# DP Flow Measurement Best Practices For Better Plant Safety, Availability & Efficiency

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Differential Pressure, Flow, Best Practices, Availability, Efficiency, Installed Costs, Repeatability, Compensated Flow, Process Variability, Mass Flow, Permanent Pressure Loss, Improved Reliability

## ABSTRACT

Accurate, repeatable and reliable measurements are vital to safe and efficient plant operations. The reliability, process variability and total cost of ownership of a differential pressure (DP) flow measurement point can be optimized by eliminating impulse lines, compensating for changing primary element discharge coefficients, and utilizing the most accurate DP measurement instrumentation available. Plugging, leak points, and head uncertainty are direct consequences of complex impulse tubing arrangements used in traditional DP flow measurement installations. Cost and accuracy issues associated with installation at grade were once considered a necessity, but a new generation of DP measurement instrumentation has robust characteristics that allow for direct mounting to the primary element and elimination of traditional installations. Multivariable transmitters and Distributed Control Systems (DCSs) can be programmed to alleviate introduction of bias errors attributed to discharge coefficient nonlinearity. Accuracy dividends will be particularly noticeable at low flow rates, which correspond to lower Reynolds numbers. Careful selection of instrumentation focusing on of the characteristics that most effect flow measurement can enhance system reliability and reduce your process variability.

## INTRODUCTION

For any process measurement, the first step is determining required measurement performance for each application. “Performance” is a flow context includes accuracy and repeatability over the required flow range. It is important to understand that accuracy and repeatability requirements will usually be different at different flow rates. For example, in some applications, higher accuracy may be important at higher flow rates, because that is where the process is operating the vast majority of the time. In other applications, performance is more important at lower flow rates, because that is where safety constraints operate. The determination of required performance should be made by individuals who understand the economic, environmental and safety impact of the measurement uncertainty.

The second step is to quantify the operating conditions, which are not controllable. For flow measures, these can include:

- expected ambient temperature variation
- maximum static line pressure
- static line pressure and temperature variation (for gas and steam)
- line temperature variation (for liquids)
- maximum allowable permanent pressure loss
- flow turndown

The third and final step is to select hardware and installation and maintenance procedures which will ensure that the measurement provides the required installed performance under the expected (uncontrollable) operating conditions. For example, the user can:

- select a transmitter that has better performance under a given set of “real-world” operating conditions
- use pressure and temperature compensation in gas an steam applications
- calibrate the transmitter as infrequently as possible
- size the primary element for a lower differential pressure to minimize pressure loss

While the first and second step involve gathering data, the third step can be accomplishes by following the "Best Practice" procedures to improve your DP flow measurement point.

- Measuring mass flow (base volumetric) in Gas and Steam to reduce process variability.
- Minimizing pressure loss to lower operating costs, improve capacity.
- Eliminating impulse lines where possible to improve reliability, lower installed cost, and minimize maintenance.
- Selecting in-line flowmeters for smaller lines and insertion flowmeters for larger lines to minimize installed cost.

Following these steps will significantly reduce your capital and operating expenditures.

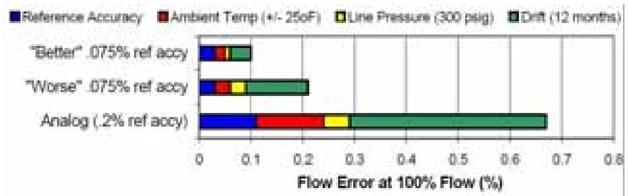
## MEASURING MASS FLOW IN GAS & STEAN TO REDUCE PROCESS VARIABILITY

In any DP flow system, there are three sources of flow error, DP transmitter errors, pressure and temperature variation and primary element errors. Users need to minimize all three sources of these errors for best accuracy and repeatability:

