. Alternatively, a thermo-well can be installed inside the meter body upstream of the cone and the meter calibrated with it in position. For installations where temperatures are stable, a thermocouple or temperature probe may be attached to the outside of the upstream piping and covered with insulation.

Impulse Tubing Considerations

Before connecting impulse tubing between the NuFlo Cone Meter and the transmitter, consider the following tips for optimizing your system's measurement accuracy. In a well-designed installation, fluids will drain freely from the process lines and gases will vent to the atmosphere.

Tubing Size Selection

Impulse tubing (that connects the DP Cone meter tap holes to the transmitter) diameters vary with service conditions. The bore should be no smaller than ¼ in. (6 mm); a minimum diameter of 3/8 in. (10 mm) is recommended. The internal diameter (ID) must not exceed 1 in. (25 mm). For steam applications, the ID should be 3/8 in. (10 mm) to 1 in. (25 mm).

In most process control applications, the primary concern is flow reliability. If the pressure taps or the impulse tubes become plugged, the reliability of the flow measurement is lost. This creates a safety risk and the cost incurred in regaining control can be substantial. High reliability is required for flow signals used in process safety management. A minimum tubing ID of 5/8 in. (16 mm) is recommended in industrial applications. For high temperatures in condensing vapor service, 1 in. (25 mm) is recommended.

Tubing Material

Most instrument tubing is 316 stainless steel. However, duplex steel may be preferred for offshore applications where corrosion protection against saltwater is needed.

Tubing Length and Configuration

For best performance, adhere to the following recommendations for tubing length and orientation:

- Tubing length must be short enough to ensure a high degree of accuracy, and long enough to ensure proper cooling of high-temperature fluids before they reach the transmitter.
- Make sure the installation permits access to the impulse tubes, valves, valve manifolds, and transmitters.
- Limit the number of fittings and avoid long tubing sections, which can impair measurement accuracy and increase the risk of plugging.
- Avoid changes in tubing elevation and fluid temperature. Differences in elevation will cause a difference in the hydrostatic pressure of the liquid column in the process lines. Temperature differences will cause a difference in the density of the fluids in the two lines, which will change the amount of pressure generated. Both can result in inaccurate differential pressure measurements. Fasten the process lines together, if possible.
- Install process lines so that they slope in only one direction (up or down). If piping must slope in more than one direction, do not allow more than one bend and install a liquid or gas trap, as applicable. A liquid trap should be installed at the lowest point in a gas service installation. A gas trap should be installed at the highest point in a liquid service installation.

Extreme Temperature Applications

Steam temperatures can reach 1500°F (815°C), well exceeding the temperature rating of a standard DP transmitter (200°F or 93°C). A condensate chamber can be used to isolate the transmitter from the extreme temperatures. Alternatively, a long tube section can be installed to allow the fluid to cool before it reaches the transmitter.

As a general guideline when planning tubing lengths for temperature control, run tubing horizontally where possible, and allow for a temperature drop of 100°F (38°C) per foot (305 mm) of tubing. This is merely a guideline, however; the operator is still responsible for ensuring that the temperature at the transmitter does not exceed the transmitter’s rating for the environmental conditions present.

In extreme cold temperature installations, thermal insulation and/or “heat tracing” of process lines may be necessary. The amount of heat used must be carefully calculated to prevent liquids from vaporizing and prevent condensable vapors from producing unwanted condensation. Fastening process lines together is recommended for keeping process lines at approximately the same temperature. Providing a temperature-controlled environment for the transmitter also helps ensure accurate metering in locations where extreme temperatures are likely (such as on offshore platforms or in desert installations).

Best Practices for Installing the NuFlo Cone Meter

Note	Read the best practice recommendations below in their entirety before installation of the NuFlo Cone Meter.

The basic steps for installing a NuFlo DP Cone Meter system are described as follows.

1. Install the meter in the meter run in accordance with the flow run requirements below.
2. Secure the manifold to the meter taps.
3. Connect the differential pressure transmitter to the manifold, observing the recommended guidelines below for pressure measuring tubes.
4. Connect the transmitter to the flow computer according to instructions in the transmitter user manual.
5. Zero the transmitter.

Flow Run Requirements

The NuFlo Cone Meter should be installed with zero to five pipe diameters of straight run upstream of the meter and zero to three pipe diameters downstream. The meter can be used in pipelines that are slightly larger than the meter tube; however, if the meter tube is larger than the pipeline, operators should contact NuFlo for installation requirements. This is usually determined before supply according to application and the degree of accuracy and performance required.

Meter Orientation and Transmitter Position

The NuFlo Cone Meter can be installed in a horizontal or vertical position. The location of the transmitter with respect to the meter should be based on the properties of the fluid or gas being measured (gas, steam, liquid, etc.) and the direction of flow through the pipeline.

The direction of flow is clearly labeled on nameplate affixed to the body of every NuFlo Cone Meter shipped. The meter must be installed so that the static pressure tap (labeled P1 in Figure 1.2) is always upstream of the differential pressure tap.

Pressure Tap Location

Location of the static pressure and differential pressure taps will vary with the product flowing through the pipeline (liquid, gas, or steam) and the orientation of the meter (vertical or horizontal).

For horizontal installations, the following installation guidelines apply:

- For measuring liquid, differential pressure taps should be located in the bottom half of the pipeline, between 4 o'clock and 5 o'clock positions, or between 7 o'clock and 8 o'clock positions.
- For measuring gas, differential pressure taps should be located in the top half of the pipeline. For wet gas, taps should be located between the 10 o'clock and 2 o'clock positions to allow proper drainage of liquids present.
- For steam, differential pressure taps should be located in the side of the pipeline.

Illustrations of typical piping configurations for liquid, gas, and steam are provided in Sections 3, 4, and 5, respectively.

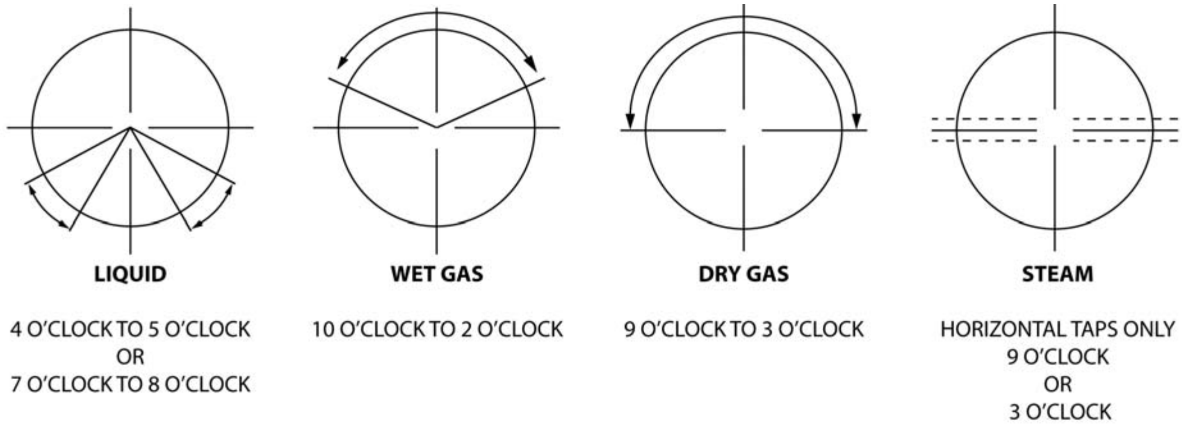


Figure 2.4—Recommended tap locations for horizontal meter installations

For vertical installations, the location of differential pressure taps is unrestricted, as long as the static pressure tap is upstream of the lower-pressure tap.

Impulse Tubing

Impulse tubing is used to connect the sensing taps of the cone meter to the manifold connected to the differential pressure transmitter. One section of tubing should connect the high-pressure tap to the high-pressure (static) side of the differential pressure transmitter; another section of tubing should connect the low-pressure tap to the low-pressure side of the differential pressure transmitter.

- Impulse tubing should be installed with a gradient larger than 1/10 to help prevent undesirable fluids from being transferred to the differential pressure transmitter.
- If tubing is installed in a horizontal orientation, install a gas/liquid separator device.
- Avoid abrupt bends in impulse tubing.
- If impulse tubing sections are long, use mounting brackets to support them.

See also "Tubing Size Selection," page 12.

WARNING

Never use excessive pressure or force when connecting impulse tubing to a differential pressure transmitter.

CAUTION

If high-temperature fluids are likely to be encountered, make sure the impulse tubing is rated for the anticipated temperature range.

See Sections 3, 4, and 5 for installation procedures recommended for liquid, gas, and steam applications, respectively. Both horizontal and vertical meter orientations are discussed as appropriate for each application.

For additional installation information, refer to ISO 5167, or contact Cameron's Measurement Systems Division.

Installation Checkpoints for the Transmitter

Before putting the NuFlo Cone Meter into service, verify that the transmitter is installed properly by reviewing the following checkpoints:

- Is the transmitter full scale correct?
- Has the transmitter zero been checked and/or adjusted?
- Are the transmitter and flow computer set to the appropriate modes—linear or square root?
- Have the transmission lines to the transmitter been purged?
- Are there any leaks in the transmission lines?
- Is the manifold cross valve closed?
- Is the NuFlo Cone Meter high pressure port located upstream of the low pressure port?

Meter Installation for Liquid Service

Installation Options

Meter Orientation

NuFlo Cone Meters can be installed in a horizontal or vertical position. Horizontal is the standard orientation, however where space is very limited, a vertical position may prove to be the best option.

Pipe Orientation

The orientation of piping is dictated by the position of the meter, the type of product being measured, and for vertical meter installations, the direction of flow. When a vertical piping system is used, the operator must give special consideration to the piping configuration to prevent gas from being trapped in liquid differential pressure lines

Wall Taps

In extremely cold environments where there is a risk of product freezing in the process lines, the low-pressure sensing port connected to the cone meter can become plugged with ice (see P2 in Figure 1.2, page 7. In such installations, a wall tap may be installed downstream of the meter and used to measure the downstream pressure. This will allow the blockage to be removed without removing the meter from the meter run, but the meter run must be isolated and depressurized before attempting to clean out the blockage.

Condensate Chamber (Drip Pot)

The condensate chamber (drip pot) is a collection vessel to avoid gas bubbles in liquid instrument tubing. It should be mounted at the highest point in the impulse tubing between the cone meter and the DP transmitter.

