Temperature & Pressure
Basics of Calibrating Pressure Transmitters
Differential Pressure and Beer Making
Temperature Measurement Accuracy
Temperature Control & Plant Performance
Effects of Cold on Pressure Instruments
Temperature and pressure are two of the four common types of control loops. Pressure loops can perform a wide variety of functions, while temperature loops are generally more difficult and important. Essential to both are the instruments that measure temperature or pressure, and how technical and environmental factors affect their operation. This edition of InTech Focus centers on the fundamentals of temperature and pressure instrumentation.

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Account Managers:

Chris Nelson
+1 919-990-9265
cnelson@isa.org

Richard Simpson
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Pressure transmitters need to be calibrated on a regular basis for maximum performance. When do you do it? How do you do it? And who does it?

Pressure transmitters used in the process industries are very durable and reliable instruments. Even so, they still require periodic maintenance and calibration to ensure optimal performance. This is an area of confusion for many, with these and other questions typical:

- Are we calibrating our transmitters too often, resulting in excessive downtime and unnecessary maintenance expense?
- Are we calibrating our transmitters too infrequently, resulting in quality issues and possible loss of product?
• Are we calibrating our transmitters correctly?
As with most things in life, there is no “one size fits all” answer. However, there are simple best-practice guidelines, which can be modified to fit specific applications. This article helps answer the basic questions facing process plant personnel with regard to calibration.

How Often?
Each process plant has to determine correct calibration intervals based upon historical performance and process-related requirements. Factors you need to consider that may influence this decision are:

Are there any local, national, safety or environmental regulations that must be observed?

What is your reason for requiring calibration: quality, safety or standard maintenance?

Process conditions:
• Is there a homogeneous process fluid with a stable pressure/temperature?
• Will the process conditions fluctuate significantly?
• Is there risk of buildup, corrosion or abrasion to the pressure transmitter?
• Will heavy vibration be present?

Ambient conditions:
• Will the pressure transmitter be installed in a well-controlled environment with low humidity, normal/stable temperatures, and few contaminants such as dust or dirt?
• Is an outdoor transmitter exposed to widely varying weather conditions or high humidity?

If you have no significant history or regulatory requirements to guide you in developing your calibration procedures, a good place to start is with the following general guidelines (Figure 1):

- Direct mounted pressure transmitters installed inside in a controlled environment on a process with stable conditions should be calibrated every four to six years.
• Direct mounted pressure transmitters installed outside on a process with stable conditions should be calibrated every one to four years, depending upon ambient conditions.

If a remote diaphragm seal is employed on a pressure transmitter, the calibration interval should be reduced by a factor of two; i.e., a four to six year interval is reduced to two to three years. This is because a remote diaphragm seal will employ more fill fluid than a direct mounted configuration. Consequently it will experience more mechanical stress from process or ambient temperature fluctuations. Most remote diaphragms are flush faced where the diaphragm/membrane is susceptible to physical damage (dents or abrasions) that can cause offset or linearity issues.

If the process regularly experiences significant pressure swings or over pressurization events, reducing the calibration interval by a factor of two is a good rule of thumb.

**How Accurate?**

How good is good enough? In other words, what is the Maximum Permissible Error (MPE) for your calibration? Many make the mistake of adopting the manufacturer’s reference accuracy as their calibration target. Unfortunately, this means they will have a MPE that is too tight, with a high rate of non-conformance in their calibration process. In the worst case with a very tight tolerance MPE, it may not be possible for their field or lab test equipment to calibrate some of their transmitters.

A manufacturer’s reference accuracy is based upon tightly controlled environmental conditions seldom if ever duplicated in a plant environment. Using that reference accuracy for a calibration target also fails to take into account the long term stability of the instrument.

Over time, all instruments will experience slight accuracy degradation due to aging and simple wear and tear on mechanical components. This needs to be considered when establishing the MPE. In general, unless there are mitigating circumstances, it is better to set a reasonable MPE achievable with standard field and lab test equipment.

Test equipment starts with an accurate pressure source to simulate the transmitter input. The corresponding output is measured with a multimeter for a 4-20mA transmitter, or with a specialized device for smart transmitters with digital outputs such as HART, Foundation Fieldbus, Profibus or EtherNet/IP.

The test equipment you intend to use should be traceable to the National Institute of Standards and Technology. As a general recommendation, your reference equipment should be at least three times more accurate than the pressure transmitter being calibrated.

**Performing the Calibration**

Once your calibration interval and MPE have been established, you are ready to perform the actual calibration procedure on your pressure transmitter. The best practice recommendation from Endress+Hauser is:

1. Mount the transmitter in a stable fixture free from vibration or movement (shown in the opening photo on page 5)
2. Exercise the sensor/membrane before performing the calibration. This means applying pressure and raising the level to approximately 90% of the maximum range. For a 150 psi cell that would mean pressurizing it to 130-135 psig. Hold this pressure for 30 seconds then vent. Your overall results will be much better than if you calibrate “cold.”

3. Perform a Position Zero Adjustment (zero the transmitter). This is important because the fixture used for calibration may be different than how the transmitter is mounted in the process. Failing to correct for this by skipping this step can result in non-conformance.

4. Begin the calibration procedure. Typically this means three points up (0% / 50% / 100%) and then three points down. The 4-20mA output should be 4mA, 12mA and 20mA at the three points (or the correct digital values for a smart transmitter). Each test point should be held and allowed to stabilize before proceeding to the next. Normally that should take no more than 30 seconds. More points can be used (Figure 2) if you require a higher confidence in the performance of the instrument.

5. Compare the results of your pressure transmitter to your reference device.

6. Document the results for your records.

The calibration should be performed in as stable an environment as possible because temperature and humidity can influence the pressure transmitter being tested as well as the pressure reference.
If the results of your calibration are within the MPE, do not attempt to improve the performance of the transmitter.

One mistake many end users make is to regularly perform a sensor trim adjustment of their pressure transmitter—even on new units from the manufacturer. A sensor trim corrects the digital reading from the sensor after the A/D conversion. Performing a sensor trim on a new transmitter is essentially a single point calibration under current plant environment conditions, as opposed to sticking with the original factory calibration.

Factory calibrations of pressure transmitters are performed in a tightly controlled environment and incorporate up to as many as 100 test points. Performing a sensor trim on a new pressure transmitter under field conditions will result in a unit that operates at less than optimal capacity. A sensor trim should only be performed by a qualified technician under the manufacturer’s guidance.

Who Should Perform the Calibrations?
Even with the sophisticated calibration and reference equipment currently available, there is no substitute for a properly trained technician (Figure 3) when it comes to calibrating pressure transmitters. Not only does the technician need to be trained on the mechanics of the calibration process, he or she also needs to be equally qualified in completing and maintaining the documentation. Repeatability is the key and in the world of calibration, if it isn’t properly documented, it didn’t happen.
Occasionally there are some calibrations that cannot be performed in a standard maintenance shop by maintenance technicians. For these cases, an ISO17025 accredited organization is required. Not only can an ISO17025 accredited organization perform more stringent calibrations, they provide other value as well:

- Accredited labs can simplify the calibration audit process.
- The process and methodology used by an accredited lab is extremely repeatable, thus producing a high level of confidence in the results from an auditor's perspective.
- Annual audits of the accredited lab ensure they are consistently performing at a high level for their registered scope of work.

