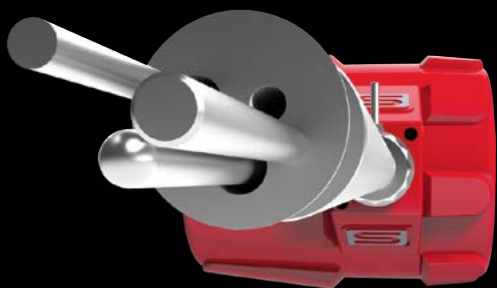


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### Valve Withstands Rigorous Conditions

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# Grasp Line Layout

Draining, venting, fouling and other considerations affect piping geometry

By Andrew Sloley, Contributing Editor

**WHEN DO** you slope a process line? When is self-draining required? How does self-draining contrast with self-venting? How do these differ from no pockets? Such issues seem to confuse many engineers. So, let's delve into line geometry.

Convenience and cost of piping runs set the overall geometry, except when special process requirements impose specific layouts. Piping designers rarely consider process needs, except for line sizing based on pressure drop or velocity.

At a minimum, the line geometry must account for startup and shutdown.

Filling a liquid line requires venting gas or air out. Draining demands getting liquid out of low points. The easiest approach is to add high-point vents and low-point drains. However, for some specific services, you may want to avoid extra valves and connections.

Liquid lines also may suffer from vapor pockets. These may block lines, preventing liquid flow. Under other conditions, a sudden shift of a vapor pocket can create slug flow — damaging equipment and creating operating or safety problems.

Many process vapor lines may accumulate condensation. Liquid also may get into lines due to upsets and entrainment from towers or separator drums. The accumulation may not be apparent until serious unit upsets occur. So, configuring piping to prevent accumulations may make sense.

As mentioned, basic pipe layouts often include high-point vents and low-point drains to deal with startup, shutdown and operating upsets. Experienced piping designers ensure the drains are easily accessible. Figure 1 shows lines with both vapor pockets and liquid pockets.

If process requirements mandate, the piping will

feature a self-draining, self-venting, no-pocket or sloped layout (Figure 1).

Self-draining lines may have a high point, so liquid can flow in either direction away from that point. Self-draining lines are relatively common in many plants. The intent is to prevent liquid slug formation and to keep liquid in vapor lines from increasing pressure drop.

Self-venting lines may have a low point, so vapor can flow in either direction away from that point. These are less common than self-draining lines because they still require a liquid drain.

No-pocket lines have a layout that allows liquid to drain down and vapor to vent up, obviating vents or drains. Process or startup and shutdown conditions may set the line sizing. If the liquid and vapor flow in the same direction during normal operation, very little extra care is needed. However, if the vapor and liquid must flow in opposite directions during

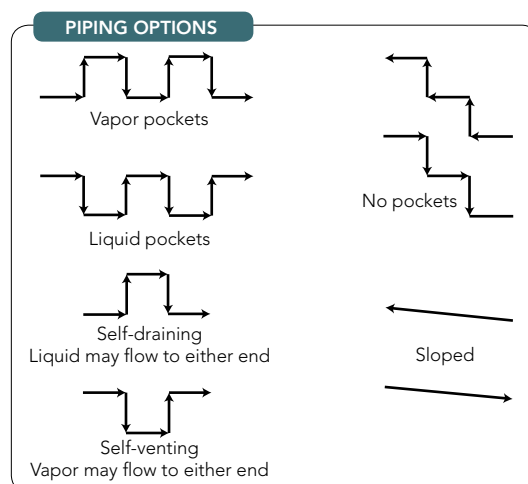


Figure 1. Line layouts may include a combination of configurations.

operation, line sizing must keep velocities low enough that holdup doesn't cause slugs of liquid or vapor.

Self-draining, self-venting and no-pocket lines may include level spots. Such a spot, especially in line sizes above 3 in., will drain most liquids without difficulty.

Continuously sloped lines are least common. These lines may be both sloped and no-pocket or sloped and self-draining; sloped and self-venting is unusual. The typical purpose of a sloped line is to keep velocity high for any liquid in vapor piping — e.g., to reduce residence time, keep fouling potential down or prevent solids' deposition. Typical slopes start at 1 in./8 ft (roughly 1%).

Sloped lines can be expensive. They require special accommodation in piperacks and are more difficult to install. In general, avoid a sloped line un-

less there's a clear reason to use one or a significant risk of a liquid pocket sticking in a small line.

Apply extra care to orifice and other head meters. Such flow meters impose a pressure drop by partially blocking the line. If enough liquid is present to justify self-draining or no-pocket lines, strongly consider eccentric orifices to prevent liquid pocket formation. Also, think about orifice plates with vapor venting holes.

Experienced piping designers consider such issues. But knowing when you require a particular geometry can help ensure the proper selection of a line layout. ●

**ANDREW SLOLEY**, Contributing Editor  
ASloley@putman.net

## CPVC Industrial Piping Systems Withstand Harsh Environments

Non-metallic piping system offers several advantages over traditional metal pipes

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Depending on pipe size, Corzan weighs about ½ that of steel pipes. Its weight, coupled with its fast installation time, makes maintenance much less complex, and reduces labor time. The piping systems are installed using a simple two-step solvent welding process, which creates a highly reliable joint by chemically fusing the pipe to the fitting.



