PIPI PCEFL001
Flow Measurement Guidelines
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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1. **Scope**

This Practice provides engineering guidance for the selection, design, and application of flow measurement systems.

This Practice provides guidelines, performance considerations, and preliminary recommendations for the selection of flow meters and their general application. This guideline applies to devices used to measure the flow of single phase, homogeneous liquids, vapors, and gases.

This Practice presents commonly accepted meter types but does not limit application choices. Unique or special requirements may require consideration of other meter types.

Specific custody transfer guidelines are not provided and are only mentioned with reference to other industry practices.

2. **References**

Applicable parts of the following Practices, industry codes and standards, and references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP PCCFL001 - *Flow Measurement Design Criteria*
- PIP PCCGN002 - *General Instrument Installation Criteria*

2.2 **Industry Codes and Standards**

- American Gas Association
  - AGA 9 - *Measurement of Gas by Multipath Ultrasonic Meters*
- American National Standards Institute (ANSI)
    Part 1 General Equations and Uncertainty Guidelines  
    Part 2 Specification and Installation Requirements  
    Part 3 Natural Gas Applications  
    Part 4 Background, Development, Implementation Procedures and Subroutine Documentation
- American Petroleum Institute (API)
  - API RP 551 - *Process Measurement Instrumentation*
  - API RP 554 - *Process Instrument and Control*
  - API Manual of Petroleum Measurement Standards (MPMS): Chapter 4 - Proving Systems  
    4.2 Conventional Pipe Provers  
    4.3 Small Volume Provers  
    4.5 Master-Meter Provers  
    4.8 Operation of Proving Systems
Chapter 5 - Metering
  5.2 Measurement of Liquid Hydrocarbons by Displacement Meters
  5.3 Measurement of Liquid Hydrocarbons by Turbine Meters

Chapter 6 - Metering Assemblies

Chapter 12 - Calculation of Petroleum Quantities
  12.2 Calculation of Liquid Petroleum Quantities Measured by Turbine or Displacement Meters

Chapter 14 - Natural Gas Fluids Measurement
  14.2 Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases (AGA Report No. 8)
  14.3 Concentric, Square-Edged Orifice Meters
  14.4 Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes
  14.5 Calculation of Gross Heating Value, Specific Gravity, and Compressibility of Natural Gas Mixtures from Compositional Analysis
  14.6 Continuous Density Measurement
  14.7 Mass Measurement of Natural Gas Liquids
  14.8 Liquefied Petroleum Gas Measurement

Chapter 21 - Flow Measurement Using Electronic Metering Systems

- American Society of Mechanical Engineers (ASME)
  - ASME MFC-1M - Glossary of Terms Used in the Measurement of Fluid Flow in Pipes
  - ASME MFC-2M - Measurement Uncertainty for Fluid Flow in the Closed Conduits
  - ASME MFC-3M - Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi
  - ASME MFC-8M - Fluid Flow in Closed Conduits - Connections for Pressure Signal Transmissions Between Primary and Secondary Devices
  - ASME MFC-9M - Measurement of Liquid Flow in Closed Conduits by Weighing Method
  - ASME MFC-10M - Method of Establishing Installation Effects on Flow Meters
  [Note: For ½” to 1-½” Orifice Meters and Integral Orifice]
– ASME B16.5 - *Pipe Flanges and Flanged Fittings*
– ASME B16.36 - *Orifice Flanges*
– ASME PTC-6 - *Performance Test Code, Steam Turbines*
• International Organization for Standardization (ISO)
• ISA, The International Society for Measurement and Control (ISA)
  – ISA RP16.1,2,3 - *Terminology, Dimensions and Safety Practices for Indicating Variable Area Meters*
  – ISA RP16.4 - *Nomenclature and Terminology for Extension Type Variable Area Meters*
  – ISA RP16.5 - *Installation, Operation, Maintenance Instructions for Glass Tube Variable Area Meters*
  – ISA RP16.6 - *Methods and Equipment for Calibration of Variable Area Meters*
  – ANSI/ISA RP31.1 - *Specifications, Installations, and Calibration of Turbine Flowmeters*

2.3 Other References
– Miller, R.W., *Flow Measurement Engineering Handbook*
– ASME - *Fluid Meters, Their Theory and Application*

3. General

3.1 Flow Metering Quality

3.1.1 Flow meter selection and installation are major contributors to the performance of a plant control system. During the conceptual design, performance requirements should be considered for the flow meter.

3.1.2 Figure 1 illustrates the two primary quality parameters likened to rifle marksmanship. “Repeatability” is a term meant to express the random errors in a measurement. It is the measurement of how closely a sequence of readings conforms to each other. As can be seen, a flow measurement may be repeatable without being highly accurate. Measurement repeatability is the essential requirement for many flow control loops. The minimum industry requirements and manufacturer’s guidelines should be followed for the flow meter technology being applied if repeatable measurement is desired for control or general indication of flow.
3.1.3 “Accuracy” (or its inverse, inaccuracy) is a term expressing the systemic error in a measurement and is the value of how far an individual reading departs from a reference standard. A higher degree of accuracy is crucial in areas where product quality control or reporting quality is the primary reason for the measurement. More rigorous selection of meter types and installation practice must be used in these cases.

![Accuracy Diagram](image)

Figure 1. Target Practice Illustration of Flow Measurement

3.1.4 “Uncertainty” is the total potential error or inaccuracy from the reference standard by the two parameters expressed above. An expression of uncertainty usually represents the limit of allowable inaccuracy for a given flow measurement without distinction of its error source. A one percent uncertainty flow meter must maintain a measurement reading within one percent of the reference standard.

3.1.5 Another requirement might include periodic flow calibration as part of operation and maintenance of the meter.

3.1.6 Overall flow measurement performance can be estimated using a root-sum-of-squares technique in combining error contributions of the metering system components that make up the measurement system.

3.1.6.1 This measurement uncertainty should be applied to the daily integrated measured quantities of steady flow through the meter.