Summary

The “correct” calibration cycle for a pressure transmitter will depend on the purpose of the calibration and the application. The same pressure transmitters employed in different operating units or processes at the same plant may require different calibration intervals.

Even more important than the calibration interval of the instrument are:

- Establishing correct and realistic MPEs
- Following correct calibration procedures
- The training of the person performing the calibration
- Proper documentation of calibration results.

Following these guidelines and using judgment based on actual plant operation conditions will help establish proper calibration practices, saving money while maintaining acceptable performance.

ABOUT THE AUTHORS

Keith Riley joined Endress+Hauser in 2008 as a Level Product Manager. In this capacity, he was responsible for business development and technical direction of level products. After four years, he became the National Product Team Leader for Pressure and Temperature Products. In this role, Keith works to market the Temperature and Pressure products. He also oversees the strategic direction for the U.S. Temperature and Pressure product business team.
Ehren Kiker has spent the past 20 years consulting on process instrumentation and control as well as electrical control and distribution equipment. He received his Bachelor’s degree in Industrial and Systems Engineering from the University of Florida, and went on to receive his MBA from the University of Houston. Ehren is the National Product Marketing Manager for Endress+Hauser US. In this role, he is responsible for technology application, marketing and business development for a wide range of pressure and temperature products.

Duane Muir is currently a Technical Product Specialist for Level and Pressure Products at Endress+Hauser with 20 years of experience in application, installation, calibration and troubleshooting instrumentation. He received his Bachelor of Science Indiana State University in Electronics Technology. In his career, Duane has specialized in five different areas of instrumentation technology and has multiple certifications from Endress+Hauser.
Electronic Differential Pressure for Precise Beer Making

When it comes to beer, a lot goes into that little can, bottle or perfect draft pour. Perfecting the process and getting the same end result every time takes a lot of different skills and knowledge. An important piece of that knowledge involves pressure and the instruments that measure it.

From local craft brewers to the major breweries known around the world, all use pressure measurements to control and monitor their process from start to finish. Pressure can be used for a range of measurements, including process pressure, hydrostatic pressure for level, and differential pressure for level or density measurements. Pressure is used not only because it's versatile; it's also reliable, repeatable, and accurate.
Using two pressure measurement values and a little math, for example, differential pressure can calculate level, flow, interface and even density. Process engineers know and trust differential pressure because it’s a tried and true method for controlling industrial processes. Its versatility and variety of outputs only make it that much more valuable across industries.

**Understanding Differential Pressure**

The traditional differential pressure measurement consists of a dual sided diaphragm that senses pressure from the bottom of the vessel on one side and from the top of the vessel on the other. These opposing pressure measurements push on opposite sides of the dual sided diaphragm, and the resultant measurement is the pressure difference between the two, or differential pressure. Traditional differential pressure covers a wide application spectrum with the ability to detect differential pressures of only a few millibars.

The connections to the vessel are traditionally made in two different ways – impulse lines or capillary lines. Impulse lines are hard lines that allow the fluid or gas in the process to directly contact the diaphragm in the measurement device, and the lines become a part of the process. Capillary lines separate the sensor from the process by using a flange with a metal diaphragm mounted to the vessel. Connected to these external diaphragms are flexible, armor coated lines filled with oil. The remote seals remove the pressure transmitter from potentially damaging process parameters such as high temperatures or caustic materials.

Both arrangements are measuring pressure. The pressure measurement at the bottom of the tank or vessel is measuring the overall pressure created by the fluid and the vapor space above it, while the pres-
Differential pressure measurement at the top is only accounting for that head or static pressure. This arrangement allows the static pressure to be “removed” from the overall measurement, leaving the pressure generated by the fluid and allowing us to infer level.

Differential pressure is used to measure level of liquids and liquefied gases in pressurized tanks. A differential pressure transmitter measures the difference between the static pressure and the overall pressure. It takes a little math to calculate level, flow, or density.

The standard hydrostatic pressure formula consists of three variables: pressure, density, and height. The sensor measures pressure, density is input as a constant by the customer, and the height is the product level. For this formula to work, density is key and must remain fairly constant. With a known density and pressure value, the pressure sensor’s electronics can accurately and reliably calculate liquid level from the differential pressure.

**Electronic Differential Pressure**

A desire to do things better and more efficiently has led to the creation of electronic differential pressure, using an innovative combination of software and hardware. This system uses two individual pressure sensors mounted directly to the vessel or tank, connected by a small electrical cable. This setup forgoes the traditional dual sided transducer and the need for impulse or capillary lines, making installation and maintenance easier.

The principle of electronic differential pressure works the same as a single transducer, using two different pressure outputs to determine the differential pressure. This method just requires a little more math to get to the level output. One pressure transmitter is the primary, providing the overall measurement of the product and the vapor space, and the secondary provides a singular pressure measurement of the vapor space for the primary sensor. The primary transmitter uses simple calculations to subtract the two, essentially removing the vapor space from the equation, and then doing a little more math using the hydrostatic formula to provide a level output.

Electronic differential pressure eliminates the need for impulse lines or capillary lines, which removes any susceptibility to outside influences causing a measurement error. It also opens up the possibilities to better diaphragm options like ceramic, which is abrasion resistant and better-suited to withstand harsh environments. Avoiding impulse or capillary lines.
illary lines and using a measurement cell ten times harder than stainless steel can prolong accurate level measurements with minimal to no maintenance.

Two separate pressure sensors working in tandem also allows for new ways of doing things, including density compensated level. This particular output uses two pressure measurements to constantly calculate density, then use the latest density to calculate continuous level. Density compensated level is ideal for measuring liquid level when the fluid properties are constantly changing in a process.

**Wort, Yeast and Density**

Near the end of the beer-making process, wort (unfermented beer) is piped into fermentation tanks. As the sugary wort is filling the vessel, yeast is slowly added. The yeast's job is to convert the sugars in the wort into alcohol and produce the flavors and carbon dioxide we expect from beer. This is an important step for brewers, so it requires an important measurement.

When the wort makes its way into one of these fermentation tanks, it arrives at a certain, known density. As the wort reacts with the yeast, the density decreases. Brewers can use electronic differential pressure to detect the changing density.

For example, Figure 3 shows two VEGABAR pressure transmitters connected by a cable installed on a vessel – one near the bottom and another near the top. These sensors monitor pressure in both places, and using the pressure formula, they can calculate the density in real-time and provide it as an output.

