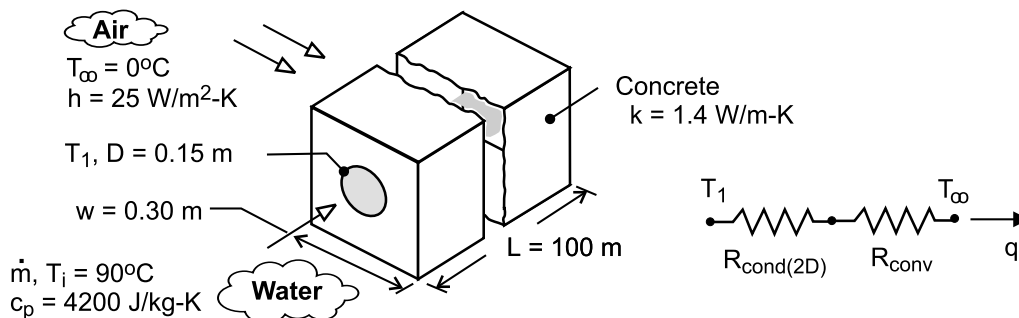# PROBLEM 4.32

KNOWN: Dimensions and thermal conductivity of concrete duct. Convection conditions of ambient air. Inlet temperature of water flow through the duct.

FIND: (a) Heat loss per duct length near inlet, (b) Minimum allowable flow rate corresponding to maximum allowable temperature rise of water.

SCHEMATIC:

ASSUMPTIONS: (1) Steady state, (2) Negligible water-side convection resistance, pipe wall conduction resistance, and pipe/concrete contact resistance (temperature at inner surface of concrete corresponds to that of water), (3) Constant properties, (4) Negligible flow work and kinetic and potential energy changes.

ANALYSIS: (a) From the thermal circuit, the heat loss per unit length near the entrance is

$$q' = \frac{T_i - T_\infty}{R'_{cond(2D)} + R'_{conv}} = \frac{T_i - T_\infty}{\dfrac{\ln\left(1.08\,w/D\right)}{2\pi k} + \dfrac{1}{h(4w)}}$$

where $R'_{cond(2D)}$ is obtained by using the shape factor of Case 6 from Table 4.1 with Eq. (4.27).
Hence,

$$q' = \frac{(90-0)\,^\circ C}{\dfrac{\ln\left(1.08 \times 0.3m/0.15m\right)}{2\pi\left(1.4\,W/m\cdot K\right)} + \dfrac{1}{25\,W/m^2\cdot K\left(1.2m\right)}} = \frac{90\,^\circ C}{\left(0.0876 + 0.0333\right)K\cdot m/W} = 745\ W/m \qquad <$$

(b) From Eq. (1.11e), with $q = q'L$ and $\left(T_i - T_o\right) = 5\,^\circ C$,

$$\dot{m} = \frac{q'L}{u_i - u_o} = \frac{q'L}{c\left(T_i - T_o\right)} = \frac{745\,W/m\left(100m\right)}{4207\,J/kg\cdot K\left(5\,^\circ C\right)} = 3.54\ kg/s \qquad <$$

COMMENTS: The small reduction in the temperature of the water as it flows from inlet to outlet induces a slight departure from two-dimensional conditions and a small reduction in the heat rate per unit length. A slightly conservative value (upper estimate) of $\dot{m}$ is therefore obtained in part (b).