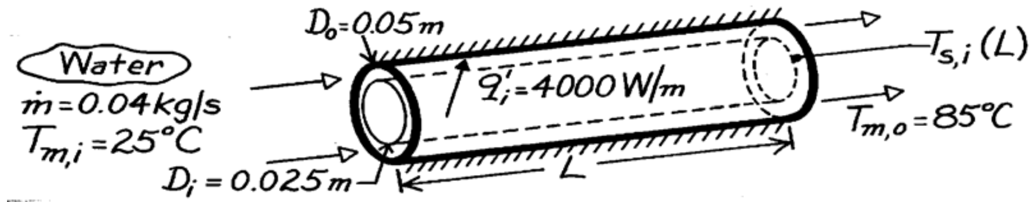
PROBLEM 8.97

KNOWN: Dimensions and surface thermal conditions for a concentric tube annulus. Water flow rate and inlet temperature.

FIND: (a) Tube length required to achieve desired outlet temperature, (b) Inner tube surface temperature at outlet.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform heat flux at inner surface, (3) Adiabatic outer surface, (4) Fully developed flow at exit, (5) Constant properties, (6) Incompressible liquid with negligible viscous dissipation.

PROPERTIES: *Table A-6*, Water $\left(\overline{T}_m = 328K\right)$: c_p = 4183 J/kg·K; ($T_{m,o}$ = 358K): $\mu = 332 \times 10^{-6}$ N·s/m^2, k = 0.673 W/m·K, Pr = 2.07.

ANALYSIS: (a) From the overall energy balance, Eq. 8.34,

$$q = q_i' L = \dot{m}\, c_p \left(T_{m,o} - T_{m,i}\right)$$

$$L = \frac{\dot{m}\, c_p \left(T_{m,o} - T_{m,i}\right)}{q_i'} = \frac{(0.04 \text{ kg/s})\, 4183 \text{ J/kg}\cdot\text{K}\,(85-25)^\circ\text{C}}{4000 \text{ W/m}} = 2.51 \text{ m.}$$ <

(b) From Eqs. 8.1 and 8.5,

$$Re_D = \frac{\rho\, u_m D_h}{\mu} = \frac{\dot{m}\, D_h}{A_c \mu} = \frac{\dot{m}\left(D_o - D_i\right)}{(\pi/4)\left(D_o^2 - D_i^2\right)\mu} = \frac{4\,\dot{m}}{\pi\left(D_o + D_i\right)\mu}$$

$$Re_D = \frac{4 \times 0.04 \text{ kg/s}}{\pi(0.075 \text{ m})\, 332 \times 10^{-6} \text{kg/s}\cdot\text{m}} = 2045.$$

Hence the flow is laminar, and with $D_i/D_o = 0.5$, it follows from Eq. 8.72 and Table 8.3

$$Nu_i = Nu_{ii} = 6.24$$

$$h_i = 6.24 \frac{k}{D_h} = 6.24 \frac{0.673 \text{ W/m}\cdot\text{K}}{0.025 \text{ m}} = 168 \text{ W/m}^2\cdot\text{K.}$$

From Eq. 8.67,

$$T_{s,i}(L) = T_{m,o} + \frac{q_i''}{h_i} = T_{m,o} + \frac{q_i'/\pi D_i}{h_i}$$

$$T_{s,i}(L) = 85^\circ\text{C} + \frac{4000 \text{ W/m}}{\pi(0.025\text{m})\; 168 \text{ W/m}^2\cdot\text{K}} = 388^\circ\text{C.}$$ <

COMMENTS: Unless the water is pressurized, local boiling would occur at the tube surface, causing h_i to be larger.