FUNDAMENTALS OF ORIFICE METERING

CLASS #1250

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Introduction

Throughout the oil and gas industry, the need exists for accurate and economical measurement of process fluids and natural gas. Orifice Meters, sometimes referred to as Orifice Fittings or head loss flow meter, satisfy most flow measurement applications and are the most common flow meter type in use today. The Orifice 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

An orifice measurement system consists of Primary and Secondary Measurement Elements. The primary element consists of, "the orifice plate, the orifice plate holder with its associated differential pressure sensing taps, the meter tube and flow conditioner, if used" as defined by the American Petroleum Institute (API). The secondary elements consist of everything external to or attached to the piping. Examples of secondary elements are chart recorders, electronic flow computers, differential pressure transmitters, etc.

The intent of this paper is to address the Primary Measurement Element of the meter. The Primary Element, therefore, includes a section of straight run pipe with a constrictive device - the orifice plate. As the fluid passes through the orifice, the velocity of the fluid increases proportionally as the area decreases as seen in the following equation (Equation 1):

$$Q = A_1 \times V_1 = A_2 \times V_2 \qquad \text{(Equation 1)}$$

Where:
Q = Flow rate
A_1= Area of pipe
A_2= Area of orifice
V_1= Velocity of fluid in pipe
V_2 = Velocity of fluid in orifice

and in turn there will be a loss of static pressure in the system. The Secondary Elements sense differential pressure across the orifice plate. This differential pressure allows for calculations of the flow rate and can be correlated to the volumetric flow through the pipe. The important factors are the diameter of the pipe, diameter of the orifice and location of the pressure taps. There are other variables that are corrected for in the flow computer to allow for accurate measurement such as fluid properties.

Through development and testing, 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 manufacture of any primary element. The primary element is required to have two pressure taps - one in each flange. However, an extra set of pressure taps is provided and located 180° from the first required pair to facilitate other equipment or give other options when fitting the sensing elements.

Primary Element Types

Orifice Flange Union

The original orifice plate holding device was the Orifice Flange Union (OFU) (Figure 1). OFUs consist of two ANSI-rated flanges with associated flange bolts, nuts, jack screws and gaskets. The jackscrews aid in spreading the flanges to allow for the installation or removal of the orifice plate.

Figure 1. Example Orifice Flange Union (OFU)

OFUs provide an economical method of measurement for installations where the pipeline fluid 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 OFUs utilize the more expensive paddle-type orifice plate and require additional labor to perform an orifice plate change or maintenance. The technician must loosen all bolts, 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, for flow measurement at wellheads and in allocation metering. OFUs are 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

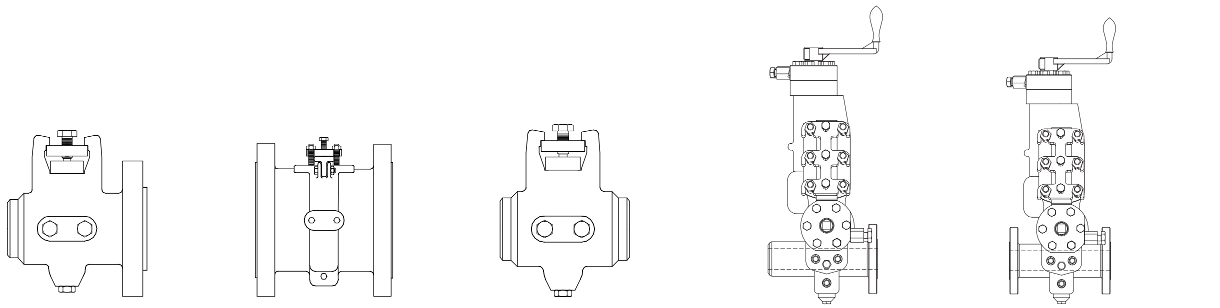
Advantages	**Disadvantages**
Low cost	Shut-down or by-pass of line is required to change plate
Few parts	More time consuming and costly to change plate
Available from many sources	Expensive paddle type orifice plate required.
Wide range of material choices	Higher risk of not getting the plate centered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

