

Measurement Best Practices For Improving Chemical Plant Safety, Availability & Efficiency (DP Flow Gas & Steam Examples)

ABSTRACT

Accurate and repeatable measurements are vital to the successful operation of a chemical process - to deliver consistent product while minimizing costs. Today, the vast majority of installed gas and steam flow measurements in most chemical plants use differential pressure-based (DP) flowmeters. Although the DP flowmeter is well established and capable of better than 1% flow accuracy and repeatability in a laboratory, most experienced users expect no better than 3-7% in the "real world" - even with a well-installed and maintained meter. This being the case, opportunity exists to improve plant operation by improving these existing DP flow measurement points.

This paper presents the key reasons for the deviation between laboratory and real world performance, and outlines methods that allow the user to quantify expected deviations prior to installation. Finally, "best practices" are detailed which will allow the user to actually obtain better than 1% mass flow repeatability from a real-world DP flowmeter.

HOW CAN BETTER FLOW MEASUREMENT IMPROVE CHEMICAL PLANT OPERATION?

In the broadest sense, the measurement of flow in a Chemical process can be grouped into three categories – Process Control, Custody Transfer and Monitoring. All three categories provide some economic benefit from reduced flow measurement uncertainty.

1. **Process Control:** There are numerous flow measurements made throughout any chemical process – for example: Feed flow to reactors, flow into and out of separators or distillation columns, flow through heat exchangers, into and out of tanks, jacketed steam and cooling water flows, etc.

While the specific impact depends on the given application, as a general example, consider a feed flow to a reactor or distillation column. If the flow is mis-measured by 3% too low, not only will costs increase due to excess raw material being used - this unaccounted variability contributes directly to the variability of the resultant product and may lead to sub-optimal operation. This variability will impact downstream processes and further reduce end product quality and process efficiency.

2. **Custody Transfer:** While custody transfer measurements are uncommon in Chemical plants (as opposed to oil & gas or district heating applications), each measurement typically has very high economic value. For example, steam may be produced by a joint venture between two or more plants, and then sold back to the two plants. As another example, most plants install a flowmeter to check the billing from the natural gas supplier. Many plants also employ "pseudo" custody transfer applications, in which the utilities and other plant units are treated as separate business entities to evaluate performance – in these cases, any transfer of steam, compressed air or other fluid can be considered as "pseudo-custody".

In these applications, a reduction in flow uncertainty is random, which means that any error has an equal probability of resulting in over-billing or under-billing. However, large uncertainties lead to disagreement between the billing and check meters, leading eventually to billing disputes, expensive flow audits, and ultimately claims for retroactive compensation.

DP Flow

3. **Monitoring:** Most flow measurements in a Chemical plant are for monitoring only. While not used directly for control, these measurements are used to detect problems and make off-line decisions that impact the efficiency of the plant:

- efficiency calculations: Which unit needs maintenance, which should be shut down when demand is light, etc
- mass, energy and steam balances
- leak detection and cost allocation

While a reduction in flow uncertainty in a monitoring application will not provide direct savings, it can lead to **better decisions**. While difficult to quantify, upgrading the wrong process or overlooking a leak due to poor measurement can have real economic costs.

While absolute accuracy is key for custody transfer, in the vast majority of chemical plant applications **repeatability** is key. For this reason, this paper will focus on improving repeatability.

WHY ARE DP FLOWMETERS COMMONLY USED TO MEASURE GAS & STEAM FLOWS?

Approximately 80% of industrial gas and steam flow applications use DP flowmeters (ARC 1997). Although a comparison of different flow technologies is beyond the scope of this paper, the key reasons usually given for selecting a DP flowmeter include:

- Well-understood = minimize training requirements and misapplications
- Standards-based = approved for custody transfer without expensive in-line proving
- Installed cost (comparatively) insensitive to line size = lower installed cost in larger line sizes
- Half as sensitive to fluid density changes (more on this later)
- One or two different DP transmitters can serve all line sizes = minimal spare parts
- Flexible – DP covers more applications than any other technology = allows standardization

HOW CAN 1% LABORATORY REPEATABILITY BECOME 3-7% INSTALLED REPEATABILITY? AND (MORE IMPORTANTLY) HOW CAN 1% MASS FLOW REPEATABILITY BE ACHIEVED IN THE “REAL-WORLD”?