### DP Transmitter Error

Even with a well-installed and well-maintained transmitter, real-world accuracy can be significantly worse than laboratory accuracy, for any measurement technology. The reason is that real-world transmitters are not installed and operated under laboratory conditions." In the vast majority of "real-world" flow measurements, the transmitter can operate at a very different ambient temperature than the temperature at which it was calibrated. In some outdoor application, ambient temperatures can vary more than fifty degrees Fahrenheit from calibration temperature. These variations can have a significant effect on accuracy. High static line pressures can have a significant affect of the accuracy of DP transmitters in "real-world' conditions. As with the ambient temperature effect described above, the output component of the transmitter will vary over time. A more stable transmitter will allow the user to obtain the equivalent accuracy and repeatability when calibrated less frequently.

FIGURE 1. Figure 1 - Flow Error from DP Transmitter(1)



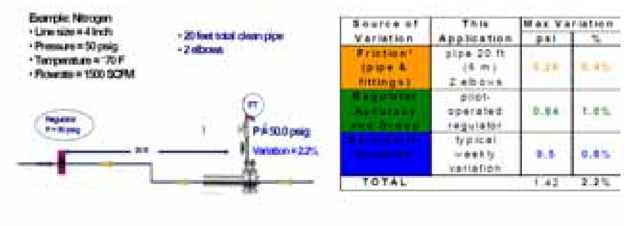

### Pressure and Temperature Variation Error

Special considerations should be considered for gas and steam applications. The mains source of flow error in gas and steam applications is due to changes in the fluid density cause by pressure and/or temperature variation. The need for mass, rather than volumetric, flow can be inferred when a flow rate is expressed in mass (lb/hr) or "standard volumetric" units, such as standard cubic feet per minute (scfm).

*(1) Published specifications as of 5/99 – Rosemount 3051 vs. competitive 0.075 reference accy transmitter*

Every gas and steam application has some variation in pressure and temperature, even small variations can cause a significant flow mis-measurement for both uncompensated DP, and velocity based flowmeters. Figure 2 is a gas example of a system in which minimal pressure or temperature variation is expected – gas flow out of a new, pilot operated regulator followed by two elbows and as short length of clean, straight pipe. Most users assume they know the pressure at the flow point because they are measuring it at a header or controlling it off a regulator some distance upstream of the flow measurement. This example shows that even a short distance of piping will cause significant pressure variability.

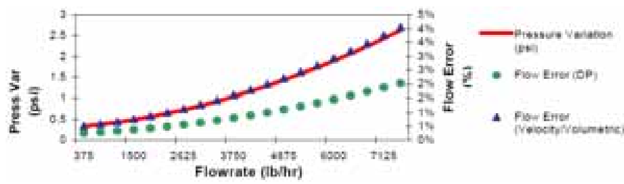
FIGURE 2. Nitrogen Example with Minimal Permanent Pressure Loss(1)




Three sources make up the total pressure variability. The first source, friction, is well established, but often un-addressed. In this example, the steam is flowing at a velocity of 180 ft/sec. This is a high velocity for most gases, but typical for a steam flow. The amount of friction loss is dependent on the geometry, the velocity and the density. The second source of error is the regulator accuracy and droop. Often people regulate higher pressures in a header down to lower pressure. Since, they regulate it, they assume that they know the pressure exactly. A brand, new regulator is 1% accurate at full scale. That means if it is regulating the pressure at 50 psig, the uncertainty is 1% of that. 0.64 psi.. The third source of error is barometric pressure changes. As high-pressure and low-pressure weather systems move in an out, a typical weekly variation is in the order of 0.5psi.

Total pressure variation is not repeatable and varies with flow rate. Figure 3 plots pressure variation against flow rate. Application with longer, rougher pipe or more fittings, particularly strainers or check valves can suffer much larger pressure variations. On-line pressure an temperature compensation using the steam tables (or compressibility calculations for gases) can virtually eliminate these errors and even for this minimal piping arrangement will yield a reduction in flow measurement error of 2%.

