Measuring Process Temperature in Small Diameter Lines

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Bill

Bill Bergquist, Sr. Applications Engineer
Jeff Wigen, National Account Manager

Jeff

Introduction

Accurate temperature measurement of fluids in 0.25 to 4.0 inch diameter lines can be difficult to achieve . . . Without proper selection and installation, even the most accurate sensing devices can have measurement errors of several degrees.

Installation errors are the most significant error source when measuring temperature in small diameter lines. There are methods to overcome these errors and achieve an accurate measurement. Burns Engineering wrote a paper on this topic which this presentation roughly follows. You may download a copy at http://www.burnsengineering.com/tech-papers/

Why?

- 5.0" and larger diameter lines can typically be effectively measured with a traditional installation
- In most cases this utilizes 4.5" of immersion to achieve a sufficiently accurate measurement
- Obviously smaller diameter lines don't allow for this depth of immersion
- Therefore special installations are required to get accurate temperature measurements

Introduction

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By choosing the proper piping design, selecting the correct sensor, and installing it correctly you can achieve the following in your small diameter line application:

- Higher measurement accuracy
- More consistent, higher quality product
- Fewer start-up and validation issues
- More efficient use of energy

Agenda

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What we'll cover today

- Technologies
- Terms and basic physical principles
- Key factors in selection and installation
- Application and installation details

Technologies

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RTDs/PRTs

- Features
  - Accuracy
  - Traceability
  - Stability
  - Repeatability

Thermocouples

- Features
  - Durability
  - Tip sensitive
  - Time response

The RTD will, in most cases, provide the best combination of accuracy, repeatability, and long term stability. Thermocouples work well for high temperature applications or where extreme durability is required due to vibration or shock present in the process.

Terms and Physical Principles

Accuracy is the degree of conformity of a measured or calculated quantity to its actual (true) value.

- Includes error sources such as interchangeability, hysteresis, drift, self heating, and others.

A quick review of a few terms used throughout this presentation is necessary. Accuracy, interchangeability, time response, and repeatability are the most important.

Terms and Physical Principles

Interchangeability (largest component of accuracy)

- Refers to the “closeness of agreement” in the resistance vs. temperature (R vs. T) relationship of a PRT to a pre-defined nominal R vs. T relationship.

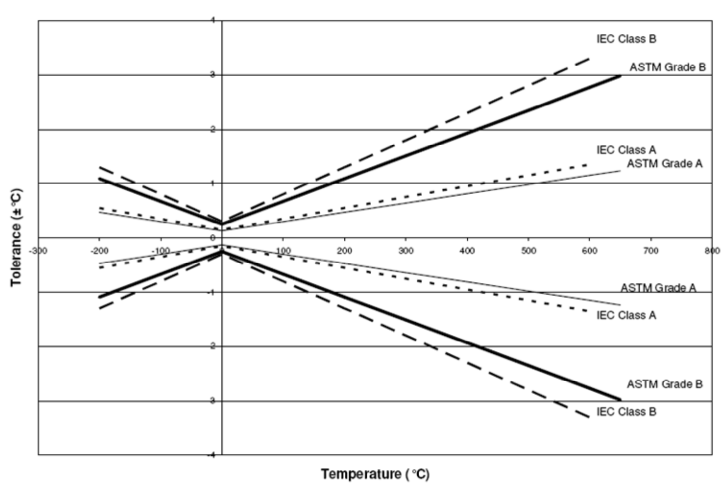
Table 1.1
Standard PRT Interchangeability Equations

Standard	Tolerance Nomenclature	Defining Equation[1]
ASTM E1137	Grade A	$\pm[\,.13 + 0.0017\,\lvert t \rvert\,]$
ASTM E1137	Grade B	$\pm[\,.25 + 0.0042\,\lvert t \rvert\,]$
IEC 60751	Class A	$\pm[\,.15 + 0.002\,\lvert t \rvert\,]$
IEC 60751	Class B	$\pm[\,.3 + 0.005\,\lvert t \rvert\,]$

Note 1: $\lvert t \rvert$ = the value of temperature in °C without regard to sign

Because nothing is perfect, manufacturers require a tolerance band to produce RTDs. ASTM and IEC have created specifications that define some performance characteristics. Interchangeability is the largest component of accuracy and is the target manufacturers shoot for when adjusting the ice point resistance of an RTD sensing element.