This virtual window into the fermenter allows brewers to ensure each brew is consistent. Whether a consumer orders a draft from a tap or brings home a case from the grocery, every beer will be identical in every way a beer should.
More than One Way to Get a Measurement (and Brew Beer)

Like beer, traditional differential pressure measurement has been around a long time. One has stood the test of time because it’s a refreshing beverage, and the other because it’s a versatile technology that uses a single measurement to provide a variety of outputs, including level. Electronic differential pressure doesn’t eliminate the need or usefulness of traditional differential pressure. It only expands upon the value differential pressure measurements can provide. Each method has its benefits and drawbacks, and users must decide what measurement they’re trying to better understand within their process.

Accuracy and consistency have only been improved upon with better sensors and electronics like VEGA’s VEGADIF 85 (Figure 4). The measurement’s versatility is only matched by the sensor, which has customizable options, including multiple housing positions, allowing this sensor to go where previous differential pressure sensors couldn’t fit. Additionally, electronic differential pressure using VEGA’s VEGA-BAR 82 can do all of this and more, opening up even more measurement options to processors. All of this demonstrates how differential pressure will continue to prove itself useful now and for much longer into the future.

ABOUT THE AUTHOR

Jeff Brand is a product manager at VEGA Americas responsible for pressure, switching and capacitance probes. He has more than 12 years of experience with industrial automation and sales, nine of which have been spent with VEGA Americas. Brand has a background in engineering mechanics, automation and instrumentation.
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Some processes do not require temperature measurement accuracy, and others do. However, you may be unsure whether accuracy is important for your particular application, or whether improving accuracy will make enough of a difference in your process results to justify the cost and effort. This paper identifies problems that result from inaccurate measurements and outlines ways to solve them that are both effective and economical.

Temperature measurements can be categorized into three groups:

1) Those which do not require accuracy. You simply need to know if the temperature is stable or going up or going down.
2) Those which do require accuracy. Strategies in this paper will help with those measurements.

3) Those where there is uncertainty about the accuracy requirement. If the measurements in this category are on a Preventive Maintenance schedule for calibration or verification, you may want to take steps to improve accuracy. The same steps we take to achieve higher accuracy also result in reduced drift, and that would have a positive impact on your maintenance frequency.

Improving accuracy and reducing measurement drift are often related and can have measurable results. This paper shows how to:

- Select the best sensor for the application
- Reduce errors caused by external environment
- Reduce errors caused by lead wires
- Reduce measurement errors

**Sensors and Accuracy**

There are times when the temperature sensor is selected based on convenience, what is on the shelf or the “plant standard.” It is not uncommon to see a Type J or K thermocouple measuring a temperature that should be measured with a Platinum RTD. ASTM and IEC temperature standards provide us with sensor measurement uncertainty. If we pick a sample temperature of 500°F (260°C), the uncertainty of a standard grade J or K thermocouple is ±4°F (±2.2°C) while a Class A 100Ω Pt RTD has an uncertainty of ±1.2°F (±0.67°C).

Many process engineers and technicians prefer RTDs. Selecting the best sensor for the application greatly affects the accuracy of the measurement and an RTD is the most accurate sensor to use when the process temperature is within its measuring range. But you will need to use less accurate thermocouples when you need to measure temperatures that are hotter than the RTD’s upper measuring limits. In these instances you will want to take specific steps with thermocouples to improve the accuracy of the measurement results.

You can improve sensor accuracy by using thermocouples constructed with Special Tolerance (also called Premium Grade) wire. The reduced error is achieved by using wire with higher purity alloys. At 500°F (260°C), the uncertainty of a Special Tolerance thermocouple is about ±2.0°F (1.1°C).

Sensor selection is very important to measurement accuracy. As stated above, a Class A Pt RTD uncertainty is about ±1.2°F (±0.67°C) at the same operating temperature. To simplify the process of choosing a sensor, you can operate from the assumption that changing from a Standard Grade thermocouple to a Premium Grade thermocouple cuts the error rate in half; changing from a Premium Grade thermocouple to a Class A RTD cuts the error in half again.
The Role of Thermocouple Extension Wire

Thermocouples wired back to a PLC or DCS must use thermocouple extension wire. Unfortunately the extension wire is yet another source of measurement error. Using standard grade J or K extension wire also adds another ±4°F (±2.2°C) error. You can cut the error rate by using premium grade extension wire, which has half the error rate of standard extension wire, just as with premium thermocouples. (These error figures are only true when the wire is new and “pure.”) Over time the error gets worse as the wire gets contaminated from the atmosphere in your plant and the wire is exposed to temperatures greater than or lower than the wire tolerances. There are many instances where contamination causes even more “drift” than the original uncertainty of new thermocouple wire.

If the uncertainty caused by thermocouples was a fixed offset, we could simply calibrate it out and be done with it. But when the error is in the form of drift that changes over time, calibration becomes a Preventive Maintenance program that few want to take on. Most plants prefer to avoid that extra labor whenever possible.

How do you solve these problems? Start by determining how much error is caused by the thermocouple extension wire. Most people overlook this option until Plant Operations declares there is a problem or a catastrophic measurement failure occurs. We all know thermocouples fail, but it is easy to forget that thermocouple extension wire also fails. When it does, it has to be replaced. If you replace the extension wire with new extension wire, you perpetuate the same problems by reintroducing the error and drift it causes. You may have to live with thermocouples, but you don’t have to live with thermocouple extension wire – you can replace it with other solutions.

Two options for replacing thermocouple extension wire are temperature transmitters and remote I/O hardware. (Figure 1) Both use copper wire to transport their signals back to the control system. Unlike thermocouple extension wire, you can expect the copper to last the life of the plant. Modern I/O products have performance characteristics similar to transmitters and can save a lot of money. You still need short sections of extension wire when you use these transmitters or I/O products. Use special grade thermocouple wire instead of standard extension wire in these cases to further minimize the error.

Compensating for RTD Lead Wire Inaccuracies

Copper wire is used for RTD lead wires. If you are familiar with 3-wire RTDs you know one lead is called the compensating lead. Between copper and a compensating lead you might believe that RTD lead wire does not contribute to the measurement error.
Unfortunately, this is not true. Copper wire can cause significant error in an RTD measurement because RTDs are resistors and copper wire is resistance. There are many contaminants in a typical process plant that cause corrosion and this corrosion changes the resistance of the copper lead wires. This resistance change in the lead wire can cause error. To eliminate lead wire error the solution is to use 4-wire RTDs.

Here is why: When a third lead wire is added to the RTD (Figure 2), the measurement is made with today’s electronics by taking two voltage measurements (as shown, V1 and V2). The important thing to remember is that these are high impedance voltage measurements. For all practical purposes, there is no current flow through that third lead; thus R2 never enters into the equation.

V1 gives the value of the lead wire resistance R1. V2 gives the value of the RTD + R4 lead resistance. Subtract V1 from V2 and as long as the lead resistances R1 = R4, only the value of the RTD remains. This is an accurate measurement.

Realize that too many things work against making R1 and R4 identical when accuracy is your primary concern. Wire gauge intolerance and work hardening varies the resistance. Even if no human error takes place during installation, corrosion constantly works against the measurement and is the main reason R1 never equals R4. So what happens if the lead’s resistances are not equal?

