The Factors That Impact Venturi Meter Accuracy

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One of the main advantages of using a Venturi meter is the long, useful life expectancy of the meter body where other types of flow meters have a comparatively short life expectancy. It is not uncommon for water and wastewater utilities around the world to still depend on 100-plus year old meters, particularly in line sizes above 48 inches.

While there is clearly an advantage to a 100-plus year life expectancy, the question that is most frequently asked is, “What accuracy should I expect after 30, 40 or more years of service?”

There is no single answer to this question. Rather, there are a number of answers depending on specific conditions (piping), minimum to maximum flow rate range, water chemistry, secondary instrumentation (type of differential pressure transmitter), the design of the Venturi meter and the selection of materials it is made of.

Timeline

From the early 1900s to the mid-1960s, the most common types of Venturi meters used for water and wastewater service were the classic long- and short-form designs. There were a number of manufacturers during that period, but, for the most part, these devices were built in accordance with ASME standards for fluid meters. The physical geometry and the performance that could be expected of the finished meter were in accordance with the ASME code.

Some key elements of the design and performance are:

- Inlet diameter and outlet diameter were full-line size, making the overall meter length quite long to achieve that requirement.
- Throat length was equal to the throat diameter — another element of the large amount of space the meter consumed.
- Annular high- and low-pressure rings were incorporated into the meter under the theory that an average pressure reading would produce a more accurate cross-sectional pressure indication than a single pressure reading.
- Accuracy of +/-1.0 to +/-2.0 percent of actual rate of flow down to approximately 125,000 pipe Reynolds number (Rd).
- Head loss ranging from eight to 14 percent of differential, depending on the beta ratio of the meter.
- Cast iron body, including the internal construction of the high- and low-pressure annular channel.
- Bronze high- and low-pressure annular rings with multiple piezometers (four, six or eight), which introduced the high and low pressure into the annular chamber and a single tap connection out of the annular chambers to the location of the differential pressure transmitter.

- Until the analog differential pressure transmitter was introduced, the secondary instrumentation consisted of a mercury well-type transmitter requiring a minimum differential signal of 2.0 inches to 2.5 inches to properly function.

During the 1950s, short body differential devices were introduced into the market as a solution to the long length and high cost of the classical design. These devices are known as “flow tubes” and they differ both in performance and design for a true Venturi meter. When they were introduced, manufacturers claimed high accuracy, low head loss and low cost were the principle attributes. By the early 1960s with the advent of better independent testing laboratories, all of the claims of superiority were proven incorrect except one, which was the short-length advantage in terms of space and cost.

In the mid-1960s, the universal Venturi tube was developed, proven and introduced to the market as the first, short-form modified, true Venturi meter. It sensed true static pressure at the high- and low-pressure points, but it did so with a short inlet section, a modified transition section, a throat with a length equal to half its diameter and a recovery cone that was truncated. The discharge diameter was less than the internal diameter of the downstream pipe, but the flange was designed to mate to the downstream pipe flange. Probably the most important benefit of the modified short-form design was that it eliminated the use of annular pressure rings at the high- and low-pressure sensing points, which, over years of service, would plug up without a good way to clean them out. Rather, the Universal Venturi Tube had a single tap at the high- and low-pressure points, providing a direct interface between the process and the differential pressure transmitter through an impulse line.

Impact on Accuracy Over Time in Service

Before being able to “estimate” the accuracy of an installed classical Venturi meter, some basic questions must be asked:

- Who made the meter? Depending on the manufacturer, there were some differences in design that need to be factored in the performance statement of the meter.
- What was the beta ratio of the meter at the time of installation? Beta is the ratio of the throat diameter over the pipe diameter.
- Do both the high- and low-pressure sensing points utilize annular chambers? In some cases, only the throat had an annular chamber.
- What is the approach piping? At the time of installation, the understanding of what the accuracy impact was for a given upstream disturber was not nearly as complete as it is today.
- What was the original minimum to maximum flow rate range at the time of installation, and what is the range today? This is particularly important when there is concern or evidence of cavitation.

