MEASUREMENT ERROR DUE TO COATING BUILD-UP

QUESTION: We measure the water temperature inside an insulated pipe with the help of a sheathed thermocouple. The installation is of the same kind as that shown in the Q&A article in *Pentronic News 2019 #2*. The water temperature is approximately 120 °C and the pipe is located in an industrial building, where the temperature is approximately 15 °C. Unfortunately, sometimes a coating builds up on the thermocouple and pipe wall. How will this coating influence the measurement result?

Martin D

ANSWER: Normally, the coating build-up would affect both the measurement error and the response time. In some cases, however, the measurement error only increases by an insignificant amount or not at all. What determines the resulting measurement error depends on what is occurring with the heat flow in the thermocouple itself to/from its attachment to the pipe wall. Usually, a heat flow exists between the liquid and the pipe's surroundings, which causes a difference between the temperature of the liquid and that of the pipe wall. This also means that we get an axial heat flow in the thermocouple and we measure a temperature that is slightly lower than that of the liquid. The measurement error depends on such factors as the thermocouple's diameter and insertion length, the axial thermal conductivity in the thermocouple, the heat transfer coefficient between the liquid and the thermocouple, and the temperature difference between the liquid and the pipe wall. For the thermocouple with no coating build-up, the measurement error, ΔT, can be estimated with the help of the equation

$$T = T_{liquid} - T_{meas.} = 2(T_{liquid} - T_{wall})/(e^a + e^{-a})$$

where, T_{meas} is the measured temperature in °C, T_{liquid} the liquid temperature in °C, T_{wall} the pipe wall's temperature in °C at the thermocouple's attachment to the wall, and a is a parameter

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

If a coating builds up on the thermocouple and the pipe wall, this affects the heat transfer to both the thermocouple and the pipe wall. The heat transfer in the thermocouple itself is affected and thereby the measurement error. We now assume that the thermocouple and the pipe wall both receive an even coating. We also assume that the coating's thermal conductivity is much lower than that of the pipe and the thermocouple. The coating build-up reduces the radial heat flow from the liquid to the thermocouple. When the thermocouple acquires 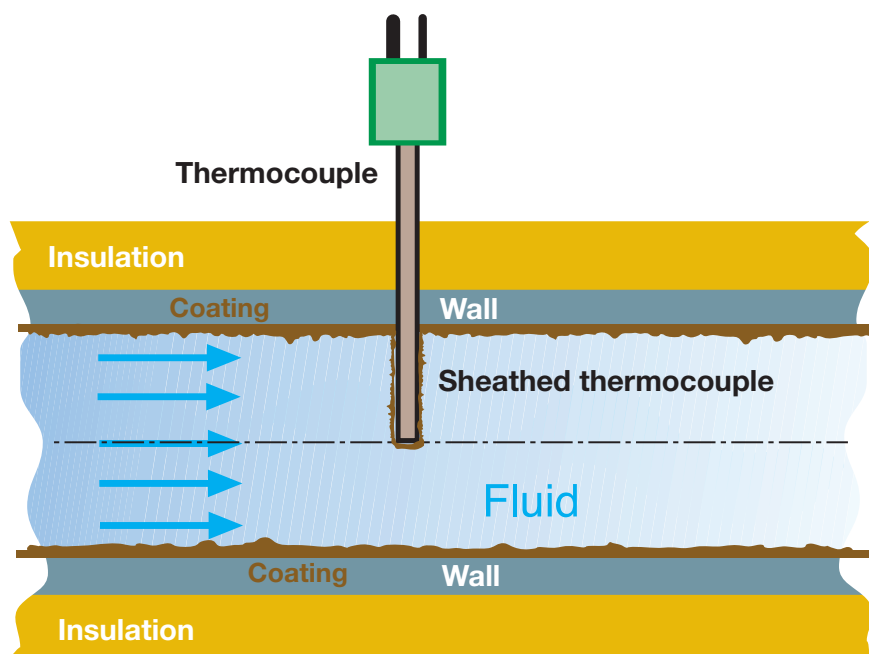such a coating, its diameter increases, which in normal cases leads to a slightly lower heat transfer coefficient. When doing rough estimates, the heat transfer coefficient can be replaced with an overall heat transfer coefficient, U, which includes both the heat transfer coefficient and the thermal conductivity of the coating. The overall heat transfer coefficient U becomes less than the heat transfer coefficient, h, which applies for the clean thermocouple, and the parameter a is lowered when h is replaced by U. Accordingly, in the case of a coating build-up, the expression $1/(e^a + e^{-a})$ increases, which in its turn means that the measurement error ΔT increases.

The heat flow through the coated pipe wall is reduced, causing a drop in the pipe temperature. The temperature difference $(T_{liquid} - T_{wall})$ increases and thereby so does the measurement error. Both the temperature reduction of the pipe wall and the reduced heat flow to the thermocouple also contribute to increasing the measurement error.

The case we have discussed here involves an even distribution of the coating build-up on the pipe wall and the thermocouple. Even if the coating's thickness varies, the same basic discussion applies.
If the temperature of the pipe wall is the same as that of the liquid, then no axial heat flow occurs in the thermocouple. For this to be the case, one requirement is that the pipe is well insulated. If the water temperature is constant and the axial heat flow in the thermocouple can be disregarded, the measured value is not affected if the thermocouple acquires a coating build-up. If the liquid temperature varies, however, the coating will extend the response time, because the heat flow from the liquid to the thermocouple decreases as a result of the coating. To determine whether the measurement error and response time are acceptable, it is necessary to produce the numeric values for the case in question.

Thermocouple

Insulation

Coating   **Wall**

Sheathed thermocouple

Fluid

Coating   **Wall**

Insulation