FIGURE 3. Pressure Variation & Flow Error(2)




## Primary Element Errors

When process conditions vary from the conditions used for sizing, errors occur in the accuracy of the primary element. Three factors can be calculated to address these errors, discharge coefficient, gas expansion and thermal expansion. By recalculation these factors real-time, theses sources of mis measurement can be eliminated. New DP flow with multivariable and embedded software makes it easy and affordable.

Typical errors due to non-constant discharge coefficients can range anywhere from 0.25% to 5% depending on the application. Errors can be broken up into two categories, uncertainty or accuracy and bias. Accuracy or uncertainty is how well the discharge coefficient is known at a give flow rate. For an orifice plate, the accuracy defined by the international standards (ISO, ASME, AGA) is 0.45% to 0.6%. Bias is the error caused by assuming the discharge coefficient is constant over the flow range. This error can be removed through dynamic compensation.

(1) *Pressure loss due to friction calculated per Crane® Handbook. Note that fittings such as: strainers, check valves, and bypass valves cause a much higher Pressure loss than elbows*

(2) *Source, Crane Technical Paper 410, 1991. Friction Factor calculated based on fully turbulent flow, in clean commercial steel pipe. All valves are assumed to be full port. Density calculated based on molecular weight of selected fluid, and assuming ideal gas. Fully compensated flow includes P&T, as well as real-time density calculations to address changes in compressibility (Z).*

Gas expansion is only a concern for gas and steams, as they are compressible fluids. For liquids, it is constant. DP flow works by relating the pressure drop across a primary element to the flow rate. For gases, the pressure drop changes the fluid density because it is compressible. This in turn impacts the pressure drop. Gas expansion factors correct for the change in gas density and it goes through the restriction of the plate. It is a well-known number defined by the international standards

Thermal expansion is usually small, but impacts the repeatability of the flow measurement because it is entirely independent of the flow rate. It is a function of process temperature only. Essentially, thermal expansion describes how the size of the pipe and the orifice bore changes with temperature due to expansion of the materials. It is most important when the materials of construction of the plate and pipe are different, because the expansion factors of the material are different.

Multivariable transmitters combine differential pressure, static pressure and temperature measurement with an integral flow computer to dynamically and continuously calculate all of the DP flow coefficient for fully compensated mass flow. Full Dynamic compensation utilities correction to the discharge coefficient, gas expansion, and thermal expansion factors in the full DP mass flow equation and continuously calculates and updates using real time measurement of differential pressure, static pressure and temperature. With real-time dynamic calculations, multivariable transmitters can improve the performance of DP flow measurement.

Better flow measurement typically means lower operating costs. The actual customer benefit depends on the application and the value of the fluid being measured. Some customers care more about repeatability than accuracy and if your reduce your process variability, it will tighten up the distribution curve. With a narrower distribution curve, you can move the operating set point closer to the optimal set point. In addition to have a more consistent product, the reduced variability can lead to savings by allowing the operating set point to be move closer to product spec. This increases efficiency in the loop and reduces scrap. In many application, the flow measure is used to make operating decisions, such as: detect leaks, determine which unit needs maintenance, determine which units should be shut down when demand is low, and check plant-wide mass balance. In these application, better flow measurement means better decisions.

## MINIMIZE PRESSUE LOSS TO LOWER OPERATING COSTS & IMPROVE CAPACITY

The are several sources that contribute to overall pressure loss of system. The sources can be valves, pipe friction, measurement devices, etc. With regards to measurement devices, the more flow meters, the more the pressure loss and the PPL consume by the flowmeters leads to additional energy being consumed. Permanent pressure loss (PPL) should be considered when designing a system because it is important in sizing the pump, compressor or boiler to meet the process conditions to deliver the desired pressure and/or flow.

