FMC Technologies **Orifice Fittings and Meter Tubes**

Technical Paper

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Introduction

Throughout the oil and gas industry, there stems the need for accurate, economical measurement of process fluids and natural gas. Orifice Meters sometimes referred to as Orifice Fittings satisfies most flow measurement applications and is 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. In other words, 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, most commonly 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 or 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, temperature, density 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 type orifice plate holder available until the invention of the Orifice Fitting or Meter.

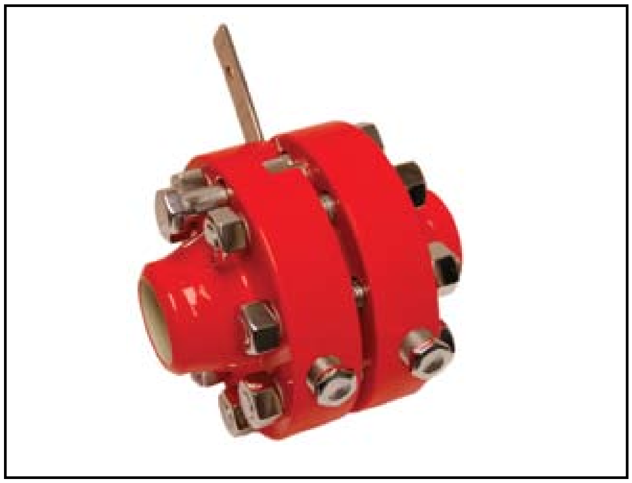

Figure 1

Orifice Flange Unions consist of two ANSI 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. Orifice measurement requires the sensing of differential pressure across the orifice plate as previously mentioned. 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 in any primary element manufacture. Thus, the OFU is required to have two pressure taps, one in each flange. Usually an extra set of pressure taps are provided and located 180° from the first required pair. The pressure taps are ½" NPT with a thru hole of either 3/8" or ½" diameter depending on the nominal flange size.

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. Gaskets must be replaced in most cases. OFU's are commonly applied in chemical plants and refineries for flow control, for flow measurement at the wellhead and allocation metering where a number of wells are centrally located. The Orifice

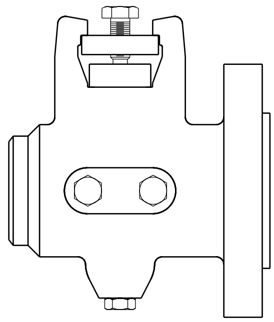

Figure 2

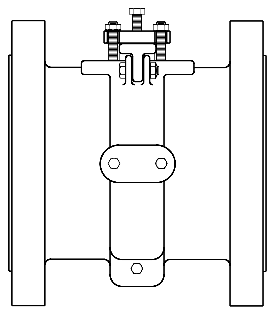

Figure 3

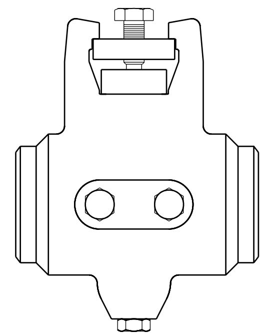

Figure 4

Flange Union is used where periodical inspection of the orifice plate is not required and the overall accuracy is usually less critical.

Advantages

- Low cost
- Few parts
- Available from many sources
- Wide range of material choices

Disadvantages

- Shut down or by-pass of line is required to change plate
- More time consuming and costly to change plate
- More expensive paddle type orifice plate required
- 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

