Fundamentals of Orifice Metering

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Introduction

Throughout the oil and gas industry, there stems the need for accurate and economical measurement of process fluids and natural gas. Orifice Meters, sometimes referred to as Orifice Fittings, satisfy most flow measurement applications and are the most common flow meter type in use today. The Orifice Meter, sometimes also called a head loss flow meter, is chosen most frequently because of its long history of use in many applications, versatility, and low cost, as compared to other available flow meter types.

Primary Element

In orifice measurement, there exists the Primary Measurement Element and the Secondary Measurement Elements. The secondary elements consist of such items as chart recorders, electronic flow computers, differential pressure transmitters, etc.; that is, everything external to or attached to the piping. The intent of this paper is to only address the Primary Measurement Element. The American Petroleum Institute (API) defines the primary element as "the orifice plate, the orifice plate holder with its associated differential pressure sensing taps, the meter tube, and flow conditioner, if used." The Primary Element, therefore, includes a section of straight run pipe with a constrictive device - the orifice plate. As the fluid or gas passes through the orifice there will be a loss of static pressure due to the increased velocity through the orifice plate bore. The Secondary Elements sense the change in pressure, or differential pressure across the orifice plate. This differential pressure combined with correction factors for the primary element and physical characteristics of the fluid or gas being measured allows for computation of the rate of flow through the Orifice Fitting. These factors and coefficients are based on measurable dimensions of the primary element, such as the pipe inside diameter and the orifice bore diameter, along with the physical properties of the liquid or gas being measured, such as specific gravity (or density), temperature, and viscosity.

Primary Element Types

Orifice Flange Union

The original orifice plate holding device was the Orifice Flange Union (Figure 1). The Orifice Flange Union (OFU) was the only orifice plate holder available until the invention of the Orifice Fitting or Meter. Orifice Flange Unions consist of two ANSI-rated flanges (usually weldneck, but slip-on or threaded types are also available) with associated flange bolts, nuts, and gaskets. The OFU also includes a pair of long threaded bolts acting as jackscrews to aid in spreading the flanges to allow for the installation or removal of the orifice plate. As previously mentioned, orifice measurement requires the sensing of differential pressure across the orifice plate. Through many years of development and testing, it has been determined that the differential pressure must be sensed 1" upstream from the orifice plate face and 1" downstream from the orifice plate face. These are critical dimensions and must be adhered to during the design and manufacturing of any primary element. Thus, the OFU is required to have two pressure taps - one in each flange. Usually, an extra set of pressure taps is provided and located 180° from the first required pair. The pressure taps are 1/2" NPT with a through hole of either 3/8" or 1/2" diameter, depending on the nominal flange size.

Figure 1. Example Orifice Flange Union (OFU)

Orifice Flange Unions provide an economical method of measurement for installations where the pipeline liquid or gas flow can be either by-passed around the OFU or shut down entirely for orifice plate removal and inspections. Though inexpensive as compared to other devices, the Orifice Flange Union utilizes the more expensive paddle-type orifice plate and requires additional labor to perform an orifice plate change. The operator must loosen all bolts and remove half of the bolts, spread the flanges by use of jackscrews, and remove the plate. In most cases, gaskets must be replaced. OFUs are commonly applied for flow control in chemical plants and refineries and for flow measurement at wellheads and in allocation metering (where a number of wells are centrally located). The Orifice Flange Union is typically used where periodic inspection of the orifice plate is not required and the measurement accuracy is usually less critical.

