
Overview of Thermowells

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Introduction

As Professional Engineers, we are responsible for understanding the projects we are in charge of designing. Recently, many engineers are putting more tasks on their vendors that they would have taken on themselves to understand in the past. Thermowells are an important component in the Basic Process Control System as well as the SIS.

Proper selection of the thermowell is important and there is often a balance to be made in this decision. A thermowell is not a complicated accessory, but improper selection can have catastrophic consequences. This course is intended to be an overview of thermowells, so that you can ask the proper questions of your vendor and you can supply them with the information they need. There will also be an overview of some of the issues and standards involved in thermowell selection. This is meant to be only an overview as standards are constantly changing.

Purpose

A thermowell is a temperature sensor accessory that is a closed end tube providing chemical and mechanical protection for a temperature sensor that is measuring the temperature of a process. The purpose of a thermowell is to protect a contact temperature sensor from damage from corrosion or mechanical failure. Thermowells also allow for sensor removal and replacement without disrupting or depressurizing the process by providing isolation between the temperature sensor and the process environment. The most common sensors used in thermowells are thermocouples or Resistance Temperature Detectors (RTD).

Uses of Thermowells

Thermowells are used extensively in the oil and gas as well as chemical process industries, but that is not where their use started. Traditionally they were used in boilers, which powered steam engines and ships. They have also been used in power applications such as steam power plants.

Types of Thermowells

Thermowells are classified according to type as well as process connection type. Thermowell types are tapered, straight, and stepped.

Tapered

The tapered shank thermowell is the most common type of thermowell. An example is shown in Figure 1. In the tapered thermowell, the outside diameter decreased as the immersion length progresses from the root (near the connection) to the tip.

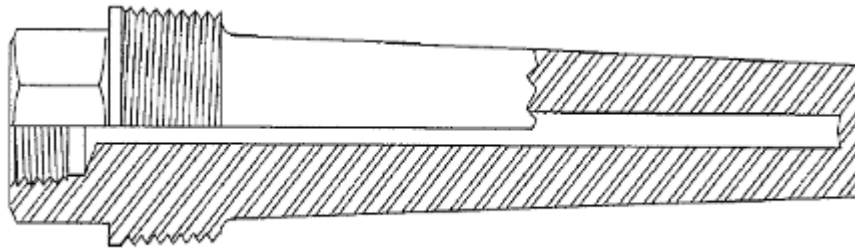


Figure 1. Tapered Shank Thermowell

Straight

The straight shank thermowell has an outside diameter that is the same at the root and at the tip. An example of a straight shank thermowell is shown in Figure 2.

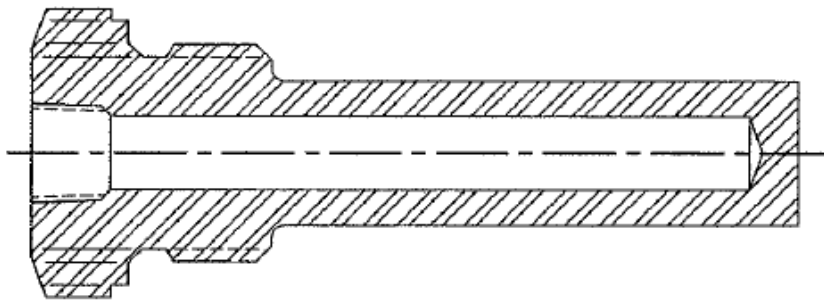


Figure 2. Straight Shank Thermowell

The straight shank thermowell will typically have a slower response time than a tapered shank thermowell of the same root size. This is due to less metal being at the tip of the thermowell near the sensor of a tapered thermowell.

Stepped

Stepped shank, or reduced tip thermowells will have a step down from a larger outside diameter at the root to a smaller outside diameter at the tip. Usually the smaller outside diameter is the last 2 ½ inches. An example of a stepped thermowell is shown in Figure 3.

