

METER SELECTION

Class # 8200.1

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General:

This paper is intended to provide general guidelines & criteria for the evaluation & selection of a high pressure gas meter, including a discussion of the basic operating principles and installation and maintenance considerations. This paper will concentrate primarily on three high pressure/high volume custody transfer flow meters, Orifice, Ultrasonic and Turbine. A short discussion will be provided for other alternative types of flow meters and different gas stream conditions.

When selecting a gas flow meter for particular application remember that **there is no one “Panacea” for flow measurement**. No one meter is the right choice for all applications. The following general criteria need to be considered in evaluating which type of meter to select:

- **Is the meter going to be used for Custody Transfer or Process Measurement?** For purposes of this paper, Custody Transfer Measurement can be thought of as sales meter. In the case of Process measurement (i.e. flow measurement inside of a plant for control purposes) the measurement personnel can use any type of measurement they feel will provide them the best technical solution. However, in the case of Custody Transfer flow measurement, the type of measurement is usually stated in the contract and will usually reference one of the Nationally/Internationally recognized Measurement Standards (AGA/API/ISO). For custody transfer measurement both parties must agree on the method of measurement.
- **What kind of gas stream are you trying to measure?** Is the Gas dry pipeline quality gas or is it full well stream wet gas? Does the gas contain H₂S? The type of gas being measured is very important to the selection of the meter and it has to be understood that custody transfer measurement standards, for the different types of meters, do not necessarily apply to all types of gas composition. When a meter is used to measure a type of gas that it has not been calibrated or tested with, it may still provide a reliable measurement but there may be an additional error incurred in the measured values. For example the orifice meter standard, AGA Report No. 3, was developed based on measuring clean dry pipeline quality natural gas. If employed in wet gas measurement (i.e. full well stream measurement) the meter will still provide a flow measurement but there can be a significant error in volume measured. Pure components, other than Methane, Ethane, Propane, Carbon Dioxide and Hydrogen are not covered by the compressibility calculations in AGA Report No. 8 – Compressibility Factors of Natural Gas and other Related Hydrocarbon Gases. The composition of the gas you are going to measure should be compared to Table 1 in AGA Report No. 8.
- **Cost vs. Financial risk exposure** – This is the process of evaluating the costs of the different metering systems against the risks incurred due to measurement errors, during normal operation. The cost of the metering system is addressed below. The financial risk can be evaluated by multiplying the volume to be measured by the meter uncertainty and then multiplying the result by the cost per unit volume. For example the financial risk for a 1BSCFD per day facility with a meter that has an uncertainty of 1% and measuring gas that sells at \$4/MSCF is $(10^9 * .01)/1000 * \$4 = \$40,000/\text{day}$. The reduction in financial risk, at this facility, by reducing the measurement uncertainty from 1% to 0.5% is \$20,000/day. This level of financial risk and risk reduction can justify significant costs for the meter installation. However, the financial risk for a 5 MMSCFD with a 1% uncertainty and \$4/MSCF is only \$200/day, which would provide significantly less justification for a costly metering installation.
- **Cost** – When determining the costs for metering system, the **“Total Installed Cost” of the metering system need to be considered not just the cost of equipment**. The total installed cost will include the equipment cost, installation cost, and yearly maintenance & operation costs. Some meters require more

regular maintenance than other meters do. For example a turbine meter, with periodic inspections, oiling, spin tests & recalibration, will normally require significantly more maintenance than an orifice meter.

- **What is the Volume Turndown or Measurement Range for the expected flow measurement?** This value is expressed as a ratio of the maximum to minimum flow rate. The Turndown ratio can vary widely for different types of meters and it is extremely important to pick a meter that can measure accurately across the entire expected flow rate range. **Significant errors can be incurred if a meter is used outside of its valid measurement range and multiple meters may be required to accurately cover the entire range of flow rates.**

Orifice Plate Measurement:

Standard – AGA Report No. 3 – “Orifice Metering of Natural Gas”, Parts 1 – 4”

The orifice meter uses a thin concentric square-edged orifice plate to develop a differential pressure to infer a mass flow rate. The differential pressure is a function of velocity of the gas as it passes through the orifice plate. The orifice plate meter is a fixed geometry device and as such is extremely repeatable. There is no flow calibration required. If the meter is sized, installed and maintained in accordance with AGA Report No. 3, the installed uncertainty of an orifice meter will be approximately $\pm 1\%$. The general principle of an is shown in Figure 1 below.

