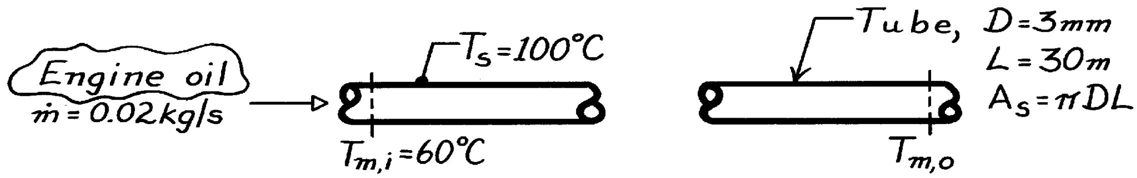
PROBLEM 8.22

KNOWN: Flow rate of engine oil through a long tube.

FIND: (a) Heat transfer coefficient, $\overline{h}$, (b) Outlet temperature of oil, $T_{m,o}$.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) Combined entry conditions exist.

PROPERTIES: *Table A-5*, Engine Oil (T_s = 100°C = 373K): $\mu_s = 1.73 \times 10^{-2}$ N·s/m^2; *Table A-5*, Engine Oil $\left(\overline{T}_m = 77^\circ C = 350K\right)$: c_p = 2118 J/kg·K, $\mu = 3.56 \times 10^{-2}$ N·s/m^2, k = 0.138 W/m·K, Pr = 546.

ANALYSIS: (a) The overall energy balance and rate equations have the form

$$q = \dot{m}\, c_p \left(T_{m,o} - T_{m,i}\right) \qquad q = \overline{h} A_s \Delta T_{1m} \qquad (1,2)$$

Using Eq. 8.42b, with P = πD, and Eq. 8.6

$$\frac{\Delta T_o}{\Delta T_i} = \frac{T_s - T_{m,o}}{T_s - T_{m,i}} = \exp\left(-\frac{PL}{\dot{m}\, c_p}\cdot \overline{h}\right). \qquad (3)$$

$$Re_D = \frac{4\dot{m}}{p\ D_m} = \frac{4\times 0.02\ kg/s}{p \times 3\times 10^{-3} m \times 3.56\times 10^{-2} N\cdot s/m^2} = 238.$$

For laminar and combined entry conditions, use Eq. 8.57

$$\overline{Nu}_D = 1.86\left(\frac{Re_D\, Pr}{L/D}\right)^{1/3}\left(\frac{m}{m_s}\right)^{0.14} = \left(\frac{238\times 546}{30m/3\times 10^{-3} m}\right)^{1/3}\left(\frac{3.56}{1.73}\right)^{0.14} = 4.83$$

$$\overline{h} = \overline{Nu}_D\, k/D = 4.83\times 0.138\ W/m\cdot K/3\times 10^{-3} m = 222\ W/m^2\cdot K.$$ <

(b) Using Eq. (3) with the foregoing value of $\overline{h}$,

$$\frac{\left(100 - T_{m,o}\right)^\circ C}{(100-60)^\circ C} = \exp\left(-\frac{p\times 3\times 10^{-3} m\times 30m}{0.02\ kg/s\times 2118\ J/kg\cdot K}\times 222 W/m^2\cdot K\right) \qquad T_{m,o} = 90.9^\circ C.$$ <

COMMENTS: (1) Note that requirements for the correlation, Eq. 8.57, are satisfied.

(2) The assumption of $\overline{T}_m$ = 77°C for selecting property values was satisfactory.

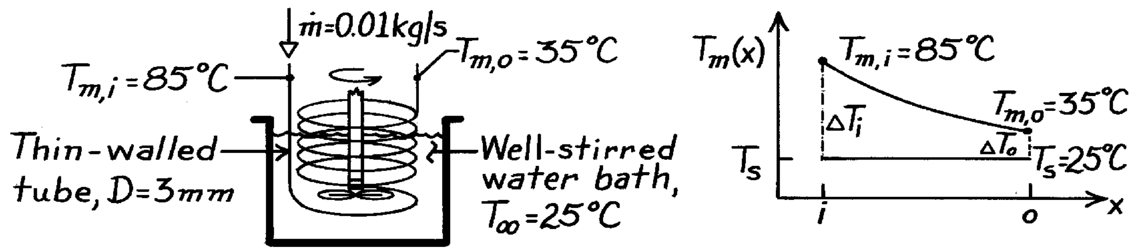
(3) For thermal entry effect only, Eq. 8.56, $\overline{h} = 201\ W/m^2\cdot K$ and $T_{m,o}$ = 89.5°C.

PROBLEM 8.26

KNOWN: Ethylene glycol flowing through a coiled, thin walled tube submerged in a well-stirred water bath maintained at a constant temperature.

FIND: Heat rate and required tube length for prescribed conditions.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Tube wall thermal resistance negligible, (3) Convection coefficient on water side infinite; cooling process approximates constant wall surface temperature distribution, (4) KE, PE and flow work changes negligible, (5) Constant properties, (6) Negligible heat transfer enhancement associated with the coiling.

PROPERTIES: *Table A-5*, Ethylene glycol (T_m = (85 + 35)°C/2 = 60°C = 333 K): c_p = 2562 J/kg·K, $\mu = 0.522 \times 10^{-2}$ N·s/m^2, k = 0.260 W/m·K, Pr = 51.3.

