FUNDAMENTALS OF ORIFICE METERING

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Introduction

The history of orifice metering began in the early 1900's. The first test data was done by the U.S. Geological Survey and in 1913 the first "Handbook of Natural Gas" was published. So, as you can tell, orifice metering has been around for over 100 years and in that time, much has been learned and improved on.

Orifice metering flow equations have been derived from test data where an orifice plate, a plate with a hole in the middle of it, was placed in the flow line causing a restriction in flow. This differential was then compared to the actual amount that passed by the orifice and from that information engineers can then ascertain by mathematical algorithms what equations to use to duplicate those results. Below is a schematic of an orifice differential being compared to a known prover volume.

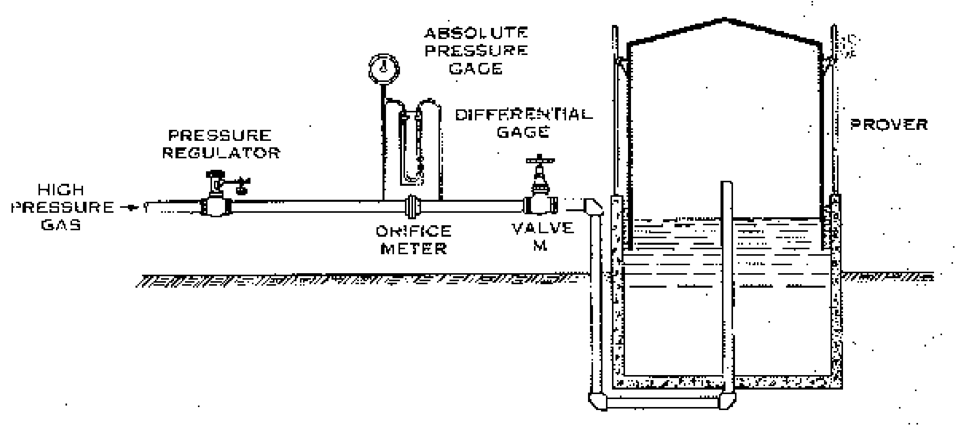

Figure 1. Orifice Meter with Prover

Orifice Metering Flow Equations.

The American Gas Association (AGA) Report #3, the American Petroleum Institute (API) Chapter 14.3 is the same standard "Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids - Concentric, Square-edged Orifice Meters". The API organization is the owner of the standard that writes and approves any revisions but the AGA committees get to vote on the final approval of any changes made to the standard. There are four parts of the AGA standard and the flow equation is in Part 1 "General Equations and Uncertainty Guidelines" and Part 3 "Natural Gas Applications".

The 1985 AGA Report #3 edition had reference tables to get the basic orifice factors for flow but with the advancement of computers the 1992 edition changed to the coefficient of discharge method to calculate the basic orifice factor.

The simplified form of the orifice meter flow equation used in the 1992 edition that combines the numerical constants and unit conversion constants in a unit conversion factor (N1) is below:

$$q_m = N_1\, C_d E_v Y d^2 \sqrt{P_t, p\Delta P} \qquad \text{Equation (1)}$$

Where: *Cd* is the orifice plate coefficient of discharge;

d is the orifice plate bore diameter

(*Tf*) is the flowing temperature

ΔP is the orifice differential pressure;

Ev is the velocity of approach factor;

*N*1 is the unit conversion factor;

qm is the mass flow rate;

ρ*t, p* is the density of the fluid at flowing conditions

Y is the expansion factor.

All the flow equation parameters used in flow calculations can be found in the API 14.3.1 standard.

Below is a diagram of the "vena contracta" which are the pressure measurement points to get the differential pressure readings for orifice measurement.