If the resistance imbalance is as little as 1 ohm, a 100Ω Pt RTD has an error of about ±4.7°F (±2.6°C). If you are trying to achieve a ±1°F (.55°C) measurement accuracy, this corrosion is standing between you and success. You can spend your life calibrating this error out or eliminate the error totally with a 4-wire RTD (Figure 3).
Remember the voltage measurement is high impedance so, for all practical purposes, there is no current flow thru R2 and R3 and no voltage drop in a 4-wire RTD. The voltage is only measured across the RTD. R1 and R4 are never measured, thus they cannot create a differential resistance and an error. When using 4-wire RTDs, for all practical purposes, there is no error caused by the lead wire.

4-wire RTDs can have a lead wire of any length and the leads can undergo constant resistance change and still cause no measurement error. It is still important to ensure your total resistance does not exceed the drive capacity of your constant current source. Typically modern day temperature transmitters offer enough current drive to support RTD circuits that have up to 3-4K ohms of total resistance. With lead wire error eliminated you are able to focus on the sensor and measuring device to further reduce error.

The only reasonable objection to using the 4-Wire RTD is that the existing legacy input card only accepts 3-wire RTDs. This is old technology and should be considered for replacement.

There is another option to consider if you are not able to use 4-wire RTDs: switch from 100Ω Pt RTDs to 1000Ω Pt RTDs. As stated earlier in this paper, 1Ω of resistance imbalance in the current carrying legs of a 100Ω Pt element produces about ±4.7°F (±2.6°C) error. If you change to a 1000Ω sensor that same 1Ω of imbalance will have one-tenth of the effect. The 1Ω of imbalance error drops to about ±0.47°F (±0.26°C).

While the use of the 1000Ω 3-wire RTD is a big improvement over the use of a 100Ω 3-wire RTD, it is not a panacea. When the lead wire resistance imbalance changes, that causes the measurement accuracy to change. That means you still need a calibration program to temporarily eliminate the error. The 4-wire RTD is still the single best solution because it removes all lead wire error and eliminates the need to calibrate due to the inevitable corrosion.

How Plant Noise Affects Accuracy
VFDs, motors and radios create “normal” levels of EMI and RFI which can cause errors on temperature measurements. Thermocouple and RTD signals are very low level mV signals. It does not take much noise to cause significant distortion of the measurements. If you are wiring these low level signals back to
the control system, use best practices to keep noise off these signal wires by using drain wires, proper grounding and physical separation.

A better solution is to convert the low level signals to high level signals as close to the temperature sensor as possible. The same amount of noise will affect high signals less than low level signals. Signals like 4-20mA, HART or RS-485 survive most typical levels of noise.

**The Temperature Measurement Device and Remote I/O**

When you finally get to the actual temperature measurement device your ability to make significant improvements to accuracy has passed. Modern temperature transmitters and temperature I/O systems from major instrument companies have similar performance specifications. If you are trying to differentiate the finer points you might compare these specifications:

- The greater the input resolution the measuring circuit can detect, the smaller the changes in the sensor’s temperature can be detected
- Long term drift spec is a measure of the transmitter’s stability
- RTD Excitation current should be low to minimize the self-heating error
- Seek the highest Input Impedance possible so that the measuring device does not draw current
- Advanced diagnostics help to predict failures

If you are pursuing the very highest accuracy, you have to deal with the final “as built” error in the RTD. The transmitter can be used to calibrate out that final offset error and match you to the ideal curve. Such a process delivers a typical transmitter and sensor combined accuracy of less than 0.05% of span.

Putting a temperature transmitter or remote I/O near your sensor digitizes your temperature measurement. You create two more errors if you then send that signal back to the control or data acquisition system using 4-20mA:

1. D/A error occurs when creating the 4-20mA
2. At the control system, an A/D error occurs when turning the signal back to digital Using the HART digital signal is one way to avoid the conversion errors. MODBUS Serial or MODBUS over Ethernet is another option to keep the measured value digital.
In summary, using transmitters and remote I/O helps:

- Eliminate errors caused by thermocouple extension wire
- Avoid errors caused by noise
- Keeps the signal digital and avoids the analog conversion errors

If you are direct wiring temperature sensors back to the DCS or PLC, it likely means that you did not want to pay for temperature transmitters for each of those data acquisition points. If you use modern remote I/O instrumentation instead, you will actually save money on instrumentation and wiring. It has the same accuracy, ambient temperature specifications and sometimes similar hazardous area certifications as you would find on temperature transmitters at a fraction of the cost. The remote I/O digitizes all the temperatures and can deliver them as 32-bit floats to the DCS or PLC MODBUS port using your choice of physical layers. Remote I/O also eliminates thermocouple extension wire and all the associated drift, errors and replacement costs.

**Practical Steps to Improve Your Measurements**

In conclusion, here are a few practical steps you can take to improve your temperature measurement accuracy. Remember that these steps also improve the stability of your measurement, which minimizes your calibration expenses.

- 4-wire RTDs eliminate the errors caused by the copper lead wire
- Use premium grade thermocouples and premium grade extension wire if the temperature to be measured requires the use of thermocouples
- Be sure to use noise protection installation techniques whenever you have long extension wire runs
- Mount transmitters or remote I/O as close to the sensors as possible in order to get rid of long thermocouple extension wire runs which are an error source, have a finite life, and are expensive to replace
- Get rid of the final RTD offset error by bath calibrating
- Buy the highest accuracy and highest stability transmitter or I/O you can afford
- Once you have spent all that money to get your signal digital, keep it digital so there are no more errors introduced

**ABOUT THE AUTHOR**

Gary Prentice is the National Sales Manager at Moore Industries. He has a BSEE from Lafayette College in Pennsylvania and more than 40 years of experience in the process control industry.
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Temperature is one of the four most common types of loops. While the other common loops (flow, level, pressure) occur more often, temperature loops are generally more difficult and important. It is the single most frequently stated type of loop of interest to users, and the concern for better control extends to the widest variety of industries.

Temperature is a critical condition for reaction, fermentation, combustion, drying, calcination, crystallization, extrusion, or degradation rate and is an inference of a column tray concentration in the process industries.

Tight temperature control translates to lower defects and greater yields during seeding, crystal pulling, and rapid thermal processing of silicon wafers for the semiconductor industry.
For boilers, temperature is important for water and air preheat, fuel oil viscosity, and steam superheat control. For incinerators, an optimum temperature often exists in terms of ensured destruction of hazardous compounds and minimum energy cost. For heat transfer fluids, such as cooling tower, chilled water, brine, or Therminol, good temperature control minimizes upsets to the users.

Good temperature control is important during the research, reaction, separation, processing, and storage of products and feeds and is thus a key to product quality. It is also of importance for environmental control and energy conservation.

Curiously, the slowness of the response of the temperature process is the biggest source of problems and opportunities for tight temperature control. The slowness makes it difficult to tune the controller because the persistence and patience required to obtain a good open- or closed-loop test exceeds the capability of most humans. At the same time, this slowness, in terms of a large major process time constant, enables gain settings larger than those permissible in other types of loop except for level.