Figure 1.1
Standard PRT Interchangeability



This is the graphical form of the tolerance bands for the two RTD standards. The ASTM has slightly tighter tolerances than the IEC standard. When specifying an RTD choose the Class A or Grade A interchangeability for the best out-of-box accuracy.

Terms and Physical Principles

Repeatability

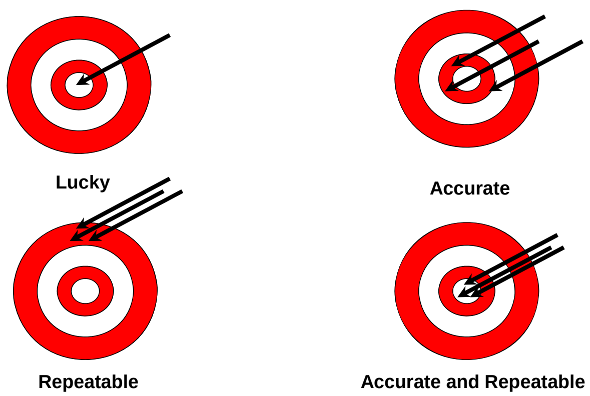
- The ability to give the same measurement under repeated, matched conditions.

Repeatability in Temperature Measurements

- Usually quantified as a percent change of the resistance at 0°C after many cycles through the temperature range.

Next to interchangeability this is the most important RTD performance characteristic. Combined with long term stability these are the most desirable characteristics for an accurate measurement.

Accuracy and Repeatability



An analogy for accuracy and repeatability is illustrated with arrows shot at a target. Hitting the bull's-eye time after time represents good accuracy and repeatability.

Terms and Physical Principles

Time Response

- Getting the sensor to follow as close to the process as possible
- Time constant – time required for the sensor to respond to 63.2% of a step change in temperature while in water moving at 3 fps
- The less thermal resistance between the sensor and the process, the better.
  - Thinner sheaths
  - Direct immersion sensors

Time response can be a large source of error in any temperature measurement. Errors of several degrees are possible if the sensor response does not keep up to the process temperature.

Agenda

Technologies and Scope
Terms and Basic Physical Principals
Key Factors in Selection and Installation
Application and Installation Details

Key Factors in Selection and Installation

Sensor
- Interchangeability
- Stability
- Repeatability

Installation
- Time response
- Stem conduction
- Ambient conditions

Maintenance
- Removable Sensor
  - Calibration
  - Replacement
- Thermowell

Cost
- Goal is to achieve lowest life cycle cost
  - Installation
  - Calibration
  - Replacement

We'll focus on the sensor and installation factors. They represent the majority of the factors affecting measurement accuracy.

Key Factors in Selection and Installation

Calibration
- Matching to RTD
- System

Instrumentation
- Transmitter
- Controller/PLC

Calibration can be used to decrease some of the interchangeability error. Including the measurement system in the calibration loop can improve accuracy by up to 85%.

Key Factors in Selection and Installation

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A good installation will ensure:

- Accurate and repeatable measurements
- High quality product
- Ease at start-up

A poor installation will result in:

- Uncertain product quality
- Wasted energy
- Added uncertainties to the measurement point

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Technologies and Scope
Terms and Basic Physical Principals
Key Factors in Selection
Application and Installation Details