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# Avoid Thermal Flow Meter Validation Pitfalls

Various methods exist for in-situ validation calibration but most don't factor in sensor drift

By Matthew J. Olin, Sierra Instruments, Inc.

**MID-TO-LARGE SIZE** facilities inevitably have hundreds of flow instruments to monitor, maintain and repair. For a reliability engineer, ensuring that all instrumentation meets ISO 9000 or similar standards is a time-consuming responsibility. These standards mandate that precision instrumentation needs to be checked (validated) or recalibrated as often as once a year. Sensor elements can become dirty, plugged, or drift over time. The resistance and capacitance of electronic components also degrades, leading to changes in sensitivity or drift.

Once an instrument drifts out of specification, it must be recalibrated to maintain its original accuracy. Thermal mass flow meters are not immune to these factors. As a precision instrument designed to measure the molecular mass flow rate of gases in ducts and pipes, these types of instruments can require cleaning, verification, and recalibration. Many flow meter manufacturers falsely claim that in-situ (or in-place) calibration is an easy and inexpensive method for both verifying the meter's original factory-calibrated accuracy and verifying the meter is in calibration. However, when evaluating thermal mass flow meters for in-situ calibration or validation capability, be aware that sensor drift will create false positives that reduce the reliability of the validation.

This article not only explores the role of stable no-drift sensor design, but examines five methods of field calibration validation to help end users choose the most accurate, stable, and cost-effective in-situ calibration solution.

## BACKGROUND: WET SENSOR DESIGN

The stability of all thermal mass flow meter sensors starts with mechanical design. The basic physics of thermal mass flow meters is attributed to Louie V. King, who published his famous King's Law in 1914, mathematically describing heat transfer between a heated wire and the fluid flow it is immersed into. King called his original instrument a "hot-wire anemometer," which measured the mass velocity at a point in the flow. The usage of hot wire anemometers grew, in particular, in research environments. This technology was not widely used in industry because of the fragile nature of the hot wires.

To solve this fragility problem, Sierra Instruments pioneered the development of an industrial-strength sensor in the '80s that could be used in a broad spectrum of industrial process control applications. The solution was to coil the platinum wire around a ceramic mandrel and mold the wire in place with a glass coating. This assembly was then placed inside of a thermowell. However, the gap or boundary layer between the thermowell and the platinum-wound mandrel needed to be filled with something other than air to assure heat transfer from the sensor to the flow. This was the key to assuring an accurate and stable thermal mass flow meter. The air gap was filled with a potting compound — a conductive epoxy called thermal grease or cement. This type of sensor is known today as a wet sensor and is used by virtually all manufacturers of thermal meters (See Figure 1).

### THE PROBLEM: WET SENSOR DRIFT

This wet sensor design proved workable, but it had an inherent weakness. The sensor would drift over time affecting the accuracy of flow measurement readings. As a function of its very principal of operation, the sensor is heated and cooled over time, expanding and contracting the cement inside the sensor, making it crack, settle, and shift from its original state. This phenomenon is analogous to freshly poured cement on a sidewalk. Eventually, the cement hardens and often cracks, shifts, and settles as it is repeatedly heated by the sun and cooled at night.

Because thermal sensors are precisely calibrated to determine the heat transfer versus flow characteristics, any change in the physical makeup of the sensor layers will invalidate this calibration, resulting in drift or outright failure. Excessive drift means users must send the meter back to the factory for recalibration.

### NO DRIFT SOLUTION

The best way to minimize drift in a thermal sensor is to remove the root cause — the epoxies, cements, and thermal greases that make up the wet sensor. In 1999, Sierra Instruments introduced a new patented sensor design. Through a proprietary, highly-controlled manufacturing process, the metal thermowell sheath is tightly formed on the mandrel and platinum-wire assembly. The sensor is designed to form such close contact that little or no air gap exists and no organic filler cements are needed (See Figure 2).

This innovative new cement-free sensor, known as a dry sensor, uses materials in the sensor that ensure the coefficients of thermal expansion are approximately the same. As a result, they expand and contract at the same rate, limiting the stress and cracking. Sierra determined that using a dry sensor was the only way a manufacturer could claim stability over the sensor's lifetime.

