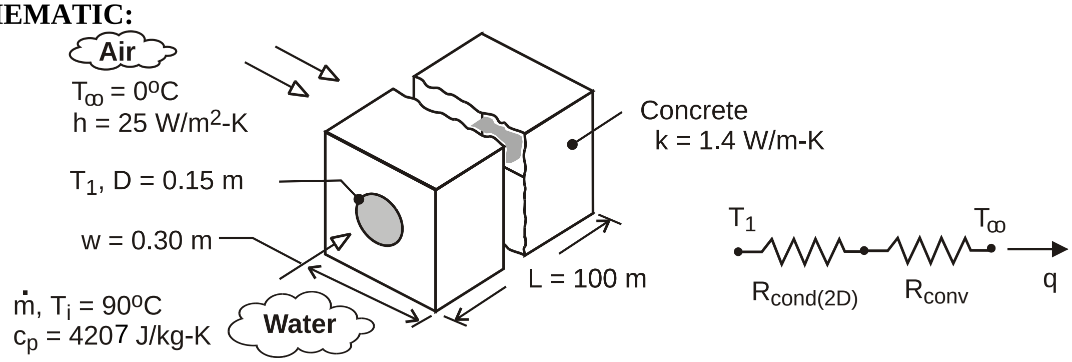
PROBLEM 4.26

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

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

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

Hence,

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

(b) From Eq. (1.12d), with $q = q'L$ and $(T_i - T_o) = 5°C$,

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

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).