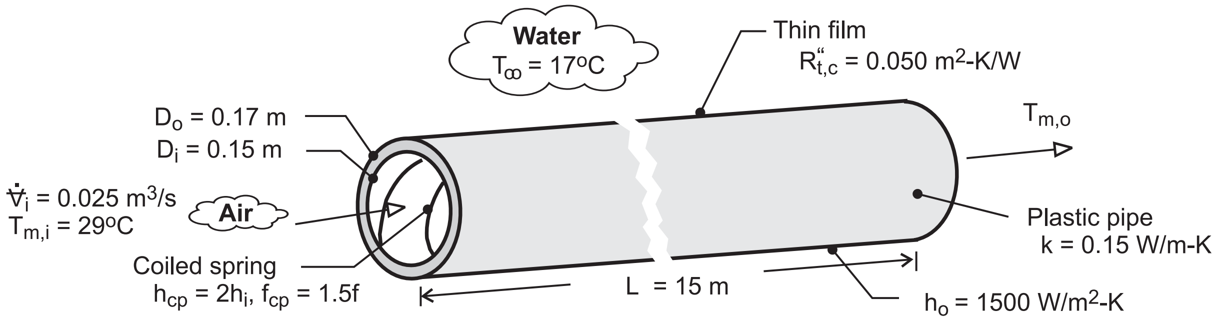
PROBLEM 8.100

KNOWN: Dimensions and thermal conductivity of plastic pipe. Volumetric flow rate and temperature of inlet air. Enhancement of inner convection coefficient and friction factor associated with coiled spring. Thermal resistance of coating on outer surface.

FIND: (a) Air outlet temperature and fan power requirement without coating and coiled spring, (b) Effect of coiled spring on air outlet temperature and fan power, (c) Effect of coating on outlet temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, (2) Negligible heat transfer from air in vertical pipe sections, (3) Air is ideal gas with negligible viscous dissipation and pressure variation, (4) Smooth interior surface without spring, (5) Negligible coating thickness, (6) Constant properties.

PROPERTIES: *Table A-4*, Air ($T_{m,i}$ = 29°C): $\rho_i = 1.155\ kg/m^3$. Air ($\bar{T}_m \approx 25°C$): $c_p = 1007$ J/kg·K, $\mu = 183.6 \times 10^{-7}\ N{\cdot}s/m^2$, $k_a = 0.0261$ W/m·K, Pr = 0.707.

ANALYSIS: (a) From Eq. (8.45a),

$$\frac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \exp\left(-\frac{\bar{U}A_s}{\dot{m}\,c_p}\right)$$

where, from Eqs. (3.36) and (3.37),

$$\left(\bar{U}A_s\right)^{-1} = R_{tot} = \frac{1}{\bar{h}_i \pi D_i L} + \frac{\ln\left(D_o / D_i\right)}{2\pi L k} + \frac{1}{h_o \pi D_o L}$$

With $\dot{m} = \rho_i \dot{\forall}_i = 0.0289\ kg/s$ and $Re_D = 4\dot{m}/\pi D_i \mu = 13{,}350$, the pipe flow is turbulent. With L/D_i = 100, we may assume fully developed flow throughout the pipe, and from Eq. (8.60),

$$\bar{h}_i = \frac{k_a}{D_i} 0.023 Re_D^{4/5} Pr^{0.3} = \frac{0.0261\,W/m \cdot K}{0.15m} 0.023 \left(13{,}350\right)^{4/5} \left(0.707\right)^{0.3} = 7.20\ W/m^2 \cdot K$$

Hence,
$$R_{tot} = \left(\frac{1}{7.20 \times \pi \times 0.15 \times 15} + \frac{\ln\left(0.17/0.15\right)}{2\pi \times 15 \times 0.15} + \frac{1}{1500 \times \pi \times 0.17 \times 15}\right)\frac{K}{W}$$

$$R_{tot} = \left(0.0196 + 0.0089 + 0.0001\right) K/W = 0.0286\ K/W$$

Hence, $\bar{U}A_s = R_{tot}^{-1} = 35.0\ W/K$ and

$$T_{m,o} = T_\infty + \left(T_{m,i} - T_\infty\right)\exp\left(-\frac{\bar{U}A_s}{\dot{m}\,c_p}\right) = 17°C + \left(12°C\right)\exp\left(-\frac{35.0\,W/K}{0.0289\,kg/s \times 1007\,J/kg \cdot K}\right) = 20.6°C \quad <$$

Continued …

From Eq. (8.21), $f = [0.790\ln(Re_D) - 1.64]^{-2} = 0.0291$. Hence, from Eqs. (8.22a) and (8.22b), with $u_{m,i} = \dot{\forall}_i / A_c = 1.415\,m/s$,

$$P \approx f\,\frac{\rho_i u_{m,i}^2}{2D_i}L\,\dot{\forall}_i = 0.0291\frac{1.155\,kg/m^3(1.415\,m/s)^2}{2(0.15m)}15m \times 0.025\,m^3/s = 0.084\,W \qquad <$$

(b) With $h_{cp} = 2h_i = 14.4\ W/m^2\cdot K$, the inner convection resistance is reduced from 0.0196 K/W to 0.0098 K/W and hence the total resistance from 0.0286 K/W to 0.0188 K/W. It follows that $\overline{U}A_s = 53.2\,W/K$ and

$$T_{m,o} = 18.9°C \qquad <$$

With $f_{cp} = 1.5f$,

$$P = 0.126\,W \qquad <$$

(c) With the coating of organic matter, there is an additional thermal resistance of the form $R_{t,c} = R''_{t,c}/(\pi D_o L) = \left(0.05\,m^2\cdot K/W\right)/(\pi \times 0.17m \times 15m) = 0.0062\,K/W$. The total resistance is then R_{tot} = 0.0348 K/W and $\overline{U}A_s = 28.7\,W/K$. Hence,

$$T_{m,o} = 21.5°C \qquad <$$

COMMENTS: (1) The fan power requirement is small, and the process is economical, with or without the coiled spring. (2) Heat transfer enhancement associated with the coiled spring is manifested by a 34% reduction in the total thermal resistance and a 1.7°C reduction in the outlet temperature. (3) *Fouling* of the outer surface increases the total resistance by 22% and the outlet temperature by 0.9°C. The penalty is not severe but could be ameliorated by periodic cleaning of the surface.