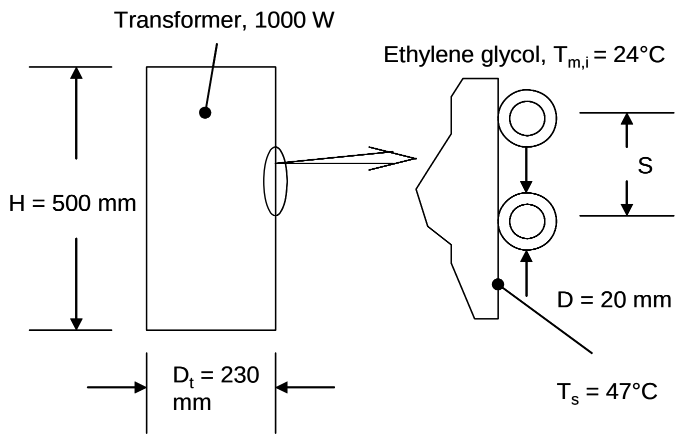
PROBLEM 8.103

KNOWN: Tubing with ethylene glycol welded to transformer to remove dissipated power. Maximum allowable coolant temperature rise of 6°C.

FIND: Required coolant flow rate, tube length and lateral spacing of turns.

SCHEMATIC:



ASSUMPTIONS: (1) Constant properties, (2) Incompressible liquid and negligible viscous dissipation, (3) Steady-state conditions, (4) Negligible tube wall thermal resistance, (5) Fully-developed flow, (6) All heat dissipated by transformer is transferred to ethylene glycol.

PROPERTIES: Table A.5, ethylene glycol: ($\overline{T}_m$ = 300 K, assumed): k = 0.252 W/m·K, c_p = 2415 J/kg·K, $\mu_f = 1.57 \times 10^{-2}$ N·s/m^2, Pr = 1151.

ANALYSIS: From an overall energy balance, the required flow rate is

$$q = \dot{m}c_p(T_{m,o} - T_{m,i}) \quad \text{or} \quad \dot{m} = q/c_p(T_{m,o} - T_{m,i})$$

$$\dot{m} = 1000\ \text{W}/\left(2415\ \text{J/kg}\cdot\text{K} \times 6\text{K}\right)$$

$$\dot{m} = 6.90 \times 10^{-2}\ \text{kg/s}$$ <

From Equation 8.41a the length of tubing may be determined,

$$L = -\frac{\dot{m}c_p}{P\overline{h}}\ln\left(\frac{T_s - T_{m,o}}{T_s - T_{m,i}}\right)$$

where P = πD. For the tube flow, find

$$Re_D = \frac{4\dot{m}}{\pi D\mu} = \frac{4 \times 6.90 \times 10^{-2}\ \text{kg/s}}{\pi \times 0.020\ \text{m} \times 1.57 \times 10^{-2}\ \text{N}\cdot\text{S/m}^2} = 279.8$$

$$C/D = (D_t + D) = 250/20 = 12.5;\ \ Re_D(D/C)^{1/2} = 279.8 \times (20/250)^{1/2} = 79.1$$

Equation 8.77 yields

Continued…

PROBLEM 8.103 (Cont.)

$$a = \left(1 + \frac{957 \times (250/20)}{(279.8)^2 \times 1151}\right) = 1.0001$$

$$b = 1 + \frac{0.477}{1151} = 1.0004$$

Therefore, Equation 8.76 is

$$Nu_D = \left[\left(3.66 + \frac{4.343}{1.0001}\right)^3 + 1.158\left(\frac{279.8 \times (20/250)^{1/2}}{1.0004}\right)^{3/2}\right]^{1/3}$$

$$= 10.99$$

$$\overline{h} = h = Nu_D \frac{k}{D} = 10.99 \times 252 \times 10^{-3}\ \text{W/m} \cdot \text{K}/20 \times 10^{-3}\text{m} = 138.5\ \text{W/m}^2 \cdot \text{K}$$

Equation 8.41a becomes

$$L = -\frac{6.90 \times 10^{-2}\text{kg/s} \times 2415\ \text{J/kg} \cdot \text{K}}{\pi \times 0.02\ \text{m} \times 138.5\ \text{W/m}^2 \cdot \text{K}} \ln\left(\frac{(47 - 30)°\text{C}}{(47 - 24)°\text{C}}\right) = 5.79\ \text{m}$$ <

The number of turns of the tubing, N, is $N = L/\pi D = 5.79\ \text{m}/\ \pi(0.25\ \text{m}) = 7.37$ and hence the spacing, S, is

$$S = H/N = 500\ \text{mm}/7.37 = 67.8\ \text{mm}$$ <

COMMENT: (1) Coiling the tube results in a convective heat transfer coefficient that is 10.99/3.66 = 3 times larger than the fully-developed value for a straight tube. (2) For a straight tube, the thermal entrance length is $x_{fd,t} = 0.05Re_D PrD = 0.05 \times 279.8 \times 1151 \times 0.02\ \text{m} = 322\ \text{m}$. The flow will not be fully-developed, and care must be taken when using the predictions.