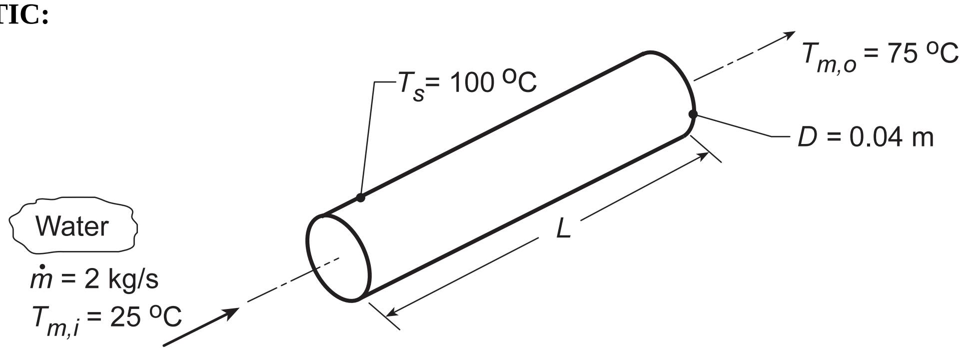
PROBLEM 8.35

KNOWN: Flow rate, inlet temperature and desired outlet temperature of water passing through a tube of prescribed diameter and surface temperature.

FIND: (a) Required tube length, L, for prescribed conditions, (b) Required length using tube diameters over the range 30 ≤ D ≤ 50 mm with flow rates $\dot{m}$ = 1, 2 and 3 kg/s; represent this design information graphically, and (c) Pressure gradient as a function of tube diameter for the three flow rates assuming the tube wall is smooth.

SCHEMATIC:



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

PROPERTIES: *Table A.6*, Water ($\overline{T}_m$ = 323 K): c_p = 4181 J/kg·K, μ = 547 × 10^{-6} N·s/m², k = 0.643 W/m·K, Pr = 3.56.

ANALYSIS: (a) From Eq. 8.6, the Reynolds number is

$$Re_D = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \times 2\,kg/s}{\pi (0.04\,m) 547 \times 10^{-6}\,N \cdot s/m^2} = 1.16 \times 10^5. \qquad (1)$$

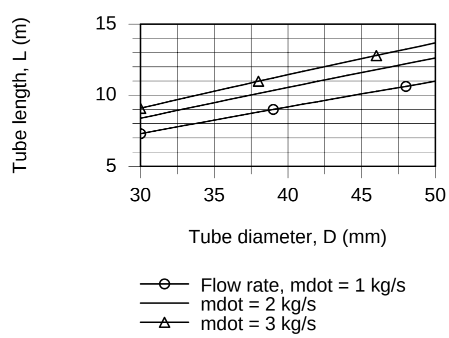
Hence the flow is turbulent, and assuming fully developed conditions throughout the tube, it follows from the Dittus-Boelter correlation, Eq. 8.60,

$$\overline{h} = \frac{k}{D} 0.023 Re_D^{4/5} Pr^{0.4} = \frac{0.643\,W/m \cdot K}{0.04\,m} 0.023 \left(1.16 \times 10^5\right)^{4/5} (3.56)^{0.4} = 6919\,W/m^2 \cdot K \qquad (2)$$

From Eq. 8.41a, we then obtain

$$L = \frac{-\dot{m} c_p \ell n \left(\Delta T_o / \Delta T_i\right)}{\pi D \overline{h}} = -\frac{2\,kg/s\left(4181\,J/kg \cdot K\right) \ell n \left(25^\circ C / 75^\circ C\right)}{\pi (0.04\,m) 6919\,W/m^2 \cdot K} = 10.6\,m. \qquad <$$

(b) Using the *IHT Correlations Tool*, *Internal Flow*, for fully developed *Turbulent Flow*, along with appropriate energy balance and rate equations, the required length L as a function of flow rate is computed and plotted on the right.



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PROBLEM 8.35 (Cont.)

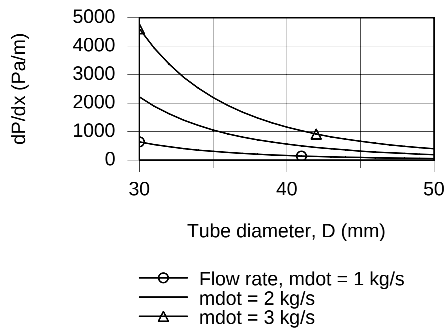
(c) From Eq. 8.22a the pressure drop is

$$\frac{\Delta p}{\Delta x} = f\,\frac{\rho u_m^2}{2D} \qquad (4)$$

The friction factor, f, for the smooth surface condition, Eq. 8.21 with $3000 \le Re_D \le 5 \times 10^6$, is

$$f = \left(0.790\,\ell n\left(Re_D\right) - 1.64\right)^{-2} \qquad (5)$$

Using IHT with these equations and Eq. (1), the pressure gradient as a function of diameter for the selected flow rates is computed and plotted on the right.



COMMENTS: (1) Since L/D = (10.6/0.040) = 265, the assumption of fully developed conditions throughout is justified.

(2) The IHT Workspace used to generate the graphical results are shown below.

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// Rate Equation Tool - Tube Flow with Constant Surface Temperature:
/* For flow through a tube with a uniform wall temperature, Fig 8.7b, the
overall energy balance and heat rate equations are */
q = mdot*cp*(Tmo - Tmi)    // Heat rate, W; Eq 8.34
(Ts - Tmo) / (Ts - Tmi) = exp ( - P * L * hDbar / (mdot * cp))        // Eq 8.41b
// where the fluid and constant tube wall temperatures are
Ts =  100 + 273          // Tube wall temperature, K
Tmi = 25 + 273                  // Inlet mean fluid temperature, K
Tmo = 75 + 273           // Outlet mean fluid temperature, K
// The tube parameters are
P = pi * D               // Perimeter, m
Ac = pi * (D^2) / 4// Cross sectional area, m^2
D = 0.040                // Tube diameter, m
D_mm = D * 1000
// The tube mass flow rate and fluid thermophysical properties are
mdot = rho * um * Ac
mdot = 1                 // Mass flow rate, kg/s

// Correlation Tool - Internal Flow, Fully Developed Turbulent Flow (Assumed):
NuDbar = NuD_bar_IF_T_FD(ReD,Pr,n)     // Eq 8.60
n = 0.4   // n = 0.4 or 0.3 for Ts>Tm or Ts<Tm
NuDbar = hDbar * D / k
ReD = um * D / nu
/* Evaluate properties at the fluid average mean temperature, Tmbar. */
Tmbar = Tfluid_avg (Tmi,Tmo)

// Properties Tool - Water:
// Water property functions :T dependence, From Table A.6
// Units: T(K), p(bars);
x = 0              // Quality (0=sat liquid or 1=sat vapor)
rho = rho_Tx("Water",Tmbar,x)        // Density, kg/m^3
cp = cp_Tx("Water",Tmbar,x)          // Specific heat, J/kg·K
nu = nu_Tx("Water",Tmbar,x)          // Kinematic viscosity, m^2/s
k = k_Tx("Water",Tmbar,x)  // Thermal conductivity, W/m·K
Pr = Pr_Tx("Water",Tmbar,x)          // Prandtl number

// Pressure Gradient, Equations 8.21, 8.22a:
dPdx = f * rho * um^2 / ( 2 * D )
f = ( 0.790 * ln (ReD) - 1.64 ) ^ -2
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