Application of the Orifice Meter for Accurate Gas Flow Measurement

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Summary

The most common device used in gas flow measurement is the orifice flow meter. It is capable of very accurate measurement provided it is properly applied, designed, installed, maintained and interpreted. It is the intention of this article to cover these aspects of the orifice meter so that the use of the device can be evaluated and a proper decision made on application.

Introduction

For most accurate measurement, the orifice meter should be applied to gas flows, which are steady or vary slowly with time, is in the turbulent flow region, and is well below sonic velocity. The gas should be single phase and not contain suspended particles. If the gas temperature is above or below the ambient temperature consideration may be given to insulating the upstream and downstream tubes and the lead lines to the recording devices or transducers. If flow changes are large (such as over 5 to 1 turn down) and slow with time (such as seasonal load changes) provision should be made to change orifices to provide a good differential at all rates. Availability of sufficient permanent pressure loss is a requirement for any head-measuring device and must be considered in its application. The coefficient of discharge of an orifice is determined empirically so that the particular orifice meter being installed must reproduce as closely as possible the installation on which the tests were run whether they be specific tests on the unit itself or general tests run by the various standards agencies. These agencies have detailed requirements of installation that have been determined while running a number of calibrations over the years. In each case deviation from the test installations may introduce errors so that a complete understanding of these requirements is necessary before changes from these standards are made.

The readout equipment on the differential across the orifice and the other variables such as density, pressure, temperature, specific gravity, composition, heating value (depending on the method of measurement and quantity units required) must be properly installed, operated, to obtain accurate gas flow measurement. This is also true of the taps to the flowing stream and the sample lines running to each piece of equipment. Proper calculation from the measured variable is required and depending on the flowing characteristics one system of readout may be advantageous to another.

With this introduction, examples will show the kind of problems that can exist if the above precautions are not taken.

There have been many papers and standards written on the basic theory of the orifice covering every aspect. However, when a metering device is being considered for an operating location these additional factors should be considered.

Physical Properties of the Gas

The accurate calculation of flow through an orifice requires a correct differential pressure and a correct density of the flowing gas and proper interpretation of their effects on the performance on the meter.

The flow pattern across the plate is very important for flow measurement accuracy. There are tow factors which control this pattern -- piping configuration, including length, roundness, smoothness, and nearest fitting (such as elbows, valves, tees). The second is the Reynolds Number, which is the guide to the shape, size and stability of the vena contracta. Fortunately, most natural gas is handled at relatively high Reynolds Numbers (above 10,000) so that it seldom is a matter of the internal viscous forces becoming a major component of the predominate inertial forces. Because of this, the high Reynolds Number range is the range that the coefficient becomes stabilized. A general range that is accepted is 10,000 for the 0.04 area ration plates in smaller runs and 200,000 for the .56 area ratio plate in larger runs. Below these values the coefficient changes rapidly and the square edge concentric orifice has a rapidly increasing tolerance on its use. Note: Area ration equals square of beta ratio.

The gas changes its density as it passes through an orifice and this is corrected for by an expansion factor. The higher the differential pressure ranges the greater the density change for a given static pressure. We have developed factors for this correction up to a Mach number of .75; however, best accuracy is obtained if .2 of the velocity of sound in the gas at flowing conditions is used as a limit. This condition is met if the differential in inches of water does not exceed the pressure in pounds per square inch absolute. This will keep the correction factor in the range of 1% and small errors due to application of a

value based on average conditions will be minimized.

One of the major sources of error in the application of an orifice is the problem of taking the square root of the differential measurement and the effects of small errors in the differential at low differentials. As an example, an error of .5 inches (1.27 cm) on a 100 inch (254 cm) manometer represents a .23% error or flow, at 75 inches (190 cm) a .33% of flow error but at 10 inches (25.4 cm) a 2.5% flow error.

Good practice then dictates that the differential be kept as high as possible within the limitations of the strength of the orifice, the range of the flow fluctuation, the range of the differential device and the limitations on the expansion factors.