Orifice Fitting (Meter)

In some installations, the flow rate of the system greatly varies over time, usually seasonally. This fluctuation requires the orifice fitting to have various sizes of orifice plates to keep the differential pressure within acceptable range of the secondary element. If the meter is used for custody transfer of the fluid, frequent inspection of the orifice plate is necessary to ensure the plate is within specification. Orifice Fittings, Single and Dual Chambered (Figure 2), are designed to reduce inspection maintenance and labor which reduces 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 (left) and Dual Chamber (right) Orifice Fittings

Orifice Fittings are usually made of cast carbon steel in various configurations (Figure 3). The typical versions are Flange by Weld, Flange by Flange and Weld by Weld with the Flange by Weld the most common. The meter body includes the same two sets of pressure taps as described in the OFU. Depending on the application pressure, these types of Orifice Fittings are 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** **Flange by Weld** **Flange by Flange**

Figure 3. Orifice Fitting Configurations

Single Chamber Orifice Fitting (Meter)

There are various designs of the Single Chamber Orifice Fitting on the market with differing internal components. Fundamentally they all have a plate carrier, rubber seals for the orifice plate (assures no by-pass of the fluid 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 orifice plate 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 a locating method and precision machining of the carrier and sealing bar. Such positioning is positive, accurate, fast, and assures compliance with measurement standards.

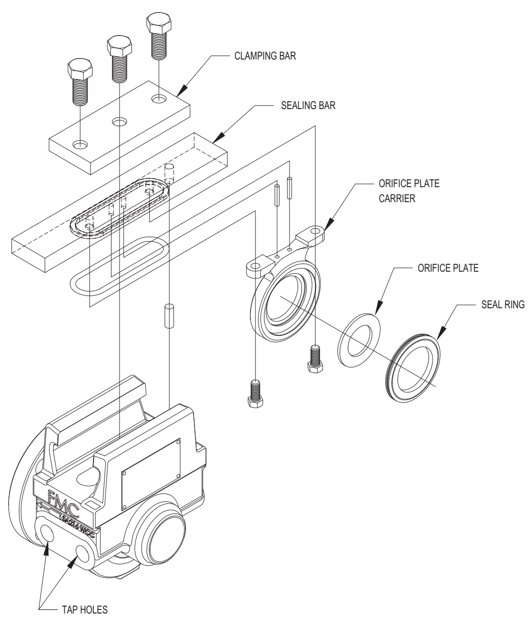


Figure 4. Principal Components of a Single Chamber Orifice Fitting

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. 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 fluid from the pipeline, which occurs when flanges are separated.

Table 2. Advantages & Disadvantages of Single Chamber Orifice

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

Dual Chamber Orifice Fitting (Meter)

Dual Chamber Orifice Fittings have 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. This is accomplished by having a chamber where the orifice plate and carrier can be isolated from the pipe. They are commonly used for custody transfer of transmission natural gas pipelines or any installation where the pipeline cannot be shut down.

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 5), the plate carrier assembly is retracted into the upper chamber. A plug valve is closed to isolate both 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. At this point the carrier plate assembly can be removed 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 after using an equalizer valve to pressurize the upper chamber.

As with a Single Chamber Fitting, the Dual Chamber the orifice plate bore is precisely positioned in the body bore by means a locating method and precision machining of the carrier.

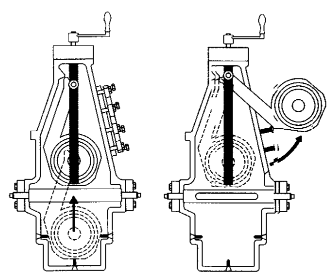


Figure 5. Dual Chamber Orifice Fitting Configurations

Table 3. Advantages & Disadvantages of Dual Chamber Orifice

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 fluid due to line blow down process	

Design Criteria to Assure Measurement Accuracy

Unlike other meter technologies, Orifice Fittings will not require flow calibration to verify accuracy if designed and manufactured to known standards. 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 fluid 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 on the order of +/-10% to 25% of reading.