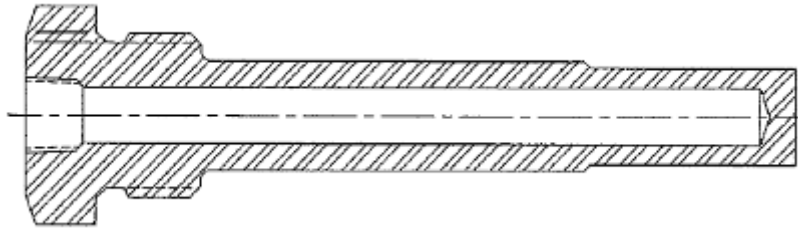


Figure 3. Stepped shank thermowell

The most common tip outside diameter for a stepped thermowell is $\frac{1}{2}$ inch, however ASME PTC 19.3-TW also allows for the use of a $\frac{7}{8}$ -inch tip for a larger root OD. The smaller tip is to provide for a faster response time to temperature changes due to less metal.

Special Types

There are also special types of thermowells for special uses. These special types fall outside what is typically thought of when we think of a thermowell.

- Protection Tubes are typically made of ceramic where they can be used at higher temperatures than most metals. Ceramic protection tubes are not as strong as metal, but do not droop at higher temperatures like metals.
- Pipewells are made of smaller OD pipe and are longer than most thermowells made from machined bar stock.
- Multipoints are made from pipe and contain several points along its immersion length where thermocouples measure the temperature. Multipoints can be inserted into reactors and can be 60 feet long or more in some instances.
- Fixed-beam thermowells can be used in pipes and where it is possible to support at both ends of the thermowell.

In thermowells, the insertion length is referred to as the “U” length. This is the unsupported length of the thermowell shank.

Process Connection Types

There are several standard process connection types available for thermowells. They are:

- Flanged
- Threaded/Screwed
- Van Stone

Figure 5 shows a cutaway drawing of a flanged thermowell.

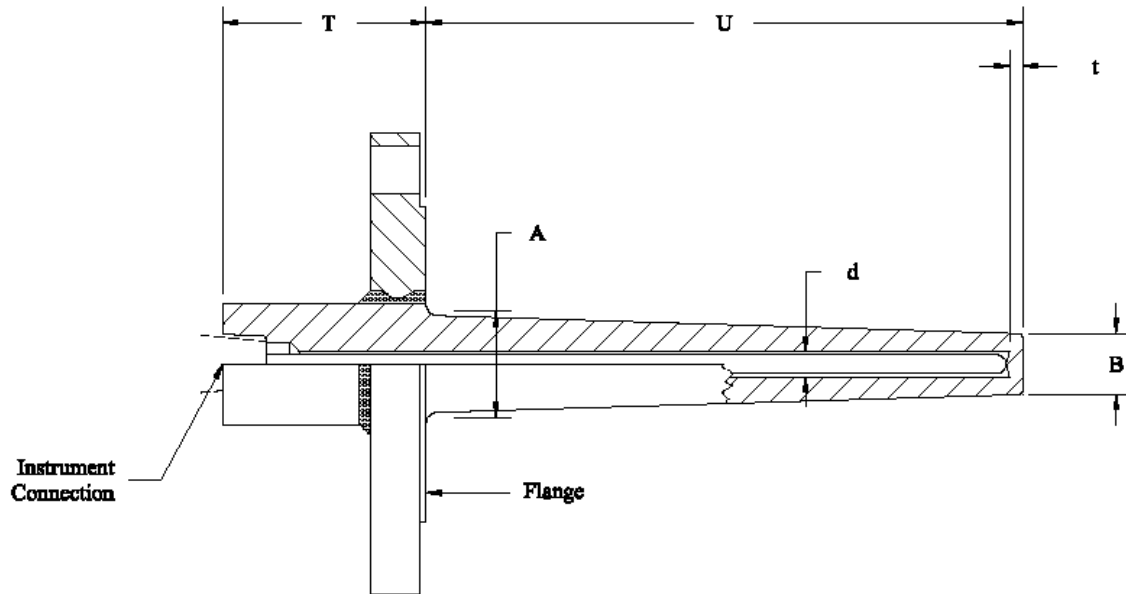


Figure 5. Flanged Thermowell

Figure 5 represents a typical thermowell. For illustration purposes, I have chosen a tapered thermowell with a flanged process connection. There are several parts of the thermowell as indicated by the letters. The parts are defined as follows:

- U: The unsupported length of the thermowell or the insertion length (L in ASME Code)
- T: The lagging extension that typically allows the thermowell to extend through insulation
- A: Outside diameter at the root or support, sometimes called “Q”
- B: Outside diameter at the tip, sometimes called “D”
- d: Bore diameter (for example 0.260” for a ¼” thermocouple element)
- t: Tip thickness

Sanitary thermowells have a finer finish (16-20 R_a) and typically use a Tri-Clamp connector to connect to a sanitary flange. They are typically used in the food and beverage industry.