### IN-SITU CALIBRATION VERIFICATION

Despite wet sensor design weaknesses, to this day, all

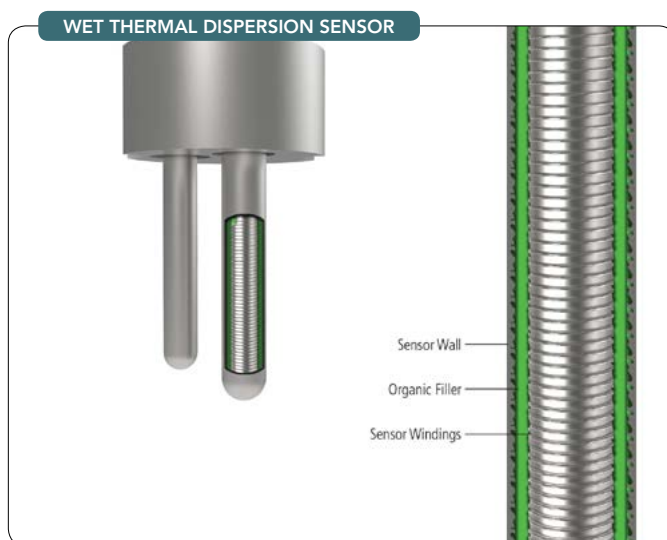


Figure 1. A typical wet sensor consists of an air gap filled with a potting compound between the sensor wall and the wire inside a thermowell.

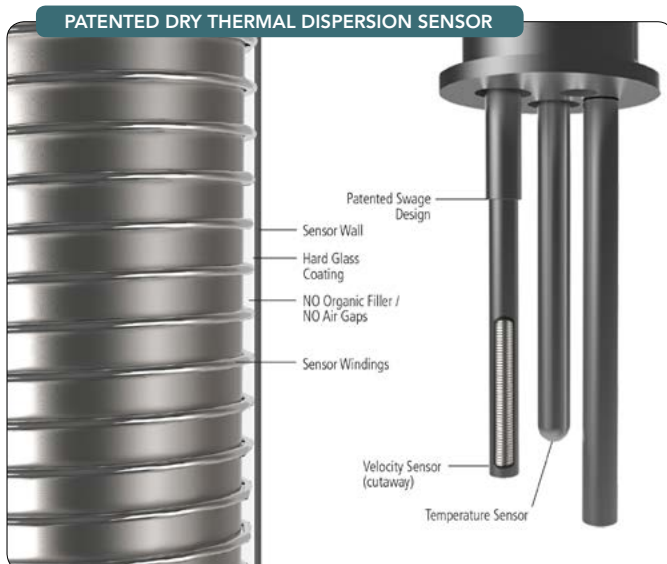


Figure 2. Cement-free sensors keep the rate of thermal expansion stable, limiting stress and cracking that sometimes plagues wet sensors.

manufacturers of thermal mass flow meters, except for Sierra, use the wet sensor design because they are easy and economical to build. In addition, all thermal meter manufacturers have generally the same method of using in-situ validation.

As expected, in-situ calibration verification of thermal flow meters is a highly marketed feature that claims to validate the sensor's accuracy on location. In-situ verification does not replace calibration. If substantial drift is found, the flow meter must be sent back to the factory for recalibration.

The following section details five principles of thermal mass flow meter sensor validation to assess which in-situ verification method will result in the most accurate results, thereby saving time and lowering costs. These five approaches are: Resistance, Zero-Flow, K-factor, Full-Flow, and Flow-Audit.

#### VALIDATION USING RESISTANCE

The simplest method measures the resistance across the velocity sensor. Since the velocity sensor is normally a platinum resistance temperature detector (PRTD), the measured resistance is directly related to the temperature of the sensor. This temperature should be equal to the space surrounding the velocity sensor once everything has come to equilibrium (See Figure 3).

This method only measures the resistance of the platinum wire that is wrapped around the platinum mandrel. As the dry versus wet sensor discussion illustrates, there is much more to a thermal dispersion sensor. Resistance measurement makes this a good troubleshooting tool in determining whether the wire has an open or short circuit and thus the sensor has totally failed.

Power must be removed from the velocity sensor, and it must be allowed to come into thermal equilibrium with its surroundings. Further, these surroundings must be at a constant temperature. In some cases, the meter can take as long as 30 minutes to reach thermal equilibrium and, for that period of time, it is not capable of measuring flow. If the temperature of the process fluid is fluctuating, this check cannot be done in-situ.

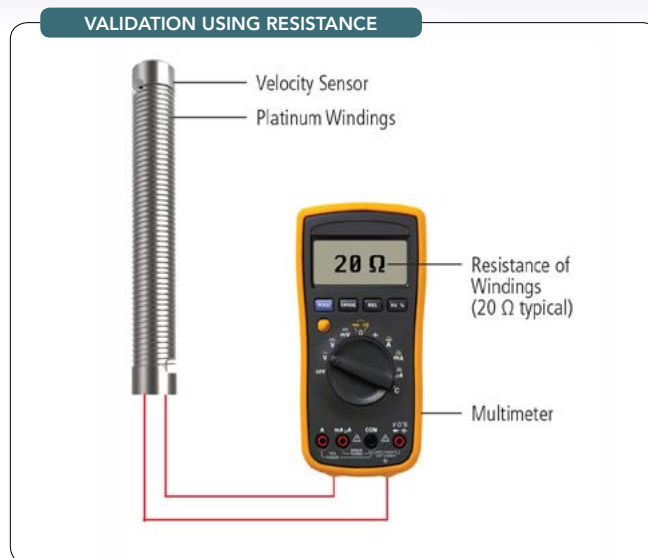


Figure 3. The simplest method measures the resistance across the velocity sensor.

