# Reducing Thermowell Conduction Errors in Gas Pipeline Temperature Measurement

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**Abstract.** It is well known that conventional thermowells will thermally "couple" with the vessel in which they are mounted resulting in an error in the temperature measurement. Conduction error, commonly called immersion error, is present whenever a temperature gradient exist between the vessel or pipe the thermowell is installed into, and the substance being measured. Sources of conduction error in gas temperature measurement and methods of reducing it, specifically the use of finned thermowells, are discussed.

## INTRODUCTION

In the gas pipeline industry, gas temperature, along with pressure and flow, is used to calculate volumetric flow. Any error in the temperature measurement results in an error in the flow calculation. This error directly shifts the bottom line, resulting in accounting for too much gas or not enough. This unaccounted error in the gas volume measurement can have significant cost associated with it. Any time there is a difference between the pipe temperature and the flowing gas temperature there will be a conduction error. Even the most accurate temperature measurement equipment will have errors. Understanding the sources of conduction error and how to minimize it will increase the accuracy of gas temperature measurement.

## THE MEASUREMENT PROCESS

To accurately measure the flowing gas temperature, the sensor must be in thermal contact with the gas, but not disturb the gas temperature. Figure 1 shows a cut-away view of a typical thermowell installation in a gas pipeline. A threaded fitting, welded to the top of the pipe, provides the mount for the thermowell. A thermowell fitting connects the thermowell to a protection head or temperature transmitter to allow field wiring to the sensor. The thermowell fitting should include a spring to keep the sensor protection tube pressed firmly into the thermowell providing a good thermal contact between the sensor tip and the bottom of the thermowell. Thermally conductive grease at the sensor tip will also improve performance as any air gap between the sensor tip and the thermowell will add to the measurement error and reduce the response time.

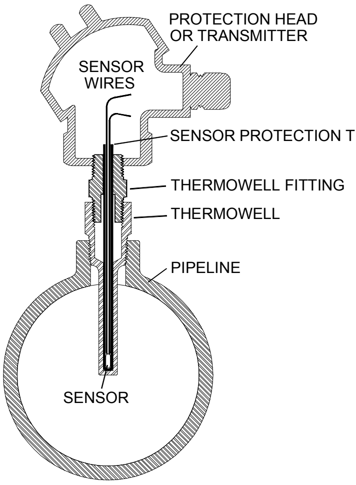

**FIGURE 1**. Typical sensor installation including thermowell and protection head for gas temperature measurement in a pipeline.

For the sensor to approach the temperature of the flowing gas there must be a thermal coupling or heat transfer between the two. For a net heat transfer from hot to cold to take place there must be a temperature difference between the sensor and the gas. When there is no heat transfer, the measurement system is in thermal equilibrium and the sensor is as close to the gas temperature as it will get. In reality, the sensor temperature will never be the same as the gas temperature due mainly to conduction errors.

## Heat Transfer

Heat transfer can be subdivided into three categories, conduction, convection, and radiation. Conduction takes place when there is a temperature gradient in a solid, liquid, or gas. The molecules in the hot area increase the violence of their vibrations as they heat up. Then, as they collide with their slower moving neighbors, some of their energy of motion is shared, and they in turn pass it on from one molecule to the next. The equation for thermal conductivity in one dimension is [1]:

$$q_{cond} = kA\frac{T_2 - T_1}{L} \qquad (1)$$

where $q_{cond}$ is the quantity of heat flow per unit time, $A$ is the cross sectional area, $T_2$-$T_1$ is the temperature difference, and $L$ is the length. When a metal rod is heated on one end, heat will be *conducted* through the metal to heat the other end.

Convection is the transfer of heat from one place to the other by the actual motion or flow of the material. The equation for convection heat transfer, also called Newton's Law of cooling is [2]:

$$q_{conv} = hA(T_s - T_\infty) \qquad (2)$$

where $q_{conv}$ is the heat power being transferred through the surface, $A$ is the surface area, $T_s$ is the surface temperature, $T_\infty$ is the temperature of the fluid distant from the surface, and h is the convection heat transfer coefficient (25 to 250 for forced convection gases [3]). An example of convection heat transfer would be a fan blowing on a hot object. The heat from the hot object is transferred to the cooler flowing air. In gas temperature measurement, the heat from the thermowell sensing-section and sensor is transferred to the flowing gas mainly by convection.

