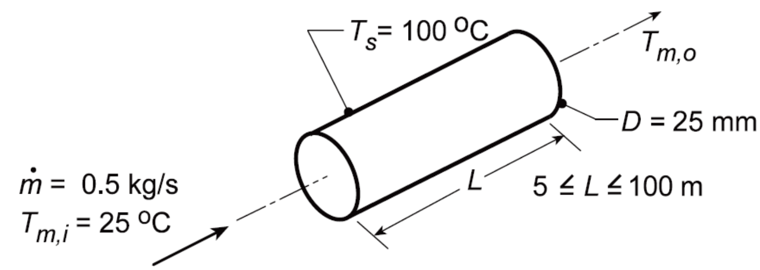
PROBLEM 8.20

KNOWN: Inlet temperature and flowrate of oil moving through a tube of prescribed diameter and surface temperature.

FIND: (a) Oil outlet temperature $T_{m,o}$ for two tube lengths, 5 m and 100 m, and log mean and arithmetic mean temperature differences, (b) Effect of L on $T_{m,o}$ and $\overline{Nu}_D$.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Incompressible liquid with negligible viscous dissipation, (3) Constant properties.

PROPERTIES: *Table A.4*, Oil (330 K): c_p = 2035 J/kg·K, μ = 0.0836 N·s/m^2, k = 0.141 W/m·K, Pr = 1205.

ANALYSIS: (a) Using Eqs. 8.41b and 8.6

$$T_{m,o} = T_s - \left(T_s - T_{m,i}\right)\exp\left(-\frac{\pi DL}{\dot{m}c_p}\bar{h}\right)$$

$$Re_D = \frac{4\dot{m}}{\pi D\mu} = \frac{4\times 0.5\,kg/s}{\pi\times 0.025\,m\times 0.0836\,N\cdot s/m^2} = 304.6$$

With $x_{fd,h} = 0.05DRe_D = 0.4$ m, it is reasonable to assume the flow is hydrodynamically fully developed. However, with $x_{fd,t} = x_{fd,h}Pr = 495$ m, the flow is thermally developing. Since thermal entry length effects will be significant and Pr > 5, use Eq. 8.57 with Eq. 8.56 for the Graetz number:

$$\bar{h} = \frac{k}{D}\left[3.66 + \frac{0.0688(D/L)Re_D\,Pr}{1+0.04\left[(D/L)Re_D\,Pr\right]^{2/3}}\right] = \frac{0.141\,W/m\cdot K}{0.025\,m}\left[3.66 + \frac{2.45\times 10^4\,D/L}{1+205(D/L)^{2/3}}\right]$$

For L = 5 m, $\bar{h} = 5.64(3.66+17.51) = 119\,W/m^2\cdot K$, hence

$$T_{m,o} = 100^\circ C - \left(75^\circ C\right)\exp\left(-\frac{\pi\times 0.025\,m\times 5\,m\times 119\,W/m^2\cdot K}{0.5\,kg/s\times 2035\,J/kg\cdot K}\right) = 28.4^\circ C \quad <$$

For L = 100 m, $\bar{h} = 5.64(3.66+3.38) = 40\,W/m^2\cdot K$, $T_{m,o}$ = 44.9°C. <

Also, *for* L = 5 m,

$$\Delta T_{\ell m} = \frac{\Delta T_o - \Delta T_i}{\ell n\left(\Delta T_o/\Delta T_i\right)} = \frac{71.6-75}{\ell n(71.6/75)} = 73.3^\circ C \qquad \Delta T_{am} = \left(\Delta T_o + \Delta T_i\right)/2 = 73.3^\circ C \quad <$$

For L = 100 m, $\Delta T_{\ell m} = 64.5^\circ C$, $\Delta T_{am} = 65.1^\circ C$ <

(b) The effect of tube length on the outlet temperature and Nusselt number was determined by using the *Correlations* and *Properties* Toolpads of IHT.

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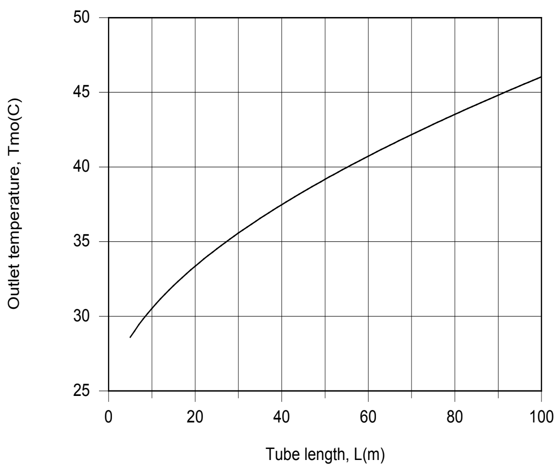

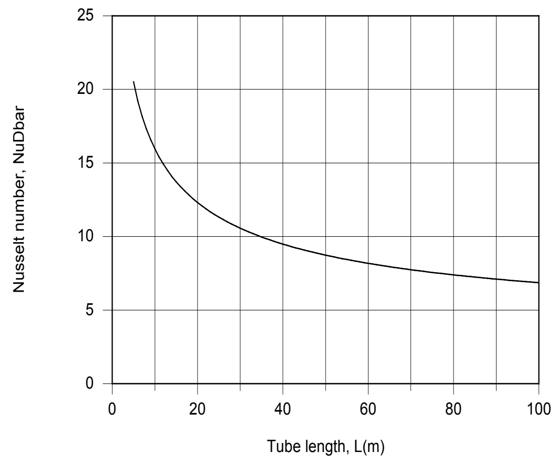

The outlet temperature approaches the surface temperature with increasing L, but even for L = 100 m, $T_{m,o}$ is well below T_s. Although $\overline{Nu}_D$ decays with increasing L, it is still well above the fully developed value of $Nu_{D,fd} = 3.66$.

COMMENTS: (1) The average, mean temperature, $\overline{\overline{T}}_m$ = 330 K, was significantly overestimated in part (a). The accuracy may be improved by evaluating the properties at a lower temperature. (2) Use of ΔT_{am} instead of $\Delta T_{\ell m}$ is reasonable for small to moderate values of $(T_{m,i} - T_{m,o})$. For large values of $(T_{m,i} - T_{m,o})$, $\Delta T_{\ell m}$ should be used.