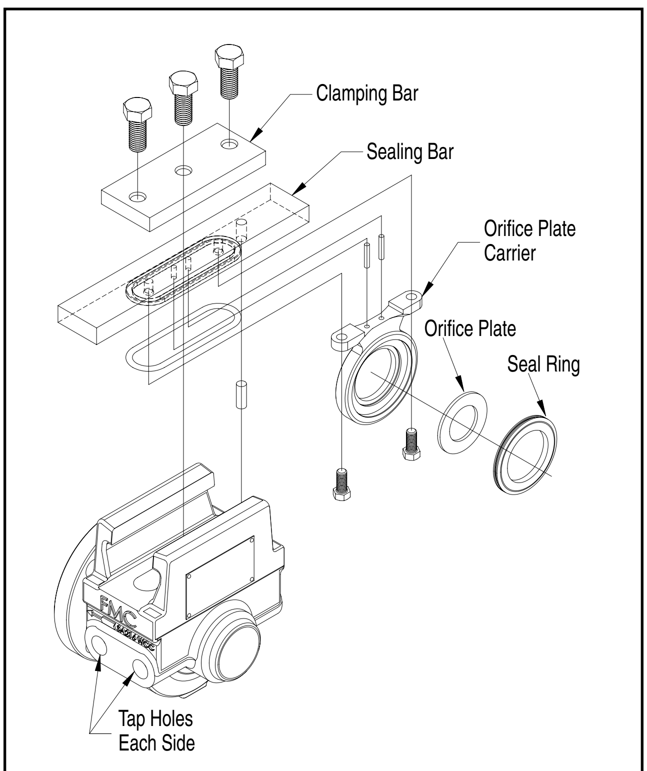

Figure 5

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 insure measurement accuracy. In some installations, flow rate will vary to the extent that various sizes of orifices are required to keep the differential pressure within range of 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.

The Single Chamber Orifice Fitting body is usually made of cast carbon steel in various configurations. Flange by Weld is the most common (Figure 2), Flange by Flange (Figure 3) and Weld by Weld (Figure 4) are also available configurations. The 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.

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), sealing bar and clamping bar. One such design is shown in Figure 5. 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 14.3 which will be discussed later in this paper.

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.

Advantages

- Simple to operate
- Positive alignment of plate to line bore
- Short down time compared to OFU

Disadvantages

- Higher cost than Orifice Flange Union
- Shut down or by-pass of line is required to change the plate
- 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.

The Dual Chamber Orifice Fitting has all the attributes of the Single Chamber Fitting plus the advantage of orifice plate inspection or change while under flowing conditions and line pressure. Dual Chamber Fittings are available in common sizes 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 (Figure 6) and Flange by Flange (Figure 7). The body includes the same two sets of pressure taps as described above.

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 8 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. Retrofit 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.

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.

Advantages

- No shut down or by-pass of line required
- 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

Disadvantages

- Highest price Orifice Fitting

Design Criteria to Assure Measurement Accuracy

Most flow meters require flow calibration to verify accuracy. However, a properly designed Orifice Fitting will not require flow calibration if designed and manufactured in accordance with acceptable design practices. Since the beginning of Orifice Measurement numerous studies and research along with field and laboratory testing has been conducted to determine what physical hydraulic changes take place in a pipeline when the liquid or gas approaches and leaves the orifice plate. Conclusions of all this work has determined that when a orifice plate is properly installed and maintained and the Orifice Fitting is properly designed and manufactured the Orifice Fitting can provide an accuracy in the range of 0.5 – 1%. However, orifice measurement is sensitive to flowing conditions, piping installation conditions, precision ma-