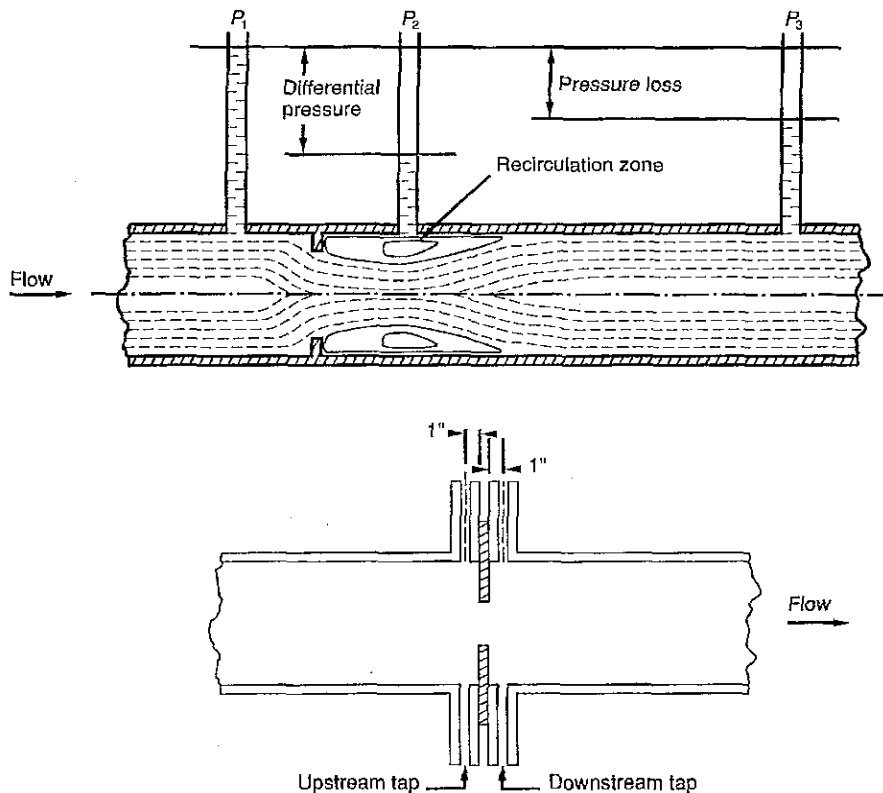


Figure 1 – Flanged Tapped Orifice Meter (Drawing from AGA Report No. 3)

However, this uncertainty can quickly increase if the meter does not meet the installation requirements of AGA Report No. 3. One of the most important of these is the proper flow conditioning of the gas stream before it enters the orifice plate. As AGA Report No. 3 states in Part 1 Section 2.6.3.1, “To ensure accurate flow measurement the fluid should enter the orifice plate with a fully developed, swirl-free flow profile. Such a condition is best achieved through the use of flow conditioners and associated pipe lengths or adequate lengths of straight pipe upstream and downstream from the orifice plate.” In Part 1, Tables 2.7, 2.8a and 2.8b give the upstream lengths, with and without a 19-Tube Bundle Flow Straightener, required for different piping configurations (i.e. combinations of elbows), in order to present the orifice with a fully developed, swirl-free flow profile. As AGA Report No. 3 states “In many piping configurations, the orifice meter may not produce results within the uncertainty of this standard.” It should be noted that the tests in this standard were done by presenting the piping configuration in the Tables

with a fully developed, swirl free profile. If your piping system has additional elbows, fittings, etc. ahead of the piping configuration you are considering for the orifice meter, the upstream lengths stated may not be adequate, particularly when the meter is installed without a flow conditioner. In that case you may want to consider installing the meter with the straight runs of pipe listed in the “Any other configuration” column.

