

# MEASUREMENT ERROR DUE TO THERMAL CONDUCTION IN A SHEATHED THERMOCOUPLE

**QUESTION:** When you calculate the measurement error when measuring with a sheathed thermocouple, you often disregard the heat transfer in the thermocouple itself. How correct is this assumption?

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**ANSWER:** To discuss this common assumption, we begin by considering a sheathed thermocouple that is measuring the temperature of a flowing liquid. We assume that the liquid's temperature is constant. We also assume that the temperature of the wall is higher than that of the liquid. Heat is now transferred from the wall to the thermocouple and along the thermocouple by means of thermal conduction. From the thermocouple, heat is transferred to the liquid by means of forced convection. The temperature of the thermocouple decreases along with the distance from the wall. The temperature of the measuring junction is influenced by the physical properties of the sheathed thermocouple and the convective heat transfer to the liquid. The temperature difference between the measuring junction in the thermocouple and the liquid,  $\Delta T$  °C, is the measurement error resulting from the thermal conduction in the thermocouple. In the stationary case, this measurement error can be estimated with the help of the following equation:

$$\Delta T = T_{\text{meas}} - T_{\text{liquid}} = \frac{2(T_{\text{wall}} - T_{\text{liquid}})}{(e^a + e^{-a})}$$

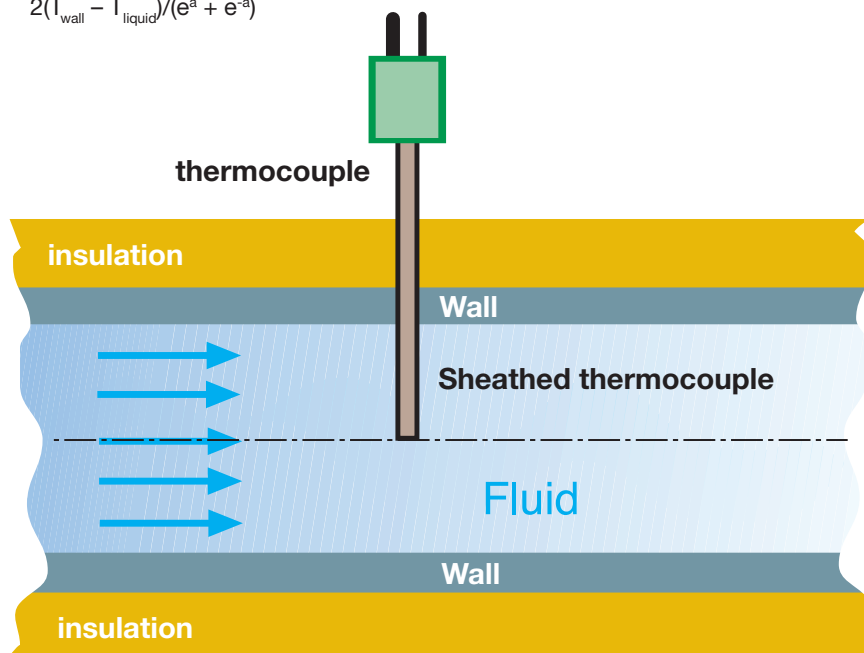
where  $T_{\text{meas}}$  is the temperature in °C of the measuring junction,  $T_{\text{liquid}}$  the temperature of the liquid in °C,  $T_{\text{wall}}$  the temperature of the wall in °C at the thermocouple's attachment point, and  $a$  is a parameter

$$a = L(4h/(kD))^{0.5}$$

where  $L$  is the thermocouple's length in metres,  $h$  the convective heat transfer coefficient between the thermocouple and the liquid in  $W/(m^2K)$ ,  $k$  the thermal conductivity of the thermocouple in  $W/(m K)$ , and  $D$  the outer diameter of the sheathed thermocouple in metres. The thermocouple consists of various materials, which means that we must use an average value for the thermal conductivity.

The longer the thermocouple is, the larger parameter  $a$  becomes. In turn, this means that the expression  $(e^a + e^{-a})$  increases and thereby the measurement error decreases. If you choose a thermocouple with a smaller diameter, parameter  $a$  also increases and the measurement error decreases. If the flow velocity increases, the convective heat transfer coefficient  $h$  will increase. Parameter  $a$  increases and the measurement error decreases. A higher value of the thermal conductivity of the thermocouple reduces parameter  $a$  and the measurement error increases.

If the flowing fluid is a gas, the same expression basically applies



## QUESTION



## ANSWER

Questions should be of general interest and be about temperature measurement techniques and/or heat transfer.

as for a liquid. In general, this type of measurement error is less when we are measuring in liquids than when we are measuring in gases, because the convective heat transfer coefficient is normally higher in liquids than in gases. When calculating the total measurement error when measuring the temperature of gases, we must also consider the possible effect of radiation.

In many cases, we do not know enough about the flow to be able to determine the convective heat transfer coefficient. This value is required if we want to determine the measurement error due to the thermal conduction in the thermocouple. By changing the thermocouple's insertion depth and studying the temperature change, we can often get some idea of the degree to which the measurement error is due to the length in the specific case in question.

### Example

In Q&A, *Pentronic News 2019*, #1 we discussed measuring the air temperature inside a long pipe with an inner diameter of 200 mm and an air flow of 5.3 m/s. The pipe temperature was 50 °C, the air temperature 15 °C, the length of the sheathed thermocouple 100 mm and its outer diameter 4 mm. In that case, the convective heat transfer coefficient was 112  $W/(m^2K)$ . Due to the radiation, the thermocouple will measure a temperature that is 1.4 °C higher than the air temperature of 15 °C.

If we consider only the thermal conduction in the thermocouple and the heat transfer from the wall to the air via the thermocouple, we find that the measurement error due to this heat flow is less than 0.1 °C, which in this case means that the error can be disregarded. However, if the thermocouple's length were 50 mm instead of 100 mm, the measurement error would be approx. 2 °C. Calculating the measurement error is based on a number of assumptions, but the result still often gives us a good idea of what measurement error we can expect.

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