Once a properly implemented temperature loop is correctly tuned, the control error is often less than the tolerance (error limits) of the sensor. If one considers the accumulated error of an installed thermocouple or RTD system is about five times larger than the error limits of the sensor, one realizes system measurement error seriously limits temperature loop performance.

**Thermocouples and Resistance Temperature Detectors**

In the process industry, 99% or more of the temperature loops use thermocouples or resistance temperature detectors (RTD). The RTD provides sensitivity (minimum detectable change in temperature), repeatability, and drift that are an order of magnitude better than the thermocouple, as shown in the table, “Accuracy, Range, and Size of Temperature Sensing Elements.” Sensitivity and repeatability are two of the three most important components of accuracy. The other most important component, resolution, is set by the transmitter. Drift is important for extending the time between calibrations. The data in this table dates back to the 1970s and consequently does not include the improvements made in thermo-

### Table 1 — Accuracy, Range, and Size of Temperature Sensing Elements

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Thermocouple</th>
<th>Platinum RTD</th>
<th>Thermistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability (°C)</td>
<td>1 - 8</td>
<td>0.02 -0.5</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>Drift (°C)</td>
<td>1 - 20</td>
<td>0.01 - 0.1</td>
<td>0.01 - 0.1</td>
</tr>
<tr>
<td>Sensitivity (°C)</td>
<td>0.05</td>
<td>0.001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Temperature range (°C)</td>
<td>-200 - 2000</td>
<td>-200 - 850</td>
<td>-100 - 300</td>
</tr>
<tr>
<td>Signal output (volts)</td>
<td>0 - 0.06</td>
<td>1 - 6</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Power (watts at 100 ohm)</td>
<td>$1.6 \times 10^{-7}$</td>
<td>$4 \times 10^2$</td>
<td>$8 \times 10^{-1}$</td>
</tr>
<tr>
<td>Minimum diameter (mm)</td>
<td>0.4</td>
<td>2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
couple sensing element technology and premium versus standard grades. However, the differences are so dramatic that the message is still the same.

Table 1, “Accuracy, range, and size of temperature sensing elements,” includes data on thermistors, which have seen limited use in the process industry despite their extreme sensitivity and fast (millisecond) response, primarily because of their lack of chemical and electrical stability. Thermistors are also highly nonlinear, but this can be addressed by smart instrumentation.

For bare sensing elements, thermistors have a much faster response than thermocouples, which are slightly faster than RTDs. This point rarely comes into play because for most industrial processes a 1- or 2-second additional lag time in a temperature loop is well within the uncertainty of the loop’s dynamics. The secondary process time lags can easily change by 10 to 20 seconds for slight changes in operating conditions. Also, once these sensing elements are put inside a thermowell or protection tube (a closed-end metal tube that encapsulates and protects a temperature sensor from process flow, pressure, vibration, and corrosion), the fit, fill, material, and construction of the thermowell have the biggest impact on temperature measurement time lags. This is shown in Table 2, “Dynamics of Bare Sensing Elements” and Table 3, “Dynamics of Thermowells.”

Protection tubes, like thermowells, provide isolation of the element from the process, but unlike thermowells, protection tubes do not necessarily provide a pressure-tight attachment to a vessel, a tapered or stepped wall, or a tight fit of the element. Protection tubes may be ceramic for high-temperature applications. The measurement lags from protection tubes are generally larger than for thermowells.

There are many stated advantages for thermocouples, but if you examine them more closely, you realize they are not as important as perceived for industrial processes. Thermocouples are more rugged than RTDs. However, the use of good thermowell or protection-tube design and installation methods makes an RTD sturdy enough for even high-velocity stream and nuclear applications. Thermocouples appear to be less expensive until you start to include the cost of extension lead wire and the cost of additional process variability from less sensor sensitivity and repeatability.

### Table 2 — Dynamics of Bare Sensing Elements

<table>
<thead>
<tr>
<th>Bare sensing element type</th>
<th>Time constant (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermocouple 1/8-inch sheathed and grounded</td>
<td>0.3</td>
</tr>
<tr>
<td>Thermocouple 1/4-inch sheathed and grounded</td>
<td>1.7</td>
</tr>
<tr>
<td>Thermocouple 1/4-inch sheathed and insulated</td>
<td>4.5</td>
</tr>
<tr>
<td>Single Element RD 1/8 inch</td>
<td>1.2</td>
</tr>
<tr>
<td>Single Element RTD 1/4 inch</td>
<td>5.5</td>
</tr>
<tr>
<td>Dual Element RTD 1/4 inch</td>
<td>8.0</td>
</tr>
</tbody>
</table>
The minimum size of a thermocouple is much smaller. While a tiny sensor size is important for biomedical applications, miniature sensors are rarely useful for industrial processes.

The main reason to go to a thermocouple is if the temperature range is beyond what is reasonable for an RTD or you do not need the accuracy of an RTD. Thus, for temperatures above 850°C (1500°F), the clear choice is a thermocouple for a contacting temperature measurement. For temperatures within the range of the RTD, the decision often comes down to whether the temperature is used for process control or just the monitoring of trends. If you have lots of temperatures for trending in which errors of several degrees are unimportant, you could save money by going to thermocouples with transmitters mounted on the thermo-well (integral mount) or nearby. If you are using temperature for process control, data analytics, statistical or neural network predictions, process modeling, or in safety systems, a properly protected and installed RTD is frequently the best choice for temperatures lower than 500°C (900°F). At temperatures above 500°C, changes in sensor sheath insulation resistance has caused errors of 10°C or more.

### Tuning Temperature Loops

The process time constant for continuous temperature loops on volumes and columns is so large that the temperature ramps in the time horizon of interest and the process can be approximated as “Near Integrating.” Temperature loops on batch processes have a “True Integrating” response. In both cases, the