Figure 1 shows real-world performance for a “traditional” and a “best practices” DP Flowmeter, in a “typical” steam flow application. Details for calculating and minimizing each of the three sources of error are provided below.

FIGURE 1. Flow Error in a “Typical” Gas or Steam Flow Application

Source of Flow Error	Traditional DP Flow	Best Practices DP Flow
1. DP transmitter	2-4%	0.6%
2. P&T variation	2-4%	0.1%
3. Primary Element	1-2%	0.6%
Mass Flow Accuracy (root sum square)	3-7%	1.0%

Best Practice #1: Use a “Better” DP transmitter for 2-4% Improvement

A “traditional” DP flowmeter uses an analog DP transmitter, with a typical “reference accuracy” of 0.2%. How can a DP transmitter with 0.2% reference accuracy contribute “2-4% flow error”, as claimed in Figure 1? Two reasons: first, “installed” accuracy is always worse than “reference” accuracy, for any flow technology. Second, with a DP flowmeter, the square root relationship between measured DP and flow magnifies small errors in the DP measurement.

Figure 2 compares flow error from three different DP transmitters at 100% flow, under typical installed conditions. These values were calculated using published specifications and the TPFE.xls spreadsheet (see “APPENDIX I: TPFE.XLS” on page 5). Note that:

- Reference accuracy is usually a small component of total DP transmitter installed error.
- Two DP transmitters with identical 0.075% “reference accuracy’s” can provide dramatically different installed accuracies.

FIGURE 2. Flow Error from DP Transmitter

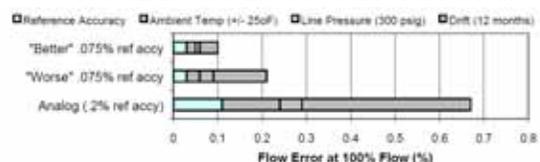


Figure 3 & Figure 4 show the impact of this error at lower flowrates. Note that:

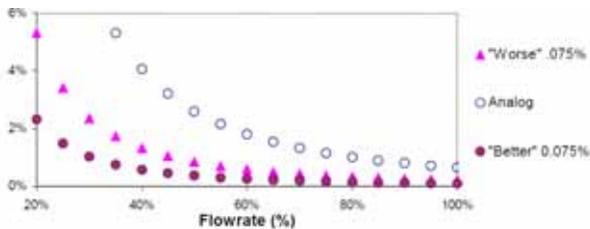
- these errors apply to accuracy and repeatability, and are fixed over the entire DP range
- $DP \propto flow^2$ – since DP declines twice as fast as flow, small errors at 100% - and small differences in transmitter accuracy - are magnified at lower flowrates

FIGURE 3. Flow Error from DP Transmitter

Flowrate (scfm)	DP	"Better" .075%	"Worse" .075%	Analog
1000	100	0.09%	0.21%	0.65%
750	50	0.16%	0.38%	1.16%
500	25	0.37%	0.85%	2.60%
250	6.25	1.48%	3.40%	10.40%

Seemingly trivial improvements in transmitter accuracy yield significantly better flow accuracy and repeatability at normal flows – the effect is dramatic at lower flows.

FIGURE 4. Flow Error from DP Transmitter



Although a comparison of flow technologies is beyond the scope of this paper, the user should note that this deviation between “reference” and “installed” accuracy can be observed for all technologies, including but not limited to Ultrasonic, Turbine, Coriolis and Vortex. “Reference accuracy” for any of these technologies may be stated in the form of a “nominal” specification – “1% over 20:1 turndown” – or may be the output of the supplier’s sizing program. As with a DP flowmeter, the user needs to convert reference to installed accuracy by adding “real-world” effects, which may include “D/A error”, “zero stability”, etc.

Best Practice #2: Pressure & Temperature Compensate for 2-4% Improvement

The second major source of flow error in any gas or steam application is error due to changes in fluid density, caused by fluid pressure and/or temperature variation. This assumes, of course, that the application requires **mass flow**. The need for mass – rather than volumetric - flow can be inferred when a flowrate is expressed in mass (lb/hr) or “standard volumetric” units, such as *standard* cubic feet per minute (scfm). In very rare cases, the user is actually concerned with volumetric flowrate, represented in volumetric units such as *actual* cubic feet per minute (acfm). In these cases, a velocity-based technology such as Vortex is usually the best solution.

