Measuring water temperature from the outside of a half-full plastic pipe

QUESTION: We have replaced an uninsulated horizontally mounted steel pipe with a plastic pipe with the same inner diameter, 100 mm. Inside the pipe, water is flowing at a temperature of 30 to 50 °C. Most of the time the pipe is full of water but during some lengthy periods it is scarcely half full. The temperature inside the room is about 16 °C. We measured the water temperature by mounting a sensor on the top outside surface of the steel pipe. Can we do the same with a plastic pipe?

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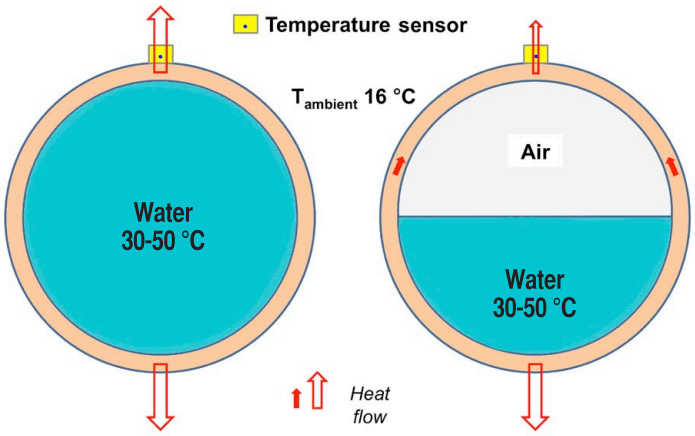
ANSWER: The heat flow from the water inside the completely full pipe to the outside surroundings occurs via forced convection on the inside surface of the pipe, thermal conduction inside the pipe wall, and convection and radiation on the pipe's outside surface. We will assume that the wall thickness is the same in both the steel pipe and the plastic pipe and that the other conditions are also the same. We will also assume that the process is static. Given the same heat flow, the temperature difference across the pipe wall will be slightly greater for the plastic pipe than for the steel pipe, which means that the plastic pipe's external temperature will be lower. However, when the steel pipe is replaced with a plastic pipe there is a reduction of the heat flow, which means that the plastic pipe's external temperature increases. When these changes are combined, the external temperature of the plastic pipe will be slightly less than that of the steel pipe. When the plastic pipe is full of water, it should normally be possible to measure the water temperature with sufficient accuracy by using an external surface mounted sensor. See further [Ref 1], which discusses surface mounted sensors.

The case of a plastic pipe that is half full of water is much more complex. In the upper section of the pipe's interior, the heat transfer is now occurring between the air and the pipe wall and not between the water and the pipe wall. The heat transfer to the pipe wall occurs mainly by natural convection in the air and not by forced convection in the water. This means that the heat transfer coefficient on the upper inside surface of the pipe is considerably less when the pipe is half full than when it is full of water. It also means that the pipe's external temperature at the sensor's location will be lower, leading to significantly greater measurement error.

In the half-full pipe some heat transfer occurs inside the pipe wall from the bottom of the pipe to the top of the pipe due to the temperature difference, which increases the wall temperature at the sensor's location and reduces the measurement error. Because thermal conductivity is significantly greater in steel than in plastic, the heat transfer inside the pipe wall from the bottom of the plastic pipe to the top is less than the corresponding heat transfer in the steel pipe. In turn, this means that the measurement error for the half-full plastic pipe is greater than for the half-full steel pipe.



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

QUESTIONS ANSWERS

If possible, you should insulate the pipe at the location of the sensor in order to reduce the measurement error. You can also place the sensor on the underside of the pipe to reduce the measurement error but this increases the risk of corrosion and of poor thermal contact between the sensor and the pipe wall. Many factors influence the possible locations for the sensor and so its placement must be decided in each individual case. Wherever you place the sensor on the pipe, you must always regularly check that it is in good contact with the pipe.

Replacing a steel pipe with a plastic one will also influence the response time when the temperature of the water changes. A half-full plastic pipe combined with a sensor that is externally mounted on top of the pipe is a particularly unfavourable situation and will lead to a long response time.

References see www.pentronic.se > News > Pentronic News > Pentronic News Archive
[Ref 1] Pentronic News 2013-4

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