Fundamentals of Orifice Metering

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Introduction

Due to the cost of production and transfer of natural gas, the industry has demanded a higher level of accuracy and an economical method for measurement. Orifice fittings and meter tubes satisfy this demand for most natural gas measurement applications today. The level of accuracy achieved in orifice measurement has been continually refined and improved upon since it was first put to use for measurement of petroleum products. The accuracy of orifice measurement is controlled by published standards currently AGA 3 Part 2 / API 14.3 April 2000 that define the requirements to achieve a known level of accuracy and eliminate error in measurement.
The intent of this paper is to focus on the basics of orifice measurement.

Orifice Meter Devices

The primary purpose of the orifice meter and associated meter tube is to properly locate the square edged orifice plate in the flow stream and control the flow conditions upstream and downstream of the orifice plate to obtain accurate measurement. This device referred to as the primary element of orifice measurement is essential in accurate orifice measurement. Secondary elements support the primary element. Equipment to sense differential pressure, temperature and other parameters associated with completing the fluid measurement are secondary elements. This paper addresses the primary element device and requirements associated with it. Orifice meters are available in several different configurations from various manufacturers. Three of the most common orifice meters/devices are:

Orifice Flange Union (OFU)

Single Chamber Orifice Fitting

Dual Chamber Orifice Fitting

The selection of the type and manufacturer of the device used should give consideration to the ability of the device to accurately locate the orifice plate for reduced error in measurement, ease of operation, safety, and continued serviceability of the product as needed.

Orifice Flange Union (OFU)

The OFU is the most economical to purchase of the three. However when the orifice plate must be inspected and/or changed out of the meter tube it is a very time consuming and costly process that requires the section of piping containing the OFU meter to be isolated from the flow stream, depressurized; remove bolting on the flanges; inspect and /or replace the gaskets; inspect and/or replace orifice plate and fasten the flanges back together.

Single Chamber Fittings

Single chamber fittings are the next most economical to purchase. However the single chamber fitting operation requires that the meter tube be isolated from the flow stream and depressurized. Following the depressurization procedure the operator must loosen the hold down screws from the clamping bar device which hold the orifice plate carrier and attached seal bar in position. The seal bar and carrier assembly can then be easily removed to inspect or replace the orifice plate. Reinstallation simply reverses the procedure and then the section containing the meter is re-pressurized. Single chamber fittings are available in varying configurations with different end connections, bore sizes, and ANSI pressure ratings.

Single Chamber Meter Advantages

- Less expensive than dual chamber meter
- Allows for change without spreading flanges as in orifice flanges
- Accurate positioning of orifice plate

Single Chamber Meter Disadvantages

- Line must be depressurized before plate change or inspection
- Flow is interrupted during plate inspection or change
- Loss of fluid during plate inspection or change

Figure 1

Dual Chamber Fittings

Dual chamber fittings consist of two separate chambers; one lower chamber through which the flow passes and the orifice plate is located when the fitting is measuring flow, and an upper chamber which is used during the plate change or inspection procedure. All dual chamber fittings have a means of isolating the upper and lower chamber, to perform plate change or inspection while still allowing for normal flow through the lower chamber. Careful consideration should be given to the design of the isolation device when selecting a dual chamber fitting. Consistent, easy operation with no lubrication and little or no maintenance gives some designs advantages over others. The ease with which the isolation device can be serviced should also be considered when selecting a dual chamber orifice fitting. Another key component to the isolation device is a positive stopping mechanism that indicates if the gate is in the open or closed position, and provides a locking device to prevent unintentional opening of the plug or gate under pressure. TMCo, Inc. Sure Shot standard patented isolation valve with Teflon sealing element "eccentric plug" pictured below. (Figure 2)

Figure 2

Although more costly than some other types of orifice metering, the dual chamber provides many more advantages over the other styles of orifice meters. It gives consistent plate location in the flow stream for repeated plate inspections and changes. With the ease of operation, the plate service can be performed in much less time with no loss of the process fluid. Flow can continue without any loss of production. Typical operation of the dual chamber fittings start by equalizing the pressure between the upper and lower chambers. This is normally done by an equalizing valve which opens a pathway around the isolation device. Once the two chambers are at the same pressure the isolation device would be opened. After opening the isolation valve the orifice plate carrier can be raised into the upper chamber by rotating the gear shafts. Once the plate carrier is in the upper chamber the isolation valve can be closed. Complete isolation of the two chambers is accomplished by closing the equalizing valve. The upper chamber can now be bled to atmospheric pressure by opening a bleed valve. The clamp bar and seal bar are then removed to extract the orifice plate carrier from the upper chamber. To reinstall, the steps are simply reversed.

