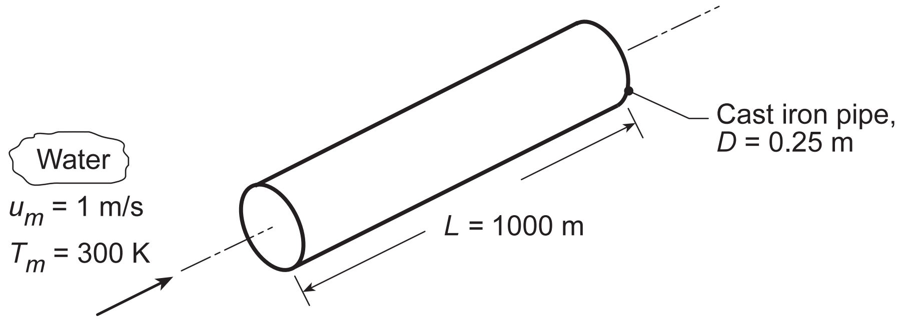
PROBLEM 8.3

KNOWN: Temperature and velocity of water flow in a pipe of prescribed dimensions.

FIND: Pressure drop and pump power requirement for (a) a smooth pipe, (b) a cast iron pipe with a clean surface, and (c) smooth pipe for a range of mean velocities 0.05 to 1.5 m/s.

SCHEMATIC:



ASSUMPTIONS: (1) Steady, fully developed flow.

PROPERTIES: *Table A.6*, Water (300 K): $\rho = 997\ \text{kg/m}^3$, $\mu = 855 \times 10^{-6}\ \text{N·s/m}^2$, $\nu = \mu/\rho = 8.576 \times 10^{-7}\ \text{m}^2/\text{s}$.

ANALYSIS: From Eq. 8.22a and 8.22b, the pressure drop and pump power requirement are

$$\Delta p = f\,\frac{\rho u_m^2}{2D}L \qquad\qquad P = \Delta p \dot{V} = \Delta p\left(\pi D^2/4\right)u_m \qquad (1,2)$$

The friction factor, f, may be determined from Figure 8.3 or Eq. 8.20 for different relative roughness, e/D, surfaces or from Eq. 8.21 for the smooth condition, $3000 \le Re_D \le 5 \times 10^6$,

$$f = \left(0.790 \ln\left(Re_D\right) - 1.64\right)^{-2} \qquad (3)$$

where the Reynolds number is

$$Re_D = \frac{u_m D}{\nu} = \frac{1\,\text{m/s} \times 0.25\,\text{m}}{8.576 \times 10^{-7}\ \text{m}^2/\text{s}} = 2.915 \times 10^5 \qquad (4)$$

(a) *Smooth surface:* from Eqs. (3), (1) and (2),

$$f = \left(0.790 \ln\left(2.915 \times 10^5\right) - 1.64\right)^{-2} = 0.01451$$

$$\Delta p = 0.01451\left(997\,\text{kg/m}^3 \times 1\,\text{m}^2/\text{s}^2 / 2 \times 0.25\,\text{m}\right)1000\,\text{m} = 2.89 \times 10^4\ \text{kg/s}^2\cdot\text{m} = 0.289\,\text{bar}$$ <

$$P = 2.89 \times 10^4\ \text{N/m}^2\left(\pi \times 0.25^2\ \text{m}^2/4\right)1\,\text{m/s} = 1418\,\text{N}\cdot\text{m/s} = 1.42\,\text{kW}$$ <

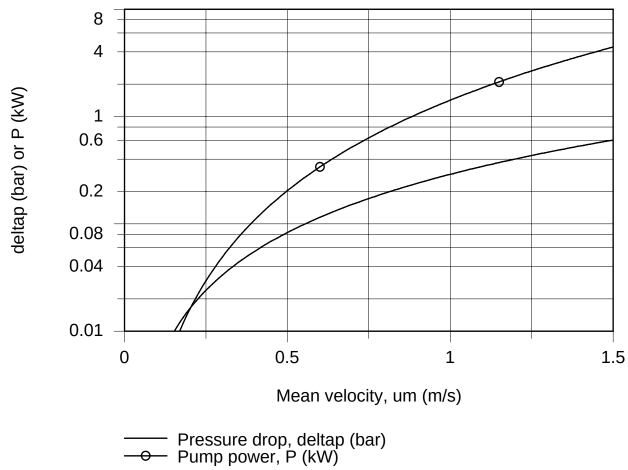
(b) *Cast iron clean surface:* with e = 260 μm, the relative roughness is $e/D = 260 \times 10^{-6}\ \text{m}/0.25\ \text{m} = 1.04 \times 10^{-3}$. From Figure 8.3 or Eq. 8.20 with $Re_D = 2.92 \times 10^5$, find f = 0.021. Hence,

$\Delta p = 0.402$ bar $\qquad$ P = 1.97 kW <

(c) *Smooth surface:* Using IHT with the expressions of part (a), the pressure drop and pump power requirement as a function of mean velocity, u_m, for the range $0.05 \le u_m \le 1.5$ m/s are computed and plotted below.

Continued...

PROBLEM 8.3 (Cont.)



The pressure drop is a strong function of the mean velocity. So is the pump power since it is proportional to both Δp and the mean velocity.

COMMENTS: (1) Note that $L/D = 4000 >> (x_{fd,h}/D) \approx 10$ for turbulent flow and the assumption of fully developed conditions is justified.

(2) Surface fouling results in increased surface roughness and increases operating costs through increasing pump power requirements.

(3) The *IHT Workspace* used to generate the graphical results follows.

```
// Pressure drop:
deltap = f * rho * um^2 * L / ( 2 * D )          // Eq (1); Eq 8.22a
deltap_bar = deltap / 1.00e5                     // Conversion, Pa to bar units
Power = deltap * ( pi * D^2 / 4 ) * um           // Eq (2); Eq 8.22b
Power_kW = Power / 1000                          // Useful for scaling graphical result

// Reynolds number and friction factor:
ReD = um * D / nu                                // Eq (3)
f =  (0.790 * ln (ReD) - 1.64 ) ^ (-2)           // Eq (4); Eq 8.21, smooth surface condition

// 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",Tm,x)         // Density, kg/m^3
nu = nu_Tx("Water",Tm,x)           // Kinematic viscosity, m^2/s

// Assigned variables:
um = 1                             // Mean velocity, m/s
Tm = 300                           // Mean temperature, K
D = 0.25                           // Tube diameter, m
L = 1000                           // Tube length, m
```