Isolating flow conditioners can be installed instead of 19 Tube Bundles. When installed in accordance with the manufacturer’s directions, these type of flow conditioners effectively “Isolate” the meter run from the effects of any type of piping configuration upstream of the meter run. The resulting flow profile will be fully developed and essentially swirl free. While no flow conditioner can “Guarantee” a perfect flow profile, regardless of the upstream piping configuration, the isolating conditioners will produce a flow profile that will ensure that the orifice plate is within the state accuracy of AGA Report No. 3.

When considering an Orifice Plate Meter particular attention needs to be paid to the flow rate turn down. The best turn down in the flow rate that can reasonably be expected for an orifice meter run is 4:1. This is due to the square root function in the mass flow rate equation. If the flow rate reduces by factor of 4 the differential pressure reduces by a factor of 16. To fully understand the significance of this let us look at an orifice meter with a dp transmitter ranged for 200 inWc of water column. If the normal flow produces a dp of 180 inWc then a reduction in the flow rate by a factor of 4 produces a dp of 11.25 inWc. For a transmitter with an uncertainty of $\pm 0.05\%$ of full scale, the error is ± 0.1 inWc. At 11.25 inWc this results in an uncertainty of $\pm 0.8\%$. In this example, if the flow rate is reduced by a factor of 5 the dp reduces by a factor of 25 and the dp will be 7.2 inWc and the resultant uncertainty will be $\pm 1.38\%$. In terms of flow rate if a meter is measuring 200MMSCFD normally the uncertainty with a 4:1 turndown will be 400 MSCFD. With a 5:1 turndown the uncertainty will be 497 MSCFD. This increased in error is due only to the increased error of the dp measurement. This type of measurement error can be greatly reduced by using “Stacked” transmitters. The “Stacked” transmitter approach requires additional transmitters and a flow computer that can accept external transmitters. However, even when using stacked transmitters, with a 5:1 or 6:1 turn down in the flow rate will result in a 5 to 7 in WC dp measurement, which, with the low pressure port on the orifice plate in the recirculation zone, could produce unstable low dp readings.

In order to ensure the accuracy of the meter, the orifice plate has to be **inspected on a regular basis**. It has to be clean, free of debris and the leading edge must be sharp, with no nicks or gouges.

In general the orifice plate remains a very popular type of meter. If the expected uncertainty and the flow rate turn down limitations in the flow measurement are acceptable, the orifice meter is a very cost effective meter. The meter requires no flow calibration in order to produce reliable repeatable measurements. Once it is installed, the orifice meter will produce the same measurement all the time for the same flow rate with the same gas composition, at the same pressure and temperature. It has very well developed standard and the basic operating principle is easily understood.

Ultrasonic

Standard AGA Report No. 9 – “Measurement of Gas by Multipath Ultrasonic Meters”

The ultrasonic gas flow meter measures the flowing velocity of the gas stream by measuring transit times of high-frequency sound pulses between pairs of transducers mounted in or on the pipe.