Horizontal Meter Installation

For horizontal installations, pressure taps must be positioned 30° to 60° below the horizontal centerline (4 o'clock to 5 o'clock or 7 o'clock to 8 o'clock). Taps at the bottom of the pipe may become plugged with solids from the liquid; taps above the centerline can accumulate air or non-condensing gases. In liquid service, the connecting lines from the meter shall slope downward to the transmitter with no upturns or pockets. The minimum recommended slope for self-venting is 1 inch per foot.

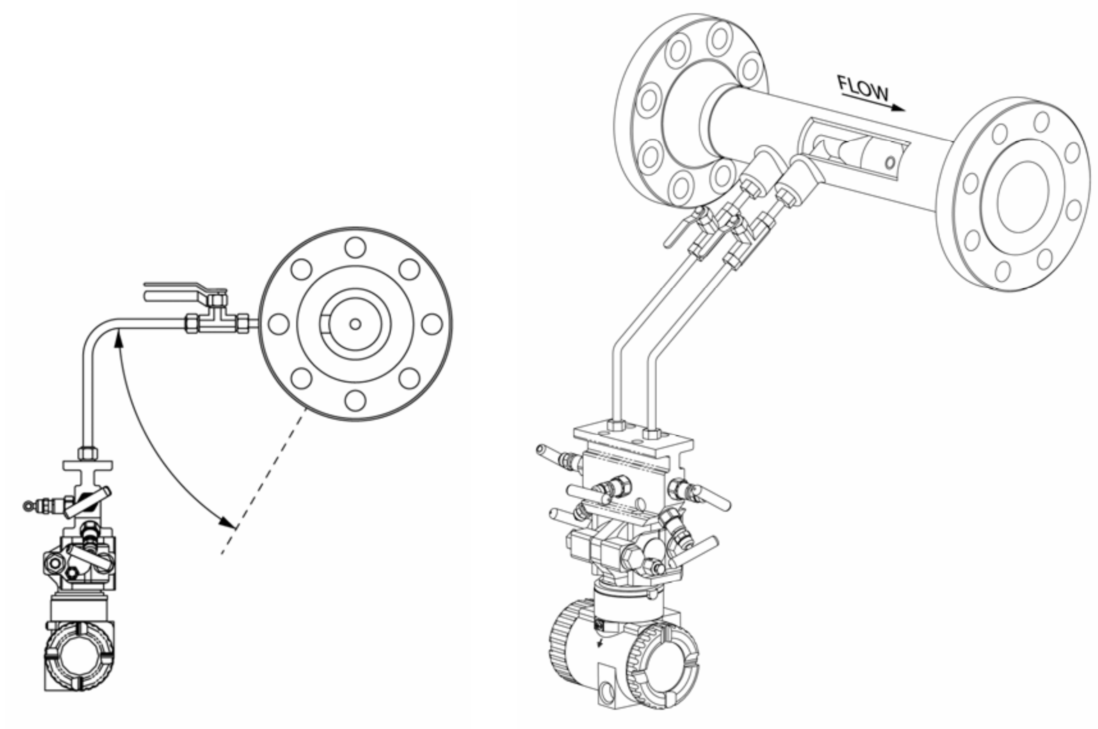


Figure 3.1—Piping installation for liquid measurement with a horizontal meter

Bubble Pot Installation (Optional)

In liquid applications where the transmitter must be mounted above the metering line, gas or vapor in the liquid can collect at the highest point in the instrument tubing and give a false differential pressure reading. Bubble pots may be the only effective solution for such installations. The piping from the meter connects to the bubble pot anywhere between the 10 o'clock and 2 o'clock positions on a horizontal plane.

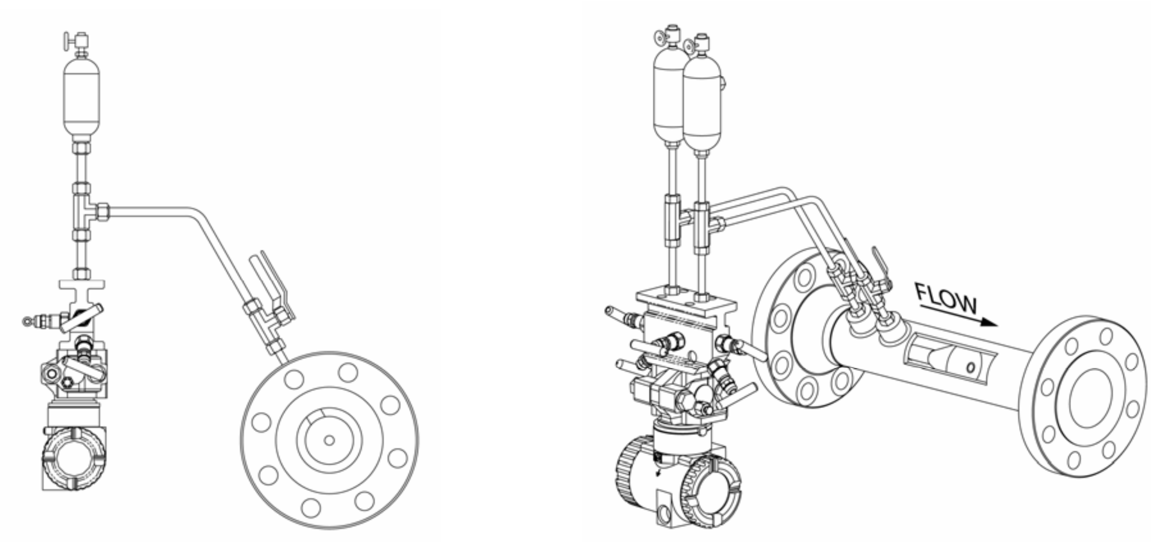


Figure 3.2—Bubble pot installation for liquid service where transmitter must be installed above the meter run

Vertical Meter Installation

In most process applications, the operator should assume that some level of gas or vapor exists in a liquid service, even if the liquid is water. As a result, the piping configuration must be designed to allow gas to rise back into the flow stream. The process piping should be extended horizontally a very short distance from the downstream tap and then sloped at a nominal 1-inch-per-foot angle to the top of the manifold block. The manifold block should be mounted horizontally below the upstream tap so that piping from the upstream tap to the manifold slopes downward also.

CAUTION	**When the process is turned off, particulates may fall into the low-pressure port. It is advisable to flush the low-pressure port with an inert fluid before starting the meter.**

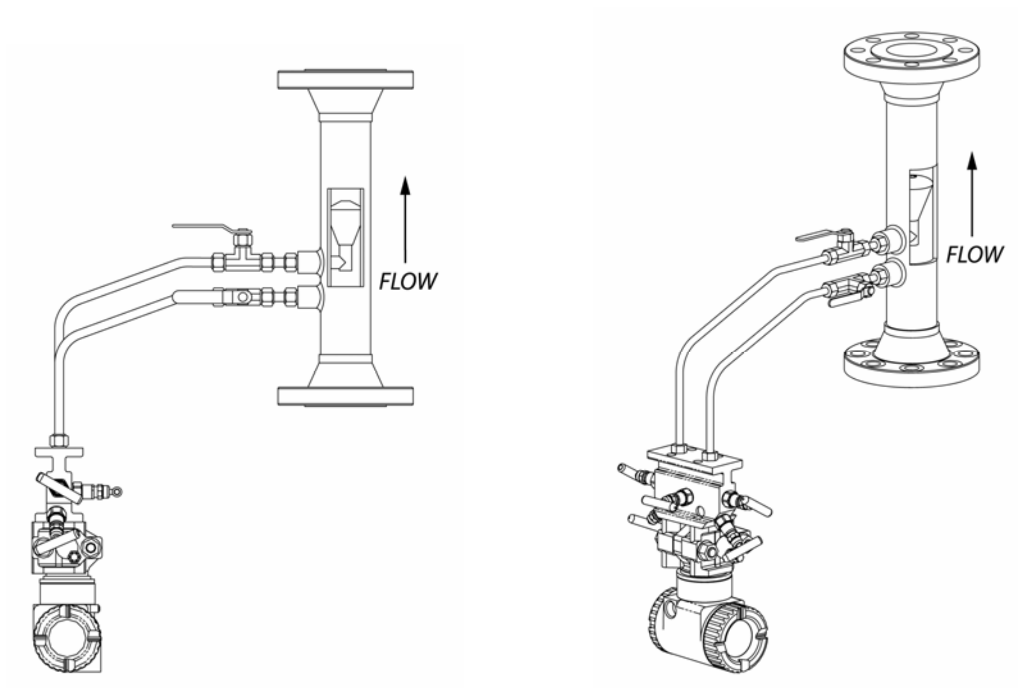


Figure 3.3—Piping installation for upward flow through a vertical meter

Note: **While downward flow through a vertically oriented meter is suitable for a gas application, downward flow piping configurations that use the standard upstream and downstream pressure ports are not recommended for liquid applications due to the risk of trapping gas. For such applications, consider the use of a vertically oriented meter with wall taps, as described below.**

Vertical Meter with Wall Taps

Both process lines should be extended horizontally for a very short distance, and then tubed downwards to a manifold block. The manifold block should be mounted horizontally below the bottom tap, and the transmitter should be mounted below the manifold block.

