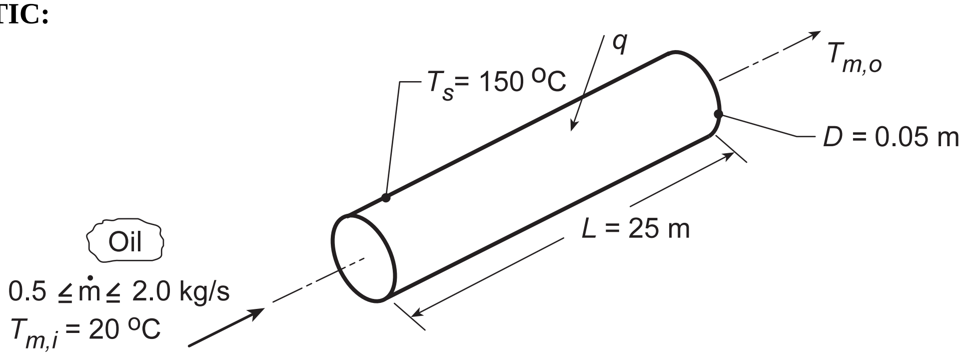
PROBLEM 8.25

KNOWN: Inlet temperature and flowrate of oil flowing through a tube of prescribed surface temperature and geometry.

FIND: (a) Oil outlet temperature and total heat transfer rate, and (b) Effect of flowrate.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible temperature drop across tube wall, (2) Incompressible liquid with negligible viscous dissipation.

PROPERTIES: *Table A.5*, Engine oil (assume $T_{m,o}$ = 140°C, hence $\overline{T}_m$ = 80°C = 353 K): $\rho = 852$ kg/m^3, $\nu = 37.5 \times 10^{-6}$ m^2/s, $k = 138 \times 10^{-3}$ W/m·K, Pr = 490, $\mu = \rho \cdot \nu = 0.032$ kg/m·s, $c_p = 2131$ J/kg·K.

ANALYSIS: (a) For constant surface temperature the oil outlet temperature may be obtained from Eq. 8.41b. Hence

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

To determine $\overline{h}$, first calculate Re_D from Eq. 8.6,

$$Re_D = \frac{4\dot{m}}{\pi D\mu} = \frac{4(0.5\,kg/s)}{\pi(0.05m)(0.032\,kg/m\cdot s)} = 398$$

Hence the flow is laminar. Moreover, from Eq. 8.23 the thermal entry length is

$$x_{fd,t} \approx 0.05D\,Re_D\,Pr = 0.05(0.05\,m)(398)(490) = 486\,m\ .$$

Since L = 25 m the flow is far from being thermally fully developed. Since Pr > 5, $\overline{h}$ may be determined from Eq. 8.57

$$\overline{Nu}_D = 3.66 + \frac{0.0668 Gz_D}{1 + 0.04 Gz_D^{2/3}}\ .$$

With $Gz_D = (D/L)Re_D Pr = (0.05/25)398 \times 490 = 390$, it follows that

$$\overline{Nu}_D = 3.66 + \frac{26}{1 + 2.14} = 11.95.$$

Hence, $\overline{h} = \overline{Nu}_D \dfrac{k}{D} = 11.95 \dfrac{0.138\,W/m\cdot K}{0.05\,m} = 33\,W/m^2\cdot K$ and it follows that

Continued...

PROBLEM 8.25 (Cont.)

$$T_{m,o} = 150^\circ C - \left(150^\circ C - 20^\circ C\right)\exp\left[-\frac{\pi(0.05\,m)(25\,m)}{0.5\,kg/s \times 2131\,J/kg\cdot K} \times 33\,W/m^2\cdot K\right]$$

$T_{m,o} = 35°C.$ <

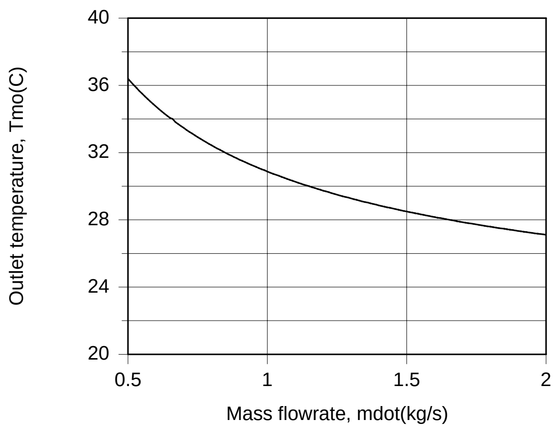
From the overall energy balance, Eq. 8.34, it follows that

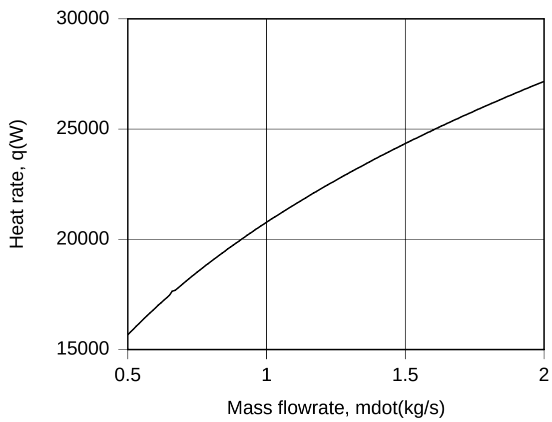
$$q = \dot{m}c_p\left(T_{m,o} - T_{m,i}\right) = 0.5\,kg/s \times 2131\,J/kg\cdot K \times (35-20)^\circ C$$

$q = 15{,}980$ W. <

The value of $T_{m,o}$ has been grossly overestimated in evaluating the properties. The properties should be re-evaluated at $\overline{T} = (20 + 35)/2 = 27°C$ and the calculations repeated. Iteration should continue until satisfactory convergence is achieved between the calculated and assumed values of $T_{m,o}$. Following such a procedure, one would obtain $T_{m,o} = 36.4°C$, $Re_D = 27.8$, $\overline{h} = 32.8\ W/m^2\cdot K$, and $q = 15{,}660$ W. The small effect of reevaluating the properties is attributed to the compensating effects on Re_D (a large decrease) and Pr (a large increase).

(b) The effect of flowrate on $T_{m,o}$ and q was determined by using the appropriate IHT *Correlations* and *Properties* Toolpads.





The heat rate increases with increasing $\dot{m}$ due to the corresponding increase in Re_D and hence $\overline{h}$. However, the increase is not proportional to $\dot{m}$, causing $\left(T_{m,o} - T_{m,i}\right) = q/\dot{m}c_p$, and hence $T_{m,o}$, to decrease with increasing $\dot{m}$. The maximum heat rate corresponds to the maximum flowrate ($\dot{m}$ = 0.20 kg/s).

COMMENTS: Note that significant error would be introduced by assuming fully developed thermal conditions and $\overline{Nu}_D = 3.66$. The flow remains well within the laminar region over the entire range of $\dot{m}$.