Table 1. Advantages & Disadvantages of Orifice Flange Unions – Compared to Other Orifice Meter Types

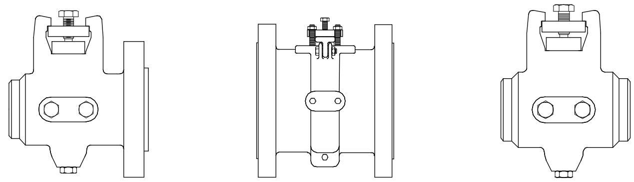
Advantages	Disadvantages
Low cost.	Shut-down or by-pass of line is required to change plate.
Few parts.	More time consuming and costly to change plate.
Available from many sources.	Expensive paddle type orifice plate required.
Wide range of material choices.	Higher risk of not getting the plate centered in the pipe bore.
	Potential environmental hazard due to spillage.
	Loss of liquid or gas in blow down process.

Single Chamber Orifice Fitting (Meter)

Frequent inspection of the orifice plate is often necessary to be certain the orifice plate is in quality condition to ensure measurement accuracy. In some installations, flow rate will vary to the extent that various size orifices are required to keep the differential pressure within acceptable range for the secondary elements. Orifice Fittings are designed to reduce the time and, thus, the cost of inspection or changing of the orifice plate. Orifice Fittings also offer precision machined critical dimensions and provide accurate centering of the orifice plate bore in the center of the pipe bore.

Figure 2. Example Single Chamber Orifice Fitting

The Single Chamber Orifice Fitting body is usually made of cast carbon steel in various configurations (Figure 3). Flange by Weld is the most common. Flange by Flange and Weld by Weld configurations are also available. The meter body includes the same two sets of pressure taps as described above for the OFU. Depending on the application pressure, this type Orifice Fitting is available from ANSI Class 150 to Class 2500, with corresponding changes to bore schedules matching the pipe bore schedule.



Flange by Weld **Flange by Flange** **Weld by Weld**

Figure 3. Single Chamber Orifice Fitting Configurations

There are various designs on the market with differing internal components. All fittings fundamentally have a plate carrier, rubber seals for the orifice plate (assures no by-pass of the liquid or gas around the plate), a sealing bar, and a clamping bar. One such design is shown in Figure 4. The orifice plate is held in the carrier by means of a seal ring. The carrier is attached to the sealing bar and can be removed from the body as one assembly, once the clamping bar is removed. The orifice plate bore is precisely positioned in the body bore by means of precision machining of the carrier and the use of a location dowel pin. Such positioning is positive, accurate, fast, and assures compliance with measurement standards such as API MPMS, Chapter 14.3 (which will be discussed later in this paper).

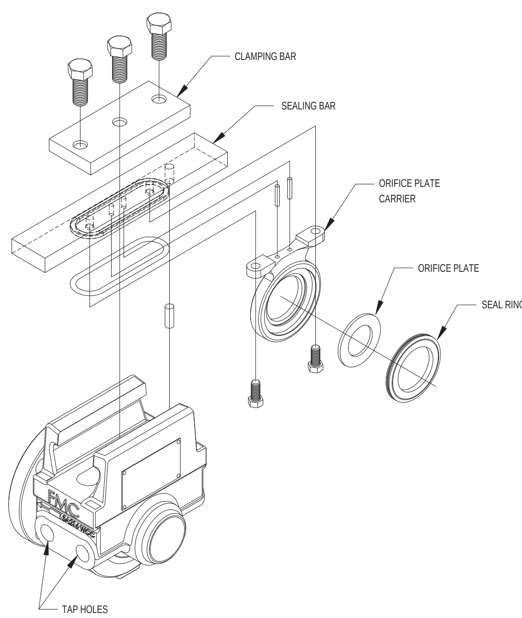


Figure 4. Principal Components of a Single Chamber Orifice Fitting

Single Chamber Orifice Fittings are used if frequent orifice plate changes are required and if the flow to the Orifice Fitting can be shut down, or by-passed and the line depressurized without costly interruption to the pipeline or process. Orifice fittings of this type do not require the removal of flange bolts or spreading of flanges to remove the orifice plate. These type fittings also avoid the loss of liquid or gas from the pipeline, which occurs when flanges are separated.