Sometime overlooked is the potential cost once the process is up and running. For example, in a gas application the compressor will need to make up the lost pressure and therefore, it will use more electricity to compress the gas. In any system, gas liquid or steam, the energy needs to be made up by the compressor, pump or boiler. By minimizing the amount of PPL in a system, the size of the compressor, pump or boiler can be minimized or the effective capacity can be increased due to lower system PPL. For the case of steam boilers, this is a powerful concept. Boilers are very expensive, and the ability to retrofit existing flow points to increase the effective capacity of the boiler is a cost-effective approach to the problem, as opposed to a new boiler.

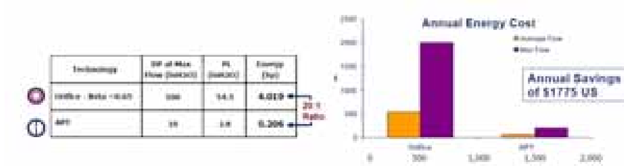
Except for obstructionless meters, magnetic and ultrasonic, every flowmeter has an overall permanent pressure loss that is greater than an equivalent straight length of pipe. The PPL is a function of three factors, density of the fluid, the velocity of the fluid and the amount of obstruction.Figure 4 is a guideline for the amount of obstruction caused by various flow technologies from the highest (1) to the lowest (7).

FIGURE 4. Guideline for Amount of PPL by Various Technologies


It is also important to consider if the flow technology will ‘necked down” in the application because reducers and expanders also create permanent pressure loss. It can range to high with reductions of 2:1 (4 inch to 2 inch). DP flow provides the ability to select and size the primary element to achieve minimum pressure loss. If the flow is high, averaging pitot tubes (APT) will create less pressure drop than virtually any other technology, especially in gas and steam. If the flow is lower, necking down may be required for other technologies, but with DP flow, an orifice can be selected as the primary element and it can be sized to create the PPL desired. As a result, a orifice plate sized at 50 to 100 inches of $H_2O$ of DP will create less PPL than another technology that need to be ‘necked down” to work properly in the application.

The example shown in Figure 5, shows a typical DP for an orifice plate and an averaging pitot tube and how much energy is consumed by each. The application is nitrogen flow in a 4-inch line size. The initial DP of the meter is not the PPL. This is because some of the initial pressure loss is received further downstream. How much is recovered, depends on how much blockage was initially created. In the example, the initial DP of the orifice was 100 inches of $H_2O$. Almost half was recovered, so the PPL is only 54.5 inches of $H_2O$. However, the recovery is greater for the APT, because it obstructed less. The APT had an initial DP of 10 inches of $H_2O$ and a PPL of only 2.8 inches, less than $^1/_3$ of the initial DP.

FIGURE 5. PPL Comparison of Orifice Plate versus APT[1]




This saving in PPL loss can be converted directly into energy costs. When the quantity of flow measurement points throughout a process plant, pipeline or distribution system are considered, the dollar savings can become very large. Energy savings costs can move to the bottom line in the accounting books, and thus, become and added company profit.

*(1) ENERGY calculations based on The “Flow Measurement Engineering Handbook” by R.W. Miller (3rd Edition)*

## ELIMINATING IMPULSE LINES WHERE POSSIBLE TO IMPROVE RELIABILITY, LOWER INSTALLED COST, AND MINIMIZE MAINTENANCE

Historically, transmitters required re-calibration or replacement and users preferred to have the ‘at grade” when access is easy. In order to get easy access to the transmitters, long impulse lines had to be run. This requires significant time in the field installing the lines. Not only is it costly, but it can result ina mis-installed solution and increased reliability concerns. Long lines meant the potential for more leak points and potential plugging. Since the impulse line were long, the cause shifts in the transmitter performance. This is cause by the long ‘legs’ that are filled with the process fluid and as ambient temperature changes, it can cause the legs to be at different heights on the high and low sides causing mis-measurement

By eliminating the impulse lines and ‘direct mounting’ the transmitter to the primary element, a user can significantly lower the cost of installation and improve their system reliability. The improvement in transmitter technology enables direct mounting to be possible. Much improved transmitter stability and reliably make calibration cycles of six to 12 months a practice of the past. ‘Best Practice”’ today is to go up to five years or more. In addition, digital communications with transmitters means that remote commination with the transmitter is possible reducing the need to have the transmitter at grade. The development of the direct mount platform on primary elements has enabled the transmitter to be close coupled to the sensing element.