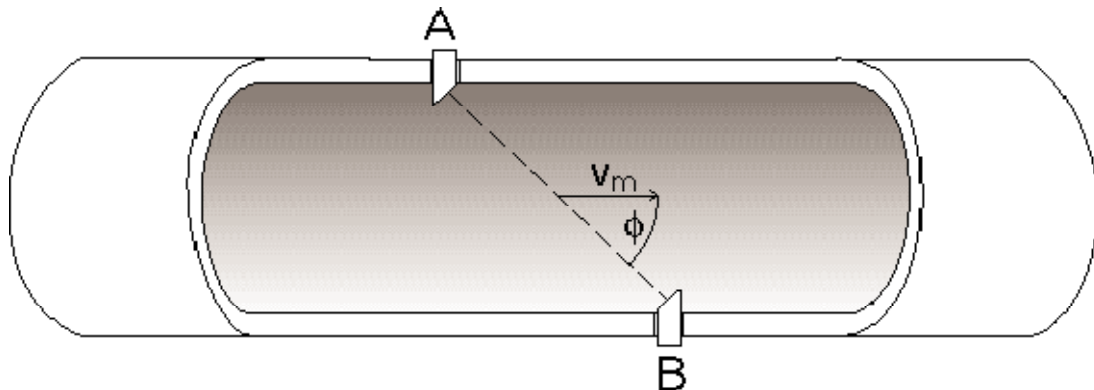


Figure 2 – Ultrasonic Meter

Figure 2 above is used to illustrate the basic principle of the ultrasonic gas flow meter. The meter will transmit an ultrasonic signal from transducer A and receive it at transducer B, measuring the transit time (time it takes for the signal to get between the two transducers). The meter will then transmit an ultrasonic signal from transducer B and receive it at transducer A, again measuring the transit time. The ultrasonic signal traveling with the gas flow will travel faster than the ultrasonic signal traveling against the gas flow. Using the difference in the transit times numeric calculation techniques are employed to calculate the axial gas velocity. The gas velocity is then multiplied by the cross sectional area of the meter to determine the flowing volumetric flow rate (ACF) at flowing conditions.

For custody transfer measurement, multiple pairs of transducers are used to provide velocity measurements at different locations over the cross sectional area of the pipe, because the velocity of the gas stream, with a well developed flow profile, will vary across the diameter of the pipe. In order to obtain an accurate average velocity measurement, multiple ultrasonic paths are required. The velocity measurements from multiple transducer pairs are averaged to obtain the average of the gas velocity across the area of the meter. The location of the transducers will vary between manufacturers and for different types of meters. Figure 3 shows a simplified drawing of the ultrasonic paths for a chordal type meter, where the ultrasonic paths cut chords across the cross sectional area of the meter. For averaging the paths are not all weighted the same. A typical weighting would be 14% for each of the outside paths and 36% for each of the center paths. The meter calculates a volumetric flow at flowing temperature and pressure (actual cubic feet ACF). This volumetric total, is then passed to a flow computer to calculate the volumes at standard base conditions (SCF).

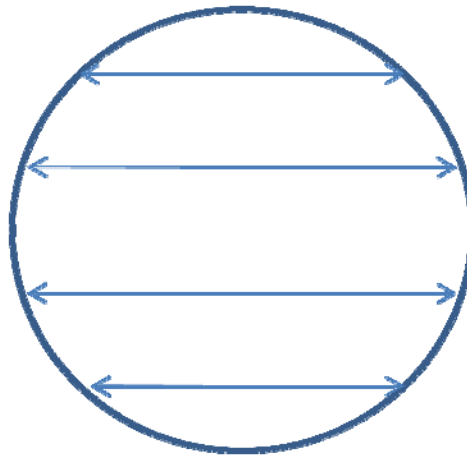


Figure 3 – USM CHORDAL PATHS

The flow computer interface of the meter to a flow computer, for the flow measurement, is essentially the same as that of a turbine meter. The USM outputs a given number of pulses for each cubic foot of gas that it measures. This value is called the K factor and is expressed as pulse/ft³. It is a requirement of AGA Report No. 9 that all Custody Transfer Metering packages be flow calibrated at a flow calibration facility that is traceable to a recognized national/international standard. The meter will be calibrated a several different gas velocities across its range of operation. The calibration facility will provide different K factors or meter factors at each of these velocities. This allows for the “Linearization” of the meter across its entire measurement range. Normally these factors are installed in the flow meter electronics but the factors could be installed in a different flow computer.

The metering package referred to above is the meter together with its adequate upstream and downstream piping. Obviously the velocity profile entering the USM is extremely important and to get the most accurate results the flow profile needs to be fully developed and swirl free. An isolating flow conditioner, as described in the discussion on orifice plate meters above is an excellent means of ensuring that the effects of the field piping are eliminated. The flow conditioner must be included in the metering package that is flow calibrated. The flow conditioner shall be installed in accordance with the manufacturer’s instructions. With a well designed meter run with and flow conditioner, a flow calibrated USM can be expected to have an installed uncertainty of less than $\pm 0.5\%$.