Table 2. Advantages & Disadvantages of Single Chamber Orifice Fitting – Compared to Other Orifice Meter Types

Advantages	**Disadvantages**
Simple to operate.	Higher cost than Orifice Flange Union.
Positive alignment of plate to line bore.	Shut-down or by-pass of line is required to change the plate.
Short down time compared to OFU.	Loss of liquid or gas in blow down process.

Dual Chamber Orifice Fitting (Meter)

Dual Chamber Orifice Fittings are used where it is necessary or desirable to remove the orifice plate from the fitting without interrupting the flow of liquid or gas in the pipeline. They are commonly used for measurement of natural gas, custody transfer, transmission pipelines or any installation where the pipeline can not be shut down.

Figure 5. Example Dual Chamber Orifice Fitting

The Dual Chamber Orifice Fitting has all the attributes of the Single Chamber Fitting plus the advantage of orifice plate inspection or change-out while under flowing conditions and line pressure. Dual Chamber Fittings are available in common line diameters from 2" to 24", with larger sizes up to 48" having been manufactured and available on request. Available pressure classes range from ANSI Class 150 to ANSI Class 1500. Typical cast carbon steel bodies are configured in Flange by Weld as the most common and Flange by Flange (Figure 6). The body includes the same two sets of pressure taps as described above.

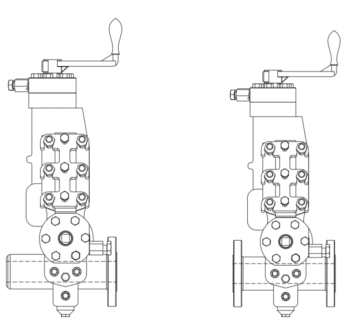


Figure 6. Dual Chamber Orifice Fitting Configurations

The Dual Chamber terminology evolved from the fittings design as there are two chambers (dual) in the body. A lower chamber and an upper chamber isolated from each by a sealing mechanism. Under flowing conditions, both chambers are under line pressure. To remove or inspect the orifice plate (referring to Figure 7), the plate carrier assembly is retracted into the upper chamber by means of a non-rising elevator screw. A dry seal plug valve in this design is rotated 90°, sealing or isolating the dual chambers. While flow continues in the lower chamber, the upper chamber pressure is released through a bleed valve, bringing it to atmospheric pressure. The cover plate clamp and sealing bar can then be removed, exposing the upper chamber. Continuing to rotate the elevator screw will lift the carrier plate assembly out of the fitting. The orifice plate can then easily be removed inspected or replaced all while the pipeline remains in operation. The reverse of this procedure will again lower the carrier assembly into its resting location in the lower chamber. Older designs of this style required the use of grease to lubricate the plug valve. The current design requires no lubrication. Retro-fit plug valve kits are available to upgrade the fitting from the old grease style to the dry seal type, should the maintenance operation desire to do so.

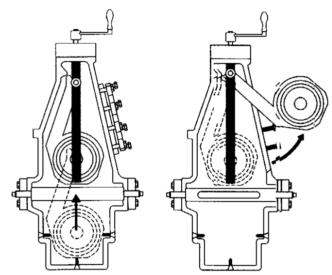


Figure 7. Dual Chamber Orifice Fitting Configurations

As with a Single Chamber Fitting, the Dual Chamber design also has a plate carrier. The plate carrier precisely locates the orifice plate bore concentric to the body bore by means of three locator pins. Two pins locate the plate horizontally and one pin in the bottom of the body locates the plate vertically.

Table 3. Advantages & Disadvantages of Dual Chamber Orifice Fitting – Compared to Other Orifice Meter Types

Advantages	**Disadvantages**
No shut down or by-pass of line required.	Highest price Orifice Fitting.
Positive alignment of plate to line bore.	
Minimal down time.	
Simple to operate.	
Ease of maintenance and plate change.	
No lost liquid or gas due to line blow down process.	