However, this method does nothing to measure drift since the test doesn't measure factors related to heat transfer from the wire through the epoxies and sheath into the flowing fluid. Therefore, this method can only be confidently used with dry sensor design which doesn't drift.

#### VALIDATION USING ZERO FLOW

Most manufacturers have realized the limitations of validation using resistance and have various methods of checking the sensor's electrical output (either power or raw sensor output voltage) at a zero-flow condition (See Figure 4). Zero flow is the only truly reproducible point between the factory calibration and the site where the meter is being used.

To understand how this process works, it is necessary to review the factors that influence a thermal dispersion flow meter's calibration:

- Gas being measured
- Temperature and pressure of the gas
- The pipe the gas is flowing inside and the maximum flow rate the meter is expected to measure

If a meter is in the same gas at the same temperature



and pressure as factory calibration and the flow is zero, it should read the same sensor output voltage or dissipate the same power as it did at the factory. If it does not, it is because the sensor, or the electronics that drive the sensor, have drifted over time.

There are a variety of reasons why this measurement can be problematic:

- As stated, this measurement is only valid at zero flow, meaning the flow in the pipe must be either shut off or the flow meter partially removed from the pipe with a hot-tap.
- Even if the meter is at zero flow, it still must be in the same gas at the same temperature and pressure as factory calibration.

For these reasons, many manufacturers provide data for checking zero at another set of more reproducible conditions: zero flow at atmospheric pressure and temperature. This requires the meter to be completely removed from the process and allowed to come to equilibrium at ambient conditions. At best, this stretches the definition of in-situ verification, as it is not “in place.”

The key drawback of validation using zero flow is that it is only valid at a single flow point. While this is a good indicator of the type of offset that can be caused by drift, it does nothing to validate the accuracy of the flow meter through its calibrated range.

#### FIELD ADJUSTMENT USING K-FACTORS

As an interim step, many manufactures enable the application of a global K-factor that works as a multiplier to the observed flow value. This is simply a linear offset most often employed to make the meter reading agree with another device. The problem with K-factors is that the inherent response curve of a thermal sensor to flow is non-linear and is best represented by a complex polynomial function, typically at least to the fifth order (See Figure 5).

In other cases, the manufacturer may allow several points on the calibration curve to be adjusted. This is typically done for large ducts and pipes as part of a flow transit. This is sometimes erroneously called an in-situ calibration.

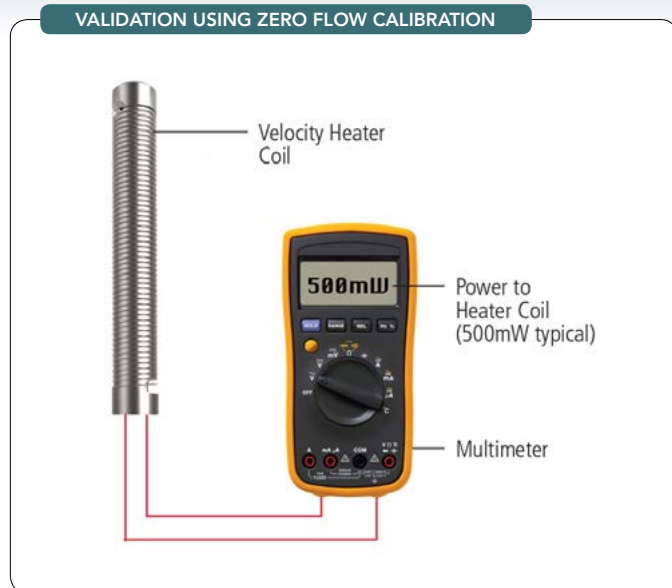


Figure 4. Zero flow is the only truly reproducible point between the factory calibration and the site where the meter is being used.

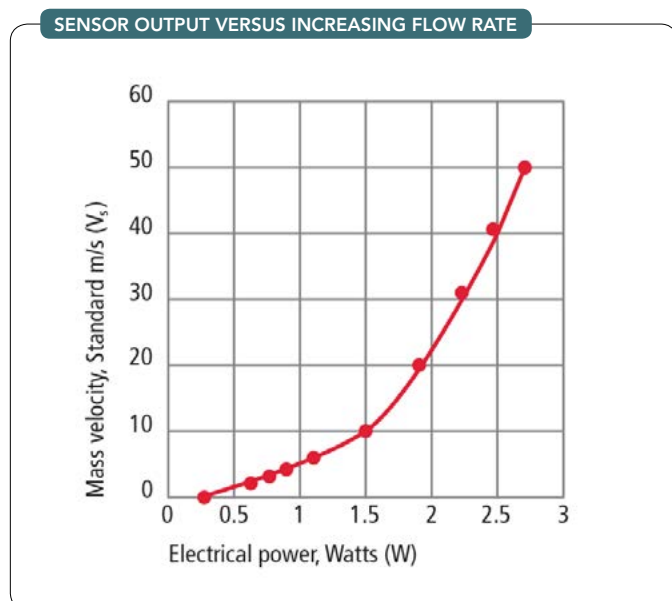


Figure 5. A global K-factor can work as a multiplier to the observed flow value.

