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Flow Measurement
PART I

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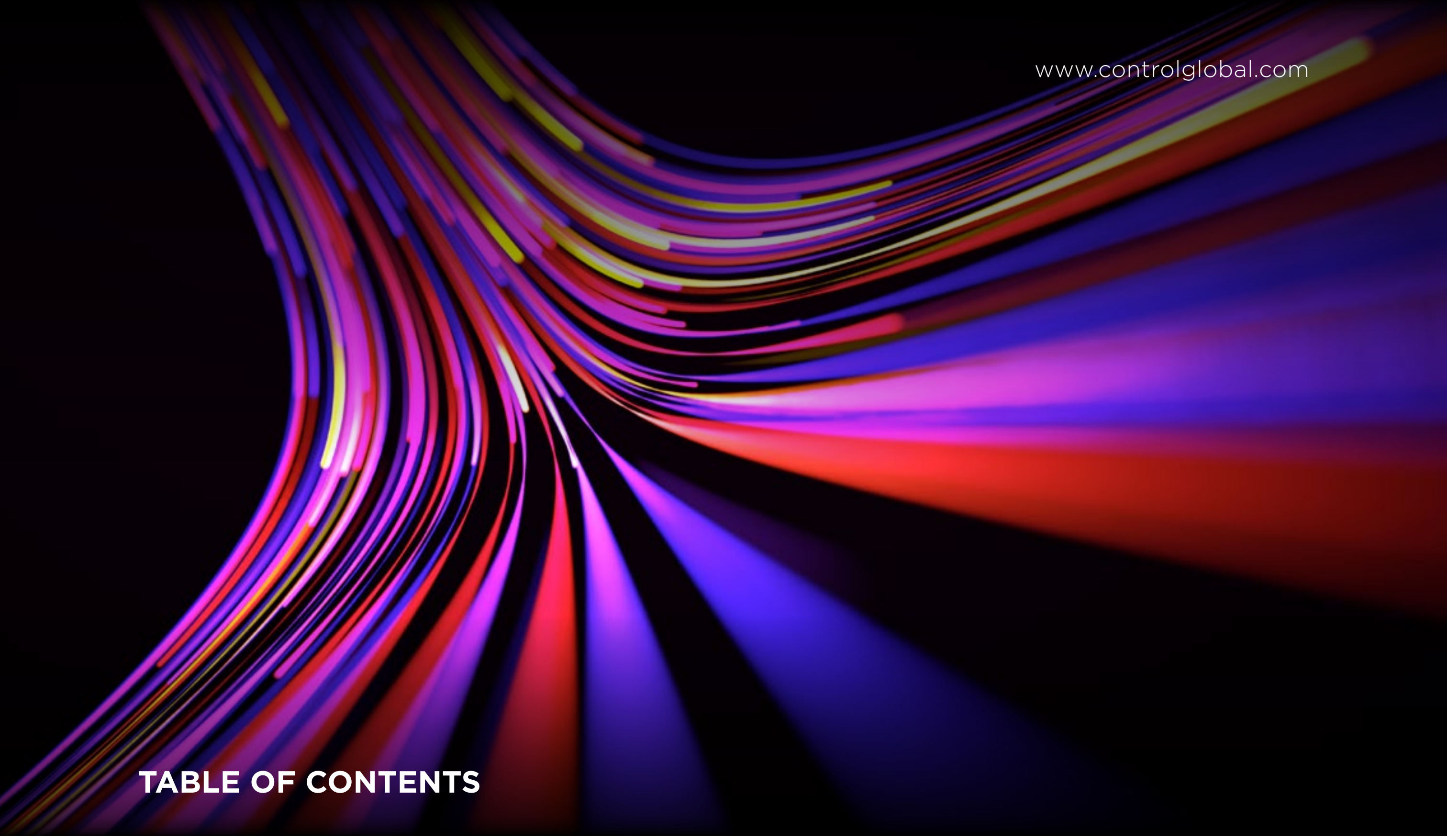

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Going with the Flow

McMillan and Weiner Continue Their Interview With Ram Ramachandran. They Discuss What Flow Sensor Works Best in Various Applications

By Greg McMillan, Stan Weiner

Greg: Flow measurements offer opportunities for feed-forward, identification of valve backlash and stick-slip, on-line metrics and diagnostics, rejection of pressure disturbance, linearization, modeling and tracking down disturbances as outlined in "Secondary Flow Loops Offer a Primary Advantage." Flow is by far the most manipulated process input for controlling process variables, optimizing process efficiency and setting throughput.

Stan: To get insights on what flow sensor works best in various applications we continue our interview with Ram Ramachandran the principal engineer at Systems Research Int'l. Inc.