## SELECTING IN-LINE FLOWMETERS FOR SMALLER LINES AND INSERTION FLOWMETERS FOR LARGER LINES TO MINIMIZE INSTALLED COST

Combining the differential producing primary and secondary element into an integrated DP flowmeter offers the lowest installation cost of any flowmeter technology, when compared to a traditional orifice plate. For any measure device, the price or material cost is only a portion of the capital expenditure on installing the device. The installed cost includes three additional categories: Engineering time, procurement time and installation time. Installed cost can be reduced by using direct-mount, pre-assembled flowmeters in-line flowmeters for smaller line sizes and insertion meters for larger line sizes.

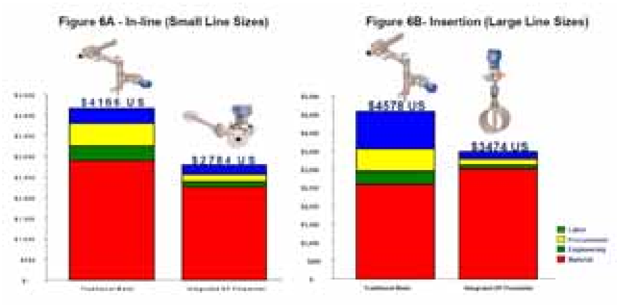
Cost savings from fully integrated DP flowmeters are realized in a number of areas including selection. Configuration, assembly and installation, specifying a DP mass flow measurement point has traditionally involved selecting differential, gauge and temperature transmitters, as well as a primary element, impulse lines, mounting hardware, RTD or thermocouple, thermowell, electrical wiring and conduit and a flow commuter.

Incorporation all components into a single units considerably reduces installation costs. Integrated flowmeters eliminate the need for fittings, tubing, valves, manifolds, adapters, and mounting brackets, which in turn reduces welding and installation time, In addition the process line need only be tapped once to accurately measure temperature, pressure and differential pressure.

Installation time alone can be reduce up to 90 percent over traditional compensated mass flow. When compared with traditional orifice installations, integrated flowmeters save installation and hardware costs while offering superior accuracy and turndown. Integration also allows for reduced chances of mechanical breakdown. No moving parts and easy access for diagnostics translates to reduced overall maintenance costs.

Figure 6 shows the total installed cost comparison for traditional installation versus 'Best Practice' installations. Figure 6A is for a 1-inch line and Figure 6B is for a 6-inch line.

FIGURE 6. Total Installed Cost Comparison – Traditional DP Flow versus Integrated DP Flowmeter[1]




## CONCLUSION

Many measurement technologies provide excellent accuracy and repeatability under laboratory conditions, Unfortunately, these same technologies will typically provide significantly worse performance under "real-world" conditions. In reinventing DP flow measurement, integrated flowmeters provide lower installation costs, lower operating costs and higher reliability than traditional DP flow measurement. Differential pressure transmitters have been used to measure flow in the process industry for many decades. Recently, a number of other technologies have emerged to compete with DP flow technology. Even with the variety of choices available, DP based flow metering continues as the primary choice in most flow applications.

The integration of the differential producing primary element and the secondary instrumentation provides a simple and inexpensive solution for DP based measurements. Users will no longer have to buy a DP transmitter and then search for a primary element supplier. Instead, the DP transmitter will come with the primary element already attached and ready to install. This will provide a single integrated solution.

*(1) Source: Richardson's Contractor Handbook Assumptions: Installation Labor Rates: $35 per hour; Engineering Labor Rates: $50 per hour; Procurement Labor Rates: $35 per hour; Cost per Purchase Order: $125; Cost per additional Line Item: $5*

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