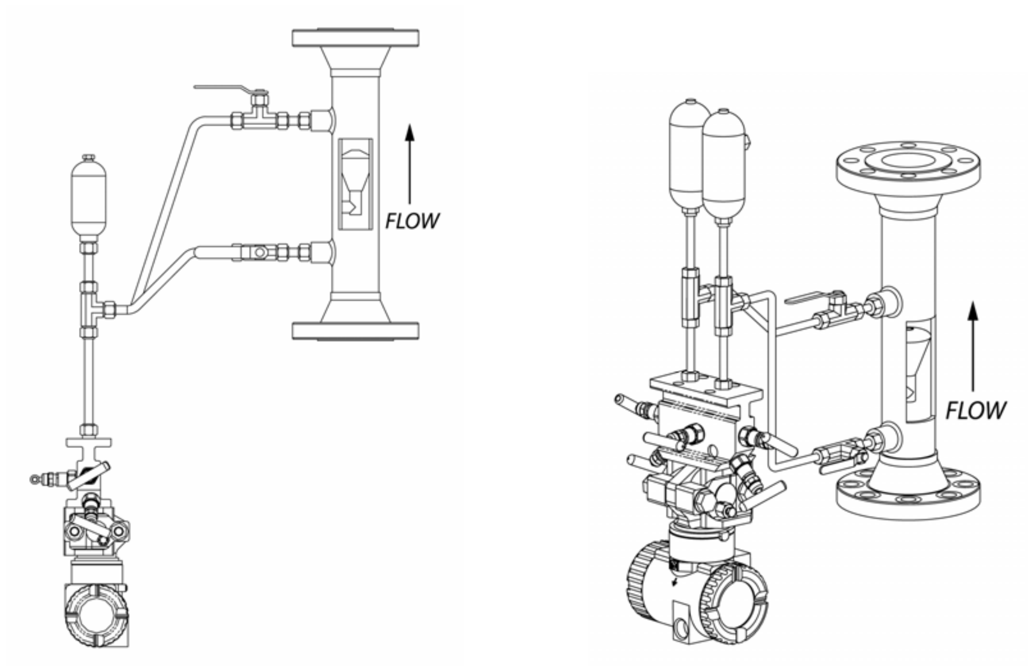


Figure 3.4—Piping installation for upward flow through a vertical meter with wall taps

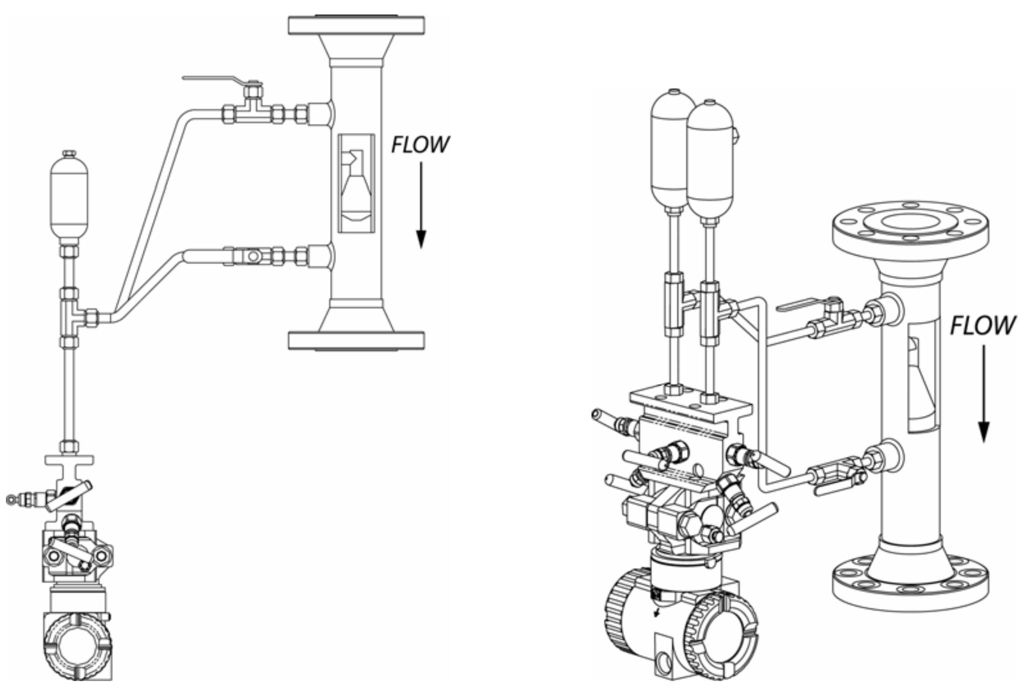


Figure 3.5—Piping installation for downward flow through a vertical meter with wall taps

Transmitter Calibration

Transmitters (differential pressure and/or multi-variable) should be calibrated according to the manufacturer's recommendations, appropriate national or company standards and contractually agreed methodology. Consideration should be given to the service in which the NuFlo Cone Meter and transmitter are installed and operated.

Meter Installation for Gas Service

Installation Options

Meter Orientation
NuFlo Cone Meters can be installed in a horizontal or vertical position. Horizontal is the standard orientation, however where space is very limited, a vertical position may prove to be the best option.

Impulse Tube Orientation
The orientation of impulse tubing is dictated by the position of the meter, the type of product being measured, and for vertical meter installations, the direction of flow. When a vertically oriented metering system is used, the operator must give special consideration to the tubing configuration to prevent liquid from being trapped in gas differential pressure lines in gas service installations

Condensate Chamber (Drip Pot)
The condensate chamber is a collection vessel that helps prevent liquid pockets from collecting in gas instrument tubing.

Horizontal Meter Installation

The pressure taps on the NuFlo DP Cone Meter should be between the horizontal centerline and the top of the pipe (3 o'clock to 12 o'clock or 9 o'clock to 12 o'clock). If the fluid is a "wet gas" (i.e., a gas containing small quantities of liquids), the pressure taps should be situated in a vertical position (12 o'clock) to allow all liquids to drain away from the transmitter (Figure 4.2). If the connecting tubing extending from the cone meter to the transmitter is not installed in a vertical position, it should slope upward (at least 1 inch per foot) to ensure proper drainage.

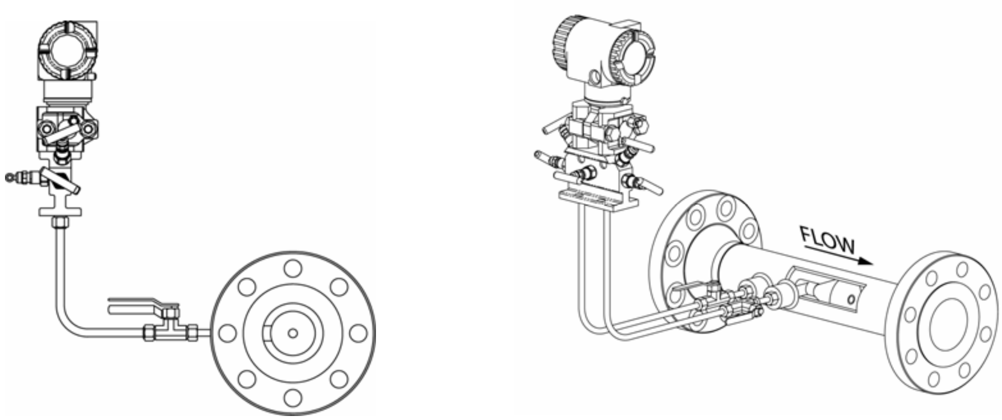


Figure 4.1—Piping installation for dry gas measurement with a horizontal meter

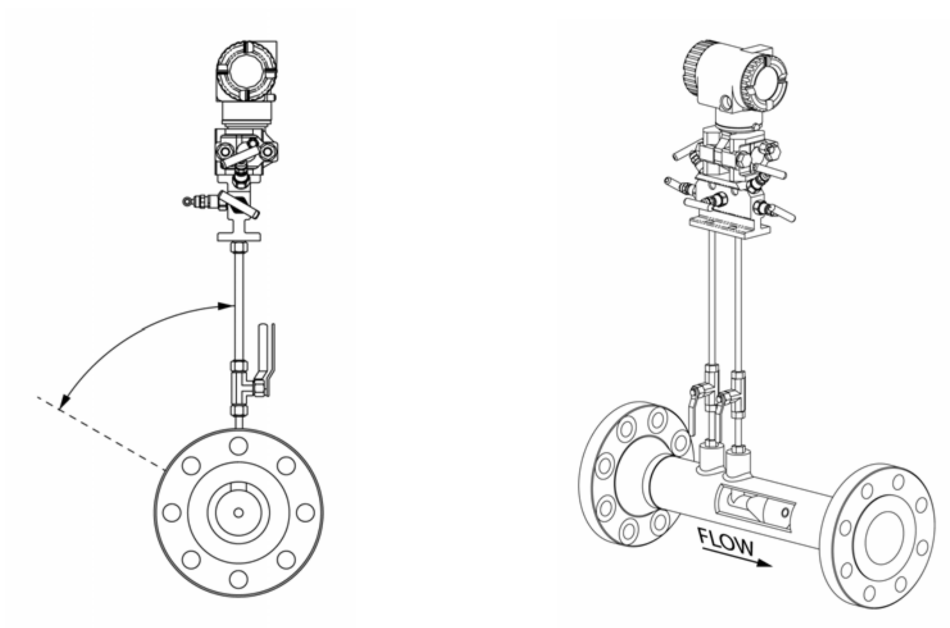


Figure 4.2—Piping installation for wet gas measurement with a horizontal meter

Drip Pot Installation (Optional for Wet Gas)

If drip pots are used, they should ideally be mounted immediately following the shutoff valves installed near the upstream and downstream pressure taps of the meter. For wet gas applications, the piping from the meter connects to the condensate chamber in a 3 o'clock or 9 o'clock position on a horizontal plane. The chambers are positioned vertically so that the meter connection and instrument connection points are at the top and drain points are at the bottom of the chambers.

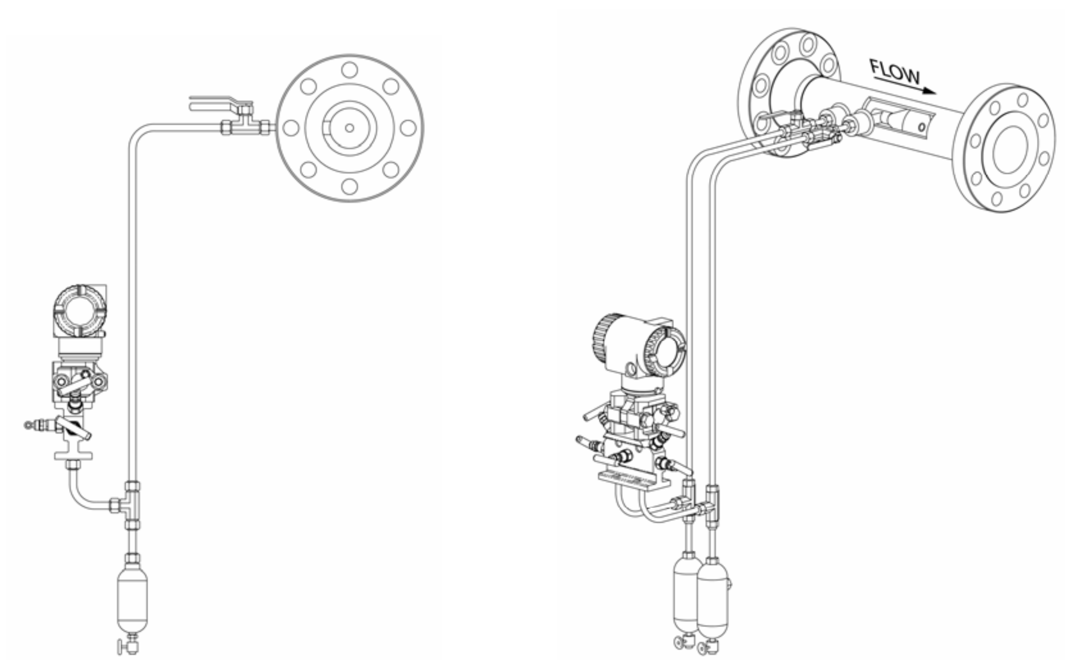


Figure 4.3—Condensation chamber (drip pot) installation

Vertical Meter Installation

When the meter is installed in a vertical position, the operator must take special care to ensure that no trap forms in the downstream tap such that gas is trapped in a liquid or liquid is trapped in a gas.