The most common thread on an instrument connection is ½” NPT. The instrument connection is used to connect the temperature sensor to the thermowell. It is often spring loaded to maintain tip contact with the bottom of the thermowell. The instrument connection is on the side of the thermowell not in contact with the process.

Materials of Construction

Thermowell materials are selected based on many factors. Some of these factors are temperature of the process as well as characteristics of the process fluid. Many vendors have compatibility charts to help select the right material for the process.

Metals

Thermowells are usually made of metal. The metal is selected to be compatible with the process conditions as well as the piping. Most metal producers have technical data sheets with mechanical properties as well as chemical compatibility. Improper selection of the metal can result in failure of the thermowell due to corrosion or erosion.

When selecting a material for a flanged thermowell you should also select the proper flange material. Remember that the flange will be the limiting factor in most cases for the pressure rating. The best practice in material selection is to use the same material for the flange as the stem. This practice can prevent galvanic corrosion. Another important reason for the same material is that some materials like alloy steels and carbon steels may require heat treatment (stress relieve). The heat treat process for one material may not be the same as for another and may actually do more damage than good.

Ceramic

Ceramics are usually chosen for use at high temperature. They are not as strong as metals, but they do not droop at high temperatures.

Protective Coatings

Metallic thermowells are sometimes coated with protective coatings to further protect against corrosion or erosion. Remember that corrosion is a chemical process and erosion is physical process where the metal is being worn away. Coatings should be selected for the process, just like the base metal. A coating suitable for a corrosive environment may not be suitable for an erosive environment.

Standards and Writings

Thermowell Resonance

One of the biggest issues in thermowell design for steady-state conditions is thermowell resonance based on flow-induced vibration. We often refer to this as von Karman vortices, named after Theodore von Karman. Most standards written on thermowells have been due to

flow-induced vibration. Vincenc Strouhal noted in 1878 that the musical tones generated by a wire were proportional to the wind speed across the wire divided by the wire thickness. Lord Rayleigh who used a violin string instead of a wire repeated his results. In 1911, von Karman conducted studies of the stability of the vortex patterns that formed behind a stationary body in a flowing fluid. This phenomenon later became known as the von Karman vortex street.

A thermowell has a natural frequency based on its characteristics. It will also vibrate at a frequency in the process flow based on the flow characteristics. To put it simply, we want to keep the vibration frequency below the natural frequency. A thermowell that vibrates at its natural frequency can fail due to fatigue. If you tap on a thermowell (like a tuning fork), you can hear its natural frequency. You can hear it in process if it is vibrating at this frequency, as it may sound as if it is singing. This is called resonance and the phenomena we want to avoid.

Most of the early studies in thermowell vibration were in steam applications. The Performance Test Code has its roots in the Power Test Code used in boiler design. ASME Power Test Code Supplement on Instruments and Apparatus-Part 3-Temperature Measurement (1929) was the forerunner of the ASME temperature measurement codes we know today. One of the most important people in the development of the thermowell portion of the ASME codes was J. W. Murdock. He was the Superintendent of the Instruments Division of the Naval Boiler and Turbine Laboratory in 1950. The ASME Power Test Code Committee was formed in 1956. Murdock's paper "Power Test Code Thermometer Wells" was published in 1959 in the Journal of Engineering for Power. This paper laid the foundation that would eventually be adopted as the thermowell portion of ASME PTC 19.3 (1974) for thermowells. Murdock's proposed thermowell in the paper was a tapered thermowell. The basic idea of Murdock's calculation is to keep the ratio of the forced frequency to the natural frequency below 0.8. This ratio was chosen based on his conversation with Professor J. P. den Hartog of MIT on the subject. Therefore, the ratio

$$r = f_w / f_n \quad (\text{Eq. 1})$$

Where,

r = Frequency ratio of the thermowell (dimensionless)

f_w = Wake frequency of the thermowell (Hz or cps)

f_n = Natural frequency of the thermowell (Hz or cps)

The maximum velocity for the ASME PTC 19.3 (1974) code calculation is 300 feet per second (fps). The code recommends using a fixed beam type thermowell for velocities above 300 fps.