3.1.6.2 Methods for determining the measurement uncertainty are given in ISO 5167.
3.1.7 Quality flow measurement is dependent on:
   a. Type of meter selected
   b. Manufacturer’s tolerances
   c. Proper installation
   d. Calibration procedures
   e. Operation and maintenance procedures
   f. Accounting methods

3.1.8 The following information should be obtained before selecting a meter:
   a. Ranges of physical and chemical characteristics of the fluid, including composition, viscosity, flowing density, vapor pressure, corrosive, abrasive or contaminated nature, lubricating quality, and plugging or fouling tendencies
   b. Acceptable materials of construction
   c. Range of flow rates expected (maximum and minimum with normal expected value)
   d. Process fluid temperature and pressure variations expected
   e. Seasonal and daily ambient temperature changes at the meter
   f. Duration of operation (continuous or intermittent)
   g. Location of meter or metering station (local or remote)
   h. Pressure drop allowable for the measurement
   i. Maintenance accessibility
   j. Meter servicing or replacement while the process is on-line
   k. Required accuracy of the overall measurement
   l. Plant equipment preferences and experiences with similar metering applications

3.2 Flow Element Selection
There are many types of flow metering technologies available. Appendix A, Flowchart 1 provides general information to aid in selecting primary flow elements.

3.3 Piping Arrangement
3.3.1 Many flow meters are sensitive to upstream and downstream velocity profile conditions.
3.3.2 Piping components such as fittings, reducers, expanders, elbows, strainers, branch connections, valves, pipe lengths, and spacing can affect the fluid’s flowing velocity profile. Many possible configurations can make it difficult to predict changes in velocity profile.
3.3.3 Flow meters’ installed performance can be adversely influenced by insufficient piping approaches and departures.
3.3.4 Straight runs before and after a primary flow element should meet established minimum upstream and downstream requirements for the specific meter.

3.3.5 Piping run length criterion for orifice meters can be applicable for other meters because they are the minimum acceptable necessary lengths to assure adequate velocity profile development.

3.3.5.1 Maximizing run lengths contributes to quality flow measurements.

3.3.5.2 Using less than minimum lengths compromises metering performance. Appendix B, Table 1 provides recommendations for the design of orifice meter runs. See API MPMS Chapter 14.3 for additional information.

3.3.6 The metering piping design should consider the possibility of increased flow resulting from debottlenecking or future process expansion. Maximizing meter run piping lengths based on a high beta ratio can accommodate the increase in flow without the added cost of piping revisions.

3.3.7 Temperature wells or connections should be located downstream of the primary flow elements to minimize velocity profile distortion.

3.3.7.1 In some cases, it may be necessary to insulate the piping to maintain temperature.

3.3.7.2 Pressure and temperature should be measured at or very near the meter if flow compensation is needed.

3.3.8 Piping should be arranged to ensure that liquid flow meters are always full of liquid (vapor free) and gas flow meters are always liquid free.

3.3.8.1 Turning down after a meter in a liquid horizontal run or turning up after a meter in a condensing vapor flow should be avoided.

3.3.8.2 In vertical piping runs, liquids should flow up while condensing vapors should flow down.

3.3.9 Piping layout should consider meter dimensions, tap orientation, and access for maintenance service work. This is especially important where close-coupled transmitter installations are used.

3.4 Flow Conditioning

3.4.1 Installation of flow conditioning devices to reduce flow velocity distortion should be considered only in special cases after all other alternatives have been exhausted.

3.4.2 Flow conditioning devices introduce pressure drop and can be dislodged causing metering error or damage to downstream equipment.

3.5 Removal of Insertion Type Flow Instruments

3.5.1 Insertion flow devices should typically be used in large line sizes.

3.5.2 If a process line cannot be practically shut down, safe meter removal should be provided using flow assemblies that are fully retractable under line pressure and process temperature.

3.5.3 The packing assembly and isolation valve should be properly sized in accordance with the piping specifications.
3.5.4 Blowout prevention should be considered as part of the installation design.
3.5.5 Ensure proper clearances and accessibility to facilitate removal.

### 3.6 Control Valve Location

3.6.1 To avoid flow profile disturbances on the meter, the preferred location of flow and pressure control valves is downstream of the meter.
3.6.2 For liquid service, locating the valve downstream of the meter can provide adequate backpressure to avoid flashing in the meter.

### 3.7 Special Equipment

3.7.1 Some types of meters may require specialized testing and calibration connections and/or equipment to operate, calibrate, and maintain.
3.7.2 Installation, calibration, and operation of the special equipment (i.e., meter provers) should be considered as part of the engineering design.

### 4. Specific Considerations

#### 4.1 Head-type (Differential Pressure) Flowmeters

4.1.1 Flow rangeability (ratio of full scale flow to minimum flow but not zero flow) should be considered carefully in choosing head type flow meters. Use of smart transmitters can improve turndown and accuracy for differential meters. In any case, the meter performance at the minimum flow rate should be evaluated along with the maximum flow rate.

4.1.2 Head type flow meters infer flow from measuring differential pressure, which varies as the square of actual flow, introducing a nonlinear characteristic that is especially apparent at low flows. Normally the signal is linearized, but this does not eliminate issues of low flow inaccuracy or instability. Square root operation in calculating flows from head type meters should be performed in the control system when using analog output of non-digital transmitters. Smart transmitters and multivariable transmitters with digital output may be used to provide a linearized output.

*Comment:* If the user wishes to use the transmitter to linearize the output signal, care must be taken to avoid the problem of multiple square root extraction.

4.1.3 Pressure and temperature compensation may be used to improve the accuracy of the flow measurement. The compensation can be done in the process control system using transmitted values or within a multivariable transmitter. Flow, pressure, and temperature values can also be used to calculate mass flow.

4.1.4 Transmitters should be located as close as practical to the primary element for differential pressure measurement applications. Impulse line length, temperature difference in the impulse lines, and long piping configurations are detrimental to the measurement.
4.1.5 Pressure Taps:

4.1.5.1 To avoid plugging or fouling of the sensing line with materials that may settle on the bottom of the pipe, pressure taps should not be connected to the bottom of the pipe.

4.1.5.2 For liquid, steam, or heat transfer media services:

a. Pressure taps should preferably be horizontal on the side of the line. This may require wider spacing of process piping at the orifice section. Or it may be necessary to raise or lower the orifice run with respect to other piping for sufficient side clearance for the tap connections.

b. Alternatively, pressure taps may be oriented 45 degrees down from horizontal.

c. The impulse lines should always slope toward the transmitter avoiding traps.

d. Review of piping layouts should be performed.