Types of Installations

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Traditional Installation

- Minimum recommended insertion

Surface Mount Sensors

- Non-intrusive, or prepackaged options

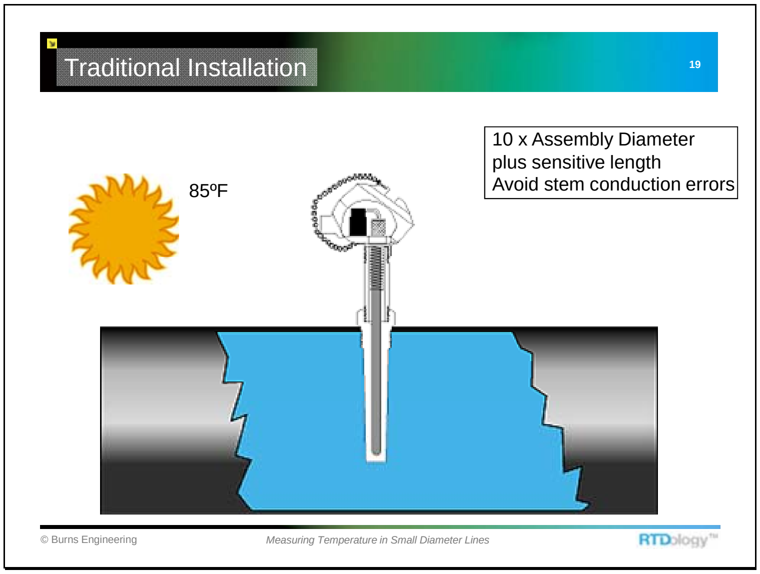
Direct Immersion Sensors

- Different installation considerations

Thermowell Installations

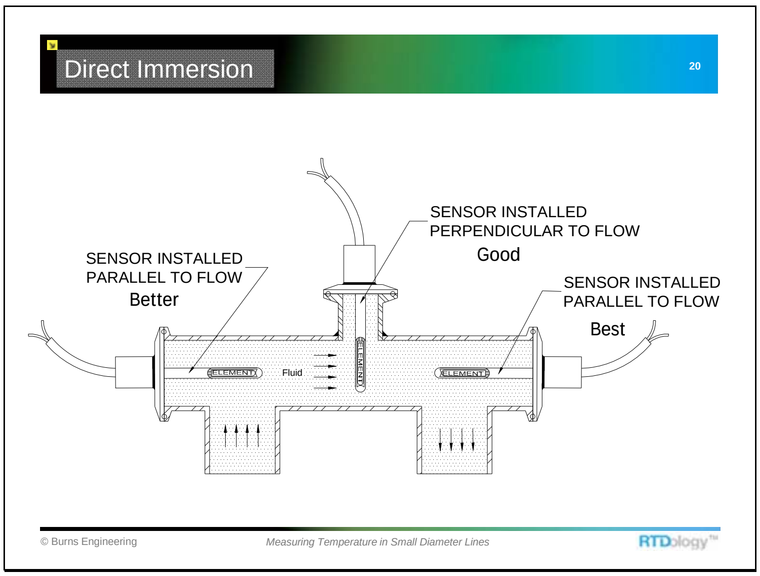
- Also referred to as “indirect immersion”

Next we’ll look at the various types of installations and discuss some of the features and benefits of each.



A rule of thumb for minimum immersion length to avoid stem conduction error is 10 times the probe diameter plus the sensitive length of the probe. Most RTDs have a sensitive length of 1.0”. So for a ¼” diameter RTD the minimum recommended immersion is 3.5”.

Thermowells require about 4.5” as a minimum for best accuracy.



In small diameter lines there is typically not enough room to get the proper immersion length to avoid stem conduction. This illustrates three methods of modifying the piping to provide extra room. The one on the right is the best method because it provides for the flow coming directly at the tip of the sensor for less stress on the probe and it also washes out the dead lag portion of the tee.

Direct Immersion

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Table 3 – Direct Immersion Sensor Advantages and Disadvantages

Advantages	Disadvantages
Fast response time	Installation requires planning
Unaffected by ambient conditions when proper immersion is used	Flow blockage and pressure drop must be considered
Simple installation	Installation could leak
Low cost	Stem conduction effects can be large if proper immersion is not used
	Must drain system to replace sensor

Elbow Style T-Wells

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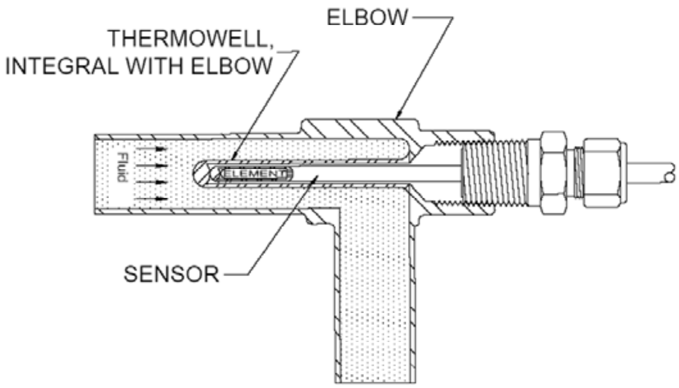

For those applications that require a thermowell, the elbow style works well if sized correctly. An immersion length of at least 4" is necessary to provide an accurate measurement. Shorter immersion lengths will work okay for some process fluids and flow rates.

