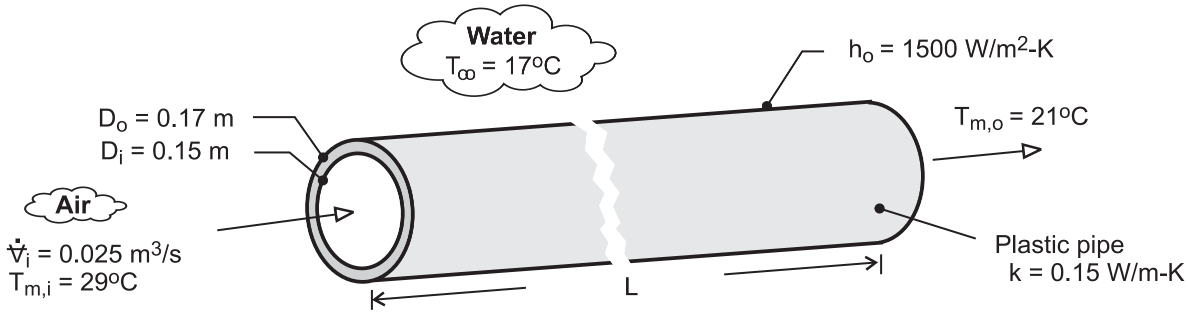
PROBLEM 8.31

KNOWN: Thermal conductivity and inner and outer diameters of plastic pipe. Volumetric flow rate and inlet and outlet temperatures of air flow through pipe. Convection coefficient and temperature of water.

FIND: Pipe length and fan power requirement.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, (2) Negligible heat transfer from air in vertical legs of pipe, (3) Ideal gas with negligible viscous dissipation and pressure variation, (4) Smooth interior surface, (5) Constant properties.

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

ANALYSIS: From Eq. (8.45a)

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

where, from Eqs. (3.34) and (3.35), $\left(\overline{U}A_s\right)^{-1} = R_{tot} = \dfrac{1}{\overline{h}_i \pi D_i L} + \dfrac{\ln\left(D_o/D_i\right)}{2\pi L k} + \dfrac{1}{h_o \pi D_o L}$

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

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

$$\left(\overline{U}A_s\right)^{-1} = \frac{1}{L}\left(\frac{1}{7.21\ W/m^2\cdot K \times \pi \times 0.15m} + \frac{\ln\left(0.17/0.15\right)}{2\pi \times 0.15\ W/m\cdot K} + \frac{1}{1500\ W/m^2\cdot K \times \pi \times 0.17m}\right)$$

$$\overline{U}A_s = \frac{L}{\left(0.294 + 0.133 + 0.001\right)} = 2.335L\ \ W/K$$

$$\frac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \frac{17-21}{17-29} = 0.333 = \exp\left(-\frac{2.335L}{0.0289\ kg/s \times 1007\ J/kg\cdot K}\right) = \exp\left(-0.0802L\right)$$

$$L = -\frac{\ln\left(0.333\right)}{0.0802} = 13.7m$$ <

From Eqs. (8.22a) and (8.22b) and with $u_{m,i} = \dot{\forall}_i / \left(\pi D_i^2/4\right) = 1.415\ m/s$, the fan power is

$$P = \left(\Delta p\right)\dot{\forall} \approx f\,\frac{\rho_i u_{m,i}^2}{2D_i} L\,\dot{\forall}_i = 0.0291\frac{1.155\ kg/m^3\left(1.415\ m/s\right)^2}{2\left(0.15m\right)} 13.7m \times 0.025m^3/s = 0.077\ W$$ <

where $f = (0.790 \ln Re_D - 1.64)^{-2} = 0.0291$ from Eq. (8.21).

COMMENTS: (1) With L/Di = 91, the assumption of fully developed flow throughout the pipe is justified. (2) The fan power requirement is small, and the process is economical. (3) The resistance to heat transfer associated with convection at the outer surface is negligible.