4.1.5.3 For dry gas services:

a. Pressure taps should preferably be vertical, up from the top of the line with connecting instrument piping lines sloped up and avoid pocketing.

b. Optionally, pressure taps may be horizontal on the side of the line or 45 degrees downward from vertical.

c. The flow transmitter should be located above the taps with impulse lines sloped to be self-draining to the process pipe.

4.2 Orifice Meters

4.2.1 Advantages of orifice meters include:

a. Easy to install
b. Common transmitters regardless of pipe size
c. Relatively low cost
d. Wide variety of types and materials available
e. Easy to re-range and troubleshoot
f. May provide a repeatable, controllable output below specified turndown
g. Has large data base to support coefficient uncertainty

4.2.2 Limitations of orifice meters include:

a. Unsuitable for non-Newtonian fluids
b. Limited turndown
c. Accuracy is severely degraded as the plate wears or fouls
d. Straight runs of upstream and downstream piping required
e. Subject to process leaks through tubing, fittings, valves, and taps
f. Significant permanent pressure loss across meter
g. Impulse lead lines subject to freezing or plugging

4.2.3 300# class flange taps are preferred for line sizes 2 inches and larger. Corner tapped honed flow meter runs or integral orifices are preferred for 1.5 inches and smaller line sizes.

4.2.4 Concentric, square-edged orifice meters should be used for services in which the Newtonian fluid is a clean, homogeneous, low viscosity liquid, vapor or gas and in a single phase, such as:
   a. Fluids in turbulent flow (pipe Reynolds number at minimum measured flow above 4000)
   b. Corrosive fluids
   c. Steam
   d. Air

4.2.5 Retractable orifice holder assemblies should be used for concentric orifices if there is a need to frequently inspect or change orifice plates (e.g., custody transfer applications).

4.2.6 For process conditions where occasional entrained liquid or gas can exist, the use of a drain or vent hole is suggested. Consider using an eccentric or segmental plate if suspended solids may be present. Quadrant edge or conic type orifice plates should be considered if the maximum measured flow pipe Reynolds number is below 10,000 or if the anticipated process viscosity changes would cause significant errors with standard square-edge orifices.

4.2.7 Appendix B, Table 1, gives design guidelines for flange tap concentric, square-edged orifice meters.

4.2.8 Orifices should typically have a beta ratio (ratio of orifice bore diameter to pipe internal diameter) greater than or equal to 0.2 and less than or equal to 0.7. See Appendix B, Table 1, for recommended beta ratio ranges for measurement performance.

4.2.9 For best accuracy, the flow sizing and calculation should be based on actual meter tube internal dimensional data. See Appendix B, Table 1.

4.2.10 A preferred DP calibration range should be 0-100 inches of water (2500 mm). Other ranges may be considered to meet the application requirements (e.g., low pressure gas or to meet beta ratio constraints). High DP may cause deformation in orifice plates and adds excessive energy loss.

4.2.11 The upstream and downstream piping configuration for an orifice plate should follow Table 1 or 2 of PCCFL001, Flow Measurement Design Criteria. Table 1 shows dimensions for ½ % additional uncertainty in accordance with ISO-5167-2, Column B; ½% uncertainty is typically used for flow control and monitoring applications. Table 2 shows dimensions in accordance with API 14.2.3 (and ISO-5167-2, Column A) for 0% additional uncertainty; 0% uncertainty can be used where increased accuracy measurement is required.
4.3 Flow Nozzles

4.3.1 Advantages of flow nozzles include:
   a. Slightly lower permanent pressure loss than orifice at similar beta ratios
   b. Good for fluid flows with entrained solids
   c. Lower cost than venturi
   d. Dimensionally more stable at higher temperatures and velocities than an orifice

4.3.2 A limitation of flow nozzles is that the quality of workmanship varies because flow nozzles are fabricated. Inspection is generally desirable before shipment and required before installation.

4.3.3 Flow nozzles can be used for low viscosity, non-abrasive fluids at high flow rates in which:
   a. Lower head loss than an orifice plate is desired
   b. A contoured element is needed for long service life where a sharp edge would wear

4.3.4 Installation and removal of the nozzle should be considered in the piping design. However in high pressure steam applications (greater than 1000 psig), the flow nozzle should be welded directly into the pipe.

4.3.5 The upstream and downstream piping configuration for a flow nozzle should follow Table 3 of PCCFL001, Flow Measurement Design Criteria.

4.4 Venturi

4.4.1 Advantages of a venturi include:
   a. Very low permanent pressure loss
   b. Good for fluid flows with entrained solids
   c. Upstream run length is less than for orifice meters

4.4.2 Limitations of a venturi include:
   a. Expensive in larger sizes
   b. Big and heavy in larger sizes
   c. Quality of workmanship varies because they are fabricated. Inspection is generally desirable before shipment and required before installation.
   d. Limited data set for coefficient and upstream straight pipe requirements
   e. Higher measurement uncertainty at pipe Reynolds numbers less than 100,000

4.4.3 A venturi can be used for low viscosity, non-abrasive fluids at high flow rates if only a small pressure drop or permanent head loss is allowed.

4.4.4 For high accuracy applications, the venturi should be flow calibrated.

4.4.5 The upstream and downstream piping configuration for a flow nozzle should follow Table 3 of PCCFL001, Flow Measurement Design Criteria.
4.5 Averaging Pitot Elements

4.5.1 Advantages of an averaging pitot include:
   a. Low cost
   b. Low permanent pressure loss
   c. Negligible flow obstruction
   d. May be installed using hot taps
   e. Shorter upstream and downstream piping requirements than for orifice

4.5.2 Limitations of an averaging pitot include:
   a. Very low differential pressures developed, so signal may be noisy
   b. Impulse lines should be kept to minimum length due to low differential pressures involved
   c. Turndown limited due to low differential pressure
   d. Subject to plugging or fouling
   e. Subject to vibration induced fatigue failure if maximum velocity limit is exceeded

4.5.3 Averaging pitot tubes may be an alternative to orifice plates if lower head loss is needed, lower cost is desired, and less accuracy is acceptable.

4.5.4 Averaging pitot tubes are subject to plugging and should be limited to clean process liquids and gases.

4.5.5 Depending on velocity profile characteristics, averaging pitot tubes should be more accurate than pitot tubes.

4.5.6 In large line sizes, where long traverse lengths may be encountered, opposite side support should be provided or heavier walled elements used.