The differential error combined with the error in the static pressure measurement at low pressures makes the orifice less accurate and have less range since we restrict the differential range by the .2 Mach number requirement.

Errors in the temperature have a small effect on flow accuracies for most natural gas since the absolute ambient temperature range of measurement causes approximately .2% error in flow rate per degree centigrade error.

Specific gravities make about .1% error in flow for each .001 error in reading and this can introduce fairly good size errors on gases with changing compositions unless this measurement is integrated into the volume calculation rather than averaged over a time period.

The compressibility factor of natural gas (which corrects for the ratio of actual volume to ideal volume) is roughly a .5% correction in volume per 100 psi of pressure at usual measuring conditions. Hence, an error of several per cent in factor is only a small error in volume. However, if the gas is reduced near its critical point correction factors as much as 225% are required and small errors in measured variables are reflected as large errors in volume. Likewise, gases with large concentrations of non-hydrocarbon gases in their mixtures are difficult to calculate accurately, since little data is available on these mixtures. Some of theoretical values obtained by the pseudo - critical method based on the mixture composition have shown errors of several percent when compared with empirically determined test data on the same gas. This problem becomes more pronounced as the percentage of methane is reduced. If the value of the product handled is sufficient, then compressibility tests are recommended for confirmation of the theoretical data to the tolerances required.

If a specific weight device (commercially referred to as densitometer) is used, the calculation of flow rate is simplified, and the number of sources of errors reduced. These have only recently begun to be used to any extent, however, assuming an accurate device, the mathematical calculation of volume can be improved and the accuracy tolerance reduced. The usual four variables: Temperature, Pressure, Specific Gravity, and Compressibility are reduced to one, density if mass is being measured, or two density and specific gravity if volume is the unit of measurement desired.

In each of the cases sighted on errors of the measured variables there are two sources which cause errors: one, the measurement of the variable, and secondly, the conversion of the measurement to a mass or volume by use of the flow formula.

Primary Elements

While the orifice plate is the most inexpensive item in the entire measurement station it is the most important part, as its physical condition can be largely responsible for the overall accuracy of the measurement. Therefore, it is of extreme importance to manufacture the orifice plate in accordance with the tolerances recommended by the American Gas Association Gas Measurement Committee Report Number Three and the International Organization for Standardization Recommendation 541. It is of equal importance that the orifice plate be handled with care and a regular inspection routine should be instigated to insure the maximum quality of the condition of the plate at all times.

Inspection should be set up on a regular routine so that the orifice plate can be examined for any changes from its initial condition. If the inspector finds any conditions to exist that were not present originally that can not be corrected by cleaning, the orifice plate should be removed from the line and replaced with a new orifice plate, as this particular item is inexpensive and readily availablefrom most any manufacturer's stock. The importance of a regular routine inspection of this portion of the primary element cannot be stressed enough.

The orifice plate must be properly centered and housed, and this is done with the orifice fitting or flange. There are but a few basic types of orifice fittings, and the primary function of each of these is to hold the orifice plate concentrically in the line so that the differential pressure can be measured properly and also to facilitate removing the orifice plate for periodic changing or inspection.

Orifice Plate Holders

There are other styles of plate holding devices that offer easier access to the orifice plate. One style of plate holding device requires the loosening of several set screws from the top of the fitting and the orifice plate is removed from the line by lifting out the sealing bar, as the orifice plate and carrier are bolted to this sealing bar. This arrangement does not put any strain on the line and does allow considerably easier access to the orifice plate. Once again as in the orifice flange, the orifice plate holder must properly align the orifice plate. This type device does require either a complete shutdown of the line or the fitting needs to be by-passed during plate removal and inspection.