The flow rate turn down, with no loss in accuracy, for most ultrasonic flow meters will be in the range of 10:1 to 20:1. Calibration facilities like CEESI will typically flow calibrate the meters from 2.5ft/sec to

100ft/sec. A typical operating range would be from a minimum of 5 – 10 ft/sec to a maximum of 70 – 80 ft/sec. However, some facilities will operate over an extended range of 1 to 100 ft/sec. At the maximum flow rates the concern is erosion of the meter and pipe due to the high gas velocities with the possibility of dirt and debris in the gas stream. The cleaner the gas stream the higher the maximum flow rate can be. API 14D provides a method of calculating what the erosional velocity will be. At the low flow rates there is the concern that the thermal currents and thermal stratification may occur. In addition, the flow profile may not be as well developed as expected. However, the flow calibration at these low flow rates accounts for changes in the flow profile and “calibrates out” any profile effects. Obviously, to provide the most accurate measurement, the flow meter should be sized so that the normal flow is in the upper two thirds of the flow calibrated range. However, if the normal flow is in the normal range of 5 – 80 ft/sec but there are times of short duration where the flow can go down to 1 ft/sec or up to 100 ft/sec, serious consideration needs to be given to extending the allowable operating range of the meter. At the low end any increase in uncertainty would be at a very low flow rate. Therefore the risk of loss is at a minimal. At the high end, the meter and meter run will not experience any damage, due to erosion, if the time frame is short. A very conservative approach for a possible 100:1 turn down would be to install a second meter run. However, it is also very expensive.

Is recalibration after a period of service required? There are a number of thoughts on this question. First there are no moving parts in the USM and most USM's come with very good diagnostic software. This software allows you to evaluate the performance and condition of the meter and meter run. For example, if the meter were experiencing build up of debris and dirt on the transducers, the Gain for the paths would go up. Build up of debris on the wall of the meter will certainly affect the meter (at the very least it is reducing the cross sectional area of the meter). Some meters see very little effect of Wall Build up <0.1% some see more >0.3%. It has been shown that, for most meters, if you clean the meter it will return to its flow calibrated condition. How often this needs to be done would depend on how dirty the gas stream is. All AGA Report No. 9 says is that the decision to recalibrate is left to the parties concerned. It goes on to say that “Test results show that meters free of internal contamination perform as originally flow calibrated, within the uncertainty of the flow calibration facility”.

The USM works with use of ultrasonic sound and is susceptible to other ultrasonic noise caused by piping components. This is particularly true with regard to low noise trim pressure control valves. The low noise trim on these valves tends to reduce the audible noise and increase the ultrasonic noise. The higher the pressure drop, the more ultrasonic noise is generated. The valves should always be installed downstream of the USM however the noise will still travel back up the gas flow. Some meters have better noise immunity than others. However, to ensure that there is no noise interference, sound abatement piping can be installed between the meter and the control valve.

The Ultrasonic Gas Flow meter is capable of very accurate measurement over a wide flow rate range, with very little pressure drop. It is the meter of choice for many users for high pressure & high volume applications. In cost comparisons with orifice meters the size of the meter and the flow rate turndown of the meter need to be given careful consideration. For example a facility may be able to use an 8” USM instead of 12” orifice meter. When all of the valves and piping is taken into consideration, the USM may be more cost effective. **When high volumes and wide turn downs are being considered a USM is usually far more cost effective than multiple orifice meter runs.**

TURBINE METERS

Standard AGA Report No. 7 – “Measurement of Natural Gas by Turbine Meters”

“Turbine gas flow meter is an inferential meter that measures gas flow by counting the number of revolutions of a rotor, with blades, which turns in proportion to the velocity of the flowing gas. Based on the physical dimensions and geometry of a given meter, the gas volume (ACF) at line conditions can be inferred by counting the number of revolutions.” The revolutions are transferred into either a local digital readout (Figure 4) or electronic pulses by some combination of mechanical gearing, generated electronic or optical pulses or frequency. The interface to a flow computer is very similar to the Ultrasonic Gas Flow meter, described above. Typically, when using a flow computer, the meter will have an integral electronic pickup (Figure 5) that will provide a pulse each time a rotor blade passes. The flow computer is then provided with a “K” factor (pulses/ft³) that converts the number of pulses into volumetric cubic feet (ACF) at flowing conditions. “Typical use is the measurement of fuel grade natural gas and associated hydrocarbon gases either a pure hydrocarbons or as a mixture of pure hydrocarbons and diluents.”