4.5.7 Since most designs of averaging pitot type devices only average flow over a single plane of the full cross-section of the conduit, the flow profile distortions can have an adverse effect on measurement accuracy.

4.5.8 If a failed pitot tube could enter and damage downstream rotating equipment, another element type should be considered.

4.5.9 If a pitot tube is used, opposite side support should be considered.

4.5.10 Manufacturer recommendations should be followed with regard to the need for wake frequency calculations.

4.6 Integral Orifice

4.6.1 An advantage of an integral orifice is that it is suitable for small line sizes and very low flows.

4.6.2 A limitation of an integral orifice is that it is subject to plugging.

4.6.3 If low flow rates dictate a meter tube less than 2 inches (50 mm), an integral orifice assembly can be used.
4.6.4 Integral orifices and honed pre-fabricated meter tubes can be designed in sizes that meter comparable flow rates. Selection between the two should be based on cost (both hardware and installation), metallurgy requirements, transmitter mounting options, on-line servicing requirements, and metering accuracy needs.

4.6.5 Integral orifices are available in two types of configurations.

4.6.5.1 One design type routes the process flow through one or both chambers of the differential pressure transmitter.

4.6.5.2 The other design is much like a standard orifice flange except the transmitter connection is machined (like a manifold flange) so the transmitter can be mounted directly up against the orifice assembly.

4.6.6 If the meter needs to be serviced while the process is on-line, isolation valves should be specified.

4.6.6.1 Process line block and bypass valves should be required for servicing the flow-through design while on-line.

4.6.6.2 For an adjacent transmitter design, root valves (or a flange by flange manifold) allow servicing the transmitter.

4.6.6.3 If the expected on-line servicing includes checking a small bore for plugging, then the block and bypass arrangement should be required for either integral orifice design.

4.6.6.4 Even small leakage through a meter bypass can result in significant flow measurement errors of small integral orifices. The bypass valve should be capable of zero leakage.

4.6.7 If small bores are dictated, the fluid should be of low viscosity and contain no solids.

4.6.8 A strainer installed upstream of the meter run and located beyond the manufacturer’s minimum recommended pipe diameters upstream of the orifice may be required.

4.6.9 Normal process operating conditions, as well as potential start up contaminants (pipe scale, welding slag, etc.), should be considered.

4.7 Wedge Type Meters

4.7.1 Advantages of wedge type meters include:

a. Good for slurries and very dirty fluids
b. Relatively low permanent pressure loss
c. Self-cleaning
d. Good for low Reynolds number applications. Minimum Reynolds number of 500.
e. May be used in bi-directional service

4.7.2 Limitations of wedge type meters include:

a. Some installations may require remote seals
b. More expensive than orifice installation
4.8  **V-Cone Meter**

4.8.1 Advantages of a V-cone meter include:
   a. Short straight run requirements
   b. No obstruction at the bottom of the pipe, allowing debris to pass
   c. Pressure taps can be threaded or socket weld
   d. Meter is suitable for dry gas, wet gas, clean liquids, or liquids with some debris

4.8.2 Limitations of a V-cone meter include:
   a. Higher installed cost relative to orifice installation
   b. Factory flow calibration is required to get the 0.5% accuracy for many applications
   c. Not suited for high viscosity fluids
   d. Higher differential pressure losses

4.8.3 V-cone meters are used when minimal straight run. The meter requires 3D upstream and 1D downstream.

4.8.4 V-cone meters produce a higher differential pressure across the meter in order to produce a useful DP signal at low flows.

4.9  **Turbine Meters (Liquid)**

4.9.1 Advantages of turbine meters include:
   a. High accuracy
   b. High turndown
   c. Easy to install
   d. Low permanent pressure loss
   e. Linear output (frequency or analog output available)
   f. Insertion style available, subject to special installation requirements

4.9.2 Limitations of turbine meters include:
   a. Easily damaged
   b. Normally requires more maintenance than other meters because of moving parts
   c. Fluid must be clean
   d. Sensitive to viscosity changes
   e. Bearings will wear and reduce accuracy
   f. Requires physical protection of the meter from debris in the piping

4.9.3 Turbine meters may be used in fluids that are clean, provide lubricity, in single phase (not operated near the liquid vapor pressure), and are limited in viscosity changes.
4.9.4 Full line sized turbines are typically used in lines 8 inches (200 mm) and below. Insertion type turbine meters may be used on larger lines.

4.9.5 Bearing types and materials of construction should be evaluated for fluid and process stream compatibility.

4.9.6 Strainers, filters, air or vapor eliminators, or other protective devices should be provided upstream of turbine meters to remove solids or contaminants that will cause wear and measurement errors.

4.9.7 Turbine meter damage can occur if the process lines are blown clear with gas or steam. Special provisions may be required to protect the meter.

4.9.8 Liquid turbine meters should only be used in moderate to low viscosity services. Turbine meters are velocity profile sensitive and flow profile conditioning devices upstream of the turbine should be considered.

4.9.9 API MPMS Chapter 5 should be considered for high accuracy application guidelines. For plant applications ISA RP 31.1 should be consulted.

4.10 Positive Displacement Meters

4.10.1 Advantages of positive displacement meters include:
   a. High accuracy
   b. Wide rangeability
   c. Suitable for high viscosity
   d. No straight upstream piping required
   e. Linear volumetric output
   f. Good for local totalization
   g. Can be installed at remote locations without power

4.10.2 Limitations of positive displacement meters include:
   a. Moving parts are subject to wear which introduces measurement error
   b. Requires periodic maintenance
   c. High permanent pressure drop
   d. Not suitable for fluids with entrained or abrasive solids or gases
   e. Can completely disrupt the flow if mechanical failure jams or locks the moving parts of the meter

4.10.3 Strainers and air eliminators should be considered upstream of the meter.

4.10.4 Liquid positive displacement meters can be used for custody transfer if other meters capable of operating in the service conditions do not meet accuracy or rangeability requirements.

