Q1)  

**Solution:** For SAE 10 oil, take \( \rho = 870 \text{ kg/m}^3 \) and \( \mu = 0.104 \text{ kg/m} \cdot \text{s} \). The Reynolds number based on side length \( a \) is \( \text{Re} = \rho a \nu / \mu = 335 \), so the flow is *laminar*. The bottom side of the triangle is \( 2(2 \text{ cm}) \sin 40^\circ \approx 2.57 \text{ cm} \). Calculate hydraulic diameter:

\[
A = \frac{1}{2} (2.57)(2 \cos 40^\circ) \approx 1.97 \text{ cm}^2; \quad P = 6.57 \text{ cm}; \quad D_h = \frac{4A}{P} \approx 1.20 \text{ cm}
\]

\[
\text{Re}_{D_h} = \frac{\rho D_h \nu}{\mu} = \frac{870(2.0)(0.0120)}{0.104} \approx 201; \quad \text{from Table 6.4, } \theta = 40^\circ, \quad f \text{Re} \approx 52.9
\]

Then \( f = \frac{52.9}{201} \approx 0.263 \), \( \Delta p = f \frac{L}{D_h} \frac{\rho}{2} \nu^2 = (0.263) \left( \frac{0.6}{0.012} \right) \left( \frac{870}{2} \right) (2)^2 \approx 23000 \text{ Pa} \quad \text{Ans.}
\]

Q2)  

**Solution** Two pipes of identical diameter and material are connected in parallel. The length of one of the pipes is twice the length of the other. The ratio of the flow rates in the two pipes is to be determined.

**Assumptions** 1 The flow is steady and incompressible. 2 The flow is fully turbulent in both pipes and thus the friction factor is independent of the Reynolds number (it is the same for both pipes since they have the same material and diameter). 3 The minor losses are negligible.

**Analysis** When two pipes are parallel in a piping system, the head loss for each pipe must be same. When the minor losses are disregarded, the head loss for fully developed flow in a pipe of length \( L \) and diameter \( D \) can be expressed as

\[
h_L = f \frac{L}{D} \frac{\nu^2}{2g} = f \frac{L}{D} \frac{1}{2g} \left( \frac{\nu}{A_c} \right)^2 = f \frac{L}{D} \frac{1}{2g} \frac{\nu}{\pi D^2 / 4} = \frac{8fL}{Dg} \frac{1}{\pi D^2} \frac{\nu^2}{D^4}
\]

Solving for the flow rate gives

\[
\nu = \sqrt{\frac{\pi^2 h_L g D^5}{8kL}} = k \sqrt{L} \quad (k \text{ is a constant})
\]

When the pipe diameter, friction factor, and the head loss is constant, which is the case here for parallel connection, the flow rate becomes inversely proportional to the square root of length \( L \). Therefore, when the length is doubled, the flow rate will decrease by a factor of \( 2^{-0.5} = 1.41 \) since

If \( \nu_A = \frac{k}{\sqrt{L_A}} \)

Then \( \nu_B = \frac{k}{\sqrt{2L_A}} = \frac{k}{\sqrt{2} \sqrt{L_A}} = \frac{k}{\sqrt{2}} \frac{\nu_A}{\sqrt{2}} = 0.707 \nu_A \)

Therefore, the ratio of the flow rates in the two pipes is 0.707.

**Discussion** Even though one pipe is twice as long as the other, the volume flow rate in the shorter pipe is *not* twice as much – the relationship is nonlinear.
Q3)

**Solution:** For water at 20°C, take \( \rho = 998 \text{ kg/m}^3 \) and \( \mu = 0.001 \text{ kg/m} \cdot \text{s} \). For galvanized iron, \( \varepsilon = 0.15 \text{ mm} \). Assume turbulent flow, with \( \Delta p \) the same for each leg:

\[
h_{f1} = f_1 \frac{L_1}{d_1} \frac{V_1^2}{2g} = h_{f2} + h_{m2} = \frac{V_2^2}{2g} \left( f_2 \frac{L_2}{d_2} + 1.5 \right),
\]

and \( Q_1 + Q_2 = (\pi/4)d_1^2 V_1 + (\pi/4)d_2^2 V_2 = Q_{\text{total}} = 0.036 \text{ m}^3/\text{s} \)