Design Criteria to Assure Measurement Accuracy

Most flow meters require flow calibration to verify accuracy. However, an Orifice Fitting will not require flow calibration if designed and manufactured in accordance with acceptable design practices. Since the beginning of orifice flow measurement, numerous research studies have been conducted to determine what physical changes take place in a pipeline when flowing liquid or gas passes through an orifice plate. Conclusions of all this work have determined that when an orifice plate is properly installed and maintained and the Orifice Fitting is properly designed and manufactured, the Orifice Fitting can produce a measurement accuracy on the order of +/-0.5 to 1.0% of reading. However, orifice flow measurement is sensitive to the flowing conditions, the adjacent piping installation configuration, the precision machining of the fitting and its attachment to the adjacent straight run of pipe, plus the cumulative error of the secondary instrumentation. Overall accuracy of the metering installation under average operating conditions could be in the range of +/-2 to 5% of reading. If not properly maintained and inspected periodically, the Orifice Fitting could produce measurement accuracy only on the order of +/-10 to 25% of reading.

To help achieve the highest degree of measurement accuracy in orifice measurement, the American Petroleum Institute (API) published installation guidelines and manufacturing design parameters for the gas measurement industry to follow. These recommendations are set forth in what has become known as API MPMS Chapter 14.3. The full title is Manual of Petroleum Measurement Standards (MPMS) Chapter 14 – Natural Gas Fluids Measurement Section 3 – Concentric, Square-Edged Orifice Meters Fourth Edition, April 2000. The European community has adopted ISO-5167, which is similar but not identical to API MPMS Chapter 14.3. The updating and evolution of these standards are a result of all the research and testing that has taken place to formulate an industry best practice publication.

If one wants to be assured of the highest degree of measurement accuracy when purchasing Orifice Fittings, you must ask for an API MPMS Chapter 14.3 compliant fitting. There are Orifice Fittings available that are not API 14.3 compliant and, of course, these are less expensive than those that are compliant. To assure compliance, one should ask the manufacturer for the Orifice Fitting calibration record on which specific measurements and tests are performed and recorded to assure the fitting is within the manufacturing design parameters recommended in API MPMS Chapter 14.3.

Some of the parameters are as follows:

TAP HOLES

The differential pressure sense points are through the tap holes. The holes are to be drilled and taped radially through the fitting and perpendicular to the centerline of the fitting bore, in the same plane. The inside edge of the hole is to be without any burrs. The hole diameter should be measured and recorded on the fitting calibration record. For 4" diameter and larger fittings, the holes are to be 0.5" diameter +/-0.016" and for 2" and 3" fittings the holes are to be 0.375" +/-0.016".

The location of the holes is critical and their dimensional measurements should be recorded on the fitting calibration record. Their location is 1" upstream and 1" downstream from the orifice plate face. Their location tolerance is fitting size and β ratio (beta ratio; that is, the ratio of the orifice plate bore diameter to Orifice Fitting bore diameter) dependent. The tightest tolerance is for a 0.75 β design. For line sizes 4" in diameter and larger, it is 1" +/-0.035". For 2" and 3" diameter, it is 1" +/-0.015".

ECCENTRICITY

The orifice plate bore must be concentric with the bore of the fitting. The eccentricity maximum tolerance is line size and β (beta ratio) dependent. When measured in a plane parallel to the tap holes both upstream and downstream of the orifice plate, for a 0.75 β design and 2" size the maximum tolerance is 0.006" for 3" it is 0.009". When measured perpendicular to the tap hole axis the allowable tolerance may be 4 times greater e.g. 2" is 0.024" and 3" is 0.036". Refer to API MPMS Chapter 14.3, Paragraph 2.6.2.1 for allowable tolerances. These as-built dimensions should be recorded on the fitting calibration record.

FITTING HYDROTEST

The fitting should be pressure tested in accordance with the relevant piping design code. This test is usually conducted at a pressure of 1.5 times greater than the maximum allowable working pressure of the Orifice Fitting. Such a test will assure the integrity of the fitting body and seals in preventing leaks when placed in normal operation. The pressure and time parameters should be recorded and made available for review.