4.10.5 Manufacturer’s recommendations should be followed for viscosity and flow rate limitations.
4.11 **Magnetic Flow Meters**

4.11.1 Advantages of magnetic flow meters include:
   a. No flow obstruction
   b. Low or no pressure loss
   c. Good for plugging services and slurries
   d. Good for corrosive services by using liners
   e. Not affected by physical property changes in fluid other than conductivity
   f. Minimal straight piping requirements
   g. Can be set up for bi-directional flow

4.11.2 Limitations of magnetic flow meters include:
   a. Fluid must have electrical conductivity (generally 2 micromhos per cm or greater)
   b. Liners can be fragile or easily damaged
   c. Cannot use on gases
   d. Grounding is a major concern to prevent errors resulting from stray field currents
   e. Requires separate power source
   f. Large meters are heavy
   g. Installed cost may be prohibitive on large meters
   h. Coating of electrodes may be a problem
   i. May be temperature limited

4.11.3 Magnetic flow meters can be used on conductive fluids that are:
   a. Corrosive
   b. Contain suspended or abrasive solids
   c. Very low flow

4.11.4 Proper liner material and electrode selection is needed for process fluid compatibility. The manufacturer should be consulted for material availability.

4.11.5 A minimum fluid conductivity in micromhos/centimeter is needed for the meter to operate properly. The manufacturer should be consulted for the minimum requirement.

4.11.6 The application of magnetic flow meters should be evaluated for startup and cleanout conditions (fluids, conductivity, and temperature).

4.11.7 Grounding method should be in accordance with the manufacturer’s recommendations.

4.11.8 Liner damage due to over-tightening of bolts and crushing the liner during installation should be avoided.
4.11.9 A magnetic flowmeter should not be subjected to thermal shock. The meter’s specified temperature limits should not be exceeded.

4.12 Mass Meters (Coriolis)

4.12.1 Advantages of coriolis mass meters include:
   a. Accurate direct mass measurement
   b. Good for most types of liquids and some high density gases
   c. Minimal restriction to flow
   d. Can measure density of fluid in addition to mass flow
   e. High turndown capability
   f. Good for low flow applications

4.12.2 Limitations of coriolis mass meters include:
   a. Cannot be used for two-phase flow
   b. Slugs of gases will affect the measurement
   c. Available in limited sizes
   d. High pressure drop

4.12.3 Mass meters should be sized for the desired accuracy at minimum and normal flow rates without exceeding the permissible pressure drop at the maximum flow rate. This should put the maximum full scale flow rate in the upper one-third of the meter range. A larger meter may be required to reduce pressure drop at the maximum flow rate.

   Comment: Meters should be sized as small as possible for economic reasons. Coriolis meters have large turndown, so a larger meter can be used without losing accuracy when small flow rates and low pressure drops are required.

4.12.4 Corrosion mechanisms should be given extra consideration.

4.12.5 Vibration of the meter tube increases the potential for stress related corrosion.

4.12.6 Other alloy materials may be required in applications where 316 SS would otherwise be acceptable.

4.12.7 Most meter tubes have no corrosion allowance, particularly galvanic corrosion from dissimilar metals.

4.12.8 Meters should be installed in accordance with manufacturer’s recommendations. Meters should be installed to be liquid full for liquid applications and self-draining for gas applications.

4.12.9 Adequate discharge back pressure should be ensured in liquid service to prevent flashing in meter tube.

4.12.10 Care should be taken to avoid subjecting the meter body to piping induced stresses.
4.12.11 If entrained gas is present, the meter manufacturer should be consulted. Meter performance can deteriorate significantly due to the presence of entrained gases in the liquid.

4.12.12 Secondary containment should be considered if using coriolis meters for measuring highly corrosive or hazardous materials.

4.12.13 Meters to be used in highly viscous slurries, shear-sensitive slurries, or fluids that could solidify or settle out to block the flow path may require additional tube/sensor design considerations.

4.12.14 The application of meters should be evaluated for startup and cleanout conditions (entrained gas, temperature extremes, plugging, slug flow, etc.).

4.12.15 Typically, block valves are installed upstream and downstream of the meter to isolate the meter for zeroing under normal operating conditions.

4.12.16 Coriolis meters are available in either curved-tube or straight tube designs. The straight tube design is more compact, provides lower pressure drop and is less prone to pipeline stresses, but has lower rangeability and accuracy than the curved-tube design.

4.13 Mass Meters (Thermal)

4.13.1 Advantages of thermal mass meters include:
   a. Good for low velocity pure component gas or air measurement
   b. Very low pressure loss
   c. Probe type thermal meters can be cost effective for large flows
   d. Cost effective flow switch

4.13.2 Limitations of thermal mass meters include:
   a. May be affected by coatings on probe-fluid should be relatively clean
   b. Some designs can be fragile
   c. Relatively slow response time
   d. Cost is generally higher for low flow applications (flow-through type meters)
   e. May be difficult to maintain
   f. Accuracy is affected by fluid composition and property changes
   g. Entrained liquids in gas streams can render this technique unacceptable

4.13.3 Thermal sensors should only be applied where the fluid thermal conducting properties are well known. Changes in thermal conductivity can cause shifts in sensor responses and give false flow readings. The thermal conductivity for most process streams is not listed nor is readily available.

4.13.4 To obtain stated accuracy, the meter should be calibrated using the actual fluid being measured.

4.13.5 Thermal mass meters (insertion probe type) should be easily removable for cleaning while line is in service.
4.14 Ultrasonic Meters

4.14.1 Advantages of ultrasonic meters include:
   a. Some liquid models can be installed outside the pipe (clamp-on), so there is no contact with process fluid and the meters can be installed while process is running.
   b. No pressure drop
   c. Can be bi-directional
   d. Good for clean or dirty fluids
   e. May provide high turndown
   f. Multi-path meters can provide accuracies that are acceptable for custody transfer applications.
   g. Can meet a wide range of process applications

4.14.2 Limitations of ultrasonic meters include:
   a. Straight piping runs are required.
   b. Sensors are somewhat limited on temperature.
   c. Meter should be matched with fluid, and fluid properties should be consistent.
   d. Clamp-on devices may have limited accuracy.

4.14.3 Application and installation requirements for ultrasonic meters depend on parameters such as:
   a. Process fluid speed of sound characteristics
   b. Presence or absence of echo particles in the fluid
   c. Number of transducers
   d. Minimum and maximum distance between transducers
   e. Single path or multiple chords
   f. Acoustical characteristics in the piping system
   g. Piping dimension data including pipe wall thickness

4.14.4 The manufacturer should assist in the system design and the installation should adhere to the manufacturer’s specifications and recommendations.