In this procedure, the flow profile inside a large duct or pipe is characterized by measuring the velocities at various points, generally along horizontal and vertical lines. Since a thermal flow meter is a point velocity device, it can only measure the velocity at a single point in the total flow and is affected by flow profile disturbances. A flow traverse can determine the best placement of the flow meter, and may suggest that multiple points are needed. Some manufacturers offer multipoint thermal flow meter averaging systems for this purpose (See Figure 6). A flow traverse is not an in-situ calibration. It simply refines the placement of the meter, or determines a gross correction K-factor to bring the existing calibration in line with observed results.

#### VALIDATION USING FULL-FLOW

One complex and expensive technique that validates beyond a zero flow condition checks the full-flow range by generating a series of known flow rates, from zero to full scale (See Figure 7). The system uses a small sonic nozzle opening that directs a known flow past the velocity sensor. The diameter of the nozzle is fixed, and by applying a known differential pressure across the nozzle, the flow through the nozzle can be calculated.

As with the other techniques discussed, this method has its drawbacks:

- It depends on the nozzle not becoming plugged or dirty (and thus changing the size of the nozzle from when it was calibrated) and requires precision pressure gages, which themselves need periodic recalibration.
- The meter must be removed from the process (although not necessarily the pipe), so a hot tap system is required.
- This is a rather complex and expensive technique, requiring a source of pressurized air or nitrogen, a variable pressure regulator, tubing, and the nozzle. Such a system cannot be back-fitted, and the nozzle is a permanent fixture of the probe assembly.

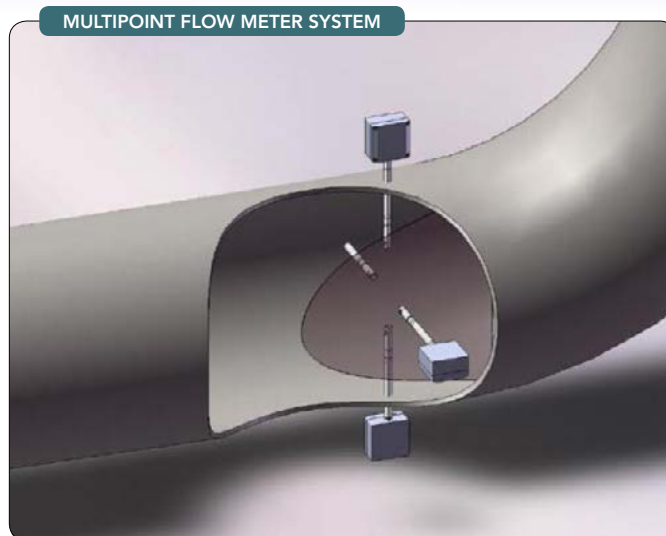


Figure 6. A multipoint thermal flow meter averaging system can help determine the best placement for a flow meter when a flow traverse reveals multiple points are needed.

#### VALIDATION USING FLOW-AUDIT METHOD

The flow-audit method is perhaps the very best in-situ calibration verification. This method uses a high-accuracy flow standard to prove the accuracy of the flow device under test (DUT). A flow-audit is performed with a similarly calibrated meter that is installed into the pipe via hot-tap near the DUT, or even at the same measurement point if the meter under test can be removed. The key words above are “similarly calibrated;” a meter calibrated for natural gas cannot be used to check a meter on compressed air for instance. Likewise, the temperature and pressure as well as pipe size must be matched.

The ideal meter for the flow audit method has the application flexibility to work on different gases and pipe sizes and dynamically compensate for temperature and pressure differences. Many companies buy thermal insertion mass flow meters as audit meters because of their ability to insert the sensor into the flow via hot tap. This adds convenience and avoids costly process shutdowns. However, traditionally, a

thermal meter needs to be purchased for each specific application at the facility. For the majority of users, this is cost prohibitive.

For gas flow auditing, a solution now exists that allows a single thermal flow meter to be used across multiple pipe sizes and gases. The QuadraTherm 640i insertion thermal mass flow meter has been rapidly adopted as a flow-audit meter to check other thermal meters at a facility. Due to its high accuracy of 0.75% of reading, it is also commonly used to check many different gas mass and volumetric flow technologies.

Coupled with a hot-tap insertion point located near the DUT, the 640i is a “universal” flow meter that can be reconfigured in the field to match nearly any flow measurement point in a facility. The flow meter has Sierra’s patented no-drift dry sensor as discussed earlier in this article. The result is a stable reliable measurement. As seen in Figure 8, the user programs the instrument to the exact gas and pipe size of the device under test and inserts the ¾-in. (19mm) sensor probe into the pipe near the DUT. Engineering units can even be programmed to match the DUT.

The flow-audit meter (Figure 9) will immediately start reading flow. Compare this flow to the DUT. If the two units read close to each other, the DUT can be signed off as validated and reading properly.

#### IN-SITU VALIDATION ISN'T CALIBRATION

For four of the calibration validation methods, if the meter does not pass the validation, it generally must be returned to the factory for recalibration. However, using the flow-audit method allows the end user to adjust a DUT using the K-factor method discussed earlier to adjust the DUT to match the exact flow reading of the audit meter.