Figure 5 is a schematic of a system in which minimal pressure or temperature variation is expected – steam flow out of a new, pilot-operated regulator followed by two elbows and a short length of clean, straight pipe.

FIGURE 5. Piping Schematic

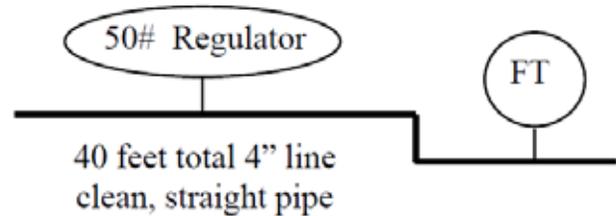
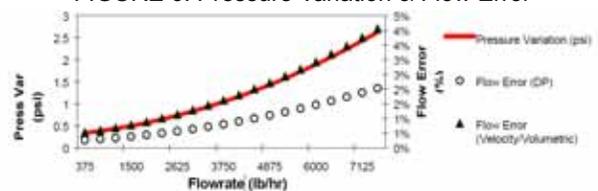


Figure 6 plots pressure variation against flowrate, and is obtained by using the P&T.xls spreadsheet (see Appendix II). Major sources of pressure variation:

- pipe friction – calculated by P&T.xls using Crane (1991) – increases exponentially with flow
- “typical” regulator droop – increases with increasing flow (1% assumed - note that an older direct-acting regulator will typically suffer from 5-10% droop)
- barometric variation – typical week-to-week variation of 0.3 psi – independent of flowrate

FIGURE 6. Pressure Variation & Flow Error



DP Flow

Zero temperature variation was assumed for this saturated steam application. However, temperature variation can be as significant as pressure variation for superheated steam or gases:

- variation in “source” temperature (for example, ambient air)
- heat conduction from uninsulated pipes

Total pressure variation is **not repeatable**, and varies with flowrate. Also, applications with longer, rougher pipe or more fittings - particularly strainers or check valves - can suffer from much larger pressure variations. Online pressure and 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%.

Although the focus of this paper is the DP flowmeter, note that linear and volumetric flow technologies such as Vortex, Ultrasonic and Turbine are twice as sensitive to pressure and temperature variation. This means that pressure and temperature compensation is **twice as important** for these other flow technologies.

Best Practice #3: Dynamically Compensate the Primary Element for 1-2% Improvement

A DP flowmeter primary element – such as an orifice – is sized by the manufacturer for one particular set of operating conditions – flow, pressure, temperature, etc. This sizing calculation determines the relationship between measured DP and flow. However, any variation from those design conditions will cause flow error. To eliminate this error, the user would need to continuously recalculate the flow to DP relationship at every new condition of flow pressure and temperature. Historically, in only the most critical applications, this level of compensation has been completed in a flow computer or Control System. More recently, with increases in microprocessor power, multivariable flow transmitters have become available which can perform these calculations inside the transmitter.

This **dynamic compensation** will improve flow accuracy and repeatability by 1-2% or more in most gas and steam flow applications, and reduce error to the uncertainty intrinsic to the primary element – for example, 0.6% for an orifice plate.

Of course, this assumes that the DP flowmeter is properly installed and maintained. Clearly, installing an orifice plate backwards or with insufficient straight pipe will cause additional flow error – usually introducing a *bias* error and affecting accuracy rather than repeatability. However, DP flowmeters are not difficult to install correctly, and any flow technology can be incorrectly installed and maintained. Also, installation effects on an “open”, standards-based flow technology, such as an orifice meter, are better documented and understood than for other “proprietary” technologies.