4.15 Ultrasonic Transit-Time Flowmeter

4.15.1 The fluid flow should be fully turbulent and clean.

*Comment:* Ultrasonic transit-time meters are principally used in process flows to flares, utility type water flow, and custody transfer of natural gas.

4.15.2 Meters with cavities (recesses for transducers) should not be used if a significant amount of solids in liquids, or liquids or solids in gases, is present. The manufacturer should be consulted for suitability and signal degradation effects.
4.15.3 If it is not possible to shut down a line to install a meter, strap-on type meters may be used. The sensors should have solid acoustic contact with the pipe wall through the use of conducting grease or material.

*Comment:* Pipe wall thickness information is required data.

4.15.4 Ultrasonic transit-time meters should not be used on piping systems that generate noise upstream of the meter. Ultrasonic transit-time meters perform best on “acoustically quiet” installations.

4.15.5 Ultrasonic transit-time meters should not be used on lined pipe and may not work properly on thick walled pipe.

### 4.16 Ultrasonic Doppler Flowmeter

Ultrasonic Doppler meters should be used only for fluids that always contain acoustically reflective medium, e.g., particulate or bubbles homogeneously dispersed.

### 4.17 Vortex Meters

4.17.1 Advantages of vortex meters include:

   a. High accuracy
   b. Low installed cost
   c. High rangeability
   d. No moving parts
   e. Linear output
   f. Low pressure drop

4.17.2 Limitations of vortex meters include:

   a. Minimum Reynolds number velocity required to operate properly
   b. Signal drops out completely below minimum flow threshold
   c. Not suitable for high viscosity, slurry, or coating services
   d. Can be affected by vibration in the pipe

4.17.3 Vortex meters can be used for relatively clean, low viscosity, non-abrasive fluids and can provide higher turndown than orifice meters.

4.17.4 Vortex meters are generally applicable to liquids of low viscosity. Accuracy, turndown, and pressure drop requirements should be carefully reviewed for gas service applications.

4.17.5 Vortex meters are often unsuitable for low density gases.

4.17.6 Vortex meters have low flow cut-off. In other words, there is an erratic or zero reading below a threshold level to register on the meter. This can have drastic effect in closed-loop control or mass balance applications. Sizing should therefore consider minimum flow rates as well as maximum. The minimum value of the pipe Reynolds number at the lowest expected flow should exceed 10,000 for liquids and 50,000 for gases. Below these values the vortex meter may not generate a reliable flow signal. These Reynolds number limitations may vary between manufacturers.
4.17.7 Line size vortex meters are available in pipe sizes between 1-1/2 and 8 inches (37 and 200 mm). Insertion type meters are available for larger line sizes.

4.17.8 The meter should be centered in the piping.

4.17.9 The meter factors should be based on the piping schedule used.

4.17.10 Welds on mounting flanges should be ground smooth. Gaskets should be selected to ensure that no part of the gasket protrudes into the flowing stream.

4.18 Variable Area Meters

4.18.1 Advantages of variable area meters include:
   a. Low cost
   b. Direct indicating
   c. No electrical power needed
   d. No straight run requirements

4.18.2 Limitations of variable area meters include:
   a. Unsuitable for non-Newtonian fluids
   b. Limited accuracy
   c. Must be vertically mounted with upward flow direction
   d. Gas use requires minimum back pressure
   e. Requires accessories for data transmission
   f. May be high maintenance items
   g. Float may stick on overflow conditions

4.18.3 Meters may be used if:
   a. Fluid measured is clean
   b. Fluid flow rate is so small that use of a differential pressure type primary element is impractical
   c. Flow of fluid is not pulsating
   d. Local flow indication is needed

4.18.4 Glass type meters should not be used for measuring fluids that contain hot or strong alkali, strong acids, steam, hydrocarbons, or other fluids that are hazardous to equipment or personnel. The use of armored type meters is preferred.

4.18.5 For purge meter applications, a check valve should be provided on the outlet of the meter to prevent back flow.
5. Custody Transfer Metering Considerations

5.1 Custody transfer generally applies to those flow metering applications where fiscal or custodial information is recorded.

5.2 Custody transfer metering information is used for exchange of monies, materials, or trades between two parties, companies, business units, or financial institutions.

5.3 The design of a custody transfer measurement system usually has a requirement for higher integrity and accuracy than conventional process measurement.

5.4 Industry standards such as American Petroleum Institute should be consulted for custody transfer metering information and requirements.

6. Flare Gas Flow Measurement Considerations

6.1 Flare gas flow measurement has taken on increasing importance in order to comply with environmental monitoring regulations. Gas flow rates and composition must be measured in order to determine the mass flow rate of volatile organic compounds (VOC) that are being sent to the flare within required accuracies (typically in the range of +/- 10% to 20%). The measurement is also important in controlling the amount of assist gas (e.g., steam or air) that is to be applied.

6.2 Flare systems need to handle low flow rates during normal process conditions and very high rates under emergency conditions, when process units must be depressurized. Flare systems are also designed with large piping to maintain low pressures and the flow measurement system must maintain a low pressure drop, typically less than 0.5 psig. Depending on the specific event, or combination of events, the gas composition going to the flare can vary widely. Thus the flow measurement system must be designed for a high turndown ratio (up to 1000:1) and take into account composition measurement of the flare gas, either through online analysis (e.g., with gas chromatographs) or periodic laboratory analysis. In order to achieve overall measurement accuracies of +/- 10% to 20%, the flow meter itself is typically specified with an inherent accuracy of +/- 2 to 5%.

6.3 Based on these challenging design conditions, averaging pitot elements, thermal mass meters and multipath, transit-time ultrasonic meters are most commonly applied for flare gas measurement. Thermal mass and ultrasonic meters can handle a greater range of gas velocities than pitot tube systems, but even these meters have a high rate limitation of approximately 300 ft/sec. Some flare systems may be designed to handle higher velocities under certain low-likelihood scenarios. In those cases, multi-measurement techniques may need to be applied or, if regulatory agencies allow, process data may be used to calculate mass flow for these worst-case events.

6.4 Advantages and disadvantages of these types of meters can be found in the applicable sections of this guideline. One particular advantage of the ultrasonic meter is that it can directly determine the gas density and thus the mass flow rate under varying gas composition. Pitot tubes and thermal mass meters require compensation for changes in gas composition. Ultrasonic meters are of considerably higher cost and are sometimes used for main measurements in the flare system, with pitot tubes or thermal mass meters being used to determine the sources of contributing flows.
6.5 As with any flow measurement application, the design must take into account the process conditions (e.g., pressure and temperature), cleanliness of service and straight run requirements for installation.

