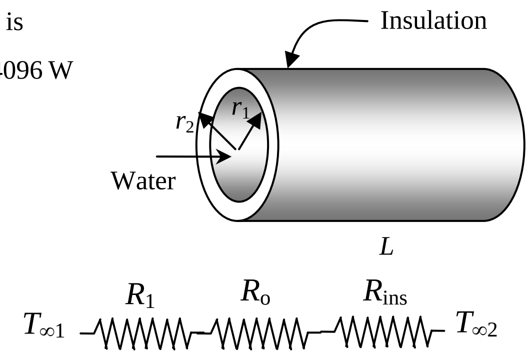
10-69 Chilled water is flowing inside a pipe. The thickness of the insulation needed to reduce the temperature rise of water to one-fourth of the original value is to be determined.

Assumptions **1** Heat transfer is steady since there is no indication of any change with time. **2** Heat transfer is one-dimensional since there is thermal symmetry about the centerline and no variation in the axial direction. **3** Thermal conductivities are constant. **4** The thermal contact resistance at the interface is negligible.

Properties The thermal conductivity is given to be $k = 0.05$ W/m·°C for insulation.

Analysis The rate of heat transfer without the insulation is



$$\dot{Q}_{old} = \dot{m}c_p\Delta T = (0.98\text{ kg/s})(4180\text{ J/kg}\cdot°\text{C})(8-7)°\text{C} = 4096\text{ W}$$

The total resistance in this case is

$$\dot{Q}_{old} = \frac{T_\infty - T_w}{R_{total}}$$

$$4096\text{ W} = \frac{(30-7.5)°\text{C}}{R_{total}} \longrightarrow R_{total} = 0.005493°\text{C/W}$$

The convection resistance on the outer surface is

$$R_o = \frac{1}{h_o A_o} = \frac{1}{(9\text{ W/m}^2\cdot°\text{C})\pi(0.05\text{ m})(150\text{ m})} = 0.004716\text{ °C/W}$$

The rest of thermal resistances are due to convection resistance on the inner surface and the resistance of the pipe and it is determined from

$$R_1 = R_{total} - R_o = 0.005493 - 0.004716 = 0.0007769\text{ °C/W}$$

The rate of heat transfer with the insulation is

$$\dot{Q}_{new} = \dot{m}c_p\Delta T = (0.98\text{ kg/s})(4180\text{ J/kg}\cdot°\text{C})(0.25°\text{C}) = 1024\text{ W}$$

The total thermal resistance with the insulation is

$$\dot{Q}_{new} = \frac{T_\infty - T_w}{R_{total,new}} \longrightarrow 1024\text{ W} = \frac{[30-(7+7.25)/2)]°\text{C}}{R_{total,new}} \longrightarrow R_{total,new} = 0.02234°\text{C/W}$$

It is expressed by

$$R_{total,new} = R_1 + R_{o,new} + R_{ins} = R_1 + \frac{1}{h_o A_o} + \frac{\ln(D_2/D_1)}{2\pi k_{ins} L}$$

$$0.02234°\text{C/W} = 0.0007769 + \frac{1}{(9\text{ W/m}^2\cdot°\text{C})\pi D_2(150\text{ m})} + \frac{\ln(D_2/0.05)}{2\pi(0.05\text{ W/m}\cdot°\text{C})(150\text{ m})}$$

Solving this equation by trial-error or by using an equation solver such as EES, we obtain

$$D_2 = 0.1265\text{ m}$$

Then the required thickness of the insulation becomes

$$t_{ins} = (D_2 - D_1)/2 = (0.05 - 0.1265)/2 = 0.0382\text{ m} = \mathbf{3.8\ cm}$$

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