Another important figure in the study of thermowells also came out of the Navy. John Brock was a Professor of Mechanical Engineering at the Naval Postgraduate School in Monterey, California. He conducted a two-year study of the mechanical and structural integrity of thermowells. In 1974, he published "Stress Analysis of Thermowells." Murdock had assumed a Strouhal number of 0.22 in his work. Brock pointed out that data since Murdock's study indicated that the Strouhal number could be as high as 0.45 for large Reynold's numbers. Brock had also expressed that he felt the frequency ratio should be kept below 0.4.

The nuclear power plant accident at the Monju Fast Breeder Reactor in 1995 was due to the failure of a thermowell that was designed according to the ASME PTC 19.3 (1974) standard. The reactor was sodium cooled and the failure of the thermowell caused a major fire. The sodium coolant was leaked but there was no radioactive materials released. It was later found that the thermowell failure was due to in-line resonance. ASME rewrote the thermowell portion of the ASME PTC 19.3 code to include in-line resonance and released ASME PTC 19.3 TW-2010. It was not confined to tapered thermowells as it also included straight and stepped thermowells. It also did not have the 300 fps maximum that the ASME PTC 19.3 (1974) code had on velocity. The present ASME code for the mechanical analysis of thermowells is ASME PTC 19.3 TW-2016, which was released in early 2016.

When a thermowell fails a calculation, we have two main options to correct the problem as far as the code is concerned. The first option is to make the thermowell shorter. Making the thermowell shorter will result in a higher natural frequency. The drawback is that it may bring the thermowell outside the optimal insertion area in the pipe, which may have an impact on the measurement. The second option is to increase the tip thickness of the thermowell. Increasing the tip results in lower wake frequency. The drawback is that the response time will increase.

Many cases require using a combination of a shorter well and larger tip. There are a few other options, but they are outside the scope of ASME PTC 19.3 TW-2016. They were discussed in Murdock's 1959 paper but were not included in the PTC 19.3 code. One method is locating the thermowell in an elbow with the tip facing upstream. The second is inserting at an angle. The idea behind these methods is that the worst-case scenario is with the thermowell installed perpendicular to the flow. A third one that is considered outside the scope of the code is using collars or rings for support.

In order to perform the calculations, certain information is required about the thermowell as well as the process. The first set of information required is the description of the thermowell. The following is required:

- 1) Process connection type (ie. Flanged, van stone, weld in, threaded, socket weld)
- 2) Root diameter
- 3) Tip diameter
- 4) Bore diameter
- 5) Unsupported length
- 6) shielded length (ie. nozzle length)
- 7) Tip thickness

The next set of information required for calculation is the process conditions. The following is required:

- 1) Temperature of the process fluid
- 2) Pressure of the process fluid
- 3) Velocity in feet per second (fps) or meters per second (mps)
- 4) Density of the process fluid at pressure and temperature given in 1 and 2
- 5) Viscosity of the process fluid

Other Standards

There have been attempts to develop a standard for specifying thermowell types and connections. One was developed by ISA as ISA dS01.02.01 for thermowells. It was never released as a standard. Another was released by ASME under ASME B40.200 (B40.9), but I have not ever seen it specified by a customer. One reason for this may be flow-induced vibration is the main issue when it comes to thermowells which deals with the mechanical design of the thermowell.

API standards consider the thermowell as part of the piping system. The 2007 version of API RP 551 requires a 2 to 5 inch immersion into the process to prevent heat from being conducted away from the sensitive end of the thermowell. It also specifies a 0.66 frequency ratio for high frequency lines citing ASME PTC 19.3, which had a 0.8 frequency ratio limit at the time API RP 551 was reaffirmed in 2007. ASME PTC 19.3 TW-2010 made a 2 to 5 inch immersion more difficult to achieve in some cases.

There are a couple of other notes about these thermowell calculations. They are only valid for metals made from bar stock or forging. API uses a thermowell with the tip cut at a 45-degree angle for a sample probe. These are outside the scope of the ASME PTC 19.3 TW-2016 code. Coatings on thermowells are also outside the code. A coating will tend to change the natural frequency of the thermowell.

Installation

Installation of the thermowell into the piping is an important factor in selecting a thermowell. Insertion into the middle of the pipe is the optimal position, but it is not always possible. Most conventions state that it is best to get into the middle 1/3 of the pipe for best response, in pipes larger than 3 inches in diameter. Figure 6 shows insertion of a thermowell into a pipe larger than 3 inches. The area labeled as “middle 1/3” is the area of best response, so this is the target area for the tip of the thermowell.