Heat can also be transferred by radiation, which is the continuous emission of energy from the surface of all objects. The equation for radiation heat transfer is [2]:

$$q_{rad} = \varepsilon A\sigma\left(T_S^4 - T_{SUR}^4\right) \qquad (3)$$

where $q_{rad}$ is the radiated power, $A$ is the surface area, $\sigma$ is the Stefan-Boltzmann constant ($5.67\text{x}10^{-8}$Watt/m$^{-2}$ x K$^{-4}$), $T_S$ is the surface temperature of the object, $T_{SUR}$ is the surface temperature of the ambient surroundings. At the relatively low temperatures seen in natural gas pipelines, typically less than 70°C, the rate of radiation heat transfer is small and is at long wavelengths producing little influence on the measurement accuracy. Radiation heat transfer can be minimize by manufacturing the thermowell of a low emissivity material, such as polished stainless steel with emissivity = 0.17 [4].

## SOURCES OF CONDUCTION ERROR

Conduction errors are present whenever there is a difference in temperature between the flowing gas and the pipeline walls. The pipeline running underground is kept at a fairly constant temperature but at the metering station, a section of the pipeline is brought above ground to allow access for the measurement equipment. The metering section of pipe and the equipment installed on the pipe, are heated and cooled by the changing ambient environment. As the temperature difference increases, the conduction error for any installation also increases.

To understand the sources of conduction errors, first consider a temperature sensor inserted into the gas stream as shown in Figure 2a.

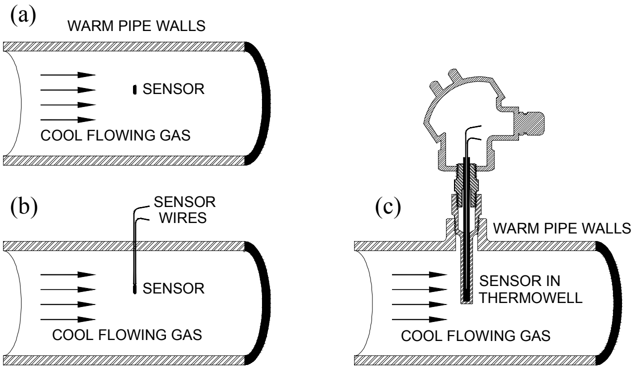

**FIGURE 2**. Cutaway pipe section showing (a) sensor in flowing gas without conduction path, (b) conduction path through the sensor wires, and (c) large conduction path through thermowell, protection tube, and sensor wires.

The sensor is only influenced by convection and a small influence from radiation heat transfer and will eventually be equal to or very near the gas temperature. There is no conduction error because there is no conduction path to the sensor. In Figure 2b, sensor wires are added, which creates a conduction path between the warm pipe and the sensor. Heat is conducted from the pipe walls through the wires to the sensor, and actually shifts the sensor temperature, resulting in a conduction error.

As long as there is a temperature difference between the pipe and the gas, the sensor will never equal the gas temperature due to the thermal energy conducted through the sensor wires. In Figure 2c, the thermowell, sensor protection tube, and protection head are added to the sensor. This significantly increases the cross sectional area of the conduction path to the sensor. Referring to Equation 1, the increased cross sectional area increases the conduction heat transfer to the sensor, increasing the conduction error. If the pipe was cooler than the gas, the same error exists for the same differential temperature but in the opposite direction. The following relation may be used to determine the extent of the conduction error [5]:

$$T_{sg} = T_i - \left[ \frac{T_w - T_{sg}}{Cosh(mL)} \right] \qquad (4)$$

where $T_{sg}$ is the static temperature of the gas, $T_i$ is the indicated sensor temperature, $T_w$ is the pipe wall temperature, $L$ is the immersion length, $m = (hp/ka)^{1/2}$ , $h$ is the convection coefficient of heat transfer, $p$ is the surface area of the thermowell (at the sensor), $k$ is the thermal conductivity of the thermowell, and $a$ is the conduction cross-sectional area of the thermowell. The larger $mL$ becomes, the closer the indicated temperature, $T_i$, approaches the true gas temperature, $T_{sd}$. Any means of increasing the $mL$ product will result in a reduced conduction error. The steady state temperature of the sensor is a result of a balance between convection heat transfer from the gas to the thermowell, and conduction and radiation heat transfer between the sensor and its surroundings.

## REDUCING CONDUCTION ERROR

The most common method for minimizing conduction errors is to increase the insertion length. Typically the insertion length of the thermowell should equal a minimum of 10 times the diameter of the thermowell [6]. Increasing the insertion length will reduce conduction errors as shown in Equation 4 but in small diameter pipes this may be impossible. Reducing the thermowell diameter, to reduce the conduction path, is not practical in high pressure, high flow velocity pipelines because the strength of the well will be compromised. Flow rates can be as high as 30 meters per second with pressures up to 7,000 kPa.