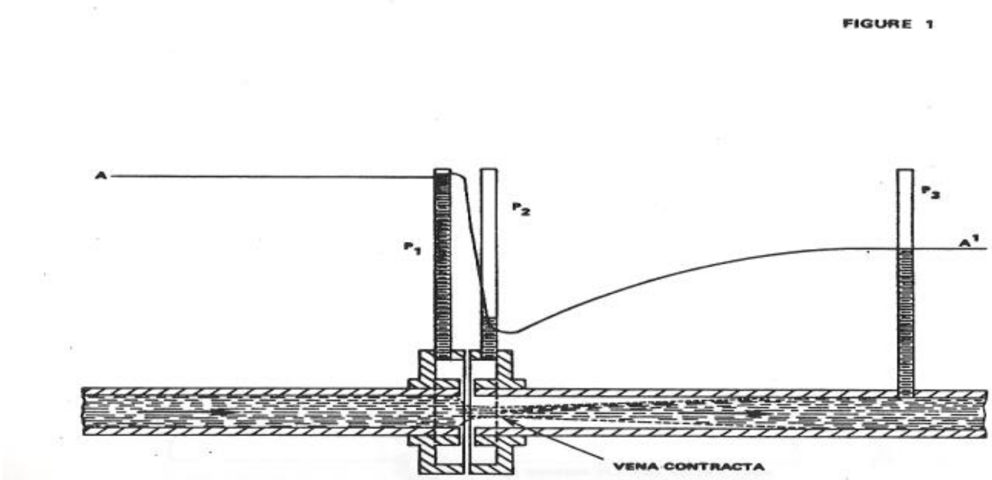

Figure 2. Vena Contracta

The Four Main Components to Orifice Metering:

Component 1: The Orifice Plate

The orifice plate is where the flow measurement starts. Requirements on how orifice plates are made are detailed in the API Standard 14.3.2 which is the same standard as the AGA Report #3 Part 2 "Natural Gas Fluids Measurement Concentric, Square-Edged Orifice Meters Part 2 Specification, and Installation Requirements". This standard will give the precision that one needs to adhere to make an orifice plate that will be used for custody flow measurement. How thick the plate needs to be? How much angle the bevel needs to be and at what plate size do you not need to have a beveled edge? The sections to reference in the API 14.3.2 standard is section 2.4.

All the flow test data proves that a flat, smooth, clean orifice plate with a sharp bevel edge with no defects is needed to duplicate the value that we get from the coefficient of discharge part of the flow equation. Test studies have also determined that having plates in service that are not flat, smooth, clean or have rough beveled edges with nicks can cause flow uncertainties to increase. The design is also for the bevel edge of the orifice to face on the downstream side of the flow with the sharp edge facing upstream.

Users of orifice metering should have processes in-place to regularly inspect orifice plates that have been in service for any type of flow application. The frequency of that inspection is determined usually between the two parties that are involved.

Figure 3. A universal orifice plate.

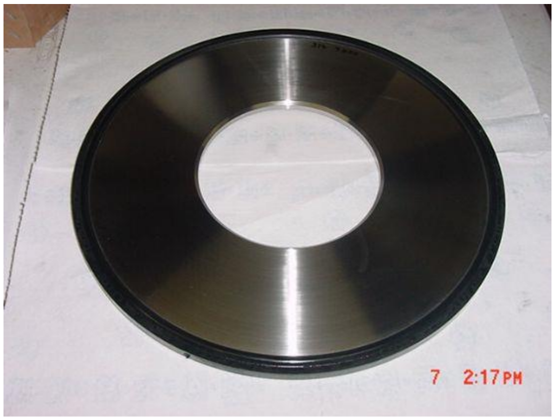

Figure 4. A universal plate with seal ring.

Component 2: The Orifice Fitting

The orifice plate that I discuss in component 1 must be installed in a flow line. The industry has developed many different types of "orifice fittings" that the orifice plate can be set in. There are 3 main fitting types that I will talk about, the flange, the single chamber, and the dual chamber. The fitting is designed to hold the orifice plate in the center of the flow line with a sealing device that will not allow any gas flow to go by the plate without going through the orifice hole. This design is specified in the API 14.3.2 and AGA Report #3 Part 2 "Concentric, Square-Edged Orifice Meters Part 2 Specification, and Installation Requirements". Each fitting will then have "tap holes" drilled so a 1/4" hole can sense the upstream and downstream pressures exactly one inch from each side of the orifice plate. These holes may be referenced as "flange tap holes". Past standards allowed for "pipe tap holes" that were a known distance upstream and downstream of the orifice plate located on the meter tube instead of the fitting. The 2000 edition of the API 14.3.2 and AGA Report #3 Part 2 don't support the use of "pipe taps".