When measuring dry, non-condensing gases, where there is absolutely no risk for liquid being present, the piping from the downstream pressure tap of the cone meter can be extended horizontally and then angled upward to connect to the manifold block. The manifold block must be mounted horizontally, and the tubing from the upstream tap of the cone meter must slope at least 1 inch per foot to the same level as the downstream tap piping to connect to the manifold.

CAUTION

If there is any liquid present in the gas, do not use the piping arrangement shown in Figure 4.4. The "U" configuration could trap liquid in the cone, changing the downstream pressure.

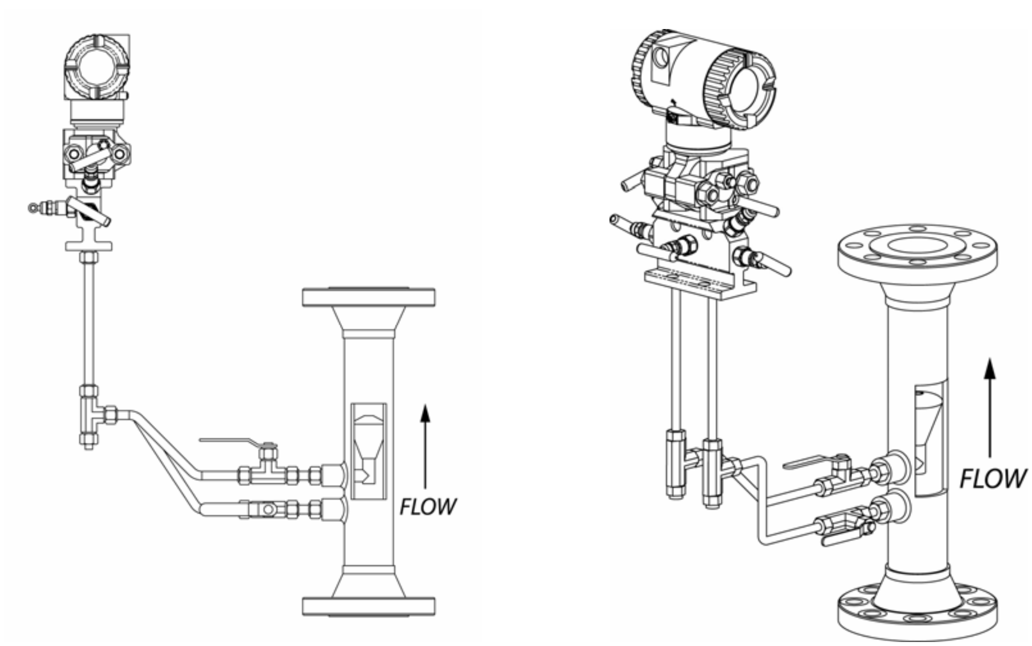


Figure 4.4—Piping installation for upward flow (dry gas) through a vertical meter

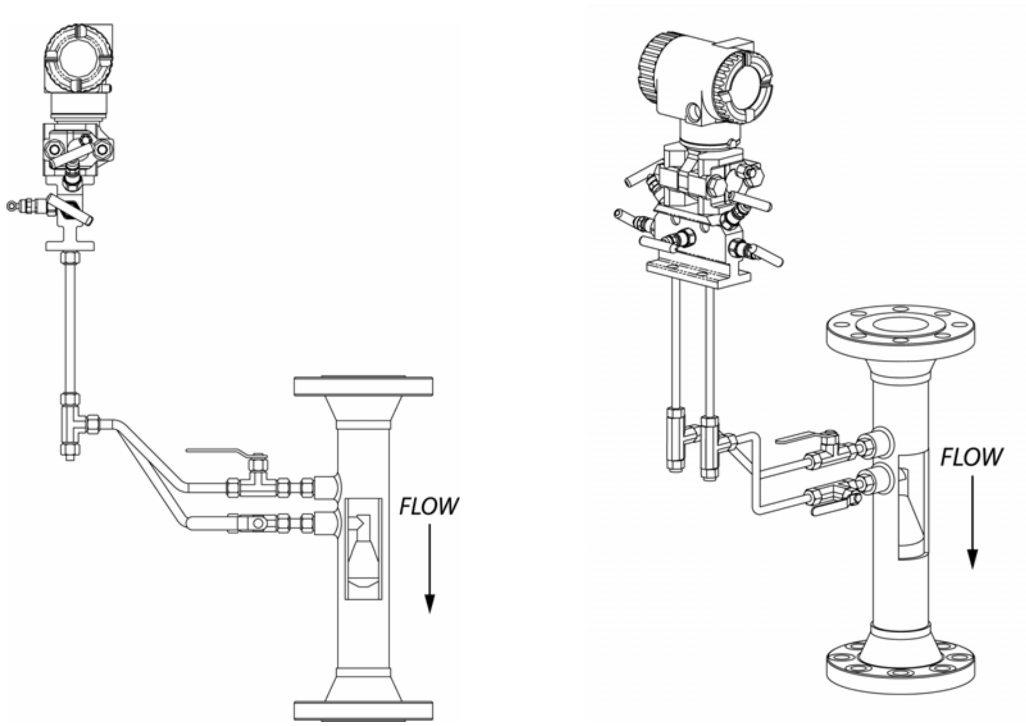


Figure 4.5—Piping installation for downward flow (dry gas) through a vertical meter

Transmitter Calibration

Transmitters (differential pressure and/or multi-variable) should be calibrated according to the manufacturer's recommendations, appropriate national or company standards and contractually agreed methodology. Consideration should be given to the service in which the NuFlo Cone Meter and transmitter are installed and operated.

Meter Installation for Steam Service

Installation Options

Steam measurement is the most difficult application for differential pressure transmitter tubing and requires careful consideration during installation. Steam is usually at a high temperature which will damage the transmitter and in addition it can be in the liquid or gaseous phase depending on temperature and pressure. Due to this the differential pressure impulse tubing must be orientated in such a manner that it can operate with a gas or liquid present.

Meter Orientation

NuFlo Cone Meters can be installed in a horizontal or vertical position. Horizontal is the standard orientation, however where space is very limited, a vertical position may prove to be the best option.

Impulse Tubing Orientation

The orientation of the impulse tubing is dictated by the orientation of the meter, the type quality of the steam being measured, and for vertical meter installations, the direction of flow. When a vertical meter run is used, the operator must give special consideration to the impulse tubing configuration to prevent liquid from being trapped in gas differential pressure lines.

Condensate Chamber

The condensate chamber is a liquid reservoir that helps prevent super-heated steam from entering the differential pressure transmitter. In most cases, a large-diameter tee is all that is required to collect the liquid (see Figure 5.1). However, if the DP measuring instrument is designed with hydraulic/pneumatic bellows (such a Barton 202E chart recorder), a larger-volume condensate chamber will be required (see Figure 5.2). Modern DP transmitters have very little diaphragm movement and do not require the large-volume condensate chamber.

Horizontal Meter Installation

The pressure taps shall be above the horizontal centerline (9 o'clock to 3 o'clock) of the primary device. In condensing hot vapor service such as steam, the fluid in the impulse lines is liquid condensed from the vapor. The use of a condensate chamber is mandatory to prevent hot process fluid from damaging the transmitter. The impulse tubing should slope upwards from the cone meter to the condensate pots. A condensate pot can be a tubing tee (for low-volume DP instruments) as shown in Figure 5.1 or a full-size condensate chamber (for high-volume DP instruments) as shown in Figure 5.2. In either case, the condensate pots should be at exactly the same level to ensure accurate differential pressure readings. The line from the bottom of the tee to the transmitter mounted below the tee should be filled to the point where excess fluid can drain back into the meter.

In many cases, water (condensed steam) is used for this fluid fill. However, in cold weather, the fluid must be protected from freezing. The fluid fill requires careful design with heat tracing and insulation to keep it in the liquid phase and to keep both the high-pressure and low-pressure legs of the tubing at the same temperature (maintaining the liquid fill at the same density). A liquid leg fill fluid other than water should be used if practical. Methanol is a possible substitute, but di-butyl phthalate is the recommended fill fluid because it is immiscible with water and remains liquid throughout a broad temperature range, -31°F to 644°F (-35°C to 340°C).

Important: Care should be taken when using di-butyl phthalate – follow all hazardous material guidelines (CAS No: 87-74-2).

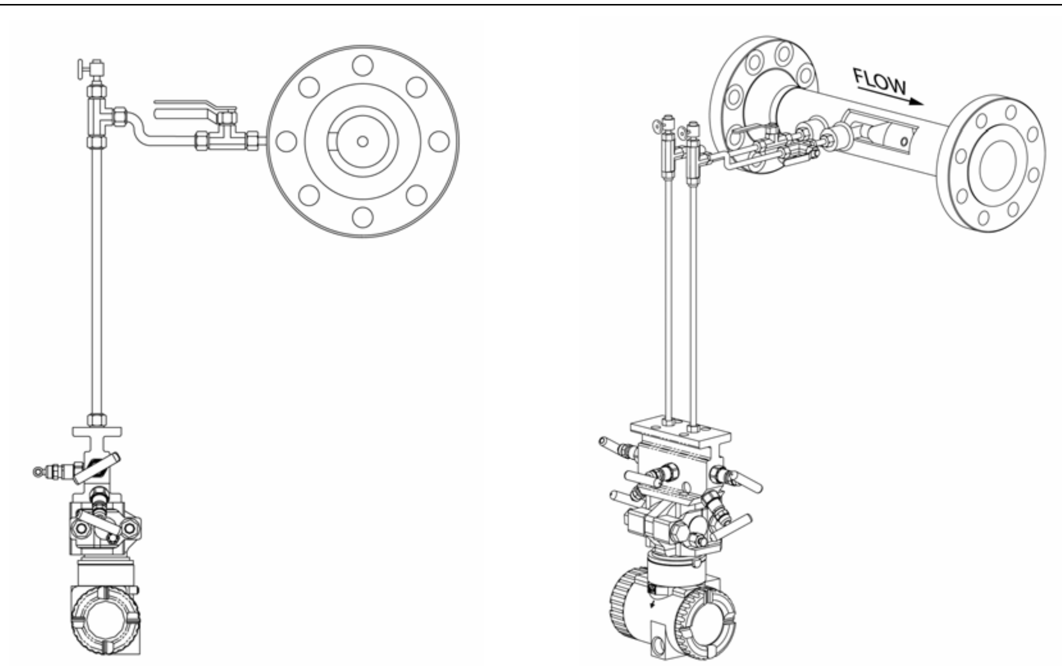


Figure 5.1—Piping installation for steam measurement with a horizontal meter and a low-volume DP instrument (straight-on into transmitter)

