1. (a)

\[
\frac{P_p - P_a}{\rho} = h_k + h_m \tag{0}
\]

To calculate \( h_k \), first evaluate \( Re \) to see the flow is laminar or turbulent.

\[
Re = \frac{DV}{\nu}
\]

\[
V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D^2} = \frac{0.7 \times 0.0038 \text{ m}^3/\text{s}}{\frac{\pi}{4} \times (0.5 \times 0.0254 \text{ m})^2} \tag{0}
\]

\[
= 21.31 \text{ m/s}
\]

\[
D = 0.0127 \text{ m}
\]

So \( Re = \frac{0.0127 \times 21.31}{10^{-6}} = 2.7 \times 10^5 \), indicating that it is turbulent flow in the pipe.

\[
h_k = f \frac{L}{D} \frac{V^2}{2}
\]

Check Fig. 8.12 for \( f \) using \( Re = 2.7 \times 10^5 \) and

\[
\frac{e}{D} = \frac{0.0015 \times 10^{-3}}{0.0127} \approx 1.2 \times 10^{-4}, \text{ we have}
\]

\[
f = 0.024 \tag{1}
\]

\[
\Rightarrow h_k = 0.024 \times \frac{3 \times (5 \times 0.3)^3}{0.0127} \approx \frac{21.31^2}{2} = 5.79 \times 10^3 \text{ m}^2/\text{s}^2 \tag{1}
\]
\[ h_{\text{fm}} = f \left( \frac{Le}{D} \right) \frac{v^2}{2} \times 2 \leftarrow \text{two standard tees} \]

Check from Table 8.4. \( \frac{Le}{D} \) for standard tee when flowing through run is 20, thus ①

\[ h_{\text{fm}} = 0.024 \times 20 \times \frac{21.31^2}{2} = 217.98 \text{ m}^2/\text{s}^2 \quad ① \]

Therefore,
\[
\boxed{p_f} = p_a + \rho (h_e + h_{\text{fm}}) \quad \text{water density at 60°F (15°C)}
\]
\[ = 1.01 \times 10^5 + 999 \times (5.79 \times 10^3 + 217.98) \]
\[ = \boxed{6.10 \times 10^6} \text{ Pa} \quad ① \]

(b). Now since two globe valves are installed, the minor loss should include their effects.

\[ h_{\text{fm}} = h_{\text{tee}} + h_{\text{val}} , \quad \text{where} \quad h_{\text{val}} = f \left( \frac{Le}{D} \right) \frac{v^2}{2} \times 2 \]
\[ = 0.024 \times 3.40 \times \frac{21.31^2}{2} \times 2 = 3.71 \times 10^3 \quad ① \]

So
\[ h_{\text{fm}} = 217.98 + 3.71 \times 10^3 = \]

\[
\boxed{p_f} = p_a + \rho (h_e + h_{\text{tee}} + h_{\text{val}}) \\
= 6.10 \times 10^6 + \rho h_{\text{val}} \\
= 6.10 \times 10^6 + 999 \times 3.71 \times 10^3 \\
= \boxed{9.81 \times 10^6 \text{ Pa}} \quad ① \]
\[
\frac{P_0 - P_{\text{atm}}}{\rho} = 720 \cdot f_{o2} \cdot V_2^2 \quad (\star\star\star)
\]

* Now set \( (\star) = (\star\star\star) \) (note: this is equivalent to saying the head losses are the same, which is a consequence of the \( \Delta p \) being the same and the pipe being horizontal and of constant diameter)

So \( 120 \cdot f_{o1} \cdot V_1^2 = 720 \cdot f_{o2} \cdot V_2^2 \), and we also know \( Q_1 + Q_2 = 0.764 \text{ ft}^3/\text{s} = 0.0936 \text{ ft}^3/\text{s} \)

\[ V_1 = \frac{Q_1}{A} \quad \text{and} \quad V_2 = \frac{Q_2}{A} \]

where \( A = \frac{\pi}{4} \left(0.5 \text{ in.} \cdot \frac{\text{ft}}{12 \text{ in.}}\right)^2 = 1.38 \cdot 10^{-3} \text{ ft}^2\)

Then \( (\star\star\star) \) becomes

\[
\frac{f_{o1}}{A^2} \cdot \frac{120}{Q_1^2} = \frac{f_{o2}}{A^2} \cdot \frac{720}{Q_2^2}
\]

\[
\Rightarrow Q_1^2 = \frac{f_{o2}}{f_{o1}} \cdot (6 \cdot Q_2^2) \Rightarrow Q_1 = \sqrt{\frac{f_{o2}}{f_{o1}}} \cdot 2.45 \cdot Q_2
\]

To find \( Q_1, Q_2 \), then guess \( f_{o2}/f_{o1} \), solve for \( Q_1, Q_2 \), then check \( f_{o2}/f_{o1} \) and iterate if necessary.