Differential head measurements using differential pressure [DP] transmitters tend to have the lowest accuracy and rangeability due to the square root relationship; the highest noise due to sensitivity to velocity profile, and the highest maintenance cost due to impulse lines. If the velocity profile and density are constant (no opening and closing of valves or changes in composition), the repeatability is good. While the hardware cost may be low, the lifecycle cost is high from installation and winterization of impulse lines and maintenance to prevent line plugging, and to keep a constant phase and fluid composition in the lines. Furthermore, the increased process variability is a hidden cost. Most people don't realize density affects even the volumetric flow through the Bernoulli equation. Then there is the poor turndown leading to loss of flexible manufacturing to minimize inventories, and match fluctuating energy costs and market demands. I stopped using them [differential head measurements] in the 1980s. Why are differential head meters used?

Ram: Many of these installations are legacy systems, still with us in large chemical plants and refineries in the United States. For high temperatures and large pipe lines in mature continuous processes (e.g., refining, chemical intermediates and pigments and dye manufacturing) with infrequent and relatively limited production rate changes, the differential head meters have been traditionally used. Elbow flowmeters with purged taps have been used when the process fluid is too hazardous, too corrosive or erosive, or pressure drop can't be tolerated, and the accuracy required is only 5%. For much better accuracy and rangeability and less noise and sensitivity to piping configuration, Venturi tubes can be used with a minimal permanent pressure drop. Flow nozzles are a lower cost solution to Venturi tubes, particularly for large lines. The lowest cost flow sensor is an averaging pitot tube. Some manufacturers offer a retractable design.

Greg: If a wireless DP transmitter is used with an averaging pitot tube, the flow measurement is portable, enabling the exploring and prototyping of process control improvements, diagnostics and metrics. The rangeability can be extended to 10:1 if a second low-range transmitter is added, and measurement noise is incredibly low from strict attention to piping straight run requirements. These meters can justify a more permanent and accurate installation.

Stan: What can you do to achieve greater accuracy, rangeability and maintainability in large lines?

Ram: Turbine meters can provide incredible accuracy (e.g. 0.05%) and rangeability (e.g. 50:1). Bearing life is a problem for non-self-lubricating liquids, such as anhydrous ammonia. EMI has a sleeve bearing design that enables use in steam and gases. Insertion turbine meters and vortex meters are used for large pipelines. Vortex meters are the lower maintenance alternative, but at the expense of 5x deterioration in accuracy (e.g. 0.25%) and rangeability (e.g. 10:1) and greater straight run requirements. Repeatability stops at low flow. Improvements in bluff body and sensor design and temperature compensation have greatly increased vortex meter performance since their introduction. However, the meter coefficient is a still a function of kinematic viscosity.

Greg: Where is volumetric displacement used for flow measurement?

Ram: The oil and gas industry uses the technology of pulsating disc flowmeters for their huge pipe lines. The measurement of reciprocating pump stroke is used for toxic and lethal fluid flow measurement. Rotating disc flowmeters are used for natural gas and water flow measurement. Since these tend to read low as they age, there is an initiative to replace these with non-mechanical meters for large users.

Stan: Magmeters offer quite a performance advantage at low flows since their accuracy is a percentage of rate rather than a percentage of full scale like most other flowmeters. Magmeters also have a very short straight run requirement and can measure reverse flow. What do you see as some of the application considerations?

Ram: The main consideration is materials of construction and fluid conductivity. While newer meters have special low-conductivity capability, still some amount of water must be present. Oil companies will not entertain the possible use of magmeters due to previous failures.

There have been some spectacular failures of soft liners (e.g. Teflon) collapsing from a vacuum condition from condensation after steam cleaning or from tearing away from the wall due to poor liner installation. Thompson Equipment perfected the art of lining magmeters and is the choice for many manufacturers. For hot, dilute HCL glas-lined magmeters are used. Electrodes are available in a wide variety of corrosion-resistant materials, including gold and platinum.

AC magmeters had some initial problems when first introduced, but now predominate because of lower drift and less of an effect of solids. For huge changes in conductivity, a DC magmeter may be used.

Greg: My personal favorite is the Coriolis meter because it has no drift or installation effects (other than vibration), incredible accuracy (e.g. 0.02%) and rangeability (e.g. 100:1) independent of composition and velocity profile, low noise, no calibration or maintenance, plus an extremely accurate density measurement that can offer an inferential measurement of concentration or percent gas or solids. Coriolis is the only true mass flow measurement. For liquid reactant feed measurement and ratio control, Coriolis meters are essential. Why isn't a Coriolis meter used?

Ram: The meter is expensive, particularly in large pipe sizes. The largest size is presently about 16 inches, but at quite a price. For slurries there must be no accumulation of solids. Straight-tube Coriolis meters are used to prevent erosion at a price of a 5x reduction in accuracy (e.g. 0.1%).

Stan: What about the measurement of flow in ducts?

Ram: Thermal gas flowmeters are predominantly used to measure refinery waste gas flow consisting of mostly ethane and methane. It is also common in material and energy balance controls in large furnaces by measuring air duct flow. Many of the emission reports to regulatory authorities are indirectly computed for total emission, based on plant throughput wherein air/gas flow measurements become critical besides direct composition analysis of stacks.

Greg: Thermal gas flowmeters depend on the thermal conductivity being constant. They are extensively used for measuring air, oxygen and carbon dioxide flow to bioreactors. For bench top and pilot-plant scale bioreactors, these flowmeters are integrated with a internal flow element and PID controller to become a mass flow controller (MFC) that gets its flow setpoint from the bioreactor control system. The tuning of these MFCs can be made fast enough to insure speed as a secondary loop is 5x faster than the primary dissolved oxygen or pH loop. What are some low-cost alternatives?

Ram: Fluidic Components Inc.'s flowmeters that measure the heat loss have a better accuracy and rangeability than thermal mass flowmeters, particularly if the stream has moisture. Two heaters are used to prevent condensation.

Stan: What is done for the flow measurement of solids?

Ram: The most accurate measurement of conveyor flow is by gravimetric feeders that are separate, specially designed sections of conveyors on load cells to measure speed and weight. Linear voltage differential transmitters (LVDT) offer an economical and fairly repeatable solution. Ultrasonic sensors are also used. Radiation sensors are more accurate than LVDT or ultrasonic, but require wipe testing every three years and permitting for maintenance by a radiation officer.

Flow out of a hopper is measured by a rotary valve in the hopper discharge. Measuring hoppers may be used at several points in a fluidized solids process, such as spar in hydrofluoric acid (HF) manufacturing. The same technique is used for cement kilns and bagging operations.

Greg: Flow can be computed from the rate of change in weight by load cells or level by radar as described last month. Centrifugal pump speed with temperature measurements for viscosity and pressure measurements for rise compensation have been used for computing polymer flow. A valve-flow model for equal percentage trim and a large valve to system drop ratio can extend the turndown of differential head and vortex meters, but should not be viewed as a replacement for flow measurements due to effects of shaft windup, backlash, stiction, composition and geometry.

Stan: How do you measure extremely low flow rates?

Ram: Coriolis meters as small as 1/8 in. are available. For even lower flows, capillary flowmeters with a DP measurement are used, keeping the system in temperature-controlled baths. Very small flow with high accuracy and resolution is achieved by using special turbine meters in pilot plants to measure 1 cc to 5 cc an hour or smaller.

Greg: Bench top bioreactors use peristaltic pumps for feeding seed cultures, amino acids, nutrients, reagents and glucose. The speed provides a volumetric flow measurement. If the choices seem too confusing, here is list of excuses to write the whole thing off.

A power-law approach to orifice calibration

Fine-tune the ideal orifice flow rate equation with an additional term and baseline measurements.

by R. Russell Rhinehart

The ISO method for orifice design and calibration [1] is grounded in the ideal square-root relation between pressure drop and flow rate; specifies the in-pipe structure for an orifice; and corrects the nonideal relation with empirical relations. Unfortunately, for the empirical correction, the complexity of the 28-coefficient Reader-Harris/Gallagher equation and the eight-coefficient expansibility relation add potential for implementation error. Further, in many applications, the structure of the device or piping can't meet ideal specifications.

Of course, for official and legal situations, you should use the methods for orifice calibration as indicated by standards. However, engineering practice desires to minimize complexity. Accordingly, for internal use, you might find that relaxing the square-root basis provides a power-law relation that's much simpler and just as accurate [2]. Further, it doesn't require the piping structure that seeks to create near ideal up- and down-stream conditions, easing installation design constraints. However, it does require application-specific calibration.

ORIFICE ESSENTIALS

An orifice is a one-point restriction in a flow line. It's commonly a disk with a hole in the center. The disk blocks the flow, all of which must squeeze through the hole. The high fluid velocity in the low diameter area reduces the pressure relative to the larger diameter up-stream entrance section. The higher the flow rate, the greater is the pressure difference.

Since pressure difference is easy to measure, and since orifice assemblies are inexpensive to make and easy to adjust, orifice flow measurement is very common. In the following analysis, the pipe diameter is indicated by D and the orifice diameter by d_0.

Analysis of the orifice flow rate-to-pressure drop relation typically starts with the Bernoulli equation, which is idealized for potential flow conditions (inviscid, constant density, isothermal, no lost work) along a streamline. Commonly derived as an undergraduate exercise, one form of the resulting orifice equation is:

$$\dot{Q} = \frac{\pi}{4} d_0^2 \sqrt{\frac{2g_c \Delta P}{\rho (1 - \beta^4)}} = a \sqrt{\frac{\Delta P}{\rho}} \quad (1)$$

Where $\beta = d_0 / D$, and a is a combination of the several constants for a particular application.

The "hole" however, could be any number of shapes, or it could have an eccentric location, both features to permit entrapped gases or solids to pass through. Further, actual devices have many other features, such as piping flanges and pressure taps at various locations. Further, turbulent flow does not have the ideal flat profile that leads to the classic square root relation. Note also that the points of pressure measurement are not where the flow has an effective diameter of either D and d_0. At the upstream pressure tap, the flow begins converging into the orifice, and has a smaller effective flow area than D would indicate. And the flow continues to converge as it exits the orifice, so the effective flow diameter at the downstream pressure tap is less than d_0.

These realities are dismissed in the conventional orifice equations, and a generally accepted correction to the ideal relation is:

$$\dot{Q} = C_D \varepsilon \frac{\pi}{4} d_0^2 \sqrt{\frac{2g_c \Delta P}{\rho_1 (1 - \beta^4)}} \quad (2)$$

Where ρ_1 is the upstream density, and C_D is a factor to correct for both fluid flow and assembly geometric nonidealities. C_D has a characteristic value of 0.62, for high Reynolds number situations. And, ε is a factor to correct for fluid compressibility effects. Both correction factors are empirical. The standard C_D relation uses flow rate (Reynolds number), so the calculated flow rate is required to calculate the C_D value needed to calculate the flow rate. Accordingly, obtaining $\dot{Q}$ from Equation (2) requires an iterative calculation procedure. That is an undesired complexity.

Further, the physical design of many orifice applications is not compliant to ISO standards. These include process installations without flow conditioners, without adequate upstream run, with pipes of less than about 2-in. diameter or integral orifice assemblies, such as flow devices on equipment and those used in pilot-scale applications. Without compliant geometries and installation, the standard equations don't provide accurate results. Providing an accurate calibration equation for non-compliant devices will improve their utility.

POWER-LAW PROPOSAL

Considering these issues, we find that a power-law relation provides an excellent and much simpler fit of the actual flow rate with respect to differential pressure. Accepting that the transmitted signal from an orifice differential pressure transducer, such as 4-20 mA, is linearly proportional to ΔP and that geometric factors are fixed for a specific installation, there's a convenience associated with combining all coefficients into one constant and representing ΔP with the scaled signal, such as i – i0 . This reduces the power-law orifice calibration equation to:

$$\dot{Q} = a\left(\frac{i - i_o}{\rho_1}\right)^b \qquad (3)$$

Here, i is the transmitted mA signal, and i_0 is the mA value at zero flow rate.

Note that Equation (3) is equivalent to the ideal Equation (1), but with an extra coefficient to account for the nonideality of fluid and device. The values for the a and b coefficients will be determined empirically to best fit experimental data.

Note that the value for the coefficient *b* should be close to the ideal 0.5, and that coefficient a should have a value close to the expected:

$$0.62 = \frac{\pi}{4}\ d_0^{\,2}\sqrt{\frac{2g_c\ \Delta P_{max}/16}{(1 - \beta^4)}}$$

where ΔP_{max} is the ΔP range that corresponds to the 4-20 mA signal, and 16 is the range of the 4-20 mA signal.

For devices where off-line or even in-line calibration is possible to determine values of coefficients *a* and *b*, Equation (3) specifies a direct, not iterative, calculation. It's simple to understand. With little complexity and few coefficient values, it reduces the opportunity for implementation errors in equation transcription, unit consistency and coefficient value transcription.

PROVEN BY EXPERIMENT

The ISA Transactions article [2] provides experimental evidence for the utility and precision of Equation (3), using both pilot-scale experiments and the database that was used to generate the C_D and ε relations [3]. Coefficient values were obtained by a best fit of model to the data. Although a linearizing log-transform can convert this nonlinear regression exercise into a simpler linear regression, linearization distorts the relative importance of high-range and low-range data [4]. Accordingly, the power-law study used nonlinear regression to determine coefficients a and b for Equation (3) to best fit the data.

On a range of liquid and gas applications, the values of power *b* vary from 0.4858 to 0.5255 for our experimental air and water tests on the pilot-scale devices, and from 0.4887 to 0.4943 on the NIST database (flanged orifice types, compliant geometries and fluids that included water, gas oil, nitrogen gas and natural gas). Further, if the square-root functionality, b = 0.5000 is presumed, then the C_D correction should express a functionality that has the complementary power (for instance 0.5000 - 0.4887 = 0.0113), which we found it does.

The accuracy and precision of Equations (2) and (3) were also compared. Accuracy is a measure of the model closeness of fit to the data, which can be indicated by any of several measures. In all of 10 cases investigated, the flow rate accuracy of Equation (3) was better than either Equation (1) or Equation (2).

Precision of the equations was assessed by a propagation of variance, which relates uncertainty on an input to the uncertainty of the calculated flow rate. The relative uncertainty values for the power-law model are lower than those for the ISO standard model. Further, they indicate that the power-law model proposed here will be useful over a wider range.

PARAMETERS AND LIMITATIONS

Even with the improved accuracy of the power-law model, orifice meters are not as accurate as some other flowmeter types. Best expectations cite a 2% error. If measurement accuracy and range are critical, another flowmeter type will likely outperform the orifice.

The power-law calibration procedure (to experimentally get values for two coefficients) requires calibration data that's specific for the device, whereas using an ISO-compliant device will rely on standard equations. A case-by-case analysis is required to determine if the accuracy benefit and device geometry convenience are worth the calibration effort.

The calibration of the two-parameter Equation (3) does require at least two experimental data points. However, experimental noise will bias the coefficients. The accuracy and precision of this study was achieved with 15 or more experimental datasets throughout the operating range. However, such extensive calibration testing may not be desirable. If accuracy is important, use another flow metering device. If operational convenience is important, then the two-point calibration may be adequate.

The computational device you're going to use might not have the ability to compute a power-law.

Noise on the i value in Equation (3) and/or calibration drift on the i0 value could result in the quantity $(I - i_o)$ having a negative value at very low or zero flow rates. To prevent an execution error, add a conditional to reset $(I - i_o)$ to zero if it is negative.

Replacing the standard equations with a

power law require a case-by-case analysis of the infrastructure surrounding the orifice technology and practice (maintenance, training, manuals, computer software, data acquisition hardware, etc).

For many industrial applications, in-line or off-line calibration testing is not practicable or compliance to standards is important. For these, compliance to the appropriate standard remains as best practice.

In conclusion, where flow conditions and assemblies don't approach ISO-compliant attributes, where off-line or in-line calibration is applicable and where the measurements are for internal use, my investigations find the power-law approach matches the nonideal fluid and device attributes, and offers advantages of calculational simplicity, precision, accuracy and rangeability over the use of the ideal square-root model.

References

1. ISO 5167, "Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full," International Standard 5167, Parts 1 and 2, 2nd Edition, the International Organization for Standardization, Geneva, Switzerland, 2003.

2. Rhinehart, R. R., S. Gebreyohannes, U. Manimegalai Sridhar, A. Patrachari, and MD Rahaman "A Power-Law Approach to Orifice Flow Rate Calibration," ISA Transactions, Vol. 50, No. 2, pp. 329-341, 2011.

3. U.S. Dept. of Commerce, NIST Standard Reverence Database 45, "GRI/NIST Orifice Meter Discharge Coefficient Database," Version 1.0, NIST (National Institute of Standards and Technology), Gaithersburg, Maryland, USA, 1994.

4. Rhinehart, R. R., Nonlinear Regression Modeling for Engineering Applications: Modeling, Model Validation, and Enabling Design of Experiments, Wiley, New York, NY, 2016.

D/P transmitter missteps; Venturi or flow nozzle?

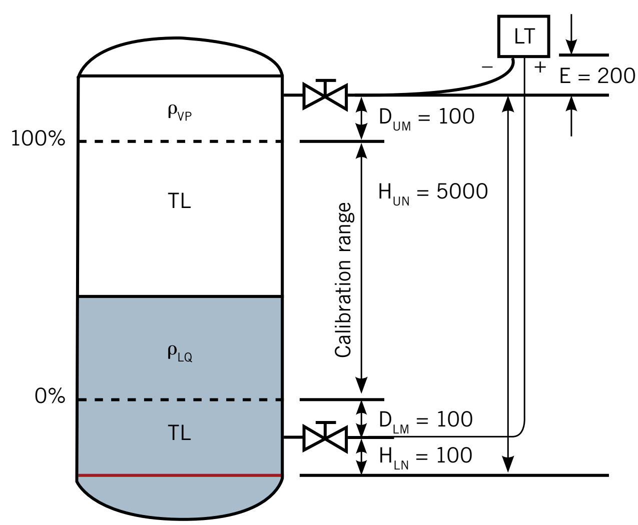
Our experts address differential pressure transmitters used for level applications, as well as Venturi vs. flow nozzle recommendations

by Béla Lipták

Q: I have the following questions concerning a conventional level detection differential pressure (D/P) transmitter which is installed above the upper pressure tap. Please see sketch of the application (Figure 1).

We have used a conventional D/P transmitter—not one with a diaphragm seal. The reason for keeping the transmitter above the top nozzle is to drain any condensate back to the vessel/tank. My questions follow:

1. Can we the put level transmitter above the upper nozzle?
2. Please help me to derive the equation of LRV and URV to be set when conventional D/P transmitter is kept above the above nozzle. I've seen a majority of level transmitters installed at lower nozzle or below the lower nozzle for head measurement. So, for this arrangement, what is the impact on calibration range when the transmitter is installed above the top nozzle?



PROPOSED D/P LEVEL CONFIGURATION
Figure 1: Condensate drain-back into tank by locating the level transmitter above the tank.

3. Is this arrangement, which does not include diaphragm seal, seal pot or purging, allowed per international standards such as API best practices?
4. When there is 10% of liquid filled up, how will liquid create head on the transmitter (high pressure side)?
5. How do we ensure that liquid head will be acting on the high-pressure leg all the time (without any vapor pocket) when the actual level inside the tank is 10-15%?
6. How do we ensure that density of vapor will be the same on impulse tubing (particularly on low pressure side), so that the chance of measurement error will be minimized?

Jatin Katrodiya, jatinkatrodiya@yahoo.com

A1: The operating pressure creates serious problems. It's my experience that everything leaks; the only question is how much. It would be very difficult to keep the high-pressure sensing line filled only with gas. Your scheme as shown will most likely fail to work even at startup. If the pressure was low enough, I would suggest a purge on both connections. That will require a compressed gas source. I would prefer to use remote chemical seals in this service.

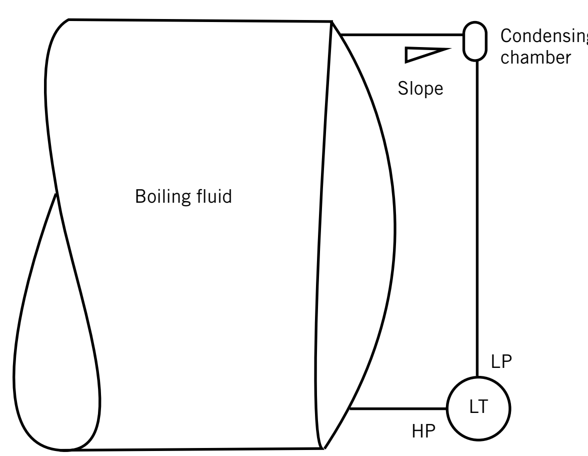
Cullen langford, cullenl@aol.com

A2: You certainly have a non-conforming installation. Most installations locate the lower leg below the tank, and use diaphragm seals on both legs. Unless the "high pressure" (HP) leg is a filled tube with diaphragm seals on both sides, I don't see how the high pressure from liquid level and vapor pressure can get to the level transmitter.

If your high pressure leg is diaphragm sealed and filled with an inert transfer fluid, it will appear to the level transmitter as the head (pressure) of the transfer fluid plus the head of the liquid in the tank plus the pressure head of the vapor space. The low pressure (LP) side will see only the pressure of the vapor space. When you subtract the HP pressure from the LP (the reading of the transmitter) you will have the liquid level in the tank plus the head of the HP leg. Since the HP leg is a constant, it can be removed by setting the zero point of the level transmitter. Now you should be able to do your math.

Dick Caro, ISA Life Fellow, RCaro@CMC.us

A3: If for some reason you don't want to use chemical seals or purge both connec-



ALTERATE D/P LEVEL SOLUTION
Figure 2: Seal-less D/P level measurement solution as often applied to boiling fluids.

tions, but you do want the condensate to drain back into the tank, you can follow Figure 2 and reverse the output of the transmitter. Naturally, you have to correct for the density difference between that of the ambient temperature condensate and the density of liquid in the tank.

Béla Lipták, liptakbela@aol.com

VENTURI VS. FLOW NOZZLE?

Q. Working as an instrument engineer in the oil and gas industry, I've specified a flow measuring device as an orifice meter, but while sizing with maximum beta ratio, the resulting permanent pressure loss is higher than what the process department allowed as the maximum allowable pressure drop. Hence, it's understood that orifice will not be suitable for this measurement purpose, and I'm considering some alternatives for the process conditions and line size. As an alternative to the orifice, in order to meet the process maximum allowable pressure drop, we decided to go with either a Venturi or flow nozzle primary element.

Now, I don't know which to chose. Can you suggest the factors or considerations in which a Venturi meter is preferred to a flow nozzle or vice versa? What are the basic considerations that have to be taken into account for selecting one or the other, and which is preferred and why so?

M. Ulangatham, Instrument Engineer,

ulaganathan.inst@gmail.com

A1: In general, you want to use Venturi measurement when the range is small, say less than 100 in. H_2O, and nozzles when you have a larger flow range. Most Venturi meters you'll calibrate for 0-10 or 0-25 in. H2O. Flow nozzles work basically as a restriction orifice (RO), so use the same basic principle.

Alex (Alejandro) Varga, vargaalex@yahoo.com

A2: The flow nozzle is a prefered choice for steam flow measurement.

Debasis Guha , debasis_guha71@yahoo.com

A3: This is a common question, so I'll give you a more detailed answer.

The meter coefficient of a typical orifice is about 0.62, while that of a Venturi or flow nozzle is almost one (0.99). Therefore, at the same ΔP and the same ß ratio (diameter of restriction divided by the pipe inside diameter), these meters pass about 40% more flow than an orifice.

The big difference between them is in their cost and pressure recovery. The cost of the Venturi is higher, say about $6,000 for an 8 in. cast iron one, while an 8 in. aluminum nozzle is about $1,200. At a beta ratio of 0.5, a standard Venturi recovers about 85% of its differential, while at the same beta ratio, an ASME flow nozzle only recovers about 35% of its differential. Consequently, because of the high pressure recovery of the Venturi, its operating costs are much lower. As a result, the savings in pumping costs can quickly compensate for the initial price difference.

Among the two, the Venturi is more accurate, about 1% full scale (FS), while the flow nozzle is about 2% FS. The rangeability of both is about 4:1. The straight run requirement of nozzles are longer (10-30 diameters) than Venturis (5-20 diameters), but not that much. Flow nozzles are available in a largerr range of beta-ratio (0.3-0.7). And as far as installation goes, flow nozzles should be installed downflow when used on wet gases, wet steam or liquids with suspended solids, but neither meter should be used on slurries or dirty fluids.

With Venturi meters, cavitation can be a problem when the downstream pressure of a liquid drops below the fluid's vapor pressure. Bubbles form, and cavitation can destroy the throat of the meter. The bottom line is: because your process people are concerned about pressure loss, a Venturi should be used.

Béla Lipták, liptakbela @aol.com


SICK
SICK
SICK

How best to apply multiple-hole orifice plates?

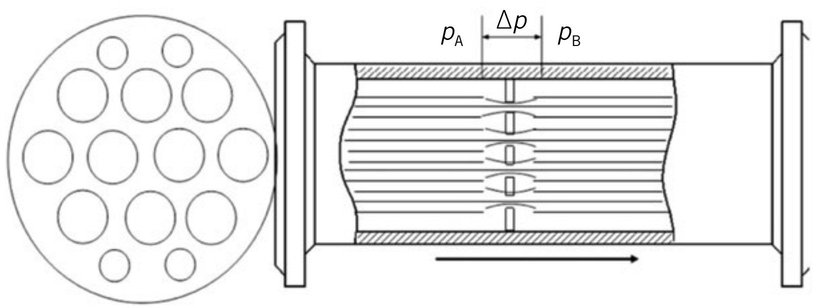
They can help measure d/p with shorter straight pipe runs, as well as tame cavitation and excessive noise

by Béla Lipták

Q: With a conditioning orifice plate, how many holes are allowed? Is the maximum limit for the pressure drop through an orifice plate the same as the maximum differential pressure of the transmitter? Are there any other limitations?

M. Ulaganathan,

ulaganathan.inst@gmail.com



RESTRICTION ORIFICE SECTION

Figure 1: One advantage of a multi-hole orifice section is it requires much less straight pipe run (about 2D on each side) than regular orifices, and can be mounted in horizontal and vertical pipe runs.

A1: Some multiple-hole orifice plates are used as "restriction orifices" (RO), serving to reduce or eliminate noise and/or cavitation. ROs are also used in front of safety devices (rupture discs, relief valves), which if they suddenly open, can overpressure downstream equipment. Therefore, it's desirable to limit the flow and the rate of pressure reduction through them, so the pressure on the upstream, protected equipment doesn't drop too fast. In a multi-hole plate, the flow is channeled into several streams through multiple holes (Figure 1). This reduces the noise that could be above acceptable limits if a single-hole device is used.

Such a unit can also be used either for pressure differential or flow measurement, depending on which variable is known. I usually estimate the flow through each opening as the total flow divided by the number of holes, ρ, as the density of the fluid, while the pressure drop (ΔP) is measured. Therefore, if ΔP is known, the flow (Q) is:

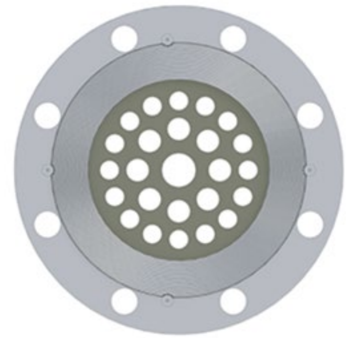
$$Q = \frac{kA\sqrt{\Delta P}}{\rho}$$

where A is the cross-sectional area of the pipe and k is a constant that includes the effects of the ratio between the total area of the holes and that of the pipe, the engineering units used and such meter characteristics as the thickness of the plate and the quality of the holes (Figure 2). For an area ratio of 0.5, the pressure drop across the multi-hole orifice is about 70–75% of the conventional single-hole orifice.

The orifice thickness is usually twice the hole's diameter, so a large diameter hole could involve an excessively thick plate. Also, while in the case of a single-hole plate there's no "neighbor turbulence" effect that chokes pressure recovery, for a multiple-hole plate the expansions of one jet will impact expansions of the others, limiting pressure recovery. That can be one reason why, for high-pressure drop applications, multiple-hole orifices are chosen.

Some studies suggest the optimum number of holes is seven, but that view is not uniformly shared, and there are other considerations concerning strength and dimension. Accuracy greatly depends on the quality of the holes, and is usually estimated at only 1-2% over a range of 3:1, but the repeatability is usually better than the accuracy. The range of the differential pressure (d/p) transmitter is usually selected to be 1.2 times the maximum Δ P expected.

Béla Lipták, liptakbela@aol.com



REDUCE NOISE AND CAVITATION

Figure 2: The flow at the inlet of a restriction orifice is channeled into several streams. Among other characteristics, this reduces the noise and/or cavitation that might occur with a single orifice.

A2: There are no codes or standards governing conditioning orifice plates—the formulas are proprietary to the suppliers of these plates. Also, there are practical limitations based on particulates and clogging of the holes. This is best discussed with the vendor.

The limit of the d/p across the orifice plate has nothing to do with the transmitter. The limitations are purely from a process sizing perspective (e.g. Reynolds number). Read ISO 5167 or other good texts such as Lipták or Miller. The transmitter range is then specified to match the orifice sizing requirements

Simon Lucchini, CFSE, MIEAust CPEng (Australia), Simon.Lucchini@Fluor.com

A3: Generally, orifice plates have either one or two holes: one for the flow and one for the drain or vent. In special applications, where you may have slurries or special fluids, then you may have more, but be aware that calculating the pressure drop is a complicated process and making the orifice plate even more difficult.

The majority of manufacturers have a maximum pressure drop that the sensing element can respond to accurately before you need to change to a sensor with different characteristics. The maximum pressure loss will depend on several factors such as line pressure and maximum line pressure drop. For example, at a line pressure of 1 bar, the pressure drop should be less than 0.1 bar, otherwise the line hydraulics will be affected.

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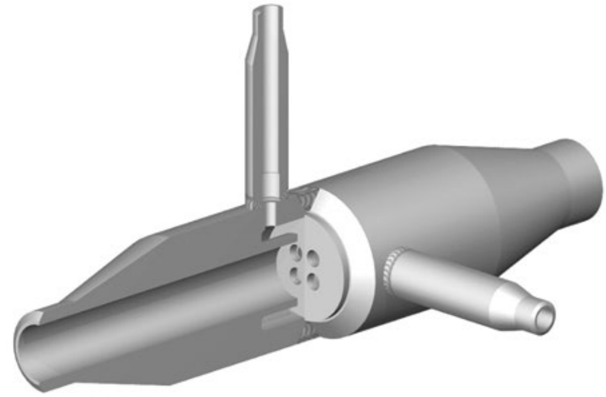
A4: There is no simple answer here, but a range of standards and handbooks show typical designs and applications. In general, the intent of a multiple-hole orifice plate is to serve as a flow conditioner, that is, to make the flow velocity pattern similar to one in a very long straight-pipe run. Again, see the handbooks and the standards.



CONDITIONING ORIFICE SPOOL-PIECE
Figure 3: Welded-in, spool-piece designs featuring conditioning orifices and pressure taps can be used to measure flows in both vertical and horizontal pipe runs.

Usually we don't want to waste energy across a flowmeter, so d/p is normally in the range of 20 to 200-inH2O (500 - 5000 mmH2O). This is high enough to realize d/p transmitter accuracy and to be certain of the Reynolds number inside the bore.

In the case of liquids near boiling temperature, excessive d/p may lead to vaporizing of the media. For gases, excessive d/p leads to inaccuracy due to the expansion of the gas not being fully compensated for in the equations. Some standards and handbooks will show at least a plot of the pressure recovery after an orifice plate; this depends mostly on the beta ratio, which is ratio of bore diameter to inside pipe diameter.

An orifice plate will deform or fail if the pressure drop is very high; this is a strength of materials issue. This is very rarely an issue except for flow restriction orifice plates. Flowmeter suppliers can provide further details.

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