PLATE SEAL TEST

There exists the possibility that the flowing liquid or gas may by-pass the orifice plate leading to inaccurate measurement. The fitting manufacturer should perform a plate seal or bubble test to assure no leakage takes place around the plate. A blind orifice plate (one with no hole) is installed in the fitting. The fitting is pressurized upstream of the plate while a detection liquid is placed on the downstream side of the plate. Any evidence of bubbles in the liquid is an indication of by-pass. The test parameters and results should be recorded on the fittings calibration record.

TAP HOLE BY-PASS TEST

As most fittings are cast carbon steel, there exists the possibility of casting porosity which may lead to pressure leakage in the tap holes. A vacuum is drawn on the tested hole. If no loss of vacuum pressure is witnessed, the next tap hole is tested, etc., until all holes have been tested and it has been verified that no leaks exist. The test parameters and results should be recorded on the fitting calibration record.

BORE SURFACE ROUGHNESS

Roughness of the inside diameter of the fitting bore as well as the straight run piping impacts the velocity profile of the liquid or gas as it approaches the orifice plate due to the viscous drag along the pipe wall. In an attempt to duplicate all the research testing and maintain consistency in fittings and piping, a maximum recommended surface roughness is specified and should be checked. As with the other tests, it is line size and β (beta ratio) dependent. For a 0.75 β design and line sizes 12" in diameter and smaller, the bore surface roughness should be no greater than 250 μ inches (micro-inches). For line sizes larger than 12" in diameter, the bore surface roughness should be no greater than 500 μ inches and, in all line sizes, no less than 34 μ inches. Measurements should be taken in a plane 1" upstream and downstream of the orifice plate. All measurements should be recorded on the fitting calibration record.

BORE DIAMETER

One of the necessary flow rate computation components is the inside diameter of the bore. The bore should be measured in four axial planes (four measurements). The first axial measurement is in the same plane as the tap holes, 1" upstream from the face of the orifice plate. These four axial measurements are averaged and the result is defined as the measured meter tube internal diameter. Two additional upstream check measurements are made. One of these is made in a region at least two pipe diameters from the face of the orifice plate. The last check measurement location is undefined but should be in a region greater than two pipe diameters from the face of the orifice plate. Check measurements are also made downstream of the orifice plate. The first is in the same plane as the tap holes, 1" downstream from the face of the orifice plate. Two additional checks are made downstream, at unspecified locations.

If all the above measurements are made, recorded and fall within the tolerances specified, the Orifice Fitting is said to be compliant to API MPMS Chapter 14.3 and should provide accurate flow measurement results. The purpose of this presentation was to address the Orifice Fitting and Meter Tube. In most cases, the Orifice Fitting is supplied without the orifice plate, which may be added by a meter run fabricator, OEM, service company, or end user, to name a few. API MPMS Chapter 14.3 also recommends, in similar fashion as above, the design parameters, measurements, and tolerances specific to just the orifice plate, for which there are numerous supply sources. Besides the Orifice Fitting being in compliance, it is just as critical to have purchased orifice plates that are in compliance to assure flow measurement accuracy.

Meter Tubes

Research has shown that the piping upstream and downstream of the Orifice Fitting must be consistent, if any degree of flow measurement accuracy is to be expected. The velocity profile of the liquid or gas as it approaches the orifice plate is important to assure accurate measurement. Pipe elbows in-plane and 90° out-of-plane, partially open valves, thermowells, probes etc. may, and most often will, distort the velocity profile. To preclude these effects, API MPMS Chapter 14.3 recommends that a minimum length of straight pipe be installed upstream and downstream of the Orifice Fitting. This length is again dependent on the installation β ratio, plus the type of piping configuration existing upstream. The minimum recommended length of unobstructed straight pipe varies from 13 to as much as 145 pipe diameters (internal pipe diameters) upstream of the orifice plate and 4.5 pipe diameters downstream of the orifice plate (Figure 8).