6.6 Additional guidance on flare flow measurement for processing plants can be found in *API Manual of Petroleum Measurement Standards*, Chapter 14-Natural Gas Fluids Measurement, Section 10-Measurement of Flow to Flares.

Appendixes

Appendix A: Table 1: Flow Meter Evaluation
Appendix B: Table 1: Flange Tap Orifice Meter Run Requirements
### Appendix A: Table 1

<table>
<thead>
<tr>
<th>Flowmeter</th>
<th>Pipe Size (in. (mm))</th>
<th>Gases (Vapors)</th>
<th>Liquids</th>
<th>Pressure</th>
<th>Viscosity</th>
<th>Slurry</th>
<th>Accuracy (Full Scale unless noted as rate)</th>
<th>Rangeability</th>
<th>Minimum Reystoles</th>
<th>Viscosity Effect</th>
<th>Maximum Temperature (degC)</th>
<th>Maximum Pressure (PSI)</th>
<th>Permanent (psi)</th>
<th>Upstream Straight Run Requirements (Pipe dia.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orifice</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M/N M</td>
<td>4:1</td>
<td>&gt;10,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>Integral</td>
<td>&lt;2&quot; (50mm)</td>
<td>M</td>
<td>M</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;10,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>NA</td>
</tr>
<tr>
<td>Eccentric</td>
<td>≥2&quot; (50mm)</td>
<td>M</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;10,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>Segmental</td>
<td>&gt;4&quot; (100mm)</td>
<td>M</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;10,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>Wedge</td>
<td>&lt;12&quot; (305mm)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;10,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>V-Conc</td>
<td>0.5 - 120&quot; (15mm - 3m)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M</td>
<td>10:1</td>
<td>&gt;8,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Venturi</td>
<td>≥2&quot; (50mm)</td>
<td>Y</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;75,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>Flow Nozzle</td>
<td>4 - 25&quot; (100-600mm)</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N</td>
<td>N/M Y/N M</td>
<td>4:1</td>
<td>&gt;50,000</td>
<td>High</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Medium</td>
<td>20</td>
</tr>
<tr>
<td>Pitot</td>
<td>≥3&quot; (80mm)</td>
<td>N</td>
<td>M/N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N/M N/M N</td>
<td>3:1</td>
<td>&gt;100,000</td>
<td>Low</td>
<td>1000°F (540°C)</td>
<td>4000</td>
<td>Low</td>
<td>20</td>
</tr>
<tr>
<td>Avg Pilot</td>
<td>4 - 72&quot; (100-1800mm)</td>
<td>N</td>
<td>M</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N/M N/M N</td>
<td>8:1</td>
<td>&gt;15,000</td>
<td>Low</td>
<td>350°F (180°C)</td>
<td>725</td>
<td>Low</td>
<td>20</td>
</tr>
<tr>
<td>Magnemeter</td>
<td>0.125 - 80&quot; (6mm-2m)</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y/M Y/Y Y</td>
<td>100:1</td>
<td>&gt;4,500</td>
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<td>350°F (180°C)</td>
<td>1500</td>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>PD Meter(1)</td>
<td>≤12&quot; (300mm)</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>M/N Y/N M</td>
<td>10:1</td>
<td>&gt;10,000</td>
<td>None</td>
<td>400°F (200°C)</td>
<td>Pipe rating</td>
<td>Low</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Turbine</td>
<td>0.25 - 24&quot; (6-600mm)</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M N/M N</td>
<td>10:1</td>
<td>Liquid &gt;5000</td>
<td>Liquid &gt;High</td>
<td>Liquid &gt;5000</td>
<td>5000</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Doppler</td>
<td></td>
<td>N</td>
<td>M</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N/M N/M N</td>
<td>10:1</td>
<td>&gt;10,000</td>
<td>None</td>
<td>400°F (200°C)</td>
<td>Pipe rating</td>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>Variable Area</td>
<td>≥0.5&quot; (15mm)</td>
<td>M</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>M/M N/M N</td>
<td>10:1</td>
<td>NA</td>
<td>Medium</td>
<td>400°F (200°C)</td>
<td>350°F - 750°F Metal</td>
<td>Medium</td>
<td>None</td>
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<tr>
<td>Vortex</td>
<td>1.5 - 16&quot; (40-400mm)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
<td>N/M N/M N</td>
<td>10:1</td>
<td>&gt;10,000</td>
<td>Medium</td>
<td>800°F (427°C)</td>
<td>1500</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>Mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coriolis</td>
<td>0.125 - 10&quot; (4-250mm)</td>
<td>M</td>
<td>M</td>
<td>M/N</td>
<td>N</td>
<td>N</td>
<td>Y/M N/M Y</td>
<td>100 to 500:1</td>
<td>NA</td>
<td>None</td>
<td>650°F (350°C)</td>
<td>6000</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>Thermal</td>
<td>≥0.5&quot; (15mm)</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>M</td>
<td>N</td>
<td>N/M N/M N</td>
<td>10:1</td>
<td>&gt;10,000</td>
<td>None</td>
<td>500°F (260°C)</td>
<td>1000</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>Open Channel</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well</td>
<td></td>
<td>N</td>
<td>N/N</td>
<td>Y</td>
<td>M</td>
<td>N</td>
<td>M/N Y/N Y</td>
<td>100:1</td>
<td>NA</td>
<td>Very Low</td>
<td>Atmospheric</td>
<td>Very Low</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Flume</td>
<td></td>
<td>N</td>
<td>N/N</td>
<td>N</td>
<td>Y</td>
<td>M</td>
<td>N/M Y/N Y</td>
<td>100:1</td>
<td>NA</td>
<td>Very Low</td>
<td>Atmospheric</td>
<td>Very Low</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- Y = Generally suitable for the application
- M = May be suitable for the application
- N = Not suitable for the application

**Notes:**
1. Non-Newtonian fluids are those whose flow properties are not described by a single constant value of viscosity.
2. Values shown are typical maximums. Actual values may vary, depending on manufacturer and style of construction.
3. If pressure loss is a concern, be certain to take into account the effect of any upstream flow conditioning devices that may be required to improve the flow profile for the meter.
4. For orifice installations, the upstream piping configuration and the beta ratio of the orifice plate can significantly impact the straight run requirements.
5. Values shown are typical. There are many types of positive displacement meters (e.g., gear, rotary vane and diaphragm) so actual values will depend on manufacturer and style of construction.
### Appendix B: Table 1

#### Flange Tap Orifice Meter Run Requirements

The following data are recommendations for the design of orifice meter runs. These can be modified by engineering judgment provided the overall metering performance meets the designated meter classification. Owner’s approval is required when deviations are needed.