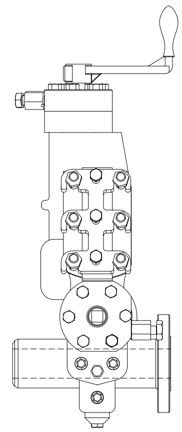

Figure 6

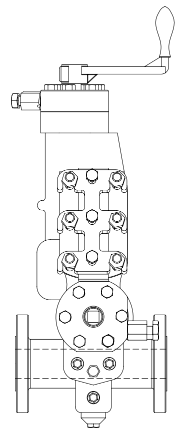

Figure 7

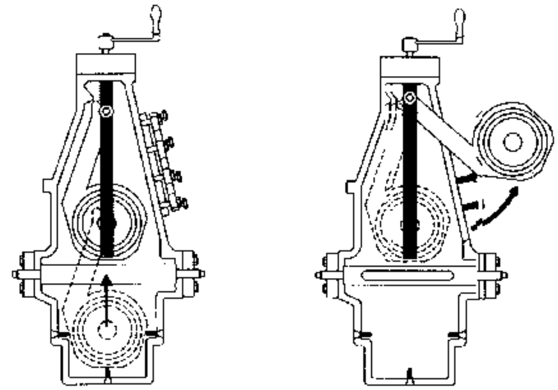

Figure 8

chining of the fitting itself and its attachment to straight run pipe plus the accumulative error of the secondary instrumentation. Overall accuracy of the metering installation under average operating conditions could be in the range of 2 – 5%. If not properly maintained and inspected periodically this accuracy could be in the order of 10 – 25%.

To increase the confidence level of obtaining the highest degree of accuracy in orifice measurement the American Petroleum Institute 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 14.3. The full title is *Manual of Petroleum Measurement Standards* 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 14.3. The updating and evolution of these standards is 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 accuracy when purchasing Orifice Fittings you must ask for an API 14.3 compliant fitting. There are Orifice Fittings available that are not API 14.3 compliant and of course are less expensive than those that are compliant. To assure compliance one should ask the manufacturer for the fittings 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 14.3.

Some of the parameters are as follows:

Tap Holes

The differential pressure sense points are thru the tap holes. The holes are to be drilled and taped radially thru 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" 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 measurement should also be measured and 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; ratio of orifice plate bore diameter to orifice fitting bore diameter) dependent. The tightest tolerance is for a 0.75 β design. Sizes 4" and larger it is 1" +/-0.035", for 2" and 3" it is 1" +/-0.015".

Eccentricity

The orifice plate bore must be concentric with the bore of the fitting. The eccentricity maximum tolerance is 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 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 fittings maximum allowable working pressure. 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 verified 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 provided and should be checked. As with the other tests it is size and β (beta ratio) dependent. For a 0.75 β design and sizes 12" and smaller the bore surface roughness should be no greater than 250 μ inches (micro-inches). For sizes larger than 12" the bore surface roughness should be no greater than 500 μ inches and in all 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 2 pipe diameters from the face of the orifice plate. The last check measurement location is undefined but should be in a region greater than 2 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 14.3 and should provide accurate 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 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 in compliance to assure measurement accuracy.

Meter Tubes

Due to the many varying installation conditions, research has shown that piping upstream and downstream of the Orifice Fitting must be consistent if any degree of 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 14.3 recommends 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 9).

Such pipe length requirements are usually not practical at most installations. To minimize liquid or gas swirl caused by piping configurations and reduce these lengths, Flow Conditioners were developed. The first conditioner applied was the 19-Tube Bundle Flow Straightner. This device is a cluster of 19 small diameter tubes that fits in the piping bore upstream of the Orifice Fitting. The straightner 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 10).

Additional research has been conducted to improve flow conditioning and thus reduce installation cost. Flow Conditioner Plates have evolved and may now be used provided they pass a series of tests defined in the API standard. Most all 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 (Figure 11).

Requirements of pipe lengths with or with out flow conditioning requires the purchasing of more than just the Orifice Fitting. End users will purchase a Meter Run consisting of the Orifice Fitting, usually a flow conditioner along with the necessary lengths of pipe all fully assembled and pressure tested (Figure 12). Orifice Fittings are attached to the pipe either by welding (most common) using a Flange x Weld Orifice Fitting or with a flange connection using a Flange x 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 blowdown are not permitted within the described 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 12).

To maintain consistency of manufacture and assure the highest degree of measurement accuracy, measurements (similar to those conducted on the Orifice Fitting) are recommended in the API 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.