Based on the above information, a performance calculation can be created representing the performance of the meter if it were brand new. The reason to do this is over the years with numerous technicians involved in meter maintenance and calibrations, the information that was used to calibrate the differential pressure transmitter may or may not be correct and a firm understanding of what the base level of performance would have been must be ascertained. From here, assumptions can be made as to what the current level of performance is subject to years of service.

Impact of Materials on Accuracy

As noted above, the body of the classical Venturi meter was made of either cast or ductile iron. The coatings used were generally in the hydrocarbon family of coal tar and the thicknesses varied depending on the application method. Experience has shown that these coatings are generally worn away by the time the meter has been in service from 15 years or more. In some cases, at the lower line velocity points within the meter body, some coating may remain but it will be found in areas downstream of the throat section — thus outside of the portion of the meter that would have any accuracy impact.

Cast and ductile iron meters may develop a scaled surface as a result of iron and calcium buildup, as well as some other materials that settled out of solution and adhered to the uncoated iron surfaces. Since the distribution of this buildup is not universal, it is difficult to predict where and how thick it may be, but it is likely to be on some portion of the inlet and transition portions of the meter. The presence of this buildup will likely have an impact on the sensed pressure at the high- and low-pressure sensing points, which will affect the accuracy of the indicated reading.

The high and low pressure-sensing locations utilize a bronze liner of some design. The classical design has annular chambers at both the high- and low-pressure zones, and the surface cover containing the piezometers is generally press fit into the chamber so the bronze is in direct contact with the iron material. Depending on water chemistry, galvanic corrosion may be present due to the dissimilarity of the bronze and iron materials — this seems to be particularly prevalent when the pH levels are below approximately 5.7.

In some cases, the interaction results in the bronze material disintegrating and voids throughout the bronze liner are common. Depending on the location and severity of the corrosion/erosion, the pressure sensed at the top location can be affected and the result is that the differential pressure developed by the meter will be part cross-sectional pressure (which is wanted) and part the result of surface abnormalities (which is unwanted), affecting the accuracy accordingly.

Buildup on the surface of the inlet, transition and throat cross sections may change the developed differential, which depends upon the meter reading either high or low, as well as on the location and severity of the buildup. Similarly, if the annular chambers are partially plugged and the approaching flow profile is not uniformly distributed across the high- and low-pressure cross sections, depending on which piezometers are plugged and to what degree, the annular chambers will not “average” the pressure, but rather process a pressure in part based on flow pattern effect and partly on cross-sectional pressure. The result will be impaired accuracy due to an impaired signal.

Depending on manufacturer’s claims, the classical design of a Venturi meter maintained a constant discharge coefficient down to a pipe Reynolds number (Rd) of approximately 200,000. This simply means that as long as the minimum flow rate Rd is maintained above this value, the discharge coefficient of the classical design (which is 0.984, in most cases) remains constant. If, however, the flow rate drops below a pipe Rd level of 200,000, there is a bias error that must be applied to the discharge coefficient, which will progressively lower its value.

For example, if the minimum flow rate Rd value is 80,000, the 0.984 coefficient cannot be used if the stated accuracy of +/-1.0 percent is to be considered valid. Stated another way, if the minimum flow rate pipe Rd is 80,000, the accuracy of the meter at that rate would be +/-2.0 percent and it would improve to +/-1.0 percent as the flow rate increased to the level where the pipe Rd was 200,000.

For a “quick” determination for pipe Rd, use the following formula: GPM x 2790/line size in inches or MGD x 1.935/line size in inches.

This will calculate to within +/-10 percent of the actual pipe Rd for liquid applications.