One of the known standards is published by API. The title of the document is: *Manual of Petroleum Measurement Standards (MPMS) Chapter 14 – Natural Gas Fluids Measurement Section 3 – Concentric, Square-Edged Orifice Meters Fourth Edition, April 2000*. Commonly it is referred to as API MPMS Chapter 14.3. The European community has adopted International Organization for Standardization (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.

Since most of these Orifice Fittings are meant to have the orifice plates inspected or maintained, the fitting should be designed to allow for the largest beta ratio (ß). The beta ratio is the ratio of the orifice plate to Orifice Fitting bore diameter. The largest beta ratio allowed by API MPMS Chapter 14.3 is 0.75. The Orifice Fitting can be designed to any specific beta ratio which will allow a greater manufacturing tolerance on the critical dimensions however this will limit the flow range of the fitting. Some of the critical parameters are as follows (following API MPMS Chapter 14.3 with ß = 0.75):

TAP HOLES

The differential pressure sense points are through the tap holes. These pressure tap sense points are located 1" upstream and 1" downstream from the orifice plate face. The holes are to be drilled and tapped radially through the fitting and perpendicular to the centerline of the fitting bore. The inside edge of the holes are to be sharp and without any burrs. The hole diameters are determined by the pipe size. For 4" diameter and larger fittings, the holes diameters are 0.5" and for 2" and 3" fittings they are 0.375".

ECCENTRICITY (of the orifice plate)

The orifice plate bore must be concentric with the bore of the fitting. When measured in a plane parallel to the tap holes both upstream and downstream of the orifice plate are defined by an equation in API MPMS Chapter 14.3, Paragraph 2.6.2.1. When measured perpendicular to the tap hole axis the allowable tolerance may be 4 times greater than the parallel plane. For example, a 2" Schedule 40 fitting has a parallel tolerance of 0.006" and a perpendicular tolerance of 0.024".

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.

PLATE SEAL TEST

If the flowing fluid bypasses the orifice plate, the result will be inaccurate measurement of the flow stream. A plate seal or bubble test is performed 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.

TAP HOLE BY-PASS TEST

As most fittings are cast carbon steel, there is the possibility of casting porosity which could 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.

BORE SURFACE ROUGHNESS

Roughness of the inside diameter of the fitting bore as well as the straight run piping affects the velocity profile of the fluid 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. In 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.

BORE DIAMETER

One of the necessary flow rate computation parameters 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.

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. This combination of upstream and downstream spools and Orifice Fitting is considered a Meter Tube or Meter Run. 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 the most common, 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.

The velocity profile of the fluid 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. 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 typically 44 to as much as 145 pipe diameters (internal pipe diameters) upstream (UL) of the orifice plate and 4.5 pipe diameters downstream (DL) of the orifice plate (Figure 6).

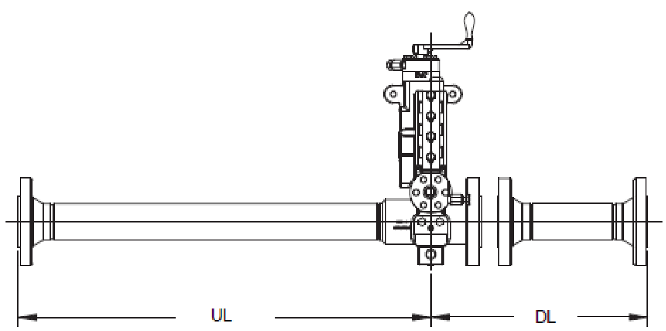


Figure 6. Required Upstream and Downstream Straight Pipe Lengths

Such pipe length requirements are usually not practical at most installations. To minimize fluid swirl caused by piping configurations and to reduce these lengths, Flow Conditioners were developed. The first conditioner was the 19-Tube Bundle Flow Straightener. The straightener will aid in the removal of any swirl as the fluid passes through the tubes. Thus, the velocity profile is “conditioned” prior to entering the Orifice Fitting and the upstream length can be shortened. The upstream (UL2) piping configuration determines the amount of straight length required for the conditioned flow (Figure 7).