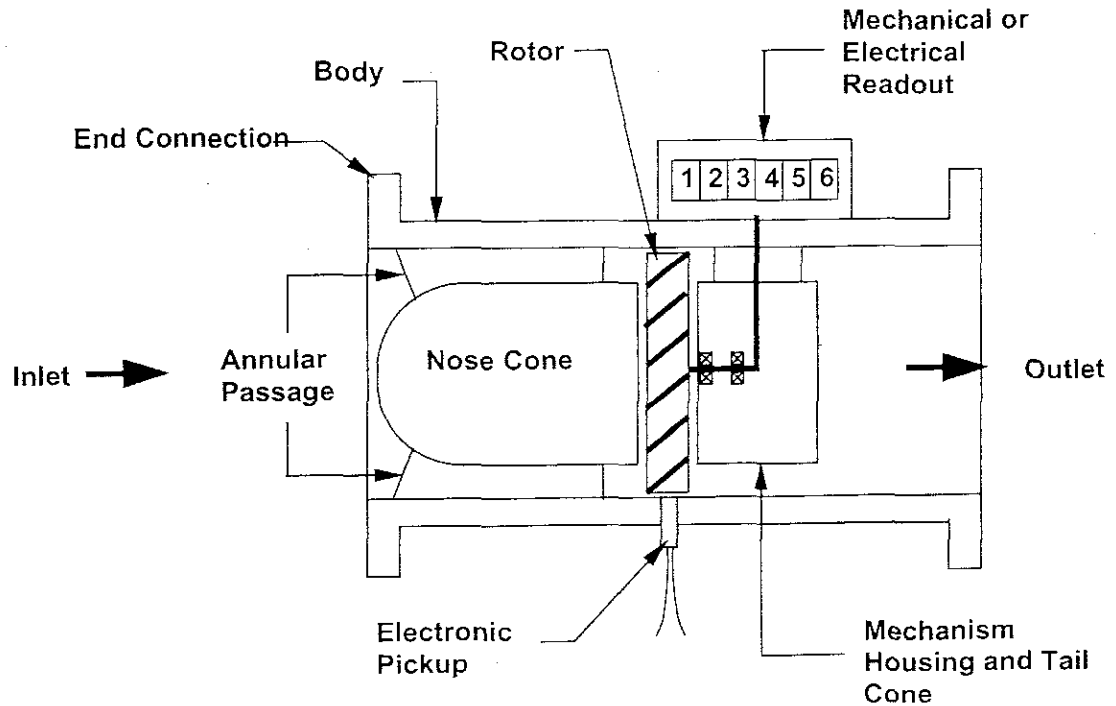


Figure 4 – Single Rotor Gas Turbine Meter – (Drawing from AGA Report No. 7)