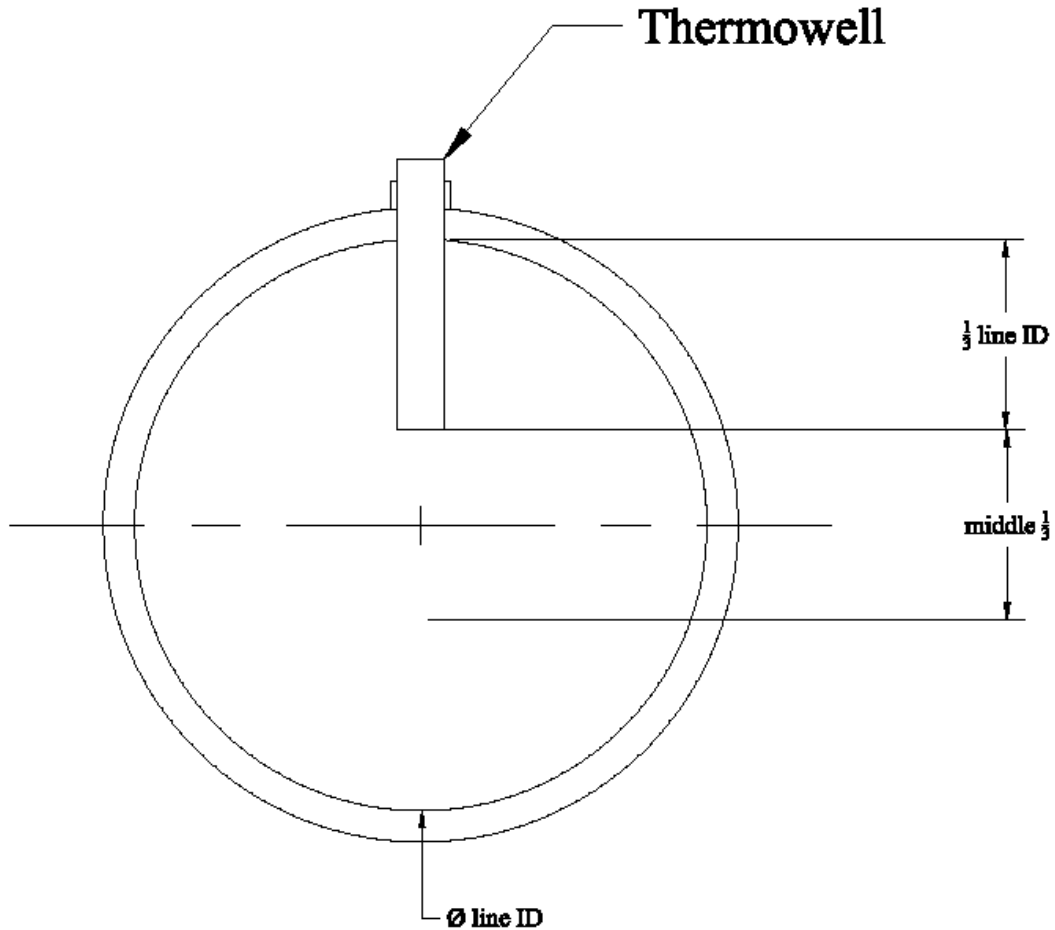


Figure 6. Insertion of the thermowell in pipe larger than 3 inches

In pipes that are smaller than 3 inches in diameter there are a couple of methods that can be used put forth in Cornell. They each have advantages and limitations. We have to take these differing approaches since our typical thermowell would block the pipe if it were to be inserted like in the larger lines. A thermowell is to assist in measurement and not represent an obstruction to flow.

One method to insert a thermowell in a line less than 3 inches in diameter is to locate the thermowell in an elbow. This method was proposed by Kamarck in Murdock's 1959 paper and is often used in high velocity applications. Figure 7 illustrates a thermowell installed in this configuration. The tip of the thermowell is installed to where it points in the opposite direction of the process fluid flow.

