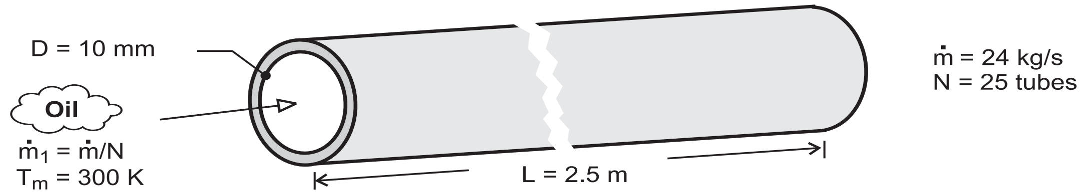
PROBLEM 8.4

KNOWN: Number, diameter and length of tubes and flow rate for an engine oil cooler.

FIND: Pressure drop and pump power (a) for flow rate of 24 kg/s and (b) as a function of flow rate for the range $10 \le \dot{m} \le 30$ kg/s.

SCHEMATIC:



ASSUMPTIONS: (1) Fully developed flow throughout the tubes.

PROPERTIES: *Table A.5*, Engine oil (300 K): $\rho = 884\ \text{kg/m}^3$, $\mu = 0.486$ kg/s·m.

ANALYSIS: (a) Considering flow through a single tube, find

$$\text{Re}_D = \frac{4\dot{m}}{\pi D \mu} = \frac{4(24\,\text{kg/s})}{25\pi(0.010\,\text{m})0.486\,\text{kg/s}\cdot\text{m}} = 251.5 \tag{1}$$

Hence, the flow is laminar and from Equation 8.19,

$$f = \frac{64}{\text{Re}_D} = \frac{64}{251.5} = 0.2545. \tag{2}$$

With

$$u_m = \frac{\dot{m}_1}{\rho\left(\pi D^2/4\right)} = \frac{(24/25)\,\text{kg/s}\,(4)}{\left(884\,\text{kg/m}^3\right)\pi(0.010\,\text{m})^2} = 13.8\ \text{m/s} \tag{3}$$

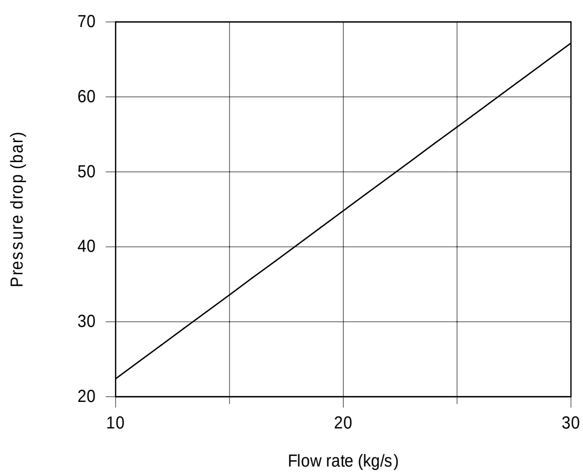
Equation 8.22a yields

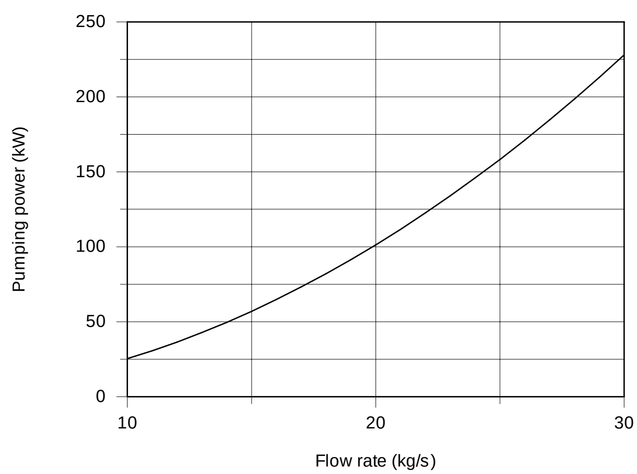
$$\Delta p = f\,\frac{\rho u_m^2}{2D}L = 0.2545\,\frac{\left(884\,\text{kg/m}^3\right)(13.8\,\text{m/s})^2}{2(0.010\,\text{m})}2.5\,\text{m} = 5.38\times10^6\ \text{N/m}^2 = 53.8\ \text{bar} \tag{4}$$ <

The pump power requirement from Equation 8.22b,

$$P = \Delta p\cdot\dot{V} = \Delta p\cdot\frac{\dot{m}}{\rho} = 5.38\times10^6\ \text{N/m}^2\,\frac{24\,\text{kg/s}}{884\,\text{kg/m}^3} = 1.459\times10^5\ \text{N·m/s} = 146\ \text{kW}. \tag{5}$$ <

(b) Using IHT with the expressions of part (a), the pressure drop and pump power requirement as a function of flow rate, $\dot{m}$, for the range $10 \le \dot{m} \le 30$ kg/s are computed and plotted below.





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In the plot above, note that the pressure drop is linear with the flow rate since, from Eq. (2), the friction factor is inversely dependent upon mean velocity. The pump power, however, is quadratic with the flow rate.

COMMENTS: (1) If there is a hydrodynamic entry region, the average friction factor for the entire tube length would exceed the fully developed value, thereby increasing Δp and P.

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

```
/* Results: base case, part (a)
P_kW        ReD      deltap_bar        f         mu       rho      um       D       N
       mdot
145.9       251.5    53.75             0.2545    0.486    884.1    13.83    0.01    25
       24                 */

// Reynolds number and friction factor
ReD = 4 * mdot1 / (pi * D * mu)        // Reynolds number, Eq (1)
f = 64 / ReD                           // Friction factor, laminar flow, Eq. 8.19, Eq. (2)

// Average velocity and flow rate
mdot1 = rho * Ac * um         // Flow rate, kg/s; single tube
mdot = mdot1 * N              // Total flow rate, kg/s; N tubes
Ac = pi * D^2 / 4             // Tube cross-sectional area, m^2

// Pressure drop and power
deltap = f * rho * um^2 * L / (2 * D)      // Pressure drop, N/m^2
deltap_bar = deltap * 1e-5                 // Pressure drop, bar
P = deltap * mdot / rho                    // Power, W
P_kW = P / 1000                            // Power, kW

// Input variables
D = 0.01              // Diameter, m
mdot = 24             // Total flow rate, kg/s
L = 2.5               // Tube length, m
N = 25                // Number of tubes
Tm = 300              // Mean temperature of oil, K

// Engine Oil property functions : From Table A.5
rho = rho_T("Engine Oil",Tm)          // Density, kg/m^3
mu = mu_T("Engine Oil",Tm)            // Viscosity,  N·s/m^2
```