---

**Table 3 — Dynamics of Thermowells**

<table>
<thead>
<tr>
<th>Process fluid Type</th>
<th>Fluid velocity (feet per second)</th>
<th>Annular clearance (inches)</th>
<th>Annular fill type</th>
<th>Time constant (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>5</td>
<td>0.04</td>
<td>Air</td>
<td>107 and 49</td>
</tr>
<tr>
<td>Gas</td>
<td>50</td>
<td>0.04</td>
<td>Air</td>
<td>93 and 14</td>
</tr>
<tr>
<td>Gas</td>
<td>150</td>
<td>0.04</td>
<td>Air</td>
<td>92 and 8</td>
</tr>
<tr>
<td>Gas</td>
<td>150</td>
<td>0.04</td>
<td>Oil</td>
<td>22 and 7</td>
</tr>
<tr>
<td>Gas</td>
<td>150</td>
<td>0.02</td>
<td>Air</td>
<td>52 and 7</td>
</tr>
<tr>
<td>Gas</td>
<td>150</td>
<td>0.005</td>
<td>Air</td>
<td>17 and 8</td>
</tr>
<tr>
<td>Liquid</td>
<td>0.01</td>
<td>0.01</td>
<td>Air</td>
<td>62 and 17</td>
</tr>
<tr>
<td>Liquid</td>
<td>0.1</td>
<td>0.01</td>
<td>Air</td>
<td>32 and 10</td>
</tr>
<tr>
<td>Liquid</td>
<td>1</td>
<td>0.01</td>
<td>Air</td>
<td>26 and 4</td>
</tr>
<tr>
<td>Liquid</td>
<td>10</td>
<td>0.01</td>
<td>Air</td>
<td>25 and 2</td>
</tr>
<tr>
<td>Liquid</td>
<td>10</td>
<td>0.01</td>
<td>Oil</td>
<td>7 and 2</td>
</tr>
<tr>
<td>Liquid</td>
<td>10</td>
<td>0.055</td>
<td>Air</td>
<td>228 and 1</td>
</tr>
<tr>
<td>Liquid</td>
<td>10</td>
<td>0.055</td>
<td>Air</td>
<td>4 and 1</td>
</tr>
</tbody>
</table>
short cut tuning method can be used where the maximum percent change in ramp rate in four deadtime intervals divided by the change in percent controller output is the integrating process gain. The short cut method reduced the tuning test time from 10 hours to 10 minutes for a bioreactor. The controller gain for maximum disturbance rejection is approximately one half the inverse of the product of this integrating process gain and the observed total loop deadtime. The reset time is simply four times the deadtime, and the rate time is set equal to the thermowell lag time. For a fast setpoint response with minimal overshoot, either a smart bang-bang control or a combination of setpoint feedforward and a PID structure with proportional action on PV rather than error can be used.

**Resistance Temperature Detectors (RTD)**

RTDs operate on the principle that the electrical resistance of a metal increases as temperature increases, a phenomenon known as thermoresistivity. A temperature measurement can be inferred by measuring the resistance of the RTD element. The thermoresistive characteristics of RTD sensing elements vary depending on the metal or alloy from which they are made.

**Wire-wound RTD Sensing Elements**

Wire-wound RTD sensing elements are constructed by coiling a platinum (or other resistance metal) wire inside (internally wound) or around (externally wound) a ceramic mandrel (spindle). Most RTD sensors for the process industry are internally wound and sheathed for protection. A dual-element, wire-wound RTD can be created by coiling a second set of wires inside or outside the ceramic mandrel. If connected to a second transmitter, a transmitter with dual-sensor capabilities, or to another distributed control system
Wire-wound RTD elements are very sturdy and reliable. Compared to thin-film RTD elements, their accuracy tends to be higher, and their time response (how quickly the output reflects the temperature change) is several seconds faster than thin-film RTD elements.

Wire-wound RTD elements work well for a variety of applications, although they may fail in high-vibration applications. Redundant, separate, single-element sensors are recommended for applications in which reliability and accuracy must be maximized. The single element has a lower gauge sensing element and smaller time constant than the dual element. The use of redundant sensors helps eliminate common mode failures and enables a better cross check of sensor drift than dual elements. Three sensors and middle-signal selection reduce noise and drift and provide inherent automatic protection against a single failure of any type.

**Thin-film RTD**

Thin-film RTD sensing elements are constructed by depositing a thin film of resistance metal onto a ceramic substrate (base piece) and trimming the metal to specifications. Sensing elements of thin-film construction are typically less expensive than those of wire-wound construction because less resistance metal is required for construction. However, thin-film RTDs tend to be less stable over time, typically have a more limited temperature range, and may be more susceptible to damage from rough handling.

**Extension Lead Wires**

To get an accurate temperature reading from an RTD, the resistance of the RTD sensing element must be measured. Each copper lead wire that connects the RTD sensing element to the resistance measuring device adds a small amount of resistance to the measurement. If this added resistance is ignored, an error is introduced, and an inaccurate temperature measurement results. The error is referred to as the lead wire effect. The longer the wire run, the greater the error, or lead wire effect, reflected in the temperature measurement. To compensate for lead wire effect, three-wire and four-wire RTDs are used instead of two-wire RTDs. Three-wire RTDs are created by connecting one additional copper wire to one of the lead wires. Four-wire RTDs are created by connecting one additional copper lead wire to each of the existing lead wires. These additional wires are used by the transmitter to compensate for lead wire resistances.

The third wire compensates for the resistance of the lead wires based on the assumption that each wire has exactly the same resistance. In fact, there is a tolerance of 10% in the resistance of standard wires. The fourth wire compensates for the uncertainty in the resistance of wires. For example, 500 feet of 20 gauge cable would add 10 ohms, which would cause a measurement error of 26°C (47°F) for a two-wire RTD. The 10% tolerance of the cable could create an error as large as 2.6°C (4.7°F) for a three-wire RTD. For high-accuracy applications or long-extension wire runs, a four-wire RTD or a transmitter mounted on the thermowell (integral mount) should be used. The increased accuracy, stability, and reliability of microprocessor-based transmitters and the advent of secure and reliable wireless networks make
integral-mounted transmitters an attractive option. Accessibility is less of an issue because maintenance requirements are drastically reduced. The transmitters rarely need removal, wiring problems are gone, and calibration checks and integrity interrogation can be done remotely.

A thermocouple (TC) consists of two wires of dissimilar metals (e.g., iron and constantan) that are joined at one end to form a hot junction (or sensing element). The temperature measurement is made at the hot junction, which is in contact with the process. The other end of the TC lead wires, when attached to a transmitter or volt meter, forms a cold or reference junction.

**Thermocouple Types**

Several types of TCs are available, each differing by the metals used to construct the element. While accuracies are better for type T and E compared to J, the type selected in industry often comes down to the plant standards and the application temperature range. The following are several types of thermocouples:

- Type E-Chromel and constantan
- Type J-Iron and constantan
- Type K-Chromel and alumel
- Types R and S-Platinum and rhodium (differing in the % of platinum)
- Type T-Copper and constantan

Hot junction configurations come in a variety of forms. Junctions can be grounded or ungrounded to the sensor sheath. With dual-element TCs (two TCs in one sheath), the elements can be isolated or connected (“unisolated”). Each configuration offers benefits and limitations:
• Grounding creates improved thermal conductivity, which in turn gives the quickest response time. However, grounding also makes TC circuits more susceptible to electrical noise (which can corrupt the TC voltage signal) and may cause more susceptibility to poisoning (contamination) over time.

• Ungrounded junctions have a slightly slower response time than grounded junctions, but they are not susceptible to electrical noise.

• Unisolated junctions are at the same temperature, but both junctions will typically fail at the same time.

• Isolated junctions may or may not be at the same temperature. The reliability of each junction is increased because failure of one junction does not necessarily cause a failure in the second junction.