CONCLUSION

A traditional DP flowmeter that can achieve 1% repeatability in a laboratory will typically provide 3-7% under “real-world”, installed conditions. To obtain **1% mass flow repeatability** in the “real-world,” use “best practices”:

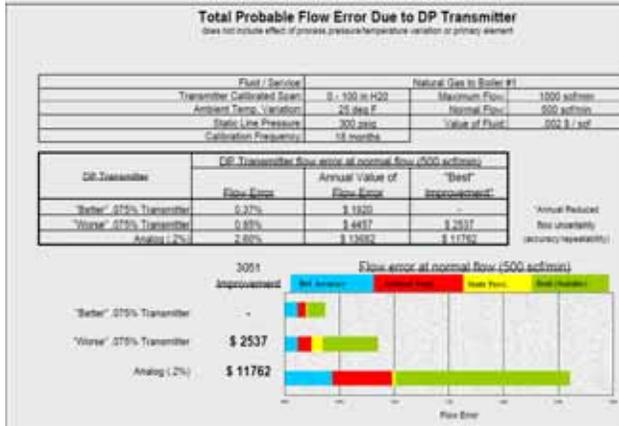
1. **DP transmitter** that provides high accuracy under real-world conditions
 - changing ambient temperature
 - high static line pressures
 - drift
2. **pressure & temperature** compensation
 - mass or standard volumetric flowrates are almost always required for gas and steam
 - pressure and temperature always vary in any gas or steam flow application
 - even minor variations have a major impact on mass flow accuracy
3. **dynamic compensation** of the primary flow element
 - to correct for operation away from the design/sizing conditions

APPENDIX I: TPF.XLS

The Total Probable Flow Error (TPFE) spreadsheet calculates flow error due to the DP transmitter, using:

- user-entered application conditions
- manufacturers' published specifications and clearly shows all calculations.

Visit www.Rosemount.com for further information.

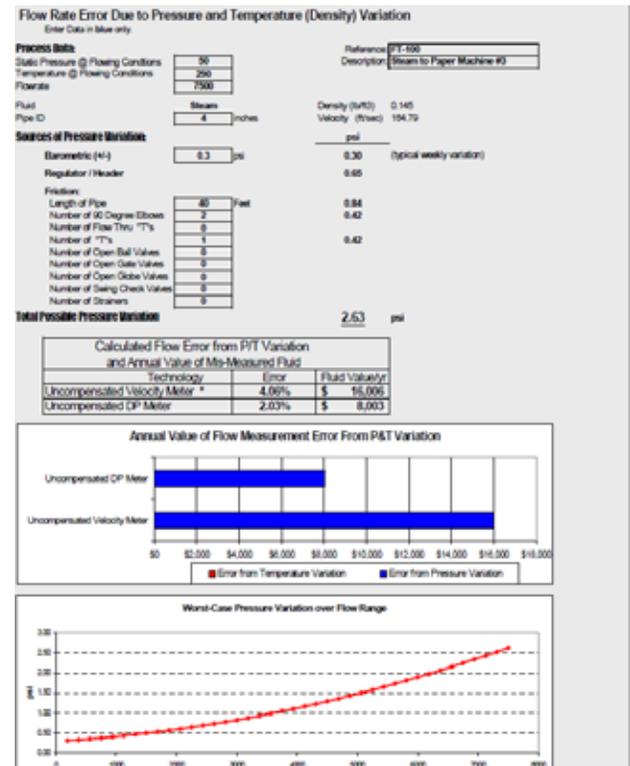


APPENDIX II: P&T.XLS

The Pressure & Temperature (P&T) spreadsheet calculates:

- pressure variation given user-entered flow conditions and piping schematic (including fittings) using Crane (1991)
- flow error for DP and velocity/volumetric flowmeters due to this calculated pressure variation, plus any user-entered temperature variation

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**Emerson Process Management
Rosemount Flow**
7070 Winchester Circle
Boulder, Colorado USA 80301
Tel (USA) 1 800 522 6277
Tel (International) +1 303 527 5200
Fax +1 303 530 8549

Emerson Process Management
Blegistrasse 23
P.O. Box 1046
CH 6341 Baar
Switzerland
Tel +41 (0) 41 768 6111
Fax +41 (0) 41 768 6300

Emerson FZE
P.O. Box 17033
Jebel Ali Free Zone
Dubai UAE
Tel +971 4 811 8100
Fax +971 4 886 5465

Emerson Process Management Asia Pacific Pte Ltd
1 Pandan Crescent
Singapore 128461
Tel +65 6777 8211
Fax +65 6777 0947
Service Support Hotline : +65 6770 8711
Email : Enquiries@AP.EmersonProcess.com