The flange orifice fitting is just that. It is a set of pipe flanges that have tap holes drilled in them. The orifice plate used is called a "paddle type" plate because it has a handle attached to it. The flange is separated and the plate is positioned between the flange bolts and then with flange gaskets installed the flange bolts are tightened. The 2000 API 14.3.2 does not support the flange fitting since that type of fitting cannot meet the concentricity and eccentricity specifications. This type fitting should only be used for operational flow meters.

The single chamber fitting is a fitting that is generally built from a stock of metal that is formed and then cut to design. It will have the same tap holes as mentioned above with a plate carrier that can be pulled from the fitting while the fitting is still welded or flanged to the meter tube. This single chamber fitting can be built to meet the 2000 API 14.3.2 fitting specifications. To inspect the orifice plate a user does have to shut in the flow of gas and blow down any pressure to safely pull the orifice from the fitting for inspection.

Figure 5. Single chamber fitting with flange tap valves

The dual chamber fitting is designed with two compartments that can be isolated from each other along with a mechanism to be able to crank the orifice plate carrier out. This fitting is used when the operator does not want to have to shut in the flow of fluid to perform the regularly scheduled orifice plate inspections. Of course, the benefit comes with an added cost compared to the single chamber fitting.

Figure 6. Dual Chamber Fitting

Single and dual chamber orifice fittings are widely used throughout the world to measure a variety of different types of fluids. Both devices can do this measurement very accurately if the referenced standard specifications are followed and regularly scheduled plate inspections are done.

Component 3: The Meter Tube

The third component to orifice metering is the meter tube. Meter tubes are the associated piping that is directly placed upstream and downstream of the orifice fitting talked about in the component 2 section. All meter tubes must be built to the specifications in the API 14.3.2 and AGA Report #3 Part 2 "Concentric, Square-Edged Orifice Meters Part 2 Specification and Installation Requirements" standard.

The standard allows for either a welded or flanged connection between the orifice fitting and the meter tube piping. The most common connection is the "weld neck – flanged fitting". This fitting will have the upstream pipe welded to the fitting and the downstream pipe will be flanged. This type meter tube will allow the user to break the flange apart to perform tube inspections and ease of getting internal micrometer readings.

The standard has specifications on how smooth the pipe should be. It also gives details on how to obtain the proper micrometer readings to get the mean average inside diameter (ID) that is used in the flow equations. The standard also gives specifications on how long the upstream and downstream tube lengths need to be. The fluid flow approaching the orifice plate needs to be free from swirls and cross currents. To do this a long length of straight pipe will need to be used for the meter tube upstream section. To reduce the overall length of the meter tube users can install flow conditioning devices such flow conditioning plates or 19 tube straightening vanes. If the measurement station is designed with regulating valves or pipe bends upstream of the orifice fitting then those stated lengths should be adhered to. All the specifications for lengths and other meter tube requirements can be found in the API 14.3.2, AGA Report #3 Part 2 sections 2.5 and 2.6.

There are also specifics on the downstream section of pipe where most operators have their collars installed for sample probes, thermowells etc. That design should not impact the vena contracta so a correct downstream pressure can be read.

The "beta ratio" (β) is the ratio of the orifice size to the inside diameter of the meter tube. Most of the meter tube specifications are based on this beta ratio.