Elbow Style T-Wells

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Table 4 – Indirect Immersion Sensor Advantages and Disadvantages

Advantages	Disadvantages
Sensor is replaceable without draining the system	Installation requires planning
Less effected by ambient conditions than surface methods	Flow blockage and pressure drop must be considered
No possibility for leaks	Stem conduction effects can be large
Sensor removal will not introduce contaminants into the process	More expensive than direct immersion methods

Surface Mount Installation

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Table 1 – Surface Sensor Advantages and Disadvantages

Advantages	Disadvantages
Simple to use	Slow response time
No line modifications required	Highly influenced by ambient environment
Installation and replacement are easy	Performance variability due to mounting
No need to drain the system to replace	Exposed insulation can be undesirable
Flexibility in location possibilities	
No possibility for leaks	
No foreign material in process	
Low cost	

Surface Mount Installation

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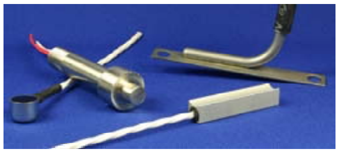
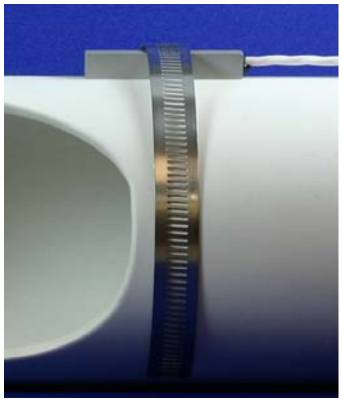
Sensor should be covered with insulation for best accuracy





Surface mount sensors are easy to install and are low cost. Sounds too good to be true, and it is. They generally do not provide a very accurate measurement of the fluid inside the vessel. Improvements can be made with the addition of insulation and the use of a heat transfer paste at the mounting location.

Non-Intrusive

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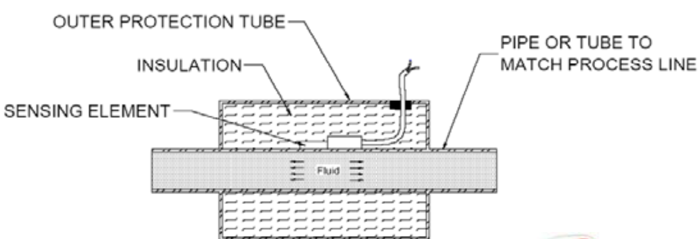

A hybrid form of surface mount sensor is the non-intrusive. A sensing element is bonded directly to the process tubing and insulated with a high efficiency material. A SS cover protects the sensor from ambient conditions. Performance is better than a standard surface mount but is not as good as an immersion style.

Non-Intrusive

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Table 2 – Non-Intrusive Sensor Advantages and Disadvantages

Advantages	Disadvantages
No immersion into process	Response time slower than immersion styles
No obstruction of process flow	Installations require planning
Element mounting and insulating are factory controlled for consistency	Must replace entire pipe section to replace sensor
Clean external envelope	Must drain system to replace sensor
Installation and replacement are easy	Calibration can require special baths
Faster response time than simple surface sensor	More expensive than most other PRT sensor options

Error Sources

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Sensor

- Interchangeability
- Stability
- Repeatability
- And about a half dozen other minor errors

Installation

- Stem conduction
- Time response
- Ambient conditions
  - Airflow
  - Vibration and shock

The main error sources for RTDs used in small diameter lines can be categorized as either sensor related or installation related. We'll discuss the largest of these errors. There are numerous smaller error sources that should be included in any measurement error calculation. For more information on these see our 3 part series on measurement accuracy at http://www.burnsengineering.com/rtdology/

Time Response

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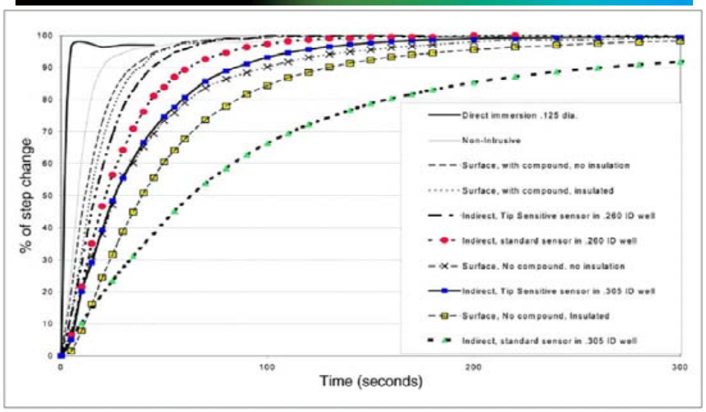

Figure 6. Response time comparison graph.