Reducing the thermal conductivity of the thermowell material (*k* in equation 4) will reduce the conducted thermal energy between the pipe walls and the sensor, resulting in a reduced influence to the measurement. The drawback is that it will also reduce the thermal conduction through the sensing section of the thermowell to the sensor, reducing the influence of the coefficient of heat transfer (*h* in equation 4) and reducing the sensor response time. The thermowell must be manufactured of materials compatible with the application. To minimize radiation heating, the material should have a low emissivity surface. Typically thermowells used in gas pipeline temperature measurement are made of polished stainless steel, a tradeoff between accuracy and strength.

Further examination of equation 4 indicates that if the surface area of the thermowell at the sensor was increased (*p* in equation 4), without increasing the conduction cross sectional area (*a* in equation 4) or the thermal conductivity (*k* in equation 4), conduction errors will be reduced. This can be accomplished by adding an array of fins at the sensing section of the thermowell. Figure 3a shows a conventional thermowell for comparison to a thermowell with the added fins to increase the surface area of the sensing section, Figure 3b. Adding the 13 fins increases the surface area in the sensing section over 7.5 times that of a conventional thermowell.

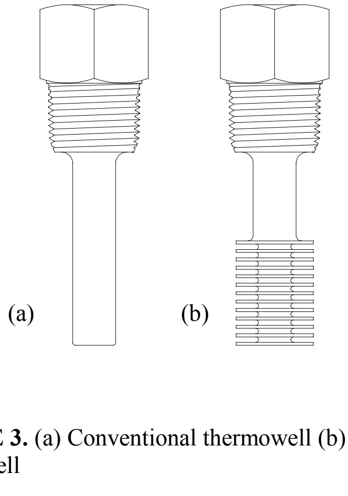

**FIGURE 3.** (a) Conventional thermowell (b) Finned thermowell

## Finned Thermowell Performance

The increased surface area at the sensing section of the finned thermowell significantly increases the convection heat transfer between the gas and the sensor, shifting the sensor temperature closer to the actual gas temperature, reducing the conduction error. Equation 2 shows that an increase in the surface area, $A$, will increase the heat power transferred, $q_{conv}$.

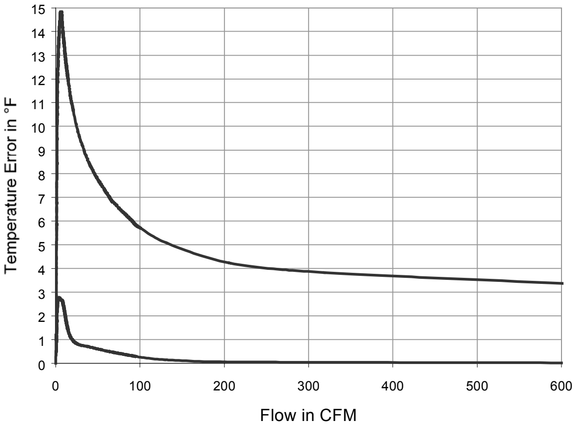

**FIGURE 4.** Flow comparison of a conventional thermowell, top curve, and a finned thermowell, bottom curve. [7]

Actual flow testing clearly shows the performance improvements the increased surface area provides. A conventional thermowell and a finned thermowell were run in a 7.5cm inside diameter schedule 80 pipe. The pipe was heated to 38˚C and held at this temperature while various flow rates were observed. Figure 4 shows the difference between the actual gas temperature and the indicated temperature. The finned thermowell, indicated by the bottom trace, was very close to the actual gas temperature. The conventional thermowell had over 1.6˚C (3˚F) error over the entire test. Slower flow velocities produced larger errors as expected. Sensor response time was four times faster using the finned thermowell [7].

## REFERENCES

1. Sears F.W., Zemansky M.W., Young H.D., *College Physics* Fifth Edition 1980.
2. Bently R.E.. *Temperature and Hummidity Measurement*, Volume 1, 1998.
3. Incropera F.P., DeWitt D.P., editors. *Fundamentals of Heat and Mass Transfer*. John Wiley & Sons, Inc. New York 1990.
4. OS550 Industrial Infrared Thermometer Users Guide, Emissivity Table (Omega Engineering).
5. ASME Temperature Measurement, (American Society of Mechanical Engineers), PTC 19.3 – 1974, reaffirmed 1998, Part 3.
6. Liptak B.G., editor-in-chief*, Process Measurement and Analysis*, chapter 4.
7. TAN-34CO-L4 Thermowell Performance Evaluation, ThermoSync Temperature Measurement System, PGI International, October 2000.