The Seebeck Effect

TCs use a phenomenon known as the Seebeck effect to determine process temperature. According to the Seebeck effect, a voltage measured at the cold junction of a TC is proportional to the difference in temperature between the hot junction and the cold junction. The voltage measured at the cold junction is commonly referred to as the Seebeck voltage, the thermoelectric voltage, or the thermoelectric EMF. As the temperature of the hot junction (or process fluid) increases, the observed voltage at the cold junction also increases by an amount nearly linear to the temperature increase.

Cold Junction Compensation

As with RTDs, each type of TC has a standard curve. The standard curve describes a TC’s voltage versus temperature relationship when the cold junction temperature is 0°C (32°F). As mentioned, the cold junc-
tion is where the TC lead wires attach to a transmitter or volt meter. Because the voltage measured at the cold junction is proportional to the difference in temperature between the hot and cold junctions, the cold junction temperature must be known before the voltage signal can be translated into a temperature reading. The process of factoring in the actual cold junction temperature (rather than assuming it is at 0°C [32°F]) is referred to as cold junction compensation.

**Installation**

The best practice for making a temperature measurement is to keep the length of the sensor wiring as short as possible to minimize the effect of electromagnetic interference and other interference on the low-level sensor signal. The temperature transmitter should be mounted as close to the process connection as possible. To minimize conduction error (error from heat loss along the sensor sheath or thermowell wall from tip to flange or coupling), the immersion length should be at least 10 times the diameter of the thermowell or sensor sheath for a bare element. Thus, for a thermowell with a 1 inch outside diameter, the immersion length should be 10 inches. For a bare element with a ¼ inch outside diameter sensor sheath, the immersion length should be at least 2.5 inches. Computer programs can compute the error and do a fatigue analysis for various immersion lengths and process conditions. For high velocity stream and bare element installations, it is important to do a fatigue analysis because the potential for failure from vibration increases with immersion length.

The process temperature will vary with process fluid location in a vessel or pipe due to imperfect mixing and wall effects. For highly viscous fluids such as polymers and melts flowing in pipes and extruders, the fluid temperature near the wall can be significantly different than at the centerline (e.g., 10 to 30°C; 50 to 86°F). Often the pipelines for specialty polymers are less than 4 inches in diameter, presenting a problem for getting sufficient immersion length and a centerline temperature measurement.

The best way to get a representative centerline measurement is by inserting the thermowell in an elbow facing into the flow. If the thermowell is facing away from the flow, swirling and separation from the elbow as can create a noisier and less representative measurement. An angled insertion can increase the immersion length over a perpendicular insertion, but the insertion lengths shown for both are too short unless the tip extends past the centerline. A swaged or stepped thermowell can reduce the immersion length requirement by reducing the diameter near the tip.

**ABOUT THE AUTHOR**

Gregory K. McMillan (Greg.McMillan@Emerson.com) is a retired Senior Fellow from Solutia/Monsanto and an ISA Fellow. McMillan contracts in Emerson DeltaV R&D via CDI Process & Industrial in Austin, Tex. McMillan received the ISA Life Achievement Award in 2010. His expertise and virtual plants are available on the following web site: http://www.modelingandcontrol.com/.
many process plant operations are located in areas where seasonality can be an operational issue. Hot summers alternating with long winters bring severe temperature extremes which can affect equipment of all sorts, particularly the sensors and actuators monitoring process units. Cars are harder to start when temperatures fall below -15 °C (5 °F), valves can stick, and field instruments can fail or lose accuracy.

For purposes of this discussion, we will explore the winter end of the scale. Low temperatures in this context are those common to higher latitudes and elevations where process plants are located, bottoming out at around -40 °C (-40 °F).

Some temperature effects are closely tied to specific numbers. The freezing point of water at 0 °C (32 °F), is a critical one given how much water is around us. When water freezes, hydrogen bonding causes it to expand with force able to burst pipes and crack foundations. Many liquids have lower freezing points, but become more viscous as the temperature goes down. This applies to many oil-based substances including lubricants.

Anyone who has tried to start a car in the cold sees many of these symptoms firsthand. The battery loses power and gasoline is more difficult to change from liquid to vapor. Those old enough to remember the days of cars with carburetors know this well, but today’s cars are much easier to start in the cold because they have been designed to be more tolerant of low temperatures. Fuel-injection systems work well even in below freezing conditions. In the same way, many field instruments and actuators available today are designed to work much better in bad weather than past designs.
Electronics in the Cold

Many electrical devices actually work better in cold weather. The electrical resistance of conductors goes down, and this relationship of temperature and resistance makes sensing technologies such as RTDs and thermistors possible. Many devices such as motors depend on their ability to dissipate heat for peak performance, and can thus operate easily in the cold.

However, problems begin to develop when sophisticated devices, such as the A/D converters and other elements of field device transmitters, were designed with more normal temperatures in mind. The electrical characteristics of semiconductors aren’t always the same at low temperatures, and combinations of dissimilar metals within the circuits can create microscopic thermocouples, with results not always predictable or consistent.

In response, electrical designers have built better circuits and the components have improved so the characteristics are better understood and their effects reduced, as shown in Figure 1. Moreover, most sensor technologies require some degree of thermal compensation in all circumstances.

A capacitive or strain-relief pressure instrument has a temperature sensor built into it already, and most vendors have found ways to increase the effective operating range in both directions on the temperature scale. A sophisticated pressure instrument is probably monitoring ambient temperature via its built-in sensor, and might also measure the temperature of the transmitter’s electronics, as both can affect reading accuracy. Whether you realize it or not, there is probably much happening in the device to ensure an accurate, repeatable reading over the widest possible temperature range.

Fluids are the Bigger Problem

Years ago, people in the north used to “winterize” their cars, which meant changing to thinner motor oil, refreshing the antifreeze and making sure the battery could hold a full charge. A sluggish battery trying to crank a cold engine with thick oil was a challenge. Plant owners in areas where the seasons change drastically from summer to winter face similar issues and winterize strategic pieces of equipment. If they don’t, the first serious cold snap can cause some strategic failures. More than one plant has suffered because a fluid froze and broke a pipe.

One of the perpetual problems when the mercury sinks is frozen impulse lines—those small tubes...
(capillaries) leading from the process penetration point to a pressure instrument, carrying either the process liquid or some other filler material to transmit pressure to the sensor (Figure 2). Those lines allow the sensor and its associated transmitter to be mounted in a location easier to reach than the actual process penetration, or allow one sensor to connect to multiple points some distance apart.

The pressure instrument might be performing various tasks. It could be measuring the actual process pressure, it could be using a differential measurement to calculate flow, or it might be using pressure to measure the level in a tank. Those impulse lines have to be filled with something, either gas or liquid, and are described as dry legs or wet legs, respectively. If the instrument is on a steam line, the fluid is probably condensate.

Differential pressure flowmeters are commonly used for measuring steam flow. The impulse lines are wet legs because steam condenses in them, filling them with condensate. Maintenance technicians often expect these to be impervious to cold weather because they are connected to the steam line, which transfers heat down the metal tubing, usually stainless steel. They’re also normally insulated, at least to some extent. Still, it’s an unhappy surprise if the first hard freeze disables the instrument and maybe ruptures the lines, all because technicians don’t realize how quickly heat can be dissipated.

