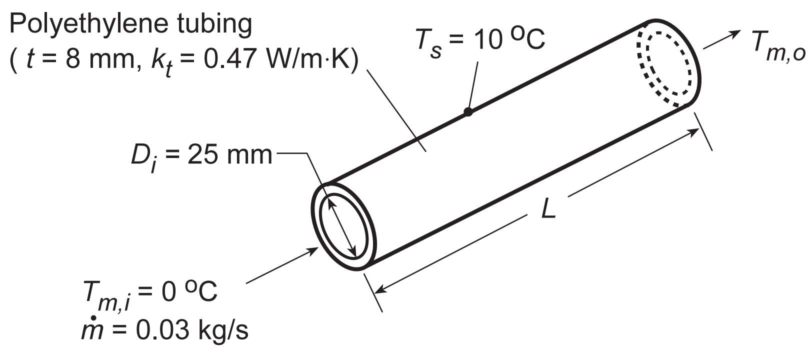
PROBLEM 8.77

KNOWN: Features of tubing used in a ground source heat pump. Temperature of surrounding soil. Fluid inlet temperature and flowrate.

FIND: (a) Effect of tube length on outlet temperature, (b) Recommended tube length and the effect of variations in the flowrate.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) Negligible conduction resistance in soil, (4) Incompressible liquid with negligible viscous dissipation, (5) Fluid properties correspond to those of water.

PROPERTIES: *Table A.6* (assume $\overline{T}_m$ = 277 K): c_p = 4206 J/kg·K, $\mu = 1560 \times 10^{-6}$ N·s/m^2, k = 0.577 W/m·K, Pr = 11.44.

ANALYSIS: (a) For the prescribed conditions, $Re_D = 4\dot{m}/\pi D_i \mu = 4(0.03\,\text{kg/s})/\pi(0.025\,\text{m})1560 \times 10^{-6}\,\text{N}\cdot\text{s/m}^2$ = 980 and the flow is laminar. With Pr > 5, Eq. 8.57 may be used to determine the average convection coefficient, with Eq. 8.56 defining the Graetz number:

$$\overline{Nu}_D = 3.66 + \frac{0.0668(D/L)Re_D\,Pr}{1 + 0.04\left[(D/L)Re_D\,Pr\right]^{2/3}}$$

With T_s used in lieu of T_∞, Eq. 8.45b may be used to determine $T_{m,o}$,

$$\frac{T_s - T_{m,o}}{T_s - T_{m,i}} = \exp\left(-\frac{L}{\dot{m}c_p R'_{tot}}\right)$$

where R'_{tot} accounts for the convection and tube wall conduction resistances,

$$R'_{tot} = R'_{cnv} + R'_{cnd} = \left(1/\pi D_i \overline{h}\right) + \ln\left(D_o/D_i\right)/2\pi k_t$$

and

$$D_o = D_i + 2t = 41\,\text{mm}.$$

Using the *Correlations* and *Properties* Toolpads of IHT, the following results were obtained for the effect of the tube length L on $T_{m,o}$.

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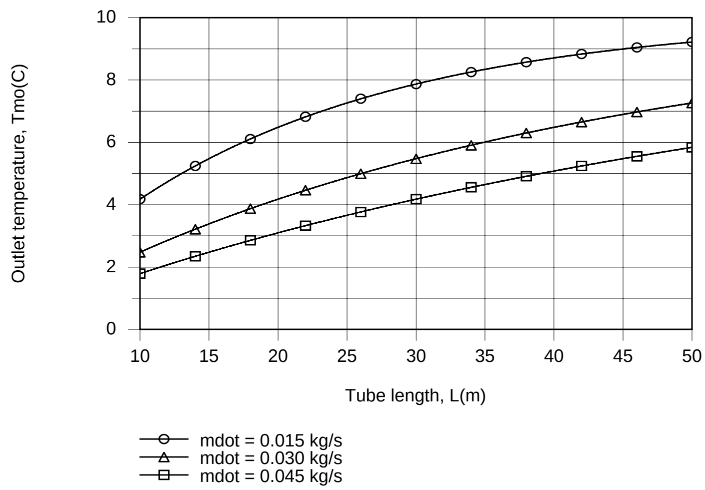

The longer the tube the larger the rate of heat extraction from the soil, and for $\dot{m}$ = 0.030 kg/s, the temperature rise of $\Delta T = (T_{m,o} - T_{m,i}) \approx 7°C$ is well below the maximum possible value of $\Delta T_{max} = 10°C$.

(b) The length should be *at least* 50 m long. If the flowrate were reduced by 50% ($\dot{m}$ = 0.015 kg/s), the corresponding temperature rise would be close to ΔT_{max} and L = 50 m would be close to optimal. However, for the nominal flowrate and a 50% increase from the nominal, the length should exceed 50 m to recover more heat and provide a heat pump inlet temperature which is closer to the maximum possible value.

COMMENTS: In practice, the tube surface temperature would be less than 10°C (if the temperature of the soil well removed from the tube were at 10°C), thereby reducing the heat extraction rate and $T_{m,o}$.