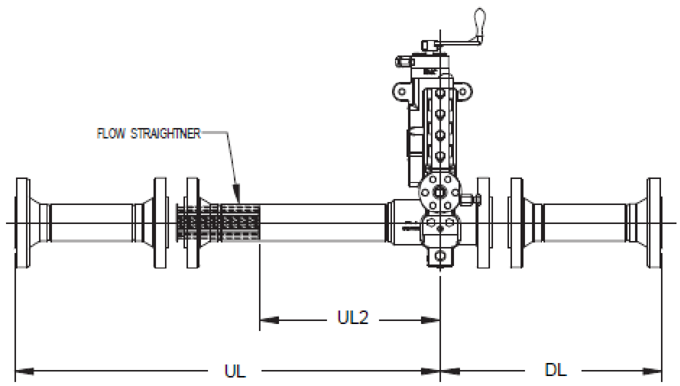


Figure 7. Upstream and Downstream Straight Pipe Lengths for a 19-Tube Bundle Flow Conditioner Installation

Additional research has been conducted to improve flow conditioning and 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 and are recognized by API. With the installation of such a conditioner in lieu of the 19-Tube Bundle, the upstream pipe length (UL2) may be reduced even more, lending to a reduced space requirement and reduced cost (Figures 8).

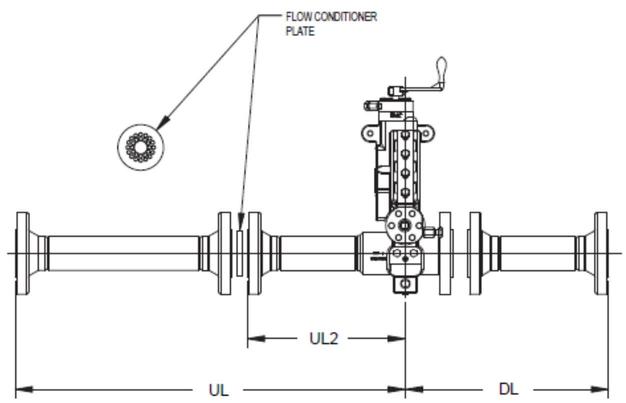


Figure 8. Upstream and Downstream Straight Pipe Lengths for a Perforated plate Type Flow Conditioner Installation

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 (DL) 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 9).

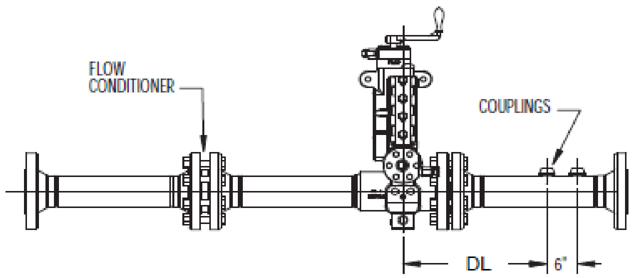


Figure 9. Downstream Straight Pipe Lengths for Instrumentation Coupling Installation

Conclusion

To maintain the highest degree of flow accuracy while using an Orifice Fitting, purchase a fitting manufactured to a known standard. The manufacture will supply a record of all of the critical dimensions for verification of compliance to the standard and for information to be entered into any secondary elements. With a preventative maintenance program for the orifice plates and fittings, one can expect years of service from the equipment.

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.