Precise thermal flow meter calibration occurs under tightly controlled temperature and pressure conditions using the same gas and the same size pipe section or flow body that the meter will be used in.

As you can imagine, such a facility is a large and expensive asset and certainly not portable.

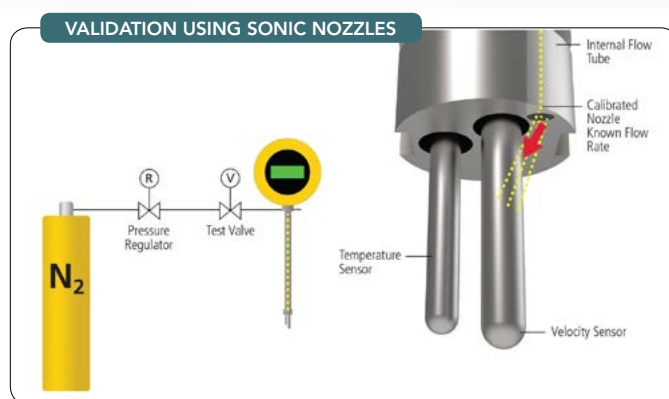


Figure 7. Technique validates beyond a zero flow condition, checking the full-flow range by generating a series of known flow rates, from zero to full scale.

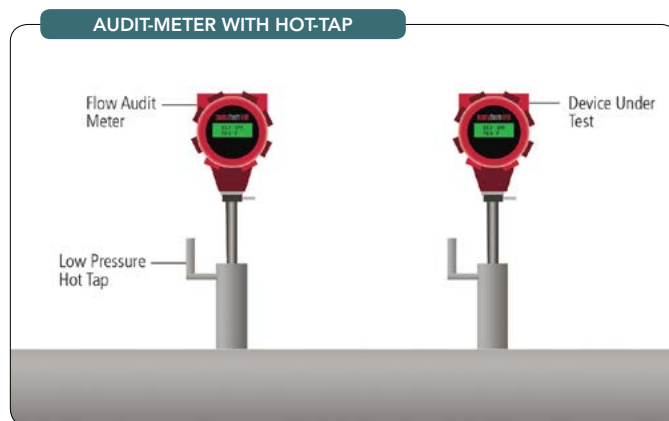


Figure 8. Users program the instrument to the exact gas and pipe size of the device under test (DUT) and insert the ¾-in. (19mm) sensor probe into the pipe near the DUT.

Consequently, if you find your meter is out of calibration, it is highly recommended to send it back to the factory or accredited flow calibration service center for recalibration.

#### VALIDATE, DON'T CALIBRATE

How can you validate a sensor that will drift out of spec due to the very nature of its mechanical design?

#### FLOW METER



Figure 9. Sierra's QuadraTherm insertion thermal mass flow meter is a dry-type, multivariable sensor with 0.5% of reading accuracy.

You can't. All validation methods assume that there is no drift.

Dry no-drift sensors have a big advantage during in-situ calibration validation. The all-metal, epoxy-free mechanical design provides the confidence that the in-situ calibration validation is actually valid. Dry sensors are validated in the same way as a wet sensor, although in this case, it is not drift that is expected, but rather dirt or mechanical damage. For this reason, Sierra offers a lifetime warranty on its patented dry sensor and guarantees there will be no drift.

As a result, there is no need to buy expensive in-situ calibration instruments. Sierra offers a free in-situ calibration validation software package called ValidCal Diagnostics that provides a complete check of all meter components including the velocity and temperature sensors, the sensor drive circuitry, the accuracy of the pressure transducer (if applicable), and all digital and analog outputs and alarm relays. This capability is included free with each meter

and provides a printed calibration certificate and diagnostics report. All of this can be accomplished without removing the meter from the process piping.

When evaluating thermal mass flow meters for in-situ calibration validation capability, be aware that sensor drift will create false positives that reduce the reliability of the validation resulting in reduced measurement quality. Assure that the instrument has a dry sensor and that the manufacturer backs up their sensor with a no-drift guarantee before you run an in-situ calibration validation procedure.

#### SENSOR STABILITY

In-situ calibration validation is one of the great benefits of thermal mass flow technology. Each of the five in-situ calibration validation approaches has varying cost and complexity, but does offer the end user the advantage of proving some aspect of flow meter performance in the field to fulfill quality requirements.

When evaluating thermal mass flow meters for in-situ calibration validation capability, beware that sensor drift will create false positives that reduce the reliability of the validation. The assumption by all manufacturers, including Sierra, is that their sensor does not drift. Only with sensor stability can users truly validate a sensor's factory-calibrated accuracy in the field. Assure that your thermal mass flow meter has a drift-free, dry sensor, which has no organics and cements that drift over time.

Finally, it is highly recommended to use the flow-audit method for the highest quality calibration validation. All forms of in-situ calibration validation discussed in this whitepaper give the end user information about the thermal meter's operating performance, but only the flow-audit method actually validates the calibration at actual flowing conditions. ●

**MATTHEW J. OLIN** is President and CEO of Sierra Instruments, Inc. For more information visit, [www.sierrainstruments.com](http://www.sierrainstruments.com).



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# How Important is Piping Symmetry?

Designers should consider the impact of unequal flows in branches

By Andrew Sloley, Contributing Editor

**WHEN WE** build multiple parallel exchangers we assume an ideal world — each exchanger getting the same flow. One way of achieving equal flow to every exchanger is making inlet and outlet piping symmetrical. So, my first thought on seeing the piping layout proposed for connecting a tower overhead to an air-fin condenser (Figure 1) was “That’s not symmetrical.” Tower overhead enters in the large line from the upper left and goes to the condenser; condensate then leaves through the line to the lower left. Both the inlet and outlet piping clearly aren’t symmetrical, despite the designer being instructed to provide a symmetrical layout.

My second thought was “Is symmetry really important here?” To evaluate this, let’s look par-

ticularly at the inlet piping because non-symmetry in the outlet piping in this case only has a minor impact.

Figure 2 shows a schematic of proposed inlet piping (the diagram on the left). It has a line of symmetry at the first flow split. As far as the piping designer was concerned this was a symmetrical layout. However, to get the exact same resistance to flow in each path, every split must be symmetrical to every other one at the same level of branching. For four inlet lines, a symmetrical layout requires two levels of branching: the first sends flow to AB and CD, the second splits that to A and B and C and D (as shown in the right-hand diagram).

To analyze the system, we start with one flow

fundamental — pressure drop in parallel paths must be equal. Flow and level, if present, will distribute to equalize pressure drop. For the proposed layout, this translates to 107% of design flow going to inner bays (B and C) and 93% to outer bays (A and D), or inner bays receiving 115% of the flow of outer ones.

While this seems like a lot, what’s the real consequence? Do we really care about the mal-distribu-

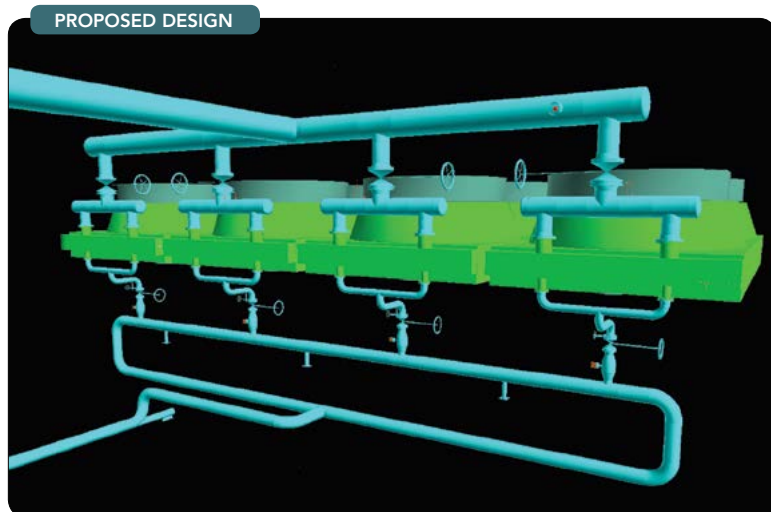


Figure 1. Both inlet and outlet piping have non-symmetrical layout.

## DIFFERENT SYMMETRY

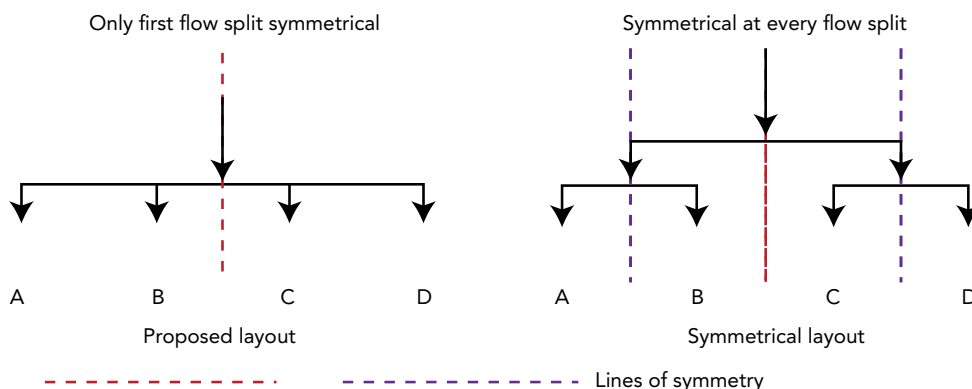


Figure 2. Original layout has one line of symmetry but three are needed for truly symmetrical design.

tion? What really counts is its impact on exchanger duty. Bays with low flow will tend to pinch against air temperature (reducing duty). Bays with high flow may be limited by surface area or may compensate due to increased temperature difference (because their outlet temperature rises).

A detailed analysis of exchanger performance shows duty in the high-flow bays (B and C) goes up, while duty in the low-flow bays (A and D) goes down, and total duty drops slightly, by 0.4%.