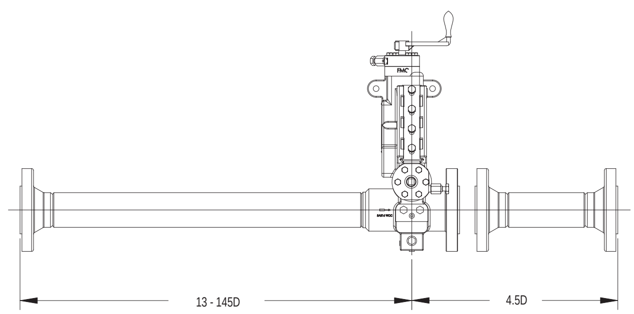


Figure 8. Required Upstream and Downstream Straight Pipe Lengths Specified in API MPMS Chapter 14.3.

Such pipe length requirements are usually not practical at most installations. To minimize liquid or gas swirl caused by piping configurations and to reduce these lengths, Flow Conditioners were developed. The first conditioner was the 19-Tube Bundle Flow Straightener. This device is a cluster of 19 small diameter tubes that fits in the piping bore upstream of the Orifice Fitting. The straightener will aid in the removal of any swirl as the liquid or gas passes through the tubes. Thus, the velocity profile is "conditioned" prior to entering the Orifice Fitting. With the use of such a conditioner, the minimum upstream length may be reduced to 29 pipe diameters with the downstream length being 4.5 pipe diameters at a max β ratio of 0.67 (Figure 9).

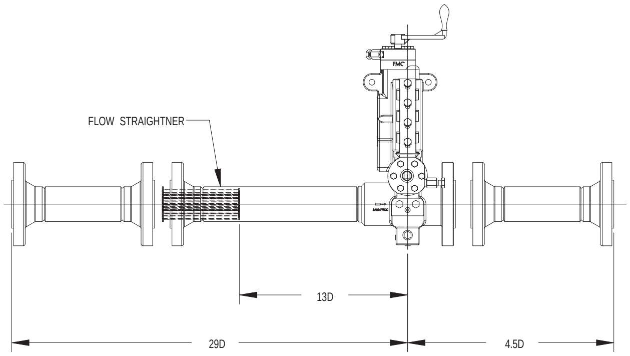


Figure 9. Required Upstream and Downstream Straight Pipe Lengths Specified in API MPMS Chapter 14.3 for a 19-Tube Bundle Flow Conditioner Installation.

Additional research has been conducted to improve flow conditioning and, thus, reduce installation cost even further by minimizing the upstream and downstream pipe length requirements. Flow Conditioner Plates have evolved and may now be used, provided they pass a series of tests defined in the API standard. Most all Flow Conditioners available today have passed the necessary testing with documented results. Having done so, API recognizes such devices and their use. With the installation of such a conditioner in lieu of the 19-Tube Bundle, the upstream pipe length may be reduced even more, lending to a reduced space requirement and reduced cost. The minimum upstream length may now be 17 pipe diameters with the downstream length the same as above (Figures 10).

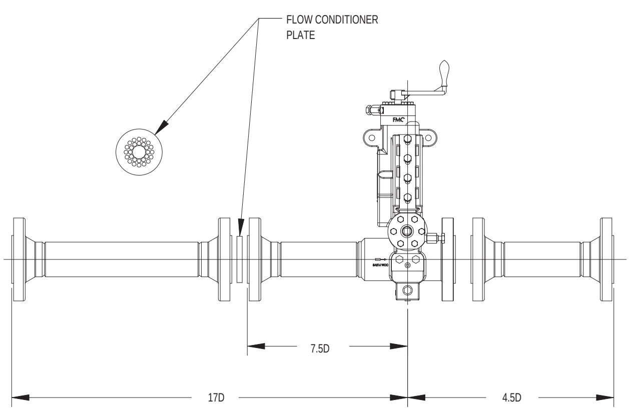


Figure 10. Required Upstream and Downstream Straight Pipe Lengths Specified in API MPMS Chapter 14.3 for a Perforated plate Type Flow Conditioner Installation.

