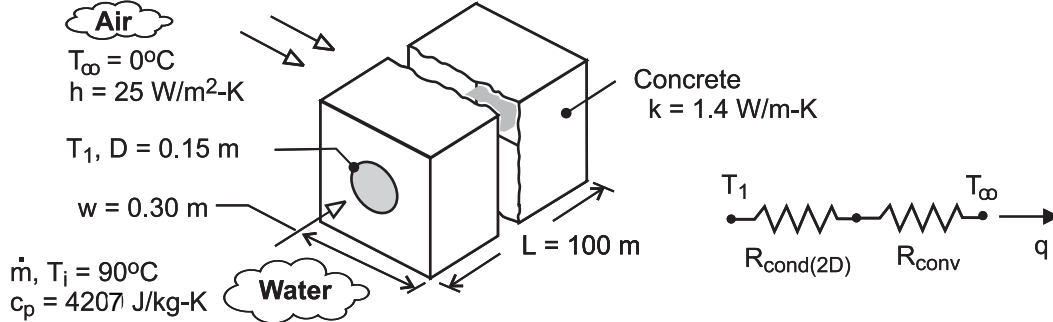


PROBLEM 4.29

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

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

where $R'_{\text{cond}(2D)}$ is obtained by using the shape factor of Case 6 from Table 4.1 with Eq. (4.21).

Hence,

$$q' = \frac{(90 - 0)^\circ\text{C}}{\frac{\ln(1.08 \times 0.30 / 0.15\text{m})}{2\pi(1.4 \text{ W/m} \cdot \text{K})} + \frac{1}{25 \text{ W/m}^2 \cdot \text{K}(1.2\text{m})}} = \frac{90^\circ\text{C}}{(0.0876 + 0.0333) \text{ K} \cdot \text{m/W}} = 745 \text{ W/m} \quad <$$

(b) From Eq. (1.12d), with $q = q'L$ and $(T_i - T_o) = 5^\circ\text{C}$,

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

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).