**Challenges of Steam Lines**

Since the process (steam) and environment are at different temperatures, the temperature along the impulse line will change as heat transfers to the environment. Insulation can slow the change but
can’t stop it. This complicates design when the process is hot and the ambient temperature varies, as is common in outdoor installations. If the impulse line is too short, not enough heat is dissipated in summer, and the instrument can become overheated and damaged. If the line is too long, too much heat dissipates in winter and it freezes.

Figure 3 shows how a typical insulated sensing line (1/4 in., 316 stainless-steel tubing) can cool by 140 °C (250 to 110 °C) in 160 mm (250 ºF in 6 in.) when ambient temperature is 0 °C. At a higher ambient temperature, 40 °C for example, heat dissipation is nearly five times slower, so the same 140 °C heat change happens in 800 mm (30 in.). At an extremely cold temperature—for example -40 °C—heat dissipation is twice as fast, so the same change happens in 80 mm (3 in.).

Problems with these impulse lines often cause maintenance technicians to replace them with oil-filled capillaries. The fluid product in the tubes has a higher molecular weight (MW) than water so it can operate at the full steam temperature without boiling off. Some silicone-based products have boiling points well beyond 300 °C (570 ºF). Unfortunately, the colder end of the line can be a problem. Viscosity becomes an issue with these fill fluids at lower temperatures. Table 1 gives examples of common products and their temperature versus viscosity characteristics.

**Table 1 — Common Fill Fluids: Boiling Point and Viscosity at Selected Temperatures**

<table>
<thead>
<tr>
<th>Fill fluid</th>
<th>Boiling Point °C</th>
<th>Viscosity @ 25°C (cSt)</th>
<th>Viscosity @ 0°C (cSt)</th>
<th>Viscosity @ -25°C (cSt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syltherm XLT</td>
<td>149</td>
<td>1.6</td>
<td>2.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Silicone DC200</td>
<td>205</td>
<td>9.5</td>
<td>16.1</td>
<td>30.7</td>
</tr>
<tr>
<td>Silicone DC704</td>
<td>315</td>
<td>39</td>
<td><strong>183</strong></td>
<td>Solid</td>
</tr>
<tr>
<td>Silicone DC705</td>
<td>370</td>
<td>175</td>
<td><strong>Solid</strong></td>
<td><strong>Solid</strong></td>
</tr>
</tbody>
</table>
When viscosity increases, response time slows down. A 5 m long capillary tube with an internal diameter of 10 mm filled with fluid with viscosity <5 cSt (CentiStokes) slows response time by 1-2 sec. The same system with a fluid viscosity of >150 cSt slows response time by >30 sec. When the fill fluid solidifies, it provides no response at all.

**Finding an All-Season Solution**

If a plant is in a location where it is either hot or cold year-round, it is relatively simple to design a solution. However, where temperatures can swing from -40 to 38 °C (-40 to 100 °F) over the span of a year, the heat dissipation characteristics of impulse lines change drastically with temperature. When using traditional methods, it is very difficult to create a single passive approach capable of avoiding both freezing in winter and overheating in summer.

One common but expensive alternative is adding thermostatically controlled heat tracing on the impulse lines. Usually these systems only add heat during the winter and can avoid overheating in the summer, however they can double or triple the cost of adding a pressure instrument, require energy to operate, and complicate maintenance tasks.

Newer capillary systems are designed to eliminate the need for impulse line heating without slowing response time. As shown in Figure 4, the seal is directly connected to the vessel or pipe containing hot fluid. The design of the seal and its internal copper tubing are optimized to conduct the right amount of heat so the oil remains in a liquid phase with low viscosity for best responsiveness during the winter, but does not conduct so much heat as to damage the transmitter during the summer.

**Figure 4a and 4b:** This thermally-optimized wireless pressure transmitter, shown in full and cutaway views, replaces impulse lines with a sealed tube.
For very hot processes, or where the instrument must be located a greater than normal distance from the process, a two-oil solution may be needed as shown in Figure 5. High MW oil is used adjacent to the hot process. This oil provides high-temperature stability and remains hot enough to ensure fast response time. Low MW oil, such as Syltherm XLT, is used after the intermediate seal where the oil is cooler and runs through the capillary to the instrument. This oil retains its low viscosity below –50 °C for fast response even in the dead of winter.

Eliminating the Root Cause
Steam flow measurement applications in cold climates are one of the most common winter-related problems. One way to eliminate the complexities of impulse lines is to eliminate them altogether. Some flowmeter types are designed as native measuring devices (Figure 6) rather than as an adaptation of a differential pressure instrument. There is no doubt the traditional method works, but dealing with condensate-filled wet legs can remain a maintenance headache.

Integrated flowmeters are built as a single unit designed around a more effective configuration, placing the pressure sensor and transmitter above the steam line rather than below it. They are generally pre-assembled, configured for this specific service, and shipped after being leak tested and calibrated. The heat dissipation components are designed to operate in warm and cold environments.

Based on this standardized approach, it’s a simple matter to calculate the heat transmission characteristics based on the process temperature and typical ambient temperatures. Extreme cases may require additional considerations, but these are not difficult to handle. Above-the-pipe mounting and single-unit construction makes installation easier and less expensive. Since there is no need for heat tracing in most situations, the total installed cost is also lower.

Self Diagnostics
Smart instruments are able to monitor the operation of the device and send data to the control system via protocols such as HART, Foundation Fieldbus, Profibus PA, EtherNet/IP, WirelessHART or ISA100.11a. These capabilities allow monitoring of temperature and the performance of the transmitter to ensure the device is performing its best. Even when used with traditional mounting approaches, a smart instruments can tell the control system when impulse lines are clogged or frozen. It can also let the control system know the ambient temperature, which can be useful for correcting pressure and other measurements.
Figure 6a and 6b: Differential pressure measurements are commonly used to measure flow. These units are configured specifically for this purpose, and thus eliminate many of the problems associated with site-designed impulse lines.

Weather-related problems will exist to some extent as long as oil, natural gas and minerals have to be extracted in difficult environments. In some extreme situations, users may be forced to install heated enclosures where all other simpler approaches fail, but these are declining as field devices become better at dealing with difficult environments. The electronic devices in transmitters are less sensitive to temperature, or do a better job of correcting for it. Modern mechanical configurations of sensors, mounting and piping are also less influenced by cold and heat.

Repairing failed devices in the winter is hazardous, expensive and hard on technicians. Fortunately, the need to perform such tasks is becoming far less frequent. Many technologies are available to help eliminate some of the traditional challenges, and utilizing dual oil fill systems with smart instruments can significantly simplify measurements in cold conditions.

ABOUT THE AUTHOR

Mark Menezes, PE, is the measurement business manager – Canada for Emerson Automation Solutions. Prior positions with Emerson included pressure marketing manager and Toronto sales manager. Menezes holds an MBA in industrial marketing from the Schulich School of Business – York University and a BASC in chemical engineering from the University of Toronto