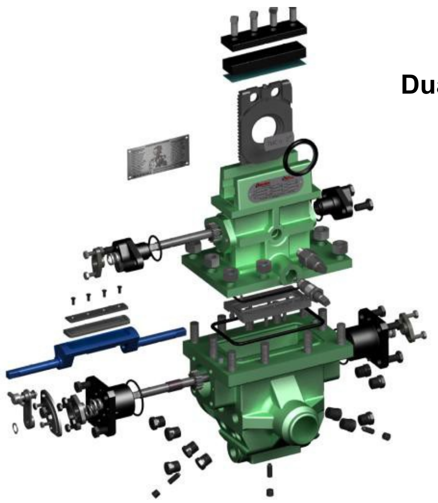
Dual Chamber Meter Advantages

Orifice inspection can be performed without depressurization

No interruption in flow

Faster than single chamber to perform plate inspection or change

Less exposure to process fluid



Dual Chamber Meter Disadvantages

More expensive to purchase than other orifice meter options

Figure 3

AGA Requirements and Tolerances to Reduce Uncertainty of Measurement

In order to provide accurate measurement with a known certainty, AGA 3 has specified a number of nominal values that must be maintained within an associated tolerance to provide a known level of accuracy in square edged concentric orifice meters. These values and tolerances apply to the orifice plate, orifice meter, and attached piping sections referred to as the meter tube. To obtain accuracy with minimal uncertainty, all of these features and tolerances as specified by AGA 3 have to be met. Numerous studies and tests have been conducted to arrive at the values and tolerances that are specified in AGA 3. This research has proven that if all the required criteria are met, the orifice meter can produce an accuracy of ±0.5%. Any deviation from the required criteria results in uncertainty beyond this level of accuracy. Each of the following features is critical to accurate orifice measurement and requires the utmost attention to insure the desired level of accuracy is met.

Orifice Plate

The orifice plate is considered to be the heart of the primary element. The importance that all criteria are met is essential. The specifications of the orifice plate are detailed in Section 2.4 of AGA 3. The quality of the orifice plate face must be flat within 1% of the dam height. $((D_m\text{-}d_m)/2)*.01$. The ratio between the mean diameter of the meter tube and the mean diameter of the orifice plate must not exceed .75. This ratio is defined as the beta ratio in AGA 3. The surfaces of orifice plates must be free from defects and abrasions that exceed 50 micro inches referred to as a R_a finish. The upstream square edge of the orifice plate must be square and sharp to the degree that it will not reflect a beam of light. The roundness of the orifice plate bore thickness, plate thickness, and downstream bevel are other features for which the section 2.4 gives criteria.

Tap Hole Differential Sensing Ports

The tap holes are the points upstream and downstream of the orifice plate at which the differential pressure is measured and these tap holes are drilled radially perpendicular to the axis of the meter bore. The tap holes are located a distance of 1” from the face of the orifice plate; at the tightest tolerance .75 beta tap holes on a 2” and 3” meter must be within a tolerance of ±0.015”. On a 4” and larger the tolerance is increased to ±0.030”. The diameter of the tap holes is also specified to be a nominal of 0.375” with a tolerance of ±0.016” on 2” and 3” meters, and 0.500” diameter with a tolerance of ±0.016” on 4” and larger meters. Tap hole edges at the intersection of the meter bore must be square and free from burrs. Tap holes must also not communicate with any other part of the casting except through the internal diameter to insure that no additional uncertainty is added by additional pathways effecting the measurement of differential pressure. This is often verified by performing a vacuum test on each one of the tap holes.