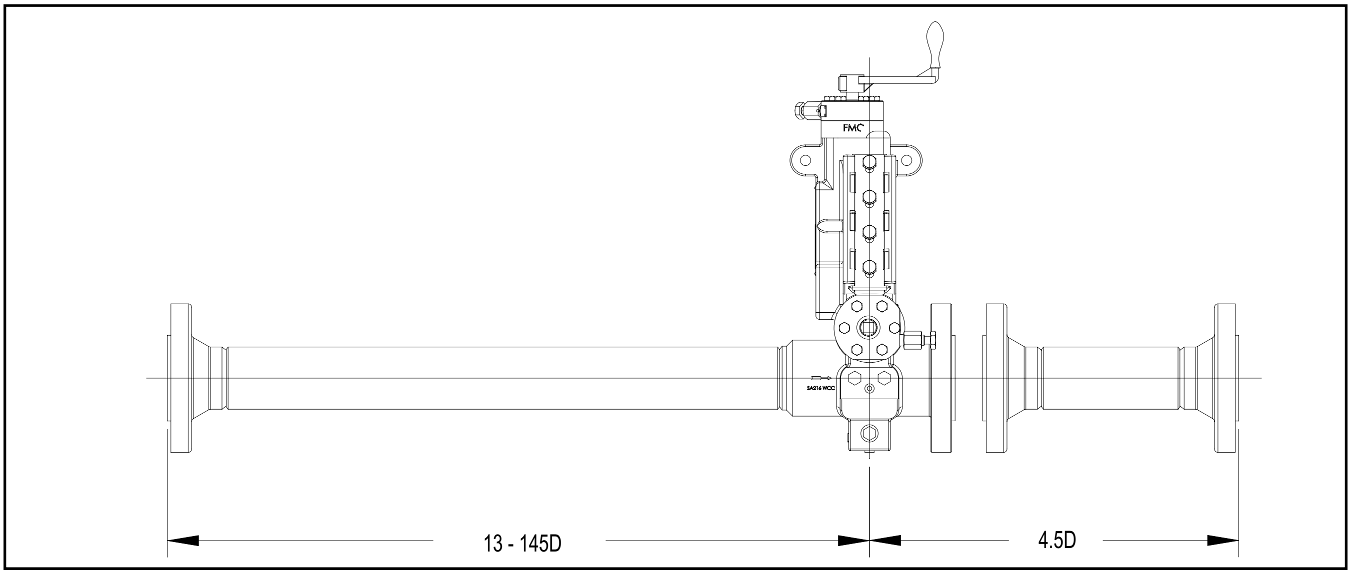

Figure 9

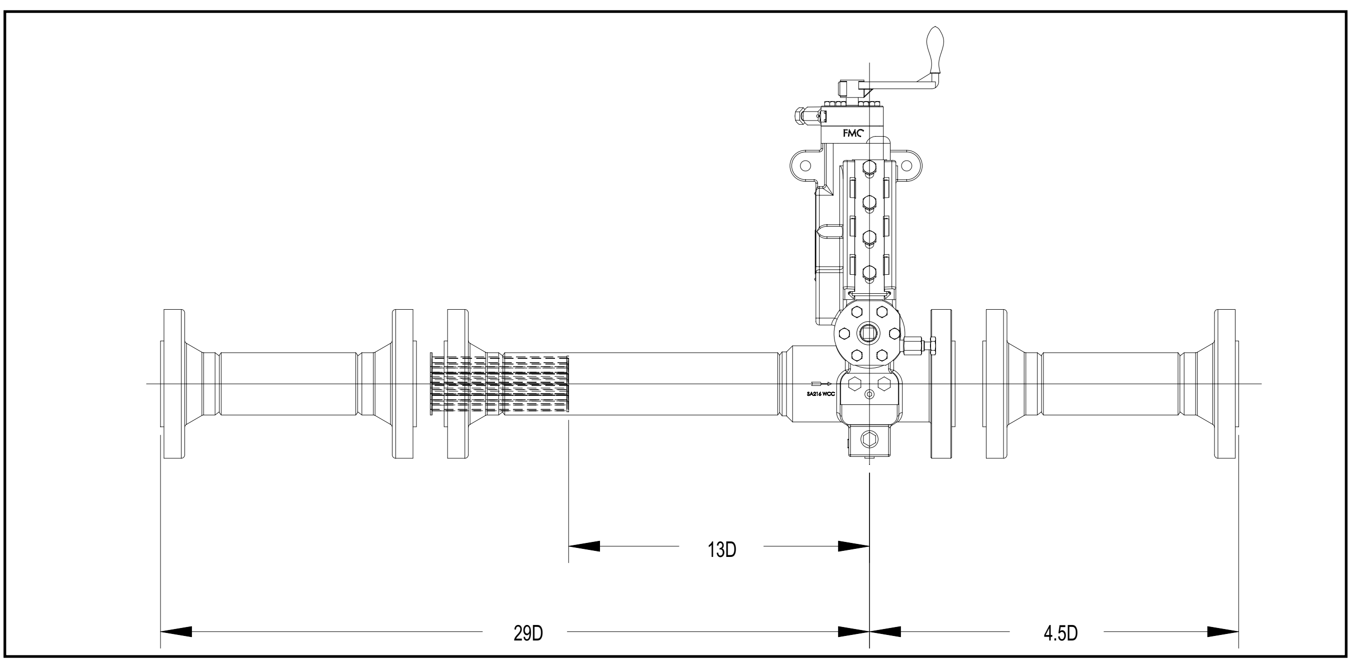

Figure 10

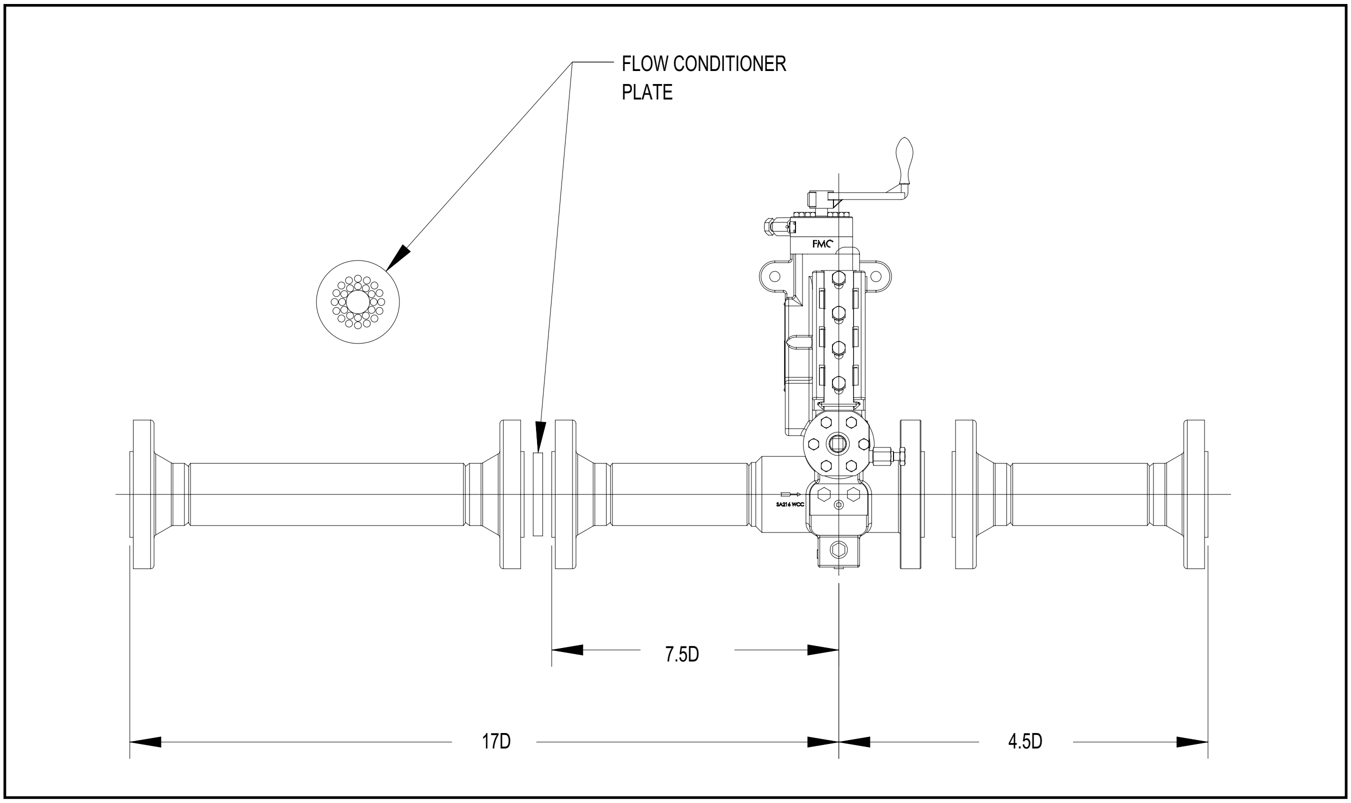

Figure 11

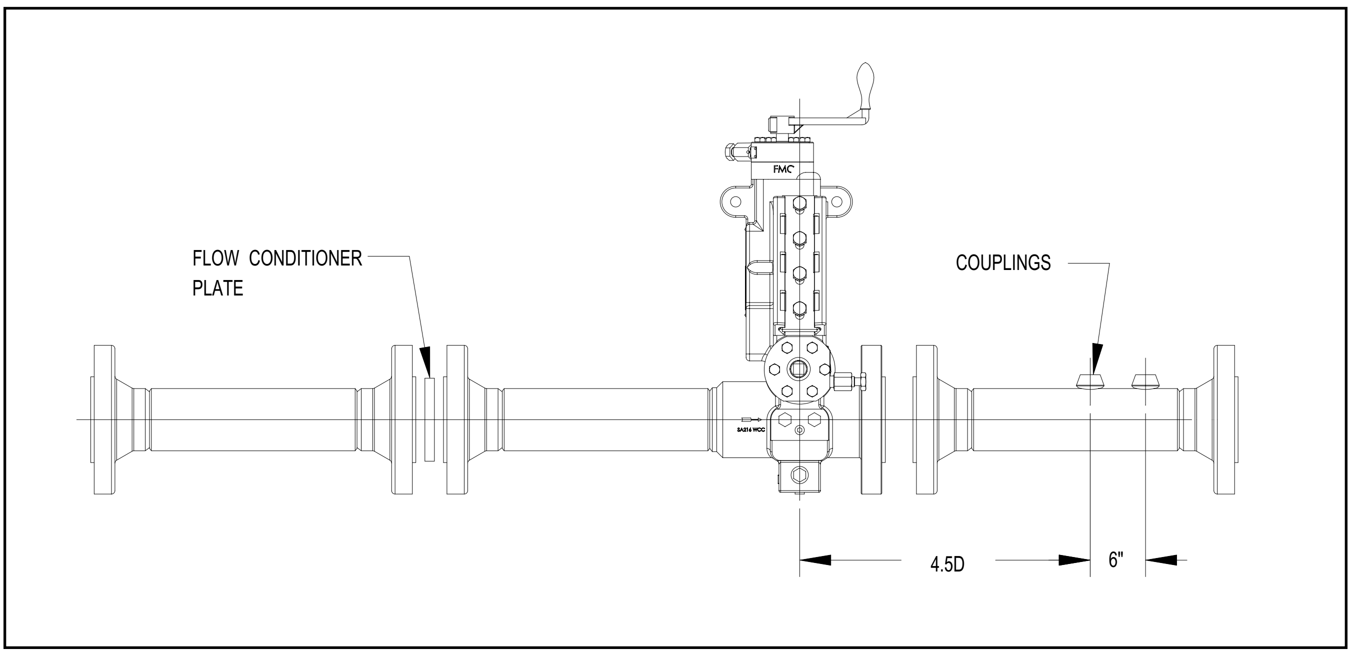

Figure 12

Conclusion

With the price of natural gas on the rise reaching all time highs the need for measurement accuracy 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, Orifice Fitting inspections and assurance that Orifice Fittings meet the highest possible standards are steps toward reporting correct revenue and improving company profitability. Insisting on procurement of API 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.

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