This graph shows the relative time response difference of the various types of sensors and installation methods. The direct immersion has the fastest response and the slowest is an RTD and thermowell assembly with a sloppy fit of the RTD into the well.
Time response can be a large error if the RTD does not keep up to a rapidly changing process temperature.

Stem Conduction

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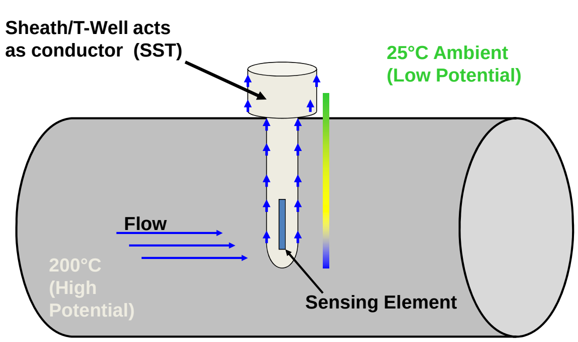
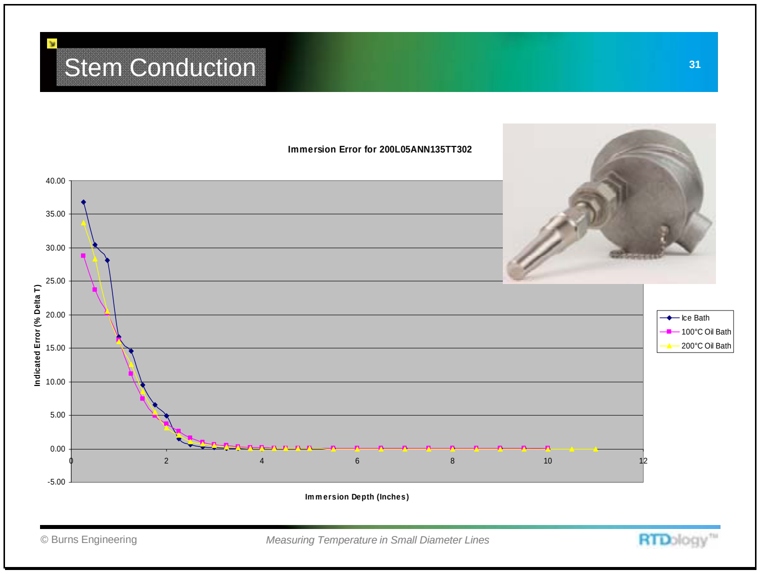
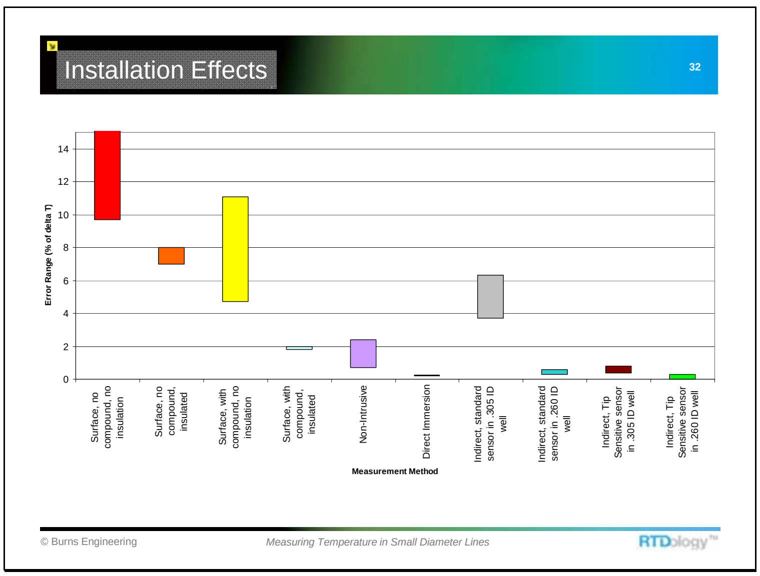


Of all the error sources stem conduction seems to cause the most problems especially in tight locations. A thermowell and RTD assembly requires at least 4.5" of immersion to minimize the error. A direct immersion RTD requires at least 10x the probe diameter plus the sensitive length. Most RTDs have a sensitive length of 1". So for a ¼" diameter RTD the minimum immersion is 3.5".
Insufficient immersion will allow the ambient conditions to have either a heating or cooling effect on the sensing element. Error magnitude increases as the difference in the ambient temperature and the process temperature increase.