<table>
<thead>
<tr>
<th>Uncertainty:</th>
<th>1%</th>
<th>2%</th>
<th>Not Designated (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orifice Run (1) tolerance</td>
<td>Per API MPMS, Chap. -14.3 Part 2 1991</td>
<td>Per API MPMS, Chap. -14.3 Part 2 1991</td>
<td>Based on Beta</td>
</tr>
<tr>
<td>Straight Run - Upstream and Downstream per PIP PCCFL001:</td>
<td>Based on Beta = 0.75</td>
<td>Based on Beta = 0.75</td>
<td>Based on Beta</td>
</tr>
<tr>
<td></td>
<td>Table 2</td>
<td>Table 1</td>
<td>Table 1</td>
</tr>
<tr>
<td>Orifice Plate Specs.</td>
<td>API 14.3 Part 2</td>
<td>API 14.3 Part 2</td>
<td>API 14.3 Part 2</td>
</tr>
<tr>
<td>Static Press. Tap Location:</td>
<td>High Side Flange Tap</td>
<td>High Side Flange Tap</td>
<td>High Side Flange Tap if required</td>
</tr>
<tr>
<td></td>
<td>(Low side if per contract)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp. Measurement Location:</td>
<td>5 to 12 DIA Downstream of Orifice(2)</td>
<td>5 to 12 DIA Downstream of Orifice(2)</td>
<td>5 to 15 DIA Downstream of Orifice(2) if required</td>
</tr>
</tbody>
</table>

#### Design Guidelines

| Range of Beta | 0.2 to 0.6 | 0.2 to 0.6 | 0.2 to 0.7 |
| Flow Coeff. Calculation | Using Measured Pipe ID and Measured Orifice Bore | Using Measured Pipe ID and Measured Orifice Bore | Using Published Pipe ID and Calculated Orifice Bore |
| Pipe Bore Reynolds No. at Mid DP Flow (3): | RD > 20,000 | RD > 10,000 | RD > 10,000 |
| Liquid | RD > 100,000 | RD > 50,000 | RD > 10,000 |
| Vapor, Gas | | | |
| Rangeability or Turndown (4) | 3 to 1 | 4 to 1 | 10 to 1 |
| Flow Rate | 9 to 1 | 16 to 1 | 100 to 1 |
| Differential Pressure | | | |
| Orifice Run Insulation (10) | 50 DIA Upstream of Orifice to 1 DIA Downstream of Temperature Element or Densitometer Connection | As Required by Process | As Required by Process |

#### Transmitters

<table>
<thead>
<tr>
<th>Flow (DP) - Mfr stated Accuracy at Calibrated Span</th>
<th>+/- 0.10 % of Span or Better</th>
<th>+/- 0.15 % of Span</th>
<th>+/- 0.15 % of Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential Limit, Gases</td>
<td>1 inch H20 per PSIA line pressure</td>
<td>1 inch H20 per PSIA line pressure</td>
<td>2 inch H20 per PSIA line pressure</td>
</tr>
<tr>
<td>Max. Nominal Differential (6)</td>
<td>0-20 to 0-200 inch w.c.</td>
<td>0-10 to 0-400 inch w.c.</td>
<td>0-10 to 0-400 inch w.c.</td>
</tr>
<tr>
<td>Maximum Density Uncertainty</td>
<td>1.5 percent</td>
<td>2.0 percent</td>
<td>4.0 percent</td>
</tr>
<tr>
<td>Density Tolerance (5) (8)</td>
<td>(Compensation usually req’d)</td>
<td>(Compensation often req’d)</td>
<td>(Compensation usually not req’d)</td>
</tr>
<tr>
<td>Temperature element</td>
<td>Calibrated Platinum RTD</td>
<td>Platinum RTD</td>
<td>Thermocouple or RTD if req’d</td>
</tr>
<tr>
<td>Temperature-Controlled Instrument Housing</td>
<td>Often required (7)</td>
<td>Generally not required (7)</td>
<td>Not required</td>
</tr>
<tr>
<td>Flow Computation</td>
<td>Flow Computer, DCS or as required by Contract</td>
<td>Flow Computer, DCS or Process Computer</td>
<td>DCS</td>
</tr>
</tbody>
</table>

NOTES:

1. Orifice runs are designed to satisfy appropriate run specification and the governing piping codes.
2. Orifice runs NPS 2 or smaller can have the temperature sensor located 10 to 25 pipe diameters downstream of the orifice.
3. Mid DP flow is defined as the flow rate at which the differential pressure is 50 percent of the calibrated span for the transmitter.
4. Maximum rangeability based on stated accuracy differential pressure transmitters. Use of digital or multiple transmitters may exceed these limits.
5. The flowing fluid density is a function of the pressure, temperature, and composition of the fluid. The density can be determined by direct measurement or calculated from the pressure, temperature, and composition.
6. 0 - 100 inches of water is the preferred starting design point.
7. The inaccuracy of the transmitters is also a function of the ambient temperature including exposure to sun and rain. This has a fairly large effect on each measurement. High quality, smart transmitters can often be used without a housing. Shields or open-sided housings may be required to meet uncertainty 1% and 2%.
8. Pressure and temperature measurements used for flow compensation should be capable of limiting the density uncertainties sufficiently to meet the required flow meters performance classification.
9. The uncertainty of measurement can range from 5 to 10% or even greater. Limited or no testing validation exists for all possible installation and operational combinations. Measurement is influenced by variation in process conditions away from design if...
uncompensated. Operating near multiple requirement limits (e.g., Beta at 0.7 and Reynolds No. at 10,000 and DP at 2 inches per PSIA) will result in measurement errors greater than 10% for portions of the measurement range.

(10) Insulating the orifice run is not always necessary and depends on the fluid and the stream condition. The ideal is constant temperature as the fluid passes through the meter run.