Orifice Fittings

Another type of orifice fitting is the dual chambered orifice fitting that allows complete accessibility to the orifice plate in a minimum of time. This type of orifice fitting has the valve built within the two chambers which allows the orifice plate to be lifted up into the upper chamber and then the slide valve is closed to separate the two chambers. In doing this it completely isolates the orifice plate in the upper chamber and allows one to easily inspect, clean or change the orifice plate under flowing conditions. In many applications it is imperative that the flowing product be continued to its delivery point and this would not allow the complete line shut-in as one would experience with some of the other types of plate holding devices mentioned. This type of orifice fitting will align the orifice plate in the line so that the orifice bore will be concentric to the pipe diameter.

Meter Tubes

The meter tube is defined as the adjacent upstream and downstream piping that is attached to the orifice fitting. Once again, AGA Report #3 and the ISO 541 recommend the guidelines and the tolerances for the manufacture of these meter tubes. This should begin with the selection of the pipe. These requirements include out round tolerances that would be difficult to meet with normal pipe. Normal commercial pipe does not meet these tolerances and this virtually eliminates the thought of field made meter tubes. Meter tube tubing is now available and it is made in sizes two inch through ten inch. The pipe walls of this meter run tubing are controlled to a very close degree, which results in a close tolerance finish of the inside pipe diameter. These tolerances will always better the tolerances as recommended by AGA Report #3 and ISO 541. This type of tubing should definitely be considered, as it is not logical to carefully bore orifice fitting and orifice flanges and then use pipe that would be out of round or exceptionally rough.

As mentioned earlier in this paper, the primary element is the producer of the signal to be received by the secondary element. As the secondary element cannot improve upon the signal that is produced by the primary element, all necessary care in the selection of materials and in the maintenance of the primary element should indeed be exercised. In following the guidelines and the procedures as recommended in the AGA Report #3 and ISO 541 Recommendations a primary element can be provided that will offer the best possible accuracy in your measurement installations.

Recording or Calculating Equipment

The final section of the measuring system that can materially affect your accuracy is the recording and calculating of the data obtained. Since all of the devices used for these jobs are secondary types of measuring equipment they must be calibrated against some standard. Likewise, when the metering devices are exposed to widely varying ambient conditions calibrations should be made covering the ranges encountered and if the effects are large enough, consideration should be given to controlling the environment in which they operate by adding housing, cooling, and heating. A balance between the accuracy required and the cost of obtaining it will determine the extent to which you can justify the testing and housing expenditures.

The indicated data must be either recorded and transferred to a central calculation office for conversion to flow rates or it may be calculated directly by equipment installed on site with mechanical, pneumatic, or electronic computers. Here again each step of recording or transducing and interpreting adds potential errors to the flow measurement so the simpler system with proper maintenance has been found to yield the best results.

Maintenance of the Meter Tube and Orifice

Another source of error is the effect of time on the orifice and the meter tube. No known pipeline for natural gas is completely clean. The best that can be expected is a minimum of rust, oil vapors, condensed liquids, lubricating greases and the like. Any of these deposited on the plate and tube in the right places can cause errors of 5 to 10% easily. What this means to an operator is that the plate and the tube should be periodically inspected, cleaned and rechecked. Where sufficient money is involved, plates have been inspected on a once-a-week basis and the meter tubes on a once-a-year basis. Where there is less value being exchanged these tests may be made monthly on the plates and every other year on the meter tubes. Where sufficient solids (rust or sand) are present there may be a slow erosion of the square edge of the orifice and periodic replacement required. This is more often seen in the production rather than the pipeline measuring stations; likewise, any pitting or build up on the meter run may require a tube replacement. However, this seldom requires any more than cleaning.

Conclusions

Any discussion of accurate flow measurement should contain a portion on what kind of results can be obtained if all precautions are taken. Without full qualification of the source of the data these numbers are meaningless. However, for some general ranges of experienced balances of measured flow inputs versus flow outputs, the large diameter high pressure pipe lines run a few tenths of a percent lost or unaccounted for. In production fields, where some of the described problems are more prevalent, the balance may be several percent at best. However, experience tells us that the only way these balances are obtained is by following all of the best practices of design, application, installation, maintenance and interpretation.

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