Secondary Instrumentation Limitations

The typical secondary instrument system consists of a differential pressure transmitter connected to the Venturi meter through impulse lines. The following are important points concerning the secondary instrument system orientation and installation:

- Air in the impulse lines or at the differential pressure transmitter location can cause errors that are difficult to estimate, but do exist. The impulse lines should be oriented so air is kept in the pipeline and not in the impulse lines. A number of solutions exist that respond to this requirement.
- Impulse lines should be as short as possible/reasonable and both the high- and low-pressure legs should be bundled together so there is no temperature inversion between them.
- In general, the most accurate performance range (minimum to maximum flow rate range) for a single digital type differential pressure transmitter is 8:1 on flow.
- For flow rate ranges beyond 8:1, a dual differential pressure transmitter system is recommended where the low-range transmitter is utilized for process flow until its accuracy exceeds allowable limits; then a high-range differential pressure transmitter covers the balance of the full range. With two differential pressure transmitters, 64:1 flow rate range is possible (assuming the minimum flow rate differential is processable); with three differential pressure transmitters, a range in excess of 700:1 is possible.
- For digital differential pressure transmitters, while there are varying opinions concerning what the minimum input differential has to be, research indicates that if there is not a lot of loop noise, the smart digital type differential pressure transmitter can process an input differential of as low as 0.10 inches. However, if one is designing a metering loop, a minimum input signal of 0.25 inches is a safer level to operate at. Note that if you are using diaphragm seals, the minimum signal should be 1.0 inch or greater due to the deflection sensitivity of the seal material.

Undocumented Flow Pattern Effects

One of the things noted over 25 years of inspecting older installations is that, at the time of their installation, a proper accounting of the approach piping effect on the Venturi meter performance was not done. Meters were installed and standard accuracies were assumed even though the piping did not support those accuracy statements. A very good database of calibrated meters has been maintained, allowing the approach piping for these older installations to be reviewed and assigned an educated value that will account for a nonstandard installation condition.

Modified Short-Form Venturi Meter Performance

The first modified short-form Venturi meter was the Universal Venturi Tube. Since the Universal Venturi Tube did not have annular chambers, the points noted above concerning the problems with annular chambers do not apply. Due to the Universal Venturi Tube's single-tap design, the interface of the piezometer face to the flow must be sharp and free from burrs or debris; otherwise, the differential pressure developed may be in error, and thus, the indicated flow rate will be inaccurate. Unfortunately, many of these devices have bronze material at both the high-pressure tap location, as well as the entire throat section (in most cases). Galvanic corrosion and/or erosion may occur at these locations and, if not corrected, may result in impaired pressure signals and therefore impaired accuracy. Undocumented flow pattern effects may also be a factor, but there is adequate test data available today that can be used to correct any misinformation from the original installation.

The pipe Rd limitations have the same effect on the Universal Venturi Tube except that the minimum pipe Rd for the Universal Venturi Tube is 80,000, which means the flow rate can be quite a bit lower than the classical, yet still maintain the standard +/-0.5 percent accuracy that is the standard accuracy for the Universal Venturi Tube. However, if the minimum flow rate was at a pipe Rd of 40,000, the accuracy of the Universal Venturi Tube at 40,000 pipe Rd would be +/-1.5 percent improving to +/-0.5 percent as the Rd value reached 80,000.

What is the Normal Change in Accuracy?

Experience has shown the discharge coefficient of the Venturi meter generally drops with a change in the internal surface condition of the meter and/or any change to the cross-sectional tolerance of the meter from its original "as built" geometry. In addition, a change from a sharp edge piezometer to a rounded edge will also result in a drop in the value of the coefficient. Because of its position in the flow formula for Venturi meters, if the coefficient drops due to change in tolerance, tap effect or surface irregularities, the indicated flow rate will be higher than it actually is — this is called "over-registration." If annular chambers are in use, the pressure produced by the high- and low-pressure rings may or may not be impaired due to internal plugging; depending on what the result is (lower high pressure, lower low pressure or both), the differential produced by the comparison of the high- and low-pressure signals internally to the differential pressure transmitter will be in error and the effect can be either under-registration or over-registration.

About the Author: Bruce Briggs is the president and principal of Primary Flow Signal Inc., a global manufacturing, engineering and technology resource focusing on highly accurate, repeatable and reliable differential flow meters. In his more than 30 years in the industry, Mr. Briggs has built, arguably, the largest team of expert flow metering, hydraulic and applications engineers, along with technicians and specialists of diverse critical expertise. The companies are comprised of a number of enterprise-owned, fully integrated manufacturing facilities offering a world-class platform for solutions and support for the oil and gas, power, municipal water, wastewater and automotive markets.