When the friction factors are correctly found from the Moody chart, these two equations may be solved for the two velocities (or flow rates). Begin by guessing \( f \approx 0.020 \):

\[
(0.02) \left( \frac{60}{0.05} \right) \frac{V_1^2}{2(9.81)} = \frac{V_2^2}{2(9.81)} \left( (0.02) \left( \frac{55}{0.04} \right) + 1.5 \right), \quad \text{solve for } V_1 \approx 1.10V_2
\]

then \( \frac{\pi}{4}(0.05)^2(1.10V_2) + \frac{\pi}{4}(0.04)^2 V_2 = 0.036 \). Solve \( V_2 \approx 10.54 \text{ m/s}, \ V_1 \approx 11.59 \text{ m/s} \)

Correct \( \text{Re}_1 = 578000 \), \( f_1 = 0.0264 \), \( \text{Re}_2 = 421000 \), \( f_2 = 0.0282 \), repeat.

The 2nd iteration converges: \( f_1 \approx 0.0264 \), \( V_1 = 11.69 \text{ m/s}, \ f_2 \approx 0.0282 \), \( V_2 = 10.37 \text{ m/s} \),

\[Q_1 = A_1 V_1 = \mathbf{0.023 \text{ m}^3/\text{s}}, \quad Q_2 = A_2 V_2 = \mathbf{0.013 \text{ m}^3/\text{s}}. \quad \text{Ans. (a)}\]

The pressure drop is the same in either leg:

\[
\Delta p = f_1 \frac{L_1}{d_1} \frac{\rho V_1^2}{2} = \left( f_2 \frac{L_2}{d_2} + 1.5 \right) \frac{\rho V_2^2}{2} \approx \mathbf{2.16E6 \text{ Pa}} \quad \text{Ans. (b)}
\]

Q4)

**Solution:** For kerosene, take \( \rho = 1.56 \text{ slug/ft}^3 \) and for water \( \rho = 1.56 \text{ slug/ft}^3 \). Use the scaling laws, Eq. (11.28):

\[
\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \left( \frac{D_1}{D_2} \right)^3 = \frac{Q_1}{22000} = \frac{710}{850}, \quad \therefore \ Q_1 = 18400 \text{ gpm}
\]

Read \( H_1 = 235 \text{ ft} \) and \( P_1 = 1175 \text{ bhp} \)

\[D_1 = D_2; \quad H_2 = 235 \left( \frac{850}{710} \right)^2 = 340 \text{ ft} \quad \text{Ans. (a)}\]

\[P_2 = P_1 (\rho_2/\rho_1) (n_2/n_1)^3 = 1175(1.56/1.94)(850/710)^3 = \mathbf{1600 \text{ bhp}} \quad \text{Ans. (b)}\]

Q5)
Solution: The efficiencies are computed from $\eta = \rho g Q H / (550 \text{ bhp})$ and are as follows:

<table>
<thead>
<tr>
<th>Q</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>0</td>
<td>0.482</td>
<td>0.753</td>
<td><strong>0.881</strong></td>
<td>0.825</td>
<td>0.756</td>
</tr>
</tbody>
</table>

Thus the BEP is, even without a plot, close to $Q \approx 6 \text{ ft}^3/\text{s}$. Ans. The specific speed is

$$N_s = \frac{nQ^{1/2}}{H^{3/4}} = \frac{2134[(6)(449)]^{1/2}}{(330)^{3/4}} = 1430 \text{ Ans.}$$

For estimating $Q_{\text{max}}$, the last three points fit a Power-law to within $\pm 0.5\%$:

$$H = 340 - 0.00168Q^{4.85} = 0 \quad \text{if} \quad Q = 12.4 \text{ ft}^3/\text{s} = Q_{\text{max}} \text{ Ans.}$$