* First guess: \( f_{o2} = f_{o1}, \quad Q_1 = 2.45 \cdot Q_2, \quad Q_1 + Q_2 = 3.45 \cdot Q_2 = 0.0936 \text{ ft}^3/\text{s} \)

So \( Q_2 = 0.0271 \text{ ft}^3/\text{s}, \quad Q_1 = 0.0665 \text{ ft}^3/\text{s} \)

Check FS:

\[
Re_1 = \frac{V_1 \cdot D}{\nu} = \left(\frac{Q_1}{(\pi/4) \cdot D^2}\right) \cdot \frac{D}{V_1} = 4Q_1 \cdot \frac{1}{\pi \cdot \frac{1}{4} \cdot \text{ft} \cdot 12 \cdot 10^{-5} \text{ m}^2/\text{s} = 1.6 \cdot 10^5 \text{ (approx)}
\]

Drawn tubing: \( e = 0.00005 \text{ ft} \) (Tab. 8.1)

\[
\frac{e}{D} = 1.2 \cdot 10^{-4} \quad \text{NOODLE:} \quad f_{o1} \approx 0.0665 \text{ (over)}
\]
Problem 1C (Modified Solution)

(Flow to first bathroom is open, \( Q_1 \))

(All pipes: drawn tubing,
I.D. 0.5 in;
L = 15 ft)

* To determine \( Q_1, Q_2 \): Write energy eq. for both paths:

* Pt. O to Pt. 1 (to bathroom)

\[ V_0 = V_1 \]

Note: At Pt. O, were only concerned about the portion of the flow that ends up going to the bathroom, since the energy eq. we write on that path only pertains to the fluid that follows that path.

Thus \( V_0 = V_1 \).

Energy Eq.

\[ \frac{P_0}{\rho} + \frac{V_0^2}{2g} + z_0 = \frac{P_1}{\rho} + \frac{V_1^2}{2g} + z_1 \]

For path 0 \( \rightarrow \) 1

\[ \frac{P_0 - P_{\text{Path}}}{\rho} = 120 \frac{f_{o_1}}{V_1^2} \] (*

* Pt. O to Pt. 2

\[ V_2 \]

(= \( V_2 \): Not same \( V_0 \) as for path 0 \( \rightarrow \) 1)

Energy Eq.

\[ \frac{P_0}{\rho} + \frac{V_0^2}{2g} + z_o = \frac{P_2}{\rho} + \frac{V_2^2}{2g} + z_2 \]

For 2 tees

\[ \frac{2f_{o_1}}{D} \]

Globe valves

\[ = 340 \]

Tee P.D. = 20

(\( \text{Tab. 8.4} \))

\[ \frac{L}{D} \]

\[ \frac{L}{D} \]

\[ \frac{1}{2} \]
Now \( \text{Re}_2 = \frac{V_2 D}{V} = \frac{1}{2.45} \frac{V_1 D}{V} = 6.9 \times 10^4 \) → Moody: \( f_{o2} \approx 0.02 \neq f_{o1} \)

- Second guess: try \( \frac{f_{o2}}{f_{o1}} \approx \frac{0.02}{0.0165} = 1.2 \)

Then \( \text{Q}_1 = \sqrt{1.2 \times 2.45 \times 0.2} = 2.68 \times 0.2 \)

\( Q_1 + Q_2 = 3.68 \times 0.2 = 0.0936 \frac{F^3}{S} \) → \( Q_2 = 0.0254 \frac{F^3}{S}, \ Q_1 = 0.0682 \frac{F^3}{S} \)

Check FS: \( \text{Re}_1 = \frac{4 \text{Q}_1}{\pi D V} = 1.72 \times 10^5 \) → \( f_{o1} \approx 0.0165 \) \( \checkmark \) O.K.

\( \text{Re}_2 = \frac{1}{2.68} \text{Re}_1 = 6.4 \times 10^4 \) → \( f_{o2} \approx 0.02 \) \( \checkmark \)

\( \Rightarrow \begin{cases} Q_1 = 0.0682 \frac{F^3}{S} = 0.51 \frac{\text{gal}}{S} \\ Q_2 = 0.0254 \frac{F^3}{S} = 0.19 \frac{\text{gal}}{S} \end{cases} \)
Problem 2

Air Conditioning Loop:

- Diameter \( D = 2' