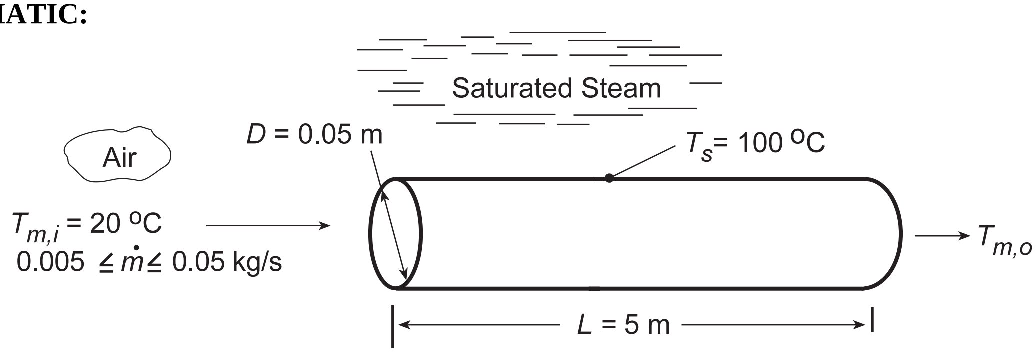
PROBLEM 8.53

KNOWN: Diameter, length and surface temperature of tubes used to heat ambient air. Flow rate and inlet temperature of air.

FIND: (a) Air outlet temperature and heat rate per tube, (b) Effect of flow rate on outlet temperature. Design and operating conditions suitable for providing 1 kg/s of air at 75°C.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, (2)Ideal gas with negligible viscous dissipation and pressure variation, (3) Negligible tube wall thermal resistance.

PROPERTIES: *Table A.4*, air (assume $\overline{T}_m$ = 330 K): c_p = 1008 J/kg·K, $\mu = 198.8 \times 10^{-7}$ N·s/m^2, k = 0.0285 W/m·K, Pr = 0.703.

ANALYSIS: (a) For $\dot{m}$ = 0.01 kg/s, $Re_D = 4\dot{m}/\pi D\mu$ = 0.04 kg/s/π(0.05 m)198.8 × 10^{-7} N·s/m^2 = 12,810. Hence, the flow is turbulent. If fully developed flow is assumed throughout the tube, the Dittus-Boelter correlation may be used to obtain the average Nusselt number.

$$\overline{Nu}_D \approx Nu_D = 0.023 Re_D^{4/5} Pr^{0.4} = 0.023(12,810)^{0.8}(0.703)^{0.4} = 38.6$$

Hence, $\bar{h} = \overline{Nu}_D (k/D) = 38.6(0.0285\,W/m\cdot K/0.05\,m) = 22.0\,W/m^2\cdot K$

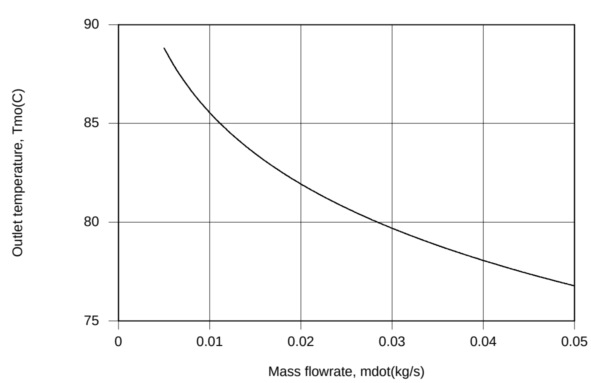
From Eq. 8.41b,

$$\frac{T_s - T_{m,o}}{T_s - T_{m,i}} = \exp\left(-\frac{\pi D L \bar{h}}{\dot{m}c_p}\right) = \exp\left(-\frac{\pi \times 0.05\,m \times 5\,m \times 22\,W/m^2\cdot K}{0.01\,kg/s \times 1008\,J/kg\cdot K}\right) = 0.180$$

$$T_{m,o} = T_s - 0.180\left(T_s - T_{m,i}\right) = 100^\circ C - 0.180\left(80^\circ C\right) = 85.6^\circ C \qquad <$$

Hence, $q = \dot{m}c_p\left(T_{m,o} - T_{m,i}\right) = 0.01\,kg/s\left(1008\,J/kg\cdot K\right)65.6\,K = 661\,W \qquad <$

(b) The effect of flow rate on the outlet temperature was determined by using the IHT *Correlations* and *Properties* Toolpads.



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Although $\bar{h}$ and hence the heat rate increase with increasing $\dot{m}$, the increase in q is not linearly proportional to the increase in $\dot{m}$ and $T_{m,o}$ decreases with increasing $\dot{m}$.

A flow rate of $\dot{m}$ = 0.05 kg/s is not large enough to provide the desired outlet temperature of 75°C, and to achieve this value, a flow rate of 0.0678 kg/s would be needed. At such a flow rate, N = 1 kg/s/0.0678 kg/s = 14.75 ≈ 15 tubes would be needed to satisfy the process air requirement. Alternatively, a lower flow rate could be supplied to a larger number of tubes and the discharge mixed with ambient air to satisfy the desired conditions. Requirements of this option are that

$$N\dot{m} + \dot{m}_{amb} = 1\,kg/s$$

$$\left(N\dot{m} + \dot{m}_{amb}\right)c_p\left(T_{m,o} - T_{m,i}\right) = 1\,kg/s \times 1008\,J/kg \cdot K\left(75-20\right)K = 55,400\,W$$

where $\dot{m}$ is the flow rate per tube. Using a larger number of tubes with a smaller flow rate per tube would reduce flow pressure losses and hence provide for reduced operating costs.

COMMENTS: With L/D = 5 m/0.05 m = 100, the assumption of fully developed conditions throughout the tube is reasonable.