Orifice Plate Seal

The orifice plate seal is the component responsible for insuring that the only path of flow from upstream of the orifice plate to downstream of the orifice plate is through the orifice plate bore. The area that receives the plate carrier, orifice plate, and orifice plate seal, commonly referred to as a seat gap, must not have any protrusions or allow any recess that exceeds the tolerance of the mean bore diameter within 0.250" of the face of the orifice plate that would restrict the flow and effect the profile of the fluid being measured. A hydrostatic or pneumatic test referred to as a "plate seal leak test" is performed to guarantee that there is no leakage around the orifice plate seal. This is done by installing an orifice plate blank, which is an orifice plate having no orifice, in the orifice plate carrier. A differential pressure is then created between the upstream and downstream sections and the results are recorded. Any recorded loss of pressure from the upstream side introduces an additional level of uncertainty and is not allowed by AGA 3.

Eccentricity

Ideally the orifice plate bore would be perfectly concentric with the bore of the orifice meter; the allowable deviation from this concentric relationship is defined as eccentricity. The maximum allowable variation of concentricity is different in the plane parallel to the differential taps vs. the plane that is perpendicular to the differential taps and these are defined as ε_x and ε_y respectively. The maximum allowable value for ε_x is $0.0025Dm/0.1+2.3\beta_m^{4}$, maximum value of ε_y is 4 times the value allowed for ε_x. A mean bore diameter of 2.067" is that of a 2" Schedule 40 and the maximum deviation from concentricity in the X plane would be 0.006" and 0.024" in the Y plane. Any deviation that exceeds the allowable eccentricity measurement will result in uncertainties of measurement outside the level of accuracy specified in AGA 3.

Meter Tube Bore Diameter Requirements

The meter tube bore diameter and surface roughness are critical features that affect the profile of the gas being measured. Both of these requirements are specified in detail in AGA 3. The bore diameter requirement is divided into three different zones.

Upstream Meter Tube Section

The first area with the tighter tolerance is defined as the area one diameter upstream from the face of the orifice plate. The deviation in this area of the meter tube cannot exceed a value greater than 0.25% of the mean bore diameter. A mean bore diameter of 2.067" that of a 2" schedule 40 would allow .005" in the section. The mean bore diameter is calculated by taking four equally spaced internal diameter readings in the plane of the upstream tap holes. The average of the four internal diameter readings determines the mean diameter of the meter tube.

The second area is outside the one diameter upstream from the face of the orifice plate and allows 0.5% deviation from the mean diameter. A mean bore diameter of 2.067 that of a 2" schedule 40 would allow 0.010" in the areas outside of one diameter.

Downstream Meter Tube Section

The third area is on the downstream side of the orifice plate. The tolerance for the downstream section 0.5% = +/- 0.010". A mean bore diameter of 2.067" that of a 2" schedule 40 would allow 0.020" in the area from the lowest to the highest internal micrometer reading.

Surface Roughness Requirements

Bore surface roughness requirements specify a range of how smooth and how rough the internal meter tube diameter can be. Sizes 12" nominal diameter and smaller allow a range of 34 – 300 micro inches R_a for a meter run if the β_r is less than or equal to 0.6 and 34 – 250 micro inches for a meter tube if the β_r is greater than or equal to 0.6. Meter runs that have a nominal diameter greater than 12" are allowed to have a range of 34 – 600 micro inches R_a if the β_r is less than or equal to 0.6, and 34 – 500 R_a if the β_r is greater than or equal to .06 β_r.

The minimum R_a finish on all nominal sizes is 34 R_a per AGA 3 2.5.1.1.

Meter Tube Design Criteria

Most meter tubes can be classified into three different categories listed in API 14.3.2 table 2-7, 2-8a, and 28b. (The fourth would be the manufacturers recommended lengths of various flow conditioners). Two section tubes usually consist of a longer section of pipe welded to the upstream side of the orifice meter and a downstream spool section which normally has additional ports for temperature, sampling, and blow down. Additional pipe diameters are necessary to condition the flow and profile the gas without the aid of a flow conditioner. Two section tubes are commonly used when space is not a consideration and the installation allows for the additional pipe diameters on the upstream section. Three section tubes have two sections upstream, one connected to the upstream side of the meter (UL2) and a second upstream spool (UL1). The two upstream sections have a flow conditioning device between them and a downstream section like that described in the two section meter tube.