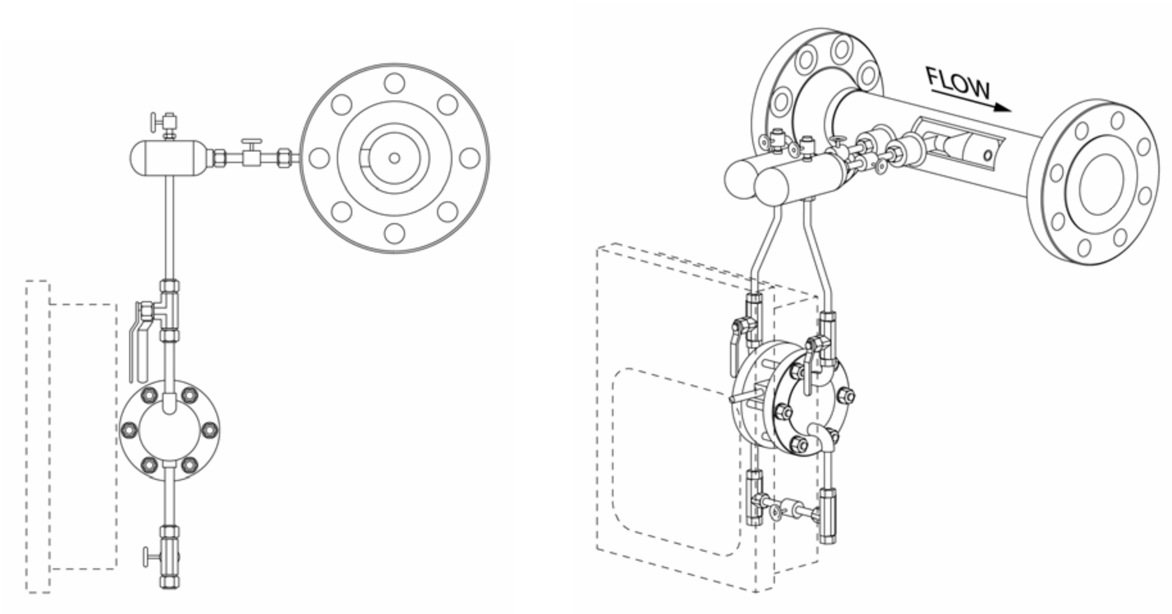


Figure 5.2— Piping installation for steam measurement with a horizontal meter and a high-volume DP instrument such as a chart recorder with DPU.

Vertical Meter Installation

For steam service installations in which the meter is oriented vertically, piping from the upstream pressure tap is extended horizontally to an "T" connector. The "T" connector enables a plug to be installed at the top for liquid filling purposes to avoid overheating of the differential pressure cell. The manifold block is positioned directly below at a distance that ensures the steam will be at a safe operating temperature by the time it reaches the differential pressure transmitter. Both lines are extended to the "T" pieces.

Note: **This configuration results in a head difference in the differential pressure lines and the differential pressure transmitter must be zeroed when zero flow has been established in the main line.**

CAUTION

When the process is turned off, particulates may fall into the low-pressure port. It may be advisable to flush the low-pressure port with an inert fluid before starting the meter.

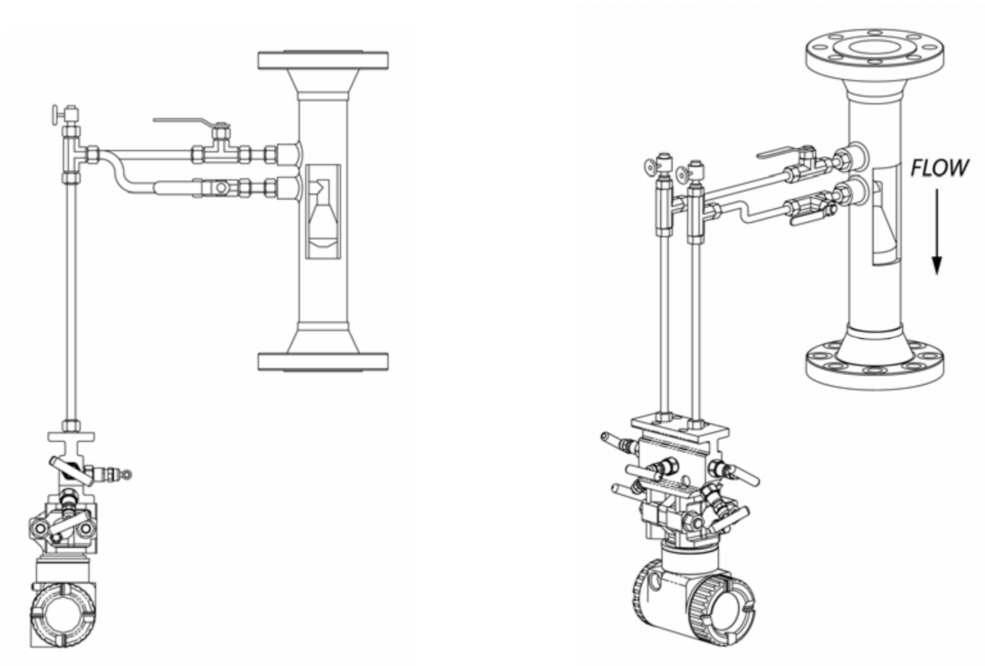


Figure 5.3—Piping installation for downward flow through a vertical meter

Transmitter Calibration

Transmitters (differential pressure and/or multi-variable) should be calibrated according to the manufacturer's recommendations, appropriate national or company standards and contractually agreed methodology. Consideration should be given to the service in which the NuFlo Cone Meter and transmitter are installed and operated.

System Modifications

Square Root Error

Differential pressure measurement is only accurate for steady-state flow. Flow pulsation (caused by reciprocating compressors, defective regulators, etc., will cause misregistration of delivered volumes.

Significant errors will occur when using differential pressure devices at the discharge of a reciprocating gas compressor where pressure pulses may exceed 10% of static pressure. This causes a condition called square root error, which may be reduced by the use of an acoustic filter. A filter design is described by E. Carreon (El Paso Natural Gas) in "Effects and Control of Pulsations in Gas Measurement," Proceedings of the Seventieth International School of Hydrocarbon Measurement, 1995.

Gauge Line Error

Gaseous fluids in small-bore pipes may start to oscillate due to an effect predicted by Helmholtz. This acoustic resonance comprising of standing pressure waves, usually occurs at a maximum of ¼ wavelengths. This phenomenon, termed gauge line error, can be due to the use of long impulse lines. To help prevent gauge line error, keep impulse lines as short as possible, use large impulse line diameters where possible, and keep impulse line diameters constant. Small diameters are more likely to result in measurement problems.

The direct mounting of the transmitter to the meter can help reduce the effects of gauge line error. Direct-mount manifolds are available from leading manifold manufacturers.

Elevation and Temperature Effects in Piping

In liquid service, it is important to keep vertical elevation of impulse lines equal. If one liquid-filled leg is longer than the other, the hydrostatic head of the lines will vary, resulting in inaccurate differential pressure measurement.

Similarly, if the temperature of liquid in one leg is different from the temperature of liquid in the other leg, the density of the fluid will be different, resulting in inaccurate differential pressure measurement. This most often occurs when one leg of the tubing is in bright sun and the other leg is shaded. To minimize the effects of temperature differences in the vertical legs of impulse lines, shade both of the legs from the sun. The effect of temperature differences is more notable in liquid service installations; gas service is not as prone to DP error due to varying line temperatures.

Appendix A

Flow Measurement Theory and Equations

Important **The NuFlo Cone Meter flow equation differs from the orifice equation. The device performing the flow calculation (flow computer, PLC, chart integrator, etc.) must be programmed to use the equations described in this section.**

Bernoulli Principle

The calculation of flow based on the differential pressure of fluid passing through a cone meter uses equations that are very similar to those used to calculate flow with all leading differential pressure devices. The principle behind the cone meter is the conservation of energy in an enclosed pipe and is described by the Bernoulli equation.

When fluid passes through a closed pipe and encounters a restriction, the pressure at the restriction decreases. This results in a differential pressure when compared to the pressure upstream of the restriction, as shown in Figure A.1. The mass flow of the fluid traveling past the restriction is proportional to the square root of the differential pressure.

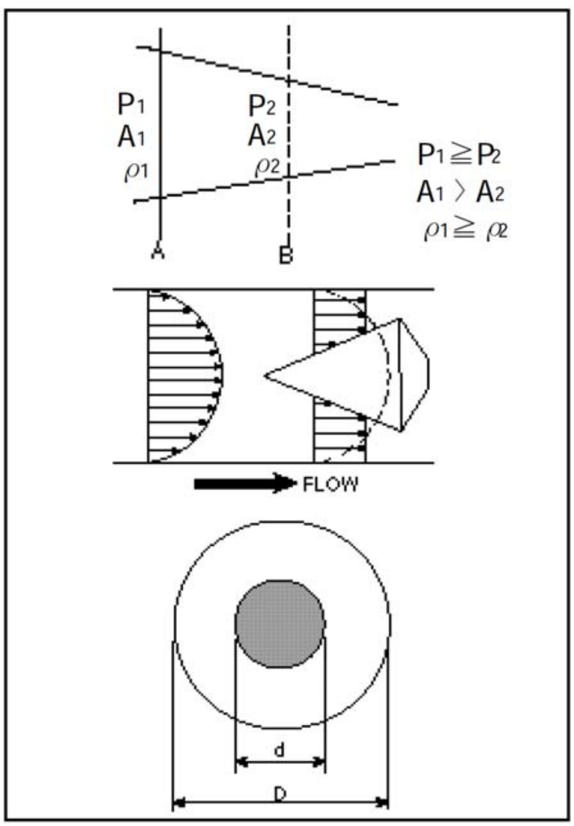


Figure A.1—Creation of differential pressure

The general mass flow equation for the DP cone meter is shown below in a format similar to the well known orifice equation. The calculation of the beta ratio is adjusted to reflect the annular area of the cone restriction, rather than the central area of an orifice meter.