A thermowell and RTD assembly was immersed in a bath to determine the stem conduction at various depths. At 4.5 inches most of the error has disappeared. As you can see the error is mostly independent of the bath temperature used. As an example a thermowell with 2.5" immersion gives us an error of about 0.45°C.



Stem conduction or immersion error is shown on this graph for various installation methods and probe types. Surface mount and incorrectly installed RTDs have the largest errors. Direct immersion and properly designed RTD/thermowell assemblies have the least error.

Installation Effects

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Table 5 – Accuracy Test Results for 4 different sensors on ½ inch diameter line
Water at 50°C (ΔT = 28°C), 3 feet per second

PRT sensor type	Error (% of ΔT) No ambient airflow	Error (% of ΔT) With ambient airflow
Surface Sensor – clamped on with:		
No thermal compound, no insulation	9.7%	26.6%
No thermal compound, insulated	7.0%	8.0%
With thermal compound, no insulation	4.7%	11.1%
With thermal compound, insulated	1.8%	2.0%
Non-Intrusive	0.7%	2.4%
Direct immersion (.125 diameter x 1.0 long)	0.2%	0.2%
Indirect immersion (.25 dia PRT):		
.305 ID well – standard PRT	3.7%	6.3%
.305 ID well – Tip sensitive PRT	0.4%	0.8%
.260 ID well – standard PRT	0.3%	0.6%
.260 ID well – Tip sensitive PRT	0.3%	0.0%

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Air flow past the external portions of the sensor can exacerbate stem conduction error. The poorer the installation the more likely that a fan blowing on the assembly can increase the error.

Installation Best Practices

Minimize conduction path between sensor and process
- Small diameter sensor
- Direct immersion
- Tip sensitive sensor in thermowell

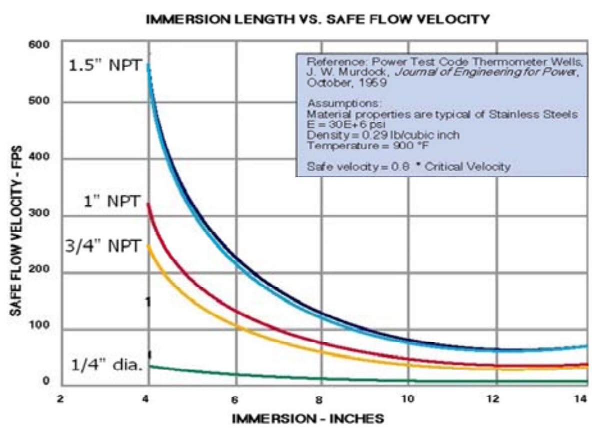
Sufficient immersion
- 10x the diameter (sensor or T-well OD) + sensitive length

Insulation

Heat transfer compound

Follow these recommendations to eliminate large amounts of the error sources.

Installation Best Practices



Just after we told you to get the most immersion possible, we are going to tell you to not make it too much. Flow induced vibration can be a significant problem for high flow rates. When an object such as a temperature sensor is placed in a fluid flow it can start to vibrate if the wake frequency matches the sensor resonant frequency. For a ¼" diameter sensor with a 4" immersion length, the maximum flow rate is about 40 ft/sec. Adding a thermowell increases the flow rate to about 250 ft/sec.
Always evaluate the affect of flow rate on the sensor. Most manufacturers can assist with this calculation.

Sensor Styles

Following are a few styles of sensors that work well in small diameter lines. This one is a direct immersion, 1/8" diameter, 1.1" minimum immersion, with a ½" clamp type sanitary fitting.

This one is an RTD and thermowell assembly that is 3/16” diameter and a 1/8” diameter RTD. At least 1.25” of immersion is necessary for an accurate measurement.

A variation of the direct immersion type has the sensor welded directly into a tube spool piece. The sensor is .083” diameter and has a 1” immersion.

An elbow thermowell works well for line sizes down to ¼”. They can be welded in or installed with clamp type fittings.

Sensor Styles

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The non-intrusive works well for products that are viscous, sticky, or have such a high flow rate that an immersion probe cannot be used.

Sensor Styles

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One of the many types of surface mount sensors available. This one mounts to the pipe with a hose clamp. A radius on the housing matches the tube to improve heat transfer. Addition of insulation and heat transfer compound improves the accuracy.

Summary

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By being aware of potential error sources and following the suggestions outlined in this presentation, you can achieve the following in your small diameter line applications:

- Higher measurement accuracy
- More consistent, higher quality product
- Fewer start-up and validation issues
- More efficient use of energy