Three section meter tubes are often used when the installation does not allow for the additional diameters on the upstream section and or a particular flow conditioner is chosen to improve the flow profile. The downstream section must also meet a minimum diameter requirement although much shorter and commonly allow for other process connections. Regardless of whether a two or three section tube is selected for an installation, the purpose of the additional diameters along with the conditioning device in either a two or three section tube is to control and properly profile the gas and reduce swirling, tumbling and other effects that can result in inaccurate measurement in the meter when the process fluid passes through the orifice bore and the differential pressure readings are taken.

Typical examples of two section meter tubes are pictured below, Figure 4 and Figure 5.

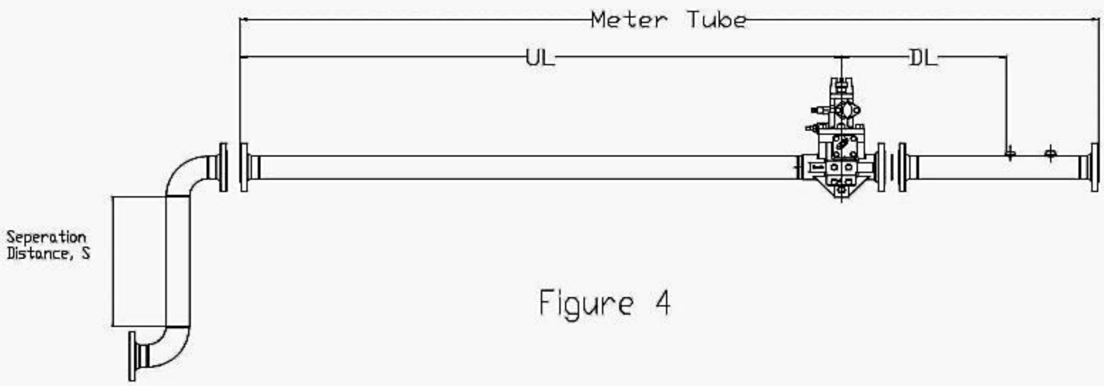


Figure 4

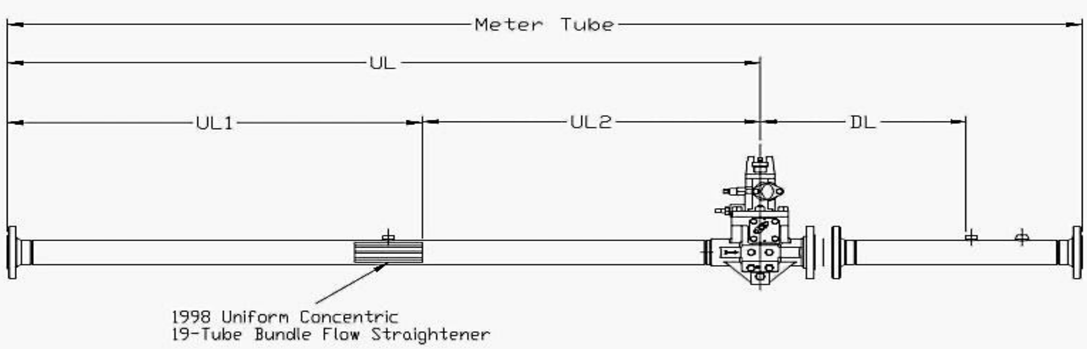


Figure 5

Conclusion

Orifice meters and meter tubes are available in a vast array of configurations to meet installation requirements. Even with the arrival of other technologies for measurement, orifice measurement has proven to be the method of choice for many. This is due to the proven history of accurate results it provides. The design requirements and tolerances have been refined through revisions made to AGA 3 to make orifice measurement more accurate and reliable when the specifications contained within are met. As technology advances and testing methods improve, we can all look forward to further advancement in the accuracy of orifice measurement.