Mass rate

$$qm = N_1\, Cd\, Ev\, Y\, (\beta\, D)^2 \sqrt{\rho_{t,p}\, \Delta P} \quad \text{.......(1)}$$

Volumetric rate at flowing conditions ("gross" or "actual" flow rate)

$$qv = \frac{qm}{\rho_{t,p}} = \frac{N_1\, Cd\, Ev\, Y\, (\beta\, D)^2 \sqrt{\rho_{t,p}\, \Delta P}}{\rho_{t,p}} \quad \text{.......(2)}$$

Volumetric rate at base conditions ("standard" flow rate)

$$Qv = \frac{qm}{\rho_b} = \frac{N_1\, Cd\, Ev\, Y\, (\beta\, D)^2 \sqrt{\rho_{t,p}\, \Delta P}}{\rho_b} \quad \text{.......(3)}$$

Where

$$Ev = \frac{1}{\sqrt{1-\beta^4}} \quad \text{.......(4)}$$

The beta ratio [1] of the cone meter is:

$$\beta = \frac{\sqrt{D^2 - d^2}}{D} \quad \text{.......(5)}$$

For compressible fluids (gases, vapours)

$$Y = 1 - (0.649 + 0.696\, \beta^4)\, \frac{\Delta P}{k\, P_f\, N_3} \quad \text{.......(6a)}$$

For incompressible fluids (water, other liquids)

$$\mathrm{Y} = 1 \quad \text{.......(6b)}$$

$N1$ = units constant - see Tables 1 and 2
Cd = discharge coefficient [1]
D = meter tube inside diameter at flowing conditions
d = cone diameter at flowing conditions
ΔP = differential pressure
P_f = absolute static pressure at the upstream tap
k = gas isentropic exponent
ρ_{tp} = fluid density at flowing conditions
ρ_b = fluid density at base conditions

[1] Shown on the meter's data plate and calibration certificate.

Table 1 - Flow Rate Equation Units Constant (Gas Measurement) N_1

	US units	US units	US units	Metric units	Metric units	MKS units
D, d	in	in	in	mm	mm	m
ΔP	lbf/in^2	in H_2O_{60}	in H_2O_{68}	mbar	kpa	pa
ρ_{tp}	lbm/ft^3	lbm/ft^3	lbm/ft^3	kg/m^3	kg/m^3	kg/m^3
ρ_b	lbm/ft^3	lbm/ft^3	lbm/ft^3	kg/m^3	kg/m^3	kg/m^3
qm	lbm/sec	lbm/sec	lbm/sec	kg/sec	kg/sec	kg/sec
qv	ft^3/sec	ft^3/sec	ft^3/sec	m^3/sec	m^3/sec	m^3/sec
Qv	Std ft^3/sec	Std ft^3/sec	Std ft^3/sec	Std m^3/sec	Std m^3/sec	Std m^3/sec
N_1	0.525021	0.0997424	0.0997019	3.51241E-4	3.51241E-5	1.11072

Table 2 - Flow Rate Equation Units Constant (Liquid Measurement) N_1

	US units	US units	US units	Metric units	Metric units	MKS units
D, d	in	in	in	mm	mm	m
DP	lbf/in^2	in H_2O_{60}	in H_2O_{68}	mbar	kpa	pa
t_{tp}	lbm/ft^3	lbm/ft^3	lbm/ft^3	kg/m^3	kg/m^3	kg/m^3
t_b	lbm/ft^3	lbm/ft^3	lbm/ft^3	kg/m^3	kg/m^3	kg/m^3
qm	lbm/sec	lbm/sec	lbm/sec	kg/sec	kg/sec	kg/sec
qv, Qv	gal/sec	gal/sec	gal/sec	liter/sec	m^3/sec	m^3/sec
N_1	3.92743	0.746125	0.745822	0.351241	3.51241E-5	1.11072

Table 3 - Expansion Factor Equation Units Constant N_3

	US units	US units	US units	Metric units	Metric units	MKS units
ΔP	lbf/in^2	in H_2O_{60}	in H_2O_{68}	mbar	kpa	pa
P_f	lbf/in^2	lbf/in^2	lbf/in^2	bar	mpa	pa
N_3	1	27.707	27.73	1000	1000	1

Table 4 - Flow Rate per Unit of Time Conversion

From	To	Multiply by
Units per second	Units per minute	60
Units per second	Units per hour	3600
Units per second	Units per day	86400

Y factor and the isentropic exponent

The Y factor correction becomes important when the differential ΔP is larger than approximately 1/30 of the static pressure P_f (in uniform pressure units). This is most likely to occur at low static pressures, for example, below 100 psi (700 kpa).

The isentropic exponent k that appears in the Y factor equation is a characteristic property of the gas being measured. Although it is possible to accurately calculate k for many substances, the calculation is usually very complex (see references 4 and 6 on page A-17). In reality, the flow equation is insensitive to variations in k, so the normal practice in industry is to treat k as a constant.

For natural gas $k = 1.3$
For steam $k = 1.4$

Diameter at flowing conditions

When the flowing temperature T_f differs significantly from the calibration temperature T_r, the meter tube and cone diameters should be corrected as follows:

$$D = D_r[1+\alpha_2 (T_f - T_r)] \quad (7)$$

$$d = d_r[1+\alpha_1 (T_f - T_r)] \quad (8)$$

D_r = meter tube inside diameter [2] at reference temperature T_r
d_r = cone diameter [2] at reference temperature T_r
α_1 = linear coefficient of thermal expansion, cone
α_2 = linear coefficient of thermal expansion, meter tube
T_f = flowing temperature
T_r is indicated on the meter's calibration sheet, normally close to 20°C (68°F)

Note that the beta ratio β shown on the calibration sheet is at T_r, not at T_f. When a diameter correction is applied, β should be recalculated from the corrected diameters.

[2] Shown on the meter's data plate and calibration certificate.

Table 5 - Linear Coefficient of Thermal Expansion (see reference 7)

	US units, in/in/°F	Metric units, m/m/°C
Stainless steel, below 150°C (300°F)	0.00000925	0.0000167
Stainless steel, above 150°C (300°F)	0.00000984	0.0000177
Carbon steel, -150°C (300°F)	0.00000620	0.00001116
Carbon steel, above 150°C (300°F)	0.00000725	0.00001305

Fluid properties

The flow equations require knowledge of the fluid's density. Density can be measured, estimated, or calculated from a suitable equation of state. For gases, find the compressibility factor *Z*, the molar mass *Mr*, and apply the following relations:

Gas density at flowing conditions

$$\rho_{t,p} = \frac{Mr\ P_f}{Z_{t,p}\ R\ T_f} \quad (9)$$

Gas density at base conditions

$$\rho_b = \frac{Mr\ P_b}{Z_b\ R\ T_b} \quad (10)$$

Gas mixture Molar mass ("molecular weight")

$$Mr = \sum_{i=1}^{n} x_i\ Mr_i \quad (11)$$

Use of a Meter Factor curve also requires the fluid's viscosity. For a gas mixture, use:

$$\mu = \frac{\sum_{i=1}^{n} x_i\ \mu_i \sqrt{Mr_i}}{\sum_{i=1}^{n} x_i \sqrt{Mr_i}} \quad (12)$$

ρ_{tp} = density at flowing conditions T_f and P_f
ρ_b = density at base conditions
μ = absolute viscosity - see tables
P_f = flowing pressure, absolute
T_f = flowing temperature, absolute
$Z_{t,p}$ = compressibility factor at flowing conditions T_f and P_f
Z_b = compressibility factor at base conditions T_b and P_b
P_b = contract base pressure, absolute
T_b = contract base temperature, absolute
X_i = mole fraction of component i
R = universal gas constant - see Table 6

Below about 1500 psi, the effect of pressure on gas viscosity is negligible, however there may be a significant temperature effect; see reference 8.

Pressure has a negligible effect on the density of most liquids, but thermal expansion is often important enough to require correction. Similarly, the viscosity of liquids can vary substantially with temperature, as indicated in Table 7 below. Also see reference 8.

Table 6 - Universal Gas Constant R

	US units	Metric units	Metric units	Metric units	Metric units
T_f	°R	°K	°K	°K	°K
P_f	lbf/in^2	kpa	mpa	bar	pa
ρ_{tp} ρ_b	lbm/ft^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
R	10.73164	8.31451	0.00831451	0.0831451	8314.51

Table 7 - Physical Properties of Selected Liquids

	Density t, lbm/ft3	Density t, kg/m3	Viscosity μ, cp
Water at 60°F (15.56°C)	62.366	999.012	1.121
Water at 68°F (20°C)	62.316	998.2	1.0016
Water at 150°F (65.55°C)	61.196	980.26	0.43
Kerosene	49.89	799.16	2.0
Aviation gas	44.90	719.23	0.4
Acetone	49.27	789.23	0.32

There are many methods available for determining gas compressibility; the standard in the natural gas industry is AGA-8 (reference 3). Alternately, the widely-used Standing-Katz diagram (Figure A.2) may be used. For a simple, accurate calculation, the Peng-Robinson method is recommended.