The exchanger was being purchased with 25% more duty capability than required. Additionally, the non-symmetrical piping layout minimized structural height and reduced overhead-of-tower-to-condenser-drum pressure drop, which was important as well. Overall, the non-symmetrical layout was a better design. So, the answer to my second question is “No, symmetry’s not really important here.”

Not every flow-splitting problem will have the same answer. How important is symmetry? You only can tell through a detailed evaluation of the specific situation.

This case had several key factors making symmetry less important:

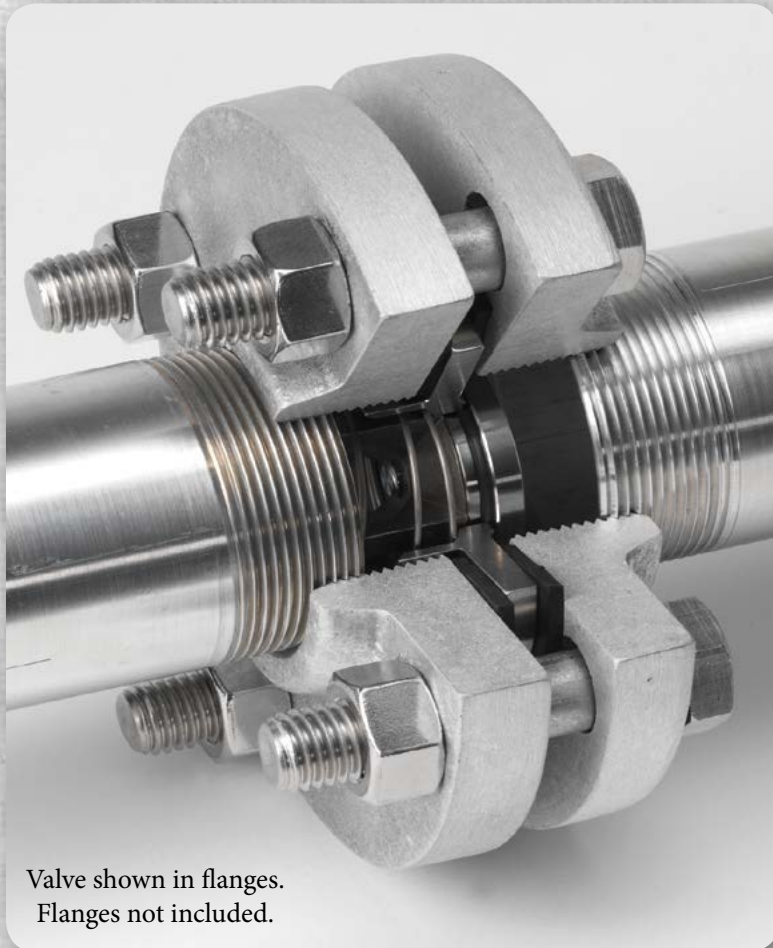
- relatively high fraction of system pressure drop in exchangers compared to piping;
- large difference between outlet temperature of process stream and air stream from condenser; and
- ample over-design in exchangers.

Symmetry is more important in overhead systems when you have to contend with factors such as:

- close temperature pinches between process and cooling medium; and
- low system pressure, as this magnifies the impact of pressure drop on the condensation curves.

Symmetry in piping is a good first step to achieve even flow and maximum equipment performance. However, in some systems, like the one here, it may not be worth the price. But don’t decide without careful analysis. ●

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Valve shown in flanges.  
Flanges not included.



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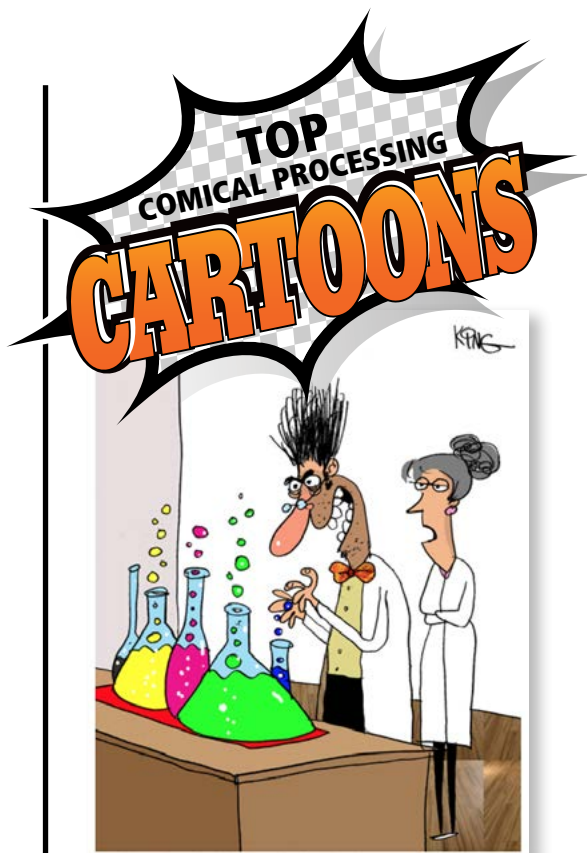
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