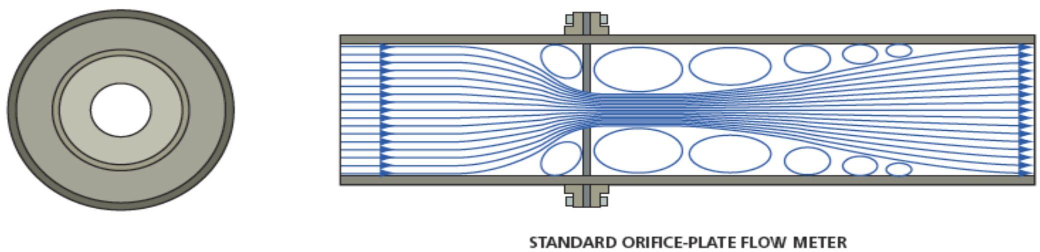

Figure 7. Vena Contracta with a good flow profile

Component 4: The Meter

The fourth component is the meter. The first three components put together are commonly called the "primary element" in flow measurement. The primary element consists of the orifice plate installed in the orifice fitting along with the associated meter tube pipe lengths. The fourth component is commonly called the "secondary element". These names give users the needed impression that the primary element comes first and needs to be done correctly so the secondary element can record accurate flow data. The secondary element will be the recording device. This device can be a chart type recorder, electronic transmitters, or a flow computer. Parameters that the secondary element needs to record constantly is the differential pressure recorded in inches of water column, the flowing pressure sometimes referred to as static pressure in absolute pressure (PSIA), and the flowing temperature.

The differential pressure is the pressure difference between the upstream tap reading in pounds per square inch (PSI) to the downstream tap reading in PSI. It is in inches of water column engineering units because the 100" water column is what the values are based from. When the chart recorder or transmitter is calibrated the 100" reading will be the same pressure it takes to move the 100" of water from one side of the U-shaped column to the other side. 1 inch is 0.03609 psi or 100 inches is 3.609 psi.

The static pressure can be recorded in gauge pressure (PSIG) or absolute pressure (PSIA). Flow measurement calculations will have to be done using PSIA. If a PSIG transmitter or bourdon tube (chart recorder) is recording in PSIG then the flow computer or the accounting office will have to add the location's atmospheric pressure to the gauge pressure readings to get the PSIA value to use in the flow equations.

The flowing temperature is recorded in Fahrenheit (F) degrees. Flow measurements will use an absolute temperature and for 60 degrees F you will add 459.67 to 60 to get a 519.67 degrees Rankin to include in the flow equations.

It is up to the recording device to accurately record the flowing parameters to enable the proper accounting of flow. For chart recorders, most of this is performed in the office but for flow computers this is done on site by the computer. There are many more parameters that go into the flow equation called "constants" and those constants should be correct too. The flow computers which are commonly called electronic gas meters (EGM) or electronic flow meters (EFM) will hold these parameters and perform the flow calculations on a by minute basis but the chart recorders will have to rely on the office to hold the correct constants and then perform the flow calculations on an hourly basis after the chart is integrated.

There is an API standard Chapter 21.1 “Flow Measurement Using Electronic Metering Systems - Electronic Gas Measurement” that gives guidance on how custody flow measurement should be done using EGM measurement systems.

The flow calculations that I mention are all based off testing that has been done by the industry and is then validated by the various industry groups such as API, GPA, and/or AGA. The NIST and ASTM organizations have also given guidance on how to accurately perform flow measurement using orifice meters.

Conclusion:

To summarize the fundamentals of orifice metering, I would like to first say that it is very important to follow the specifications and guidelines set forth in the standards that have been sighted in this paper. There are world organizations like the International Standards Organization (ISO) that have similar document standards to the American ones.

The orifice plate, the orifice fitting, and the meter tube all should be made and operated in a way that meets the standards’ specifications so flow rates and volumes can be determined fairly for all parties involved. There is a lot more details to how flow measurements are done but this paper should give you a fundamental understanding of the orifice metering systems.

As technology continues to advance the orifice metering of fluids should continue to be improved on. There are other methods to measure flow such as Ultrasonic meters, Coriolis meters, and other devices but the orifice is the most common one used today and at the time of this paper is still the most common one installed for natural gas flows.