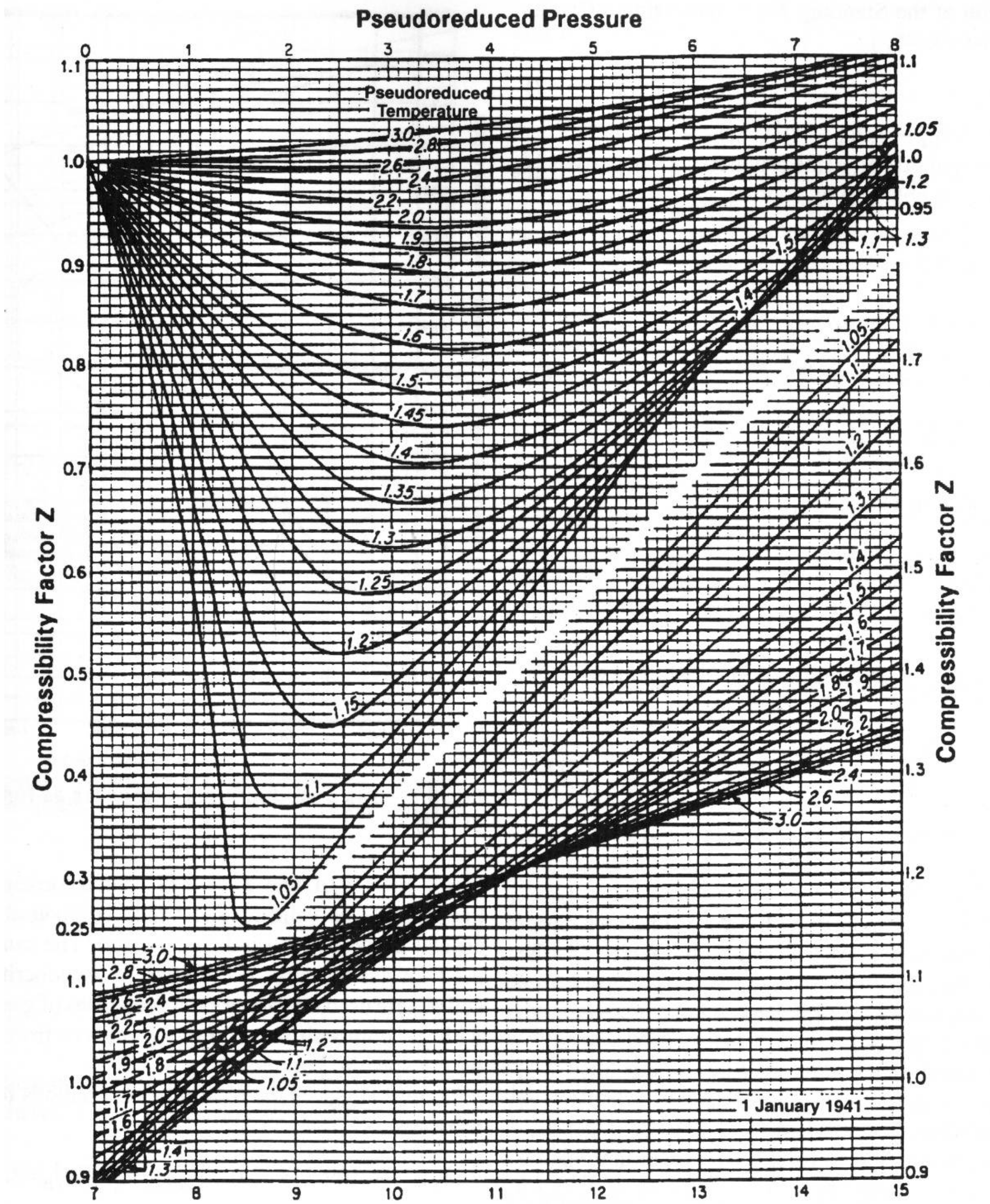


Figure A.2—Standing-Katz compressibility diagram

Compressibility may be read from the Standing-Katz diagram after calculating the reduced temperature and reduced pressure. Note that in the following equations, all pressures and temperatures are in *absolute* units (psia and °Rankin, or kpa(a) and °Kelvin).

Pseudo-critical pressure

$$P_{pc} = \sum_{i=1}^{n} x_i \, Pc_i \qquad (13)$$

Pseudo-critical temperature

$$T_{pc} = \sum_{i=1}^{n} x_i \, Tc_i \qquad (14)$$

Pseudo-reduced pressure

$$P_r = \frac{P_f}{P_{pc}} \qquad (15)$$

Pseudo-reduced temperature

$$T_r = \frac{T_f}{T_{pc}} \qquad (16)$$

where

Pc = critical pressure - see Table 8
Tc = critical temperature - see Table 8
x_i = mole fraction of component i

Locate the curve of the pseudo-reduced temperature, note where it crosses the vertical pseudo-reduced pressure line, and read the compressibility factor on the left (or right).

Table 8 - Physical Properties of Selected Gases

Gas	Molar mass Mr	Viscosity μ, cp	Critical temp Tc, °R	Critical press. Pc, psia	Critical temp Tc, °K	Critical press. Pc, kpa(a)
Methane	16.042	0.01078	343.01	667	190.56	4599
Nitrogen	28.013	0.01735	227.14	492.5	126.19	3396
Carbon dioxide	44.010	0.01439	547.47	1070	304.1	7377
Ethane	30.069	0.00901	549.594	706.6	305.33	4872
Propane	44.096	0.00788	665.59	615.5	369.77	4244
Water vapour	18.0153	0.009607	1164.77	3200.1	647.1	1311.3
Hydrogen sulphide	34.082	0.0124	672.47	1306.5	373.6	9008
Hydrogen	2.0159	0.00871	59.36	187.5	32.97	1293
Carbon monoxide	28.010	0.01725	239.26	507.5	132.7	3498
Oxygen	31.999	0.02006	278.24	731.4	154.58	5043
Iso butane	58.122	0.00724	734.08	527.9	407.82	3640
N - butane	58.122	0.00682	765.216	550.9	425.12	3798
Isopentane	72.149	—	828.65	490.4	460.36	3381
N - pentane	72.149	—	845.42	488.8	469.68	3370
Hexane	86.175	—	913.5	436.9	507.5	3012
Heptane	100.202	—	972.54	396.8	540.3	2736
Octane	114.229	—	1023.89	360.7	568.8	2487
Nonane	128.255	—	1070.47	330.7	594.7	2280
Decane	142.282	—	1111.87	304.6	617.7	2100
Helium	4.0026	0.01927	9.34	32.9	5.195	227.46
Argon	39.948	0.02201	271.55	710.4	150.87	4898
Air	18.0153	0.0179	238.7	551.9	132.61	3805

Meter Factor[3]

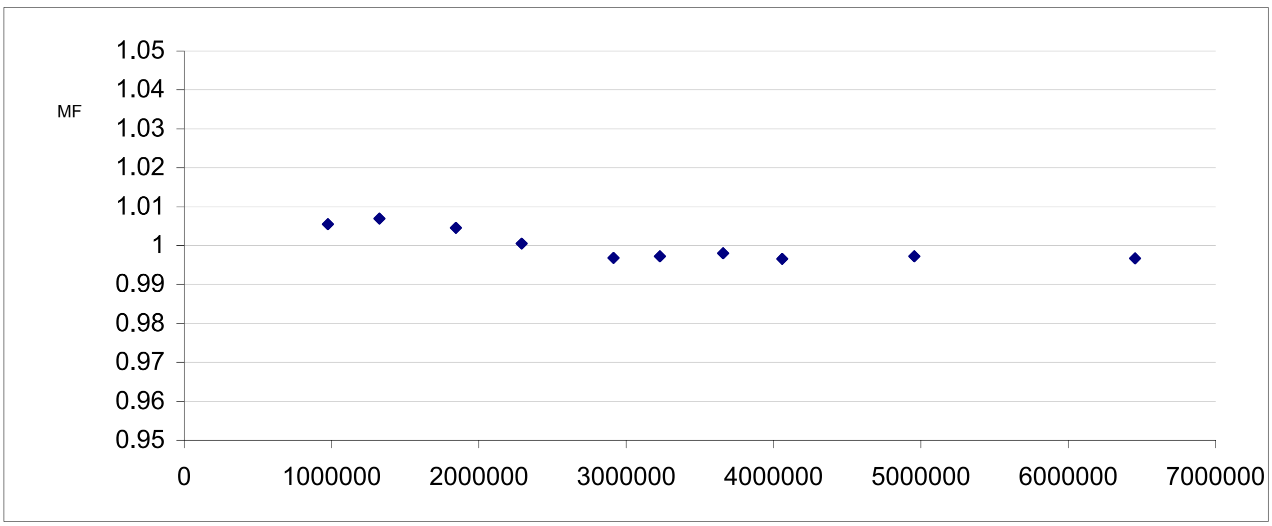
Although the cone meter's discharge coefficient varies little with Reynolds Number, accuracy can be improved, when required, by calibrating the meter over the range of Reynolds Numbers it will encounter in service.

The meter factor is defined as

$$\mathrm{MF} = \frac{\text{true rate}}{\text{indicated rate}}$$

...where *true rate* is determined by the calibration standard (the sonic flow nozzle, volumetric or gravimetric prover, etc.), and *indicated rate* is that given by the cone meter, as computed from the discharge coefficient *Cd* stamped on the meter's data plate.

A typical calibration curve is shown below.



Once the curve has been determined, the meter factor at any Reynolds Number in the range may be found by linear interpolation.

First compute the mass rate (qm); determine the fluid's viscosity μ from Eqn 12; then find the Reynolds Number *Re* from the formula:

$$Re = \frac{N_2\, qm}{\mu\, D} \qquad (17)$$

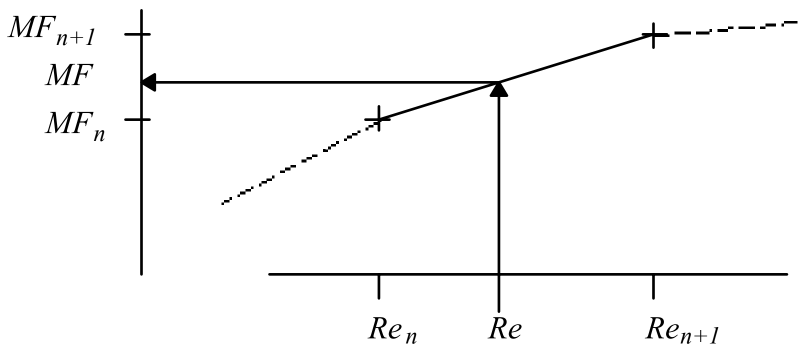
μ = fluid absolute viscosity
N_2 = units constant - see Table 9

[3] The Meter Factor method outlined here is consistent with current (2007) AGA and API standards. See references (1) & (2).

Table 9 - Reynolds Number Equation Units Constant N_2

	US units	US units	US units	Metric units	Metric units	MKS units
qm	lbm/sec	lbm/sec	lbm/sec	kg/sec	kg/sec	kg/sec
μ	lbm/ft*sec	cp	poise	cp	poise	kg/m*sec
D	ft	in	in	mm	mm	m
N_2	1.27324	22737.5	227.375	1.27324E6	12732.4	1.27324

From the calibration curve, locate the two Reynolds Numbers that bracket *Re*, such that $Re_n < Re < Re_{n+1}$



...and interpolate the meter factor from:

$$MF = \left[\left(\frac{Re - Re_n}{Re_{n+1} - Re_n}\right)(MF_{n+1} - MF_n)\right] + MF_n \quad (18)$$

The adjusted flow rate is

$$qm_{adj} = qm \times MF \quad (19)$$

Other methods of handling meter factors are described in Appendix D.3 of AGA Report No. 7 (reference 2). Note that in their respective flow equations, the cone meter's discharge coefficient (*Cd*) plays the same role as the turbine meter's K-factor, so the methods described in the report can be easily adapted to the cone meter.

