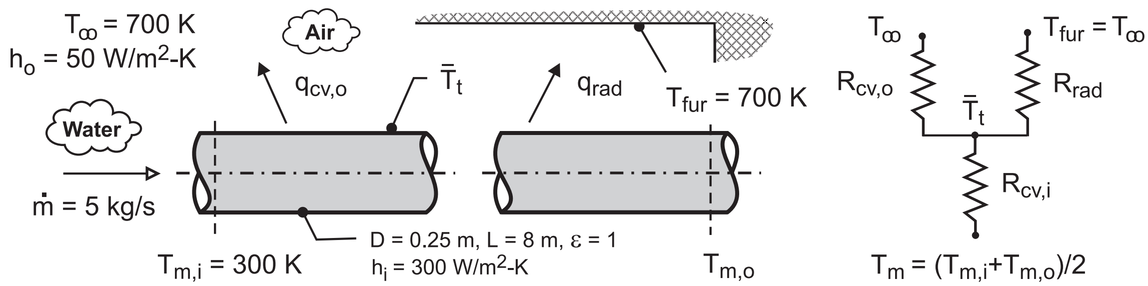
PROBLEM 8.20

KNOWN: Water at prescribed temperature and flow rate enters a 0.25 m diameter, black thin-walled tube of 8-m length, which passes through a large furnace whose walls and air are at a temperature of $T_{fur} = T_\infty = 700$ K. The convection coefficients for the internal water flow and external furnace air are 300 W/m^2·K and 50 W/m^2·K, respectively.

FIND: (a) An expression for the linearized radiation coefficient for the radiation exchange process between the outer surface of the pipe and the furnace walls; represent the tube by an average temperature and explain how to calculate this value, and (b) determine the outlet temperature of the water, T_o.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions; (2) Tube is small object with large, isothermal surroundings; (3) Furnace air and walls are at the same temperature; (4) Tube is thin-walled with black surface; and (5) Incompressible liquid with negligible viscous dissipation.

PROPERTIES: *Table A-6*, Water ($T_m = (T_{m,i} + T_{m,o})/2 = 304$ K): $c_p = 4178$ J/kg·K.

ANALYSIS: (a) The linearized radiation coefficient follows from Eq. 1.9 with $\varepsilon = 1$,

$$\bar{h}_{rad} = \sigma\left(\bar{T}_t + T_{fur}\right)\left(\bar{T}_t^2 + T_{fur}^2\right)$$

where $\bar{T}_t$ represents the average tube wall surface temperature, which can be evaluated from an energy balance on the tube as represented by the thermal circuit above.

$$T_m = \left(T_{m,i} + T_{m,o}\right)/2$$

$$R_{tot} = R_{cv,i} + \frac{1}{1/R_{cv,o} + 1/R_{rad}}$$

$$\frac{T_m - \bar{T}_t}{R_{cv,i}} = \left(\bar{T}_t - T_{fur}\right)\left(1/R_{cv,o} + 1/R_{rad}\right)$$

The thermal resistances, with $A_s = PL = \pi DL$, are

$$R_{cv,i} = 1/h_i A_s \qquad R_{cv,o} = 1/h_o A_s \qquad R_{rad} = 1/\bar{h}_{rad} A_s$$

(b) The outlet temperature can be calculated using the energy balance relation, Eq. 8.45b, with $T_{fur} = T_\infty$,

$$\frac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \exp\left(-\frac{1}{\dot{m}\, c_p\, R_{tot}}\right)$$

where c_p is evaluated at T_m. Using *IHT*, the following results were obtained.

$$R_{cv,i} = 5.31\times10^{-4}\ \text{K/W} \qquad R_{cv,o} = 3.18\times10^{-3}\ \text{K/W} \qquad R_{rad} = 3.96\times10^{-3}\ \text{K/W}$$

$$T_m = 304\ \text{K} \qquad \bar{T}_t = 396\ \text{K} \qquad T_{m,o} = 308\ \text{K} \qquad <$$

COMMENTS: Since $T_\infty = T_{fur}$, it was possible to use Eq. 8.45b with R_{tot}. How would you write the energy balance relation if $T_\infty \neq T_{fur}$?