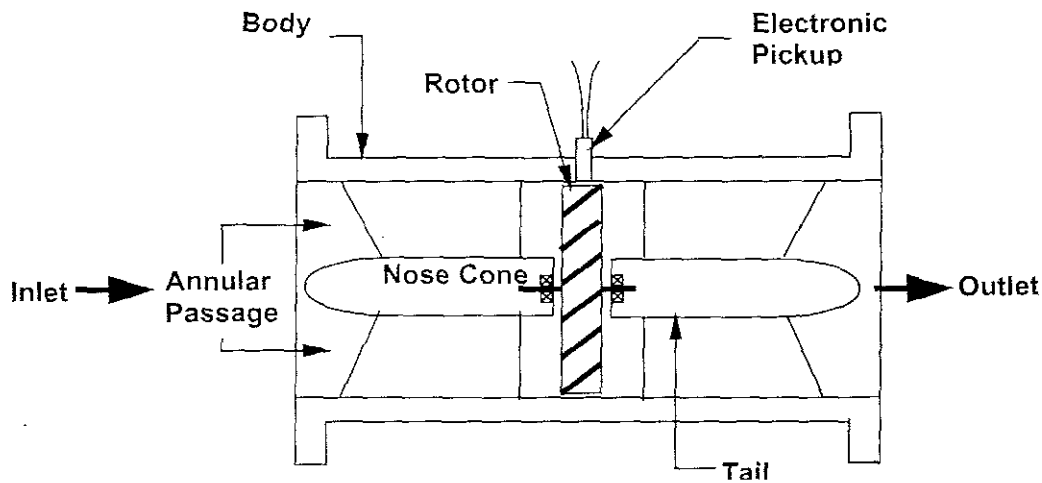


Figure 5 – Single Rotor Turbine Meter with Electronic Pickup – (Drawing from AGA Report No. 7)

According to AGA Report No. 7 section 6, for the best performance turbine meters should be flow calibrated in conditions that match the anticipated in-service conditions, including a dedicated meter body and with inlet and outlet piping. Sending the entire metering package, including upstream and downstream piping, together with the selected flow conditioner to the calibration facility will provide the most accurate results.

Obviously the velocity profile entering the turbine meter is extremely important and to get the most accurate results the flow profile needs to be fully developed and swirl free. An isolating flow conditioner,

as described in the discussion on orifice plate meters above is an excellent means of ensuring that the effects of the field piping are eliminated. The flow conditioner must be included in the metering package that is flow calibrated. The flow conditioner shall be installed in accordance with the manufacturer's instructions. With a well designed meter run with and flow conditioner, a flow calibrated Turbine Meter can be expected to have an installed uncertainty of less than $\pm 0.5\%$.

The flow rate turn down, with no loss in accuracy, for a typical turbine flow meter will be in the range of 10:1. Careful consideration has to be given to the design and operation of a turbine meter measurement facility especially with respect to gas velocities. Excessively high velocities can over speed the rotor, causing severe damage to the bearings. If surge velocities are possible in normal operation a restrictive device, to limit the flow, can be put in downstream of the meter. Particular attention must be paid during blow downs and purging operations where excessively high velocities will be common place. A block and bypass operation may be considered. At the low end of flow rate range, lower than the calibrated flow rate, the rotor revolutions may no longer be proportional to the very low gas velocities.

The Turbine meter will require more maintenance than either the orifice meter or the Ultrasonic Gas Flow Meter. There are no on board diagnostics, like the Ultrasonic Gas Flow meter but there are meters with dual rotors or a second gas flow meter can be installed in series with the Custody Meter. Comparing the outputs of the two sets of rotors will provide an indication of a problem with performance of the meter. The frequency of maintenance is dependent on the flowing gas conditions, station operation and contract requirements. Meters measuring dirty gas will require more maintenance than meters measuring clean pipeline quality gas. AGA Report No. 7, Section 8, has an excellent write up on visual inspection, cleaning & oiling and Spin Time Tests. Since the meter has moving parts, with bearings that can wear, eventually it will have to be refurbished and re-flow calibrated. There are turbine meters that have a replaceable internal cartridge that can be flow calibrated outside the meter body. However, it has been shown in tests that this type of approach can induce additional errors in the measurement.

The Turbine Gas Flow meter is capable of very accurate measurement over a wide flow rate range, with very little pressure drop. If metering system is properly designed, maintained and operated it can provide an extremely cost effective solution to measuring high gas volumes. In cost comparisons with orifice meters the size of the meter and the flow rate turndown of the meter need to be given careful consideration. For any size of meter, the initial cost of a Turbine meter will generally be less than the same size USM. A facility may be able to use a far smaller Turbine meter than an Orifice meter to measure the same flow rate and, when all of the valves and piping is taken into consideration, the Turbine Meter may be more cost effective than an orifice meter. When high volumes and wide turn downs are being considered a Turbine meter is usually far more cost effective than multiple orifice meter runs.