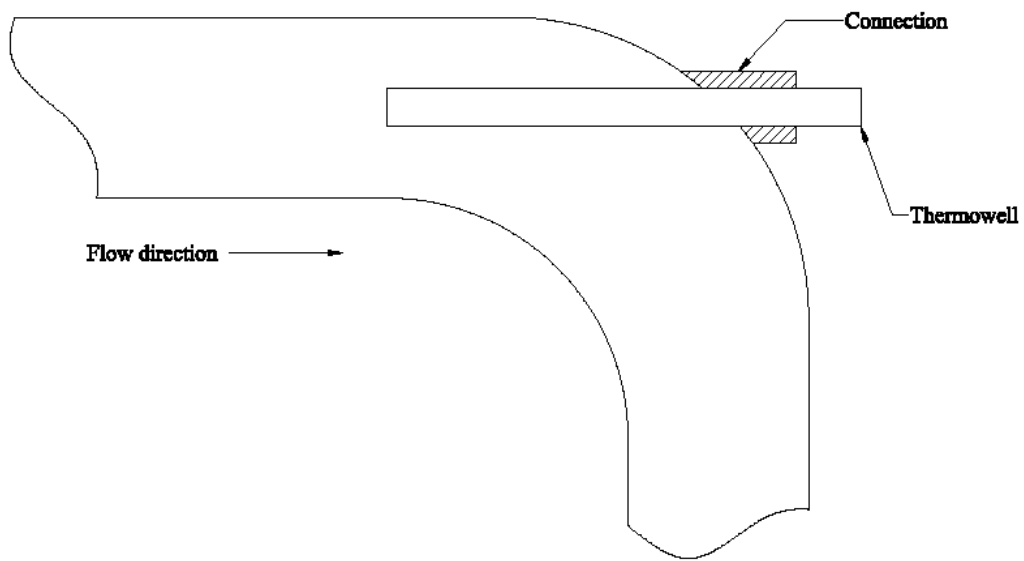


Figure 7. Installation of a thermowell in an elbow

Another method of insertion of a thermowell, in a line less than 3 inches, is by using a piping tee or a flanged connection as shown in Figure 8.

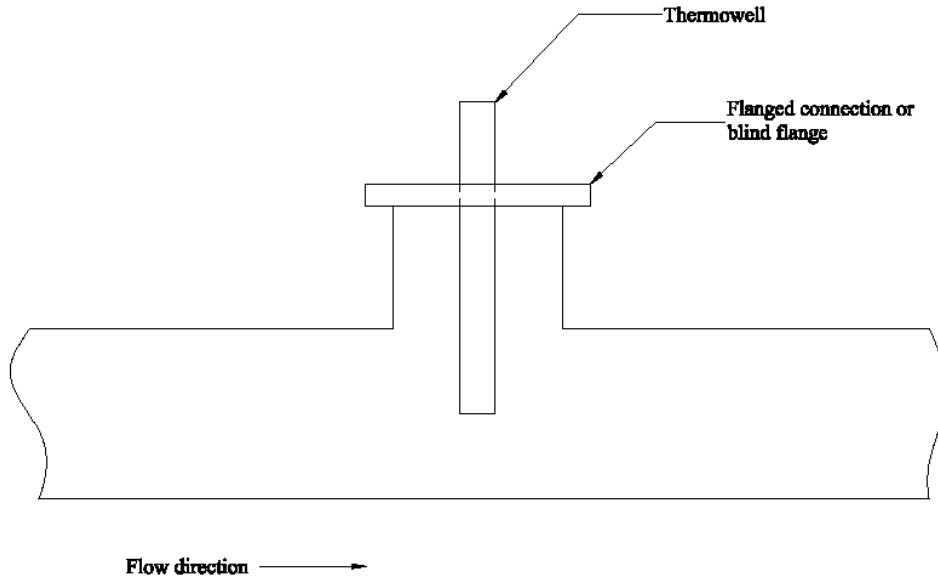


Figure 8. Insertion using a flanged connection or piping tee

One thing to keep in mind concerning thermowell insertion is that the ASME PTC 19.3-TW as well as the preceding codes assumed the thermowell to be installed perpendicular to the process fluid flow. Thermowells inserted at an angle can be evaluated as if they were installed perpendicular to the flow.

Sometimes a heat transfer medium or paste is used to improve response time. If using one of these mediums, it is important to use one that is suitable for the process temperature. If you are reusing a thermowell, it shall be thoroughly cleaned before installation. The sensor should be inserted to where the tip of the sensor touches the bottom of the thermowell.

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