SURFACE SENSORS AND BUILD-UP INSIDE A PIPE

QUESTION: We measure the temperature of water that is transported through a pipe with an internal diameter of 300 mm. We use a surface sensor on the pipe's exterior and the water temperature is about 40 °C. When we replaced a shut-off valve, I discovered a thick build-up on the inside of the pipe. Our facility is old and the pipes were previously used to transport paper pulp. The pipe is not insulated where the sensor sits. How does this build-up affect the measurement process and is it possible to estimate the measurement error?

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ANSWER: In this case there is no general answer for the size of the measurement error, but if we introduce a number of assumptions we can roughly estimate the measurement error. We assume that the pipe has an even build-up and that the pipe's surroundings are cooler than the water temperature. The surface sensor measures the temperature of the external surface of the pipe, and the heat transfer from the liquid to the surroundings means that the measured temperature is somewhat lower than the temperature of the liquid.

The heat transfer from the water to its surroundings occurs via forced convection inside the pipe and thermal conduction inside the build-up and the pipe wall. We assume that the heat flow from the pipe's external surface to its surroundings occurs via natural convection and radiation. The equation for the heat transfer is

$$Q = AU(T_{liquid} - T_{surroundings})$$

where Q is the heat flow in W, A the area in m^2, U the overall heat transfer coefficient in W/(m^2K), and T_{liquid} and $T_{surroundings}$ are the temperature in °C of the water and the surroundings respectively. To roughly estimate the measurement error, we can for the sake of simplicity assume that the thickness of the build-up and the pipe wall is small in relation to the pipe radius. This means that we can regard the

problem as a plane wall. For extremely thick build-ups or for more precise calculations, it is necessary to use the equation for pipes with a circular cross-section. The overall heat transfer coefficient U is determined by the equation

$$1/U = 1/h_{interior} + \Delta_{build-up}/k_{build-up} + \Delta_{pipe\ wall}/k_{pipe} + 1/h_{exterior}$$

where h is the heat transfer coefficient in W/(m^2K), Δ the thickness in m and k the thermal conductivity in W/(m K). In this case we assume that the heat transfer coefficient on the pipe's external surface includes both natural convection and radiation – a "total" heat transfer coefficient. We get the pipe's exterior temperature, $T_{exterior}$ in °C, from the equation

$$Q = Ah_{exterior}(T_{exterior} - T_{surroundings})$$

We begin by studying a pipe with no build-up on the inside. To estimate the measurement error, we assume that the average speed of the water is 3 m/s (760 m^3/h). The flow is turbulent and the heat transfer coefficient on the inside surface of the pipe can be estimated at 7400 W/(m^2K). We assume that the wall thickness of the steel pipe is 6 mm and the steel's thermal conductivity is 48 W/(m K). The ambient temperature is assumed to be 15 °C and the total heat transfer coefficient on the pipe's external surface is estimated at 10 W/(m^2K). The equation for the overall heat transfer coefficient is

$$1/U = 0.000135 + 0.00125 + 0.100$$

The thermal resistance on the pipe's exterior – 1/($Ah_{exterior}$) – is totally dominant and we find that $T_{exterior}$ = 39.94 °C and the measurement error is less 0.1 °C. In this case the surface sensor is basically measuring the water temperature. We assume now that the thickness of the build-up is 3 mm and that it consists of wood fibres with a thermal conductivity of 0.15 W/(m K). The equation for the heat transfer coefficient is

$$1/U = 0.000135 + 0.0200 + 0.00125 + 0.100$$

In this case we cannot disregard the thermal resistance of the build-up – $\Delta_{build-up}/(Ak_{build-up})$ – and we find that $T_{exterior}$ = 35.8 °C and the measurement error is 4.2 °C. If the build-up's thickness is 6 mm, the measurement error is 7.2 °C. These calculations are based on a number of conditions and assumptions. One problem is that we do not know either the build-up's thickness nor its thermal properties, but the result still shows that when estimating measurement error we cannot disregard the influence of the build-up inside the pipe.

If possible the pipe should be insulated on the outside. This reduces the heat flow and the temperature of the pipe's external surface approaches that of the water. With an insulation of 50 mm mineral wool with a thermal conductivity of 0.050 W/(m K), we obtain a measurement error of 0.9 °C instead of 7.2 °C. Another option is to use an insertion sensor, but this presupposes that you are not pumping paper pulp through the pipe. A surface sensor must always be inspected regularly to ensure there is good contact between the sensor and the pipe. You must also check that no corrosion has occurred on the contact surface. Poor contact and corrosion will increase the measurement error.

Summary: Build-ups inside pipes are in this case the leading cause of measurement error from surface sensors, and the thicker the build-up the greater the measurement error. One problem is that we seldom know the thickness of the build-up or its thermal properties. If you can insulate the pipe that will reduce the measurement error.

If you have questions or comments, contact Professor Dan Loyd, LiU, dan.loyd@liu.se