Adjacent pipe length requirements, with or with out flow conditioning, necessitates the purchase of more than just the Orifice Fitting. End users will usually purchase a Meter Run, consisting of the Orifice Fitting and Flow Conditioner along with the necessary lengths of upstream and downstream pipe, fully assembled and pressure tested (Figure 12). Orifice Fittings are attached to the pipe either by welding (most common) using a Flange by Weld Orifice Fitting or with a flange connection using a Flange by Flange Orifice Fitting. The welding approach is most often preferred, as it provides assurance that the pipe bore is smooth immediately upstream of the orifice plate. The finished weld is machined, honed, or ground smooth. If a flange connection is selected, care must be exercised during installation to assure the fitting bore and the pipe bore are concentric and the same diameter and any flange gaskets do not protrude into the bore.

Pipe connections to accommodate thermometers, pressure gauges or transmitters, sample probes, or blow-down valves are not permitted within the described pipe lengths above. Most of these connections are placed in the downstream section. The first connection can be no closer than 4.5 pipe diameters from the downstream face of the orifice plate. Additional connections are usually spaced every 6" from the first connection. The downstream section length then becomes dependent on the number of connections plus the minimum 4.5 pipe diameters (Figure 11).

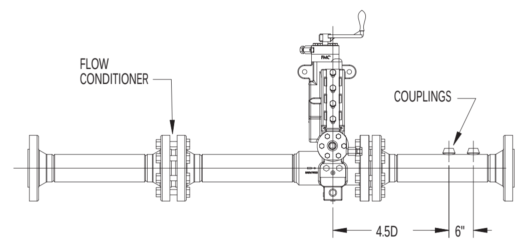


Figure 11. Required Upstream and Downstream Straight Pipe Lengths Specified in API MPMS Chapter 14.3 for a Perforated plate Type Flow Conditioner Installation.

To maintain consistency of manufacture and to assure the highest degree of flow measurement accuracy, dimensional measurements (similar to those taken on the Orifice Fitting) are recommended in the API MPMS Chapter 14.3 standard. Pipe lengths should be measured and recorded as built. Pipe bore diameter measurement checks are made in the weld region and further into the upstream tube (as previously described), as well as measurement checks made in the downstream section as described. Surface roughness checks should also be made on the pipe bore in the upstream and downstream sections, which follow the requirements of the Orifice Fitting described previously. Additionally, piping roughness upstream of the section should not exceed 600 μ inches.

Conclusion

With the price of natural gas on the rise and reaching all time highs, the need for accurate flow measurement is ever increasing. Compliance with the new Sarbanes-Oxley law, which tightens the control of financial reporting, directly affects a companies operating procedures related to the measurement of production volumes and, thus, accurately recording revenue and reporting financial results. Tightening measurement procedures, performing Orifice Fitting inspections, and assuring that Orifice Fittings meet the highest possible construction and maintenance standards are steps toward reporting correct revenue and improving company profitability. Insisting on procurement of API MPMS Chapter 14.3 compliant Orifice Fittings and Meter Tubes is a first step.

References

The following references are among those used in the preparation of this paper.

1. American Petroleum Institute (API), Manual of Petroleum Measurement Standards (MPMS), Chapter 14 – Natural Gas Fluids Measurement, Section 3 – Concentric Square Edged Orifice Meters, Part 2 – Specification and Installation Requirements, Fourth Edition, April 2000.

2. Nesler, Tim, "Gas Measurement Has Key Role in Sarbanes-Oxley Law Compliance," Pipeline & Gas Journal, September 2005, page 44.