Sample Calculation 1 (Liquid)

A stainless steel cone meter having an inside diameter of 4.026 inches (102.2604 mm) and a cone diameter of 3.362 inches (85.404 mm), measuring pure water at 150°F, generates a differential pressure of 54 in H_2O_{68}. The discharge coefficient from the meter's calibration certificate is 0.8217. Find the gross volume flow rate in US gallons per minute (neglect the meter factor and thermal expansion in the meter).

Beta and EV	Eqn 4 and 5

$$\beta = \frac{\sqrt{4.026^2 - 3.362^2}}{4.026} = \frac{\sqrt{4.9056}}{4.026} = 0.55$$

$$Ev = \frac{1}{\sqrt{1-\beta^4}} = \frac{1}{\sqrt{1-0.55^4}} = 1.04915$$

Density and flow rate	Eqn 2, Tables 2, 4, 7

water density $\rho_{t,p}$ = 61.196 lbm/ft3

$$qv = \frac{N_1\, Cd\, Ev\, Y\, (\beta\, D)^2\ \sqrt{\rho_{t,p}\, \Delta P}}{\rho_{t,p}}$$

$$qv = \frac{0.745822 \times 0.8217 \times 1.04915 \times (0.55 \times 4.026)^2 \times \sqrt{61.196 \times 54}}{61.196} = 2.96145\ gal/sec$$

$$qv = 2.96145 \times 60 = 177.68\ gal/min$$

Flow rate (simplified)	Eqn 1, Tables 1 & 4

The flow equation can also be simplified by combining the constants and unmeasured variables, e.g.,

$$qv = K\sqrt{\Delta P}$$

$$K = \frac{N_1\, Cd\, Ev\, Y\, (\beta\, D)^2 \sqrt{\rho_{t,p}} \times 60}{\rho_{t,p}}$$

$$= \frac{0.745822 \times 0.8217 \times 1.04915 \times (0.55 \times 4.026)^2 \times \sqrt{61.196} \times 60}{61.196}$$

K = 24.18017

Sample Calculation 2 (Steam)

The meter from example 1 is measuring saturated steam at 10 megapascals gauge, and produces a differential pressure of 13 kilopascals. Local atmospheric pressure is 100 kpa. Find the steam flow rate in kilograms per hour. Neglect the meter factor and correct for thermal expansion in the meter.

The absolute pressure is 10 + (100/1000) = 10.1 mpa

At 10.1 mpa, Table 2 of the IF-97 Steam Tables shows the saturation state temperature to be 311.73°C and the vapour phase specific volume to be 0.017813 m^3/kg.

Density is the inverse of specific volume, so

$$\rho_{t,p} = \frac{1}{0.017813} = 56.1388\ kg/m^3$$

Diameter correction	**Eqn 7, 8, Table 5**
$D = D_r[1+\alpha_2(T_f - T_r)] = 102.2604[1 + 0.0000177(311.73-20)] = 102.7884\ mm$	
$d = d_r[1+\alpha_1(T_f - T_r)] = 85.404[1 + 0.0000177(311.73-20)] = 85.845\ mm$	
$\beta = \frac{\sqrt{D^2 - d^2}}{D} = \frac{\sqrt{102.7884^2 - 85.845^2}}{102.7884} = 0.5500035$	
$Ev = \frac{1}{\sqrt{1-\beta^4}} = \frac{1}{\sqrt{1-0.5500035^4}} = 1.04915$	
Expansion factor	**Eqn 6a, Table 3**
$Y = 1-(0.649 + 0.696\,\beta^4)\frac{\Delta P}{k\,P_f\,N_3}$ $= 1-(0.649 + 0.696 \times 0.5500035^4)\times \frac{13}{1.4\times 10.1 \times 1000} = 0.99934$	
Flow rate	**Eqn 1, Tables 1 & 4**
$qm = N_1\,Cd\,Ev\,Y\,(\beta\,D)^2\ \sqrt{\rho_{t,p}\,\Delta P}$	
$qm = 0.0000351241 \times 0.8217 \times 1.04915 \times 0.99934 \times (0.5500037 \times 102.7884)^2$ $\ldots \times \sqrt{56.1388 \times 13}$	
$qm = 2.6127\ kg/\sec = 9405.85\ kg/hr$	

Sample Calculation 3 (Natural Gas)

The same meter is measuring natural gas consisting of 97% methane, 2% propane, and 1% iso butane. The flowing pressure is 700 psi absolute, the flowing temperature is 84 °F, and the differential pressure is 73 inH_2O_{60}. Find the flow rate in MMSCFD corrected to contract base conditions of 60 °F and 13.60 psia. Apply a diameter correction, and neglect the meter factor.

Molar mass	**Eqn 1, Tables 1 & 4**

$$Mr = (0.97 \times 16.042) + (0.02 \times 44.096) + (0.01 \times 58.122) = 17.02388$$

At 700 psia and 84°F the compressibility factor, according to AGA-8, is

$$Z_{t,p} = 0.911979$$

At base conditions 60°F and 13.6 psia:

$$Z_b = 0.997922$$

Flowing and base densities	**Eqn 9, 10, Table 5**

$$\rho_{t,p} = \frac{Mr\, P_f}{Z_{t,p}\, R\, T_f} = \frac{17.02388 \times 700}{0.911979 \times 10.73164 \times (84 + 459.67)} = 2.23965\, lbm/ft^3$$

$$\rho_b = \frac{Mr\, P_b}{Z_b\, R\, T_b} = \frac{17.02388 \times 13.6}{0.997922 \times 10.73164 \times (60 + 459.67)} = 0.041601\, lbm/ft^3$$

Diameter correction	**Eqn 7, 8, Table 5**

$$D = D_r[1 + \alpha_2\,(T_f - T_r)] = 4.026[1 + 0.00000925(84 - 68)] = 4.0265495848\, in$$

$$d = d_r[1 + \alpha_1\,(T_f - T_r)] = 3.362[1 + 0.00000925(84 - 68)] = 3.362497576\, in$$

Temperature-corrected beta	**Eqn 5**

$$\beta = \frac{\sqrt{D^2 - d^2}}{D} = \frac{\sqrt{4.026595848^2 - 3.362497576^2}}{4.026595848} = 0.55014$$

Velocity of Approach factor	**Eqn 4**

$$Ev = \frac{1}{\sqrt{1 - \beta^4}} = \frac{1}{\sqrt{1 - 0.55014^4}} = 1.0492$$

Expansion factor	**Eqn 6a, Table 3**

$$Y = 1 - (0.649 + 0.696\,\beta^4)\frac{\Delta P}{k\, P_f\, N_3} = 1 - (0.649 + (0.696 \times 0.55014^4))\frac{73}{1.3 \times 700 \times 27.707}$$

$$Y = 0.9979$$

Volume flow rate at base conditions	Eqn 3, Tables 1 & 4

$$Qv = \frac{qm}{\rho_b} = \frac{N_1\, Cd\, Ev\, Y\, (\beta\, D)^2 \sqrt{\rho_{t,p}\, \Delta P}}{\rho_b}$$

$$Qv = \frac{0.0997424 \times 0.8217 \times 1.0492 \times 0.9979 \times (0.55014 \times 4.026595848)^2 \sqrt{2.23965 \times 73}}{0.041601}$$

$$Qv = 129.4278\ std\ ft^3/sec = 11182563\ std\ ft^3/day$$

$$Qv = 11.18\ MMSCFD$$

Sample Calculation 4 (Meter Factor)

Apply the following meter factor table to sample calculation 3.

Re	MF
976250	1.0055
1326250	1.0069
1844750	1.0046
2290500	1.0006
2912750	0.9968
3229500	0.9972
3656000	0.9980
4058500	0.9966
4955000	0.9972
6452000	0.9967

Calculate the viscosity (cp).

Viscosity	**Eqn 12, Table 8**

$$\mu = \frac{\sum_{i=1}^{n} x_i \, \mu_i \sqrt{Mr_i}}{\sum_{i=1}^{n} x_i \sqrt{Mr_i}}$$

Numerator Term:

$$\sum_{i=1}^{n} x_i \, \mu_i \sqrt{Mr_i} = (0.97 \times 0.01078 \times \sqrt{16.042}) + (0.02 \times 0.00788 \times \sqrt{44.096})$$

$$\ldots + (0.01 \times 0.00724 \times \sqrt{58.122}) = 0.04348$$

Denominator Term:

$$\sum_{i=1}^{n} x_i \sqrt{Mr_i} = (0.97 \times \sqrt{16.042}) + (0.02 \times \sqrt{44.096}) + (0.01 \times \sqrt{58.122}) = 4.09414$$

$$\mu = \frac{0.04348}{4.09414} = 0.01062 \; cp$$

Initial qm from Sample Calculation 3	**Eqn 1**

$$qm = N_1 \, Cd \; Ev \; Y \, (\beta \, D)^2 \; \sqrt{\rho_{t,p} \, \Delta P}$$

$$= 0.0997424 \times 0.8217 \times 1.0492 \times 0.9979 \times (0.55014 \times 4.026595848)^2 \times \sqrt{2.23965 \times 73}$$

$$= 5.3843266 \; lbm/\sec$$

Reynolds Number	**Eqn 17, Table 9**

$$Re = \frac{N_2 \, qm}{\mu \, D} = \frac{22737.5 \times 5.3843266}{0.01062 \times 4.026595848} = 2862935.4$$

Interpolation	**Eqn 18**

The adjacent Reynolds numbers from the Meter Factor table are

Re_n = 2290500 at MF_n = 1.0006
Re_{n+1} = 2912750 at MF_{n+1} = 0.9968

$$MF = \left[\left(\frac{Re - Re_n}{Re_{n+1} - Re_n} \right) (MF_{n+1} - MF_n) \right] + MF_n$$

$$MF = \left[\left(\frac{2862935 - 2290500}{2912750 - 2290500} \right) \times (0.9968 - 1.0006) \right] + 1.0006 = 0.9971$$

Adjusted mass flow rate	**Eqn 19**

$$qm_{adj} = qm \times MF = 5.3843266 \times 0.9971 = 5.3687$$

Volume flow rate at base conditions	Eqn 3, Table 4

$$Qv = \frac{qm}{\rho_b} = \frac{7.64109455}{0.041601} = 183.6757\ std\ ft^3/\sec = 15869584.12\ std\ ft^3/day$$

$$= 11.15\ MMSCFD$$

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