ALTERNATIVE METERS

CONE METERS

These meters are a differential producer similar to an orifice plate. However, instead of the gas flow stream creating a differential pressure as the gas passes through an orifice the cone develops a differential pressure as the gas flows around a Cone, centered in the pipe (see Figure 6). Although the cone meters do not have a specific AGA or API custody transfer measurement standard, they can be qualified for custody transfer by completing the test protocol laid out in API Chapter 22.2. Cone meters have several strong points when compared to an orifice plate. First because the location of the low pressure port is in the base of the cone, the dp measurement is very stable, even at very low dp values, which aids in providing an extended turndown capacity. The cone meter does not provide a "Dam" in the pipe so there is no place for debris or liquid build up to occur. This is particularly important on full well stream allocation measurement. Because the cone meter will provide a greater flow rate than an orifice, a smaller meter can be provided. Finally the test results to date appear to confirm that the meter does not need flow conditioning and needs minimal upstream lengths of pipe in order to provide an accurate reliable measurement. These meters could provide a very cost effective alternative to orifice plate measurement.

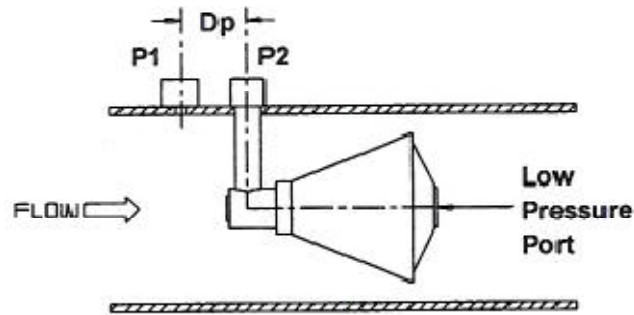


Figure 6 – Typical Cone Meter

CORIOLIS MEASUREMENT

Standard AGA Report No. 11 – Measurement of Natural Gas by Coriolis Meter

The Coriolis meter is a very accurate high pressure gas meter that measures the mass and density of the gas directly. The typical coriolis meter consists of bent parallel tubes. These tubes are caused to vibrate at their natural frequency by a drive coil. The natural frequency determines the density of the fluid. When the fluid is flowing through the tubes, a force, due to Coriolis acceleration, causes the tubes to “twist”. The amount of the twist determines the mass flow rate. These types of meters require a minimum pressure, in order for the gas density to be high enough to impart reliable mass and density measurements. This minimum pressure varies between the different manufacturers. The higher the flow rate, the better the performance of the meter. Coriolis meters do not require any flow conditioning or upstream or downstream pipe lengths and liquids and debris (i.e. fine sand and pipeline rouge) will not damage the coriolis meters, as would likely be the case with other types of meters (i.e. Turbine meters). Coriolis meters can easily have a turndown on 10:1 with an uncertainty of $\pm 0.5\%$ and they can measure extremely low flows rates. Depending on the pressure the turn down on a coriolis meter can easily be 100:1 or more, but this is with an increased uncertainty of up to $\pm 5.0\%$. The meters have been successfully used in applications where there was a 30 PSIG or more pressure drop across the meter, such as City Gate meters where the required pressure drop from line pressure to City pressure is shared between the meter and control valves. In these cases, coriolis meters can be very cost competitive. In some cases, coriolis meters can provide accurate reliable mass measurement for two phase gas flow measurement. Finally the meters are very low maintenance but they do require periodic recalibration, per AGA Report No. 11, and seasonal zero flow verification.

Rotary – Positive Displacement

Standard ANSI B109.3 – Rotary-Type Gas Displacement Meters

The rotary displacement meter is a very accurate meter that utilizes the principle of filling and emptying rotating compartments of a known size. By counting the number of times these compartments have been filled and emptied allows for the determination of the flowing gas volume. These meters need no flow conditioning or upstream lengths. They provide excellent measurement at high pressures with a typical turndown ratio of 80:1. The meter will easily provide the accurate low volume measurement that is difficult to achieve with other meters. Because the meter internals are a fixed volume the higher the operating pressure the higher the volumetric flow rates at standard conditions. The meters are a reasonably low maintenance meter but they do require periodic recalibration. Because of the low installation costs and high turndown these meters offer a very cost effective alternative.