ANALYSIS: From an overall energy balance on the tube,

$$q_{conv} = \dot{m}\, c_p \left(T_{m,o} - T_{m,i}\right) = 0.01\ \text{kg/s} \times 2562\ \text{J/kg}\left(35-85\right)^\circ \text{C} = -1281\ \text{W}. \qquad (1)$$ <

For the constant surface temperature condition, from the rate equation,

$$A_s = q_{conv} / \bar{h}\Delta T_{\ell m} \qquad (2)$$

$$\Delta T_{\ell m} = \left(\Delta T_o - \Delta T_i\right) / \ell n \frac{\Delta T_o}{\Delta T_i} = \left[\left(35-25\right)^\circ \text{C} - \left(85-25\right)^\circ \text{C}\right] / \ell n \frac{35-25}{85-25} = 27.9^\circ \text{C}. \qquad (3)$$

Find the Reynolds number to determine flow conditions,

$$Re_D = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \times 0.01\ \text{kg/s}}{\pi \times 0.003\ \text{m} \times 0.522 \times 10^{-2}\ \text{N}\cdot\text{s/m}^2} = 813. \qquad (4)$$

Hence, the flow is laminar and, assuming the flow is fully developed, the appropriate correlation is

$$\overline{Nu}_D = \frac{\bar{h}D}{k} = 3.66, \qquad \bar{h} = Nu\frac{k}{D} = 3.66 \times 0.260 \frac{\text{W}}{\text{m}\cdot\text{K}} / 0.003\text{m} = 317\ \text{W/m}^2\cdot\text{K}. \qquad (5)$$

From Eq. (2), the required area, A_s, and tube length, L, are

$$A_s = 1281\ \text{W} / 317\ \text{W/m}^2\cdot\text{K} \times 27.9^\circ\text{C} = 0.1448\ \text{m}^2$$

$$L = A_s / \pi D = 0.1448\text{m}^2 / \pi\left(0.003\text{m}\right) = 15.4\text{m}.$$ <

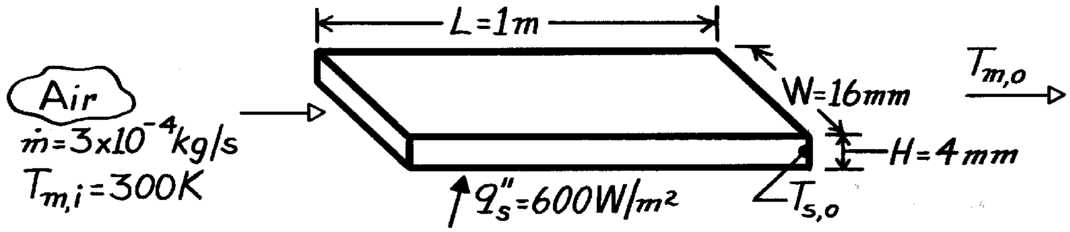
COMMENTS: Note that for fully developed laminar flow conditions, the requirement is satisfied: Gz^{-1} = (L/D) / Re_D Pr = (15.3/0.003) / (813 × 51.3) = 0.122 > 0.05. Note also the sign of the heat rate q_{conv} when using Eqs. (1) and (2).

PROBLEM 8.77

KNOWN: Flow rate and inlet temperature of air passing through a rectangular duct of prescribed dimensions and surface heat flux.

FIND: Air and duct surface temperatures at outlet.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform surface heat flux, (3) Constant properties, (4) Atmospheric pressure, (3) Fully developed conditions at duct exit, (6) Negligible KE, PE and flow work effects.

PROPERTIES: *Table A-4*, Air $\left(\bar{T}_m \approx 300\text{K, 1 atm}\right)$: $c_p = 1007$ J/kg·K, $\mu = 184.6 \times 10^{-7}$ N·s/m^2, k = 0.0263 W/m·K, Pr = 0.707.

ANALYSIS: For this uniform heat flux condition, the heat rate is

$$q = q_s'' A_s = q_s''\left[2(L\times W) + 2(L\times H)\right]$$

$$q = 600\ \text{W/m}^2\left[2(1\text{m}\times 0.016\text{m}) + 2(1\text{m}\times 0.004\text{m})\right] = 24\ \text{W}.$$

From an overall energy balance

$$T_{m,o} = T_{m,i} + \frac{q}{\dot{m}\,c_p} = 300\text{K} + \frac{24\ \text{W}}{3\times 10^{-4}\ \text{kg/s}\times 1007\ \text{J/kg}\cdot\text{K}} = 379\ \text{K}. \qquad <$$

The surface temperature at the outlet may be determined from Newton's law of cooling, where

$$T_{s,o} = T_{m,o} + q''/h.$$

From Eqs. 8.67 and 8.1

$$D_h = \frac{4\,A_c}{P} = \frac{4(0.016\text{m}\times 0.004\text{m})}{2(0.016\text{m}+0.004\text{m})} = 0.0064\ \text{m}$$

$$Re_D = \frac{\rho\,u_m\,D_h}{\mu} = \frac{\dot{m}\,D_h}{A_c\mu} = \frac{3\times 10^{-4}\text{kg/s}\,(0.0064\text{m})}{64\times 10^{-6}\text{m}^2\left(184.6\times 10^{-7}\ \text{N}\cdot\text{s/m}^2\right)} = 1625.$$

Hence the flow is laminar, and from Table 8.1

$$h = \frac{k}{D_h}5.33 = \frac{0.0263\ \text{W/m}\cdot\text{K}}{0.0064\ \text{m}}5.33 = 22\ \text{W/m}^2\cdot\text{K}$$

$$T_{s,o} = 379\ \text{K} + \frac{600\ \text{W/m}^2}{22\ \text{W/m}^2\cdot\text{K}} = 406\ \text{K}. \qquad <$$

COMMENTS: The calculations should be reperformed with properties evaluated at $\bar{T}_m = 340$ K. The change in $T_{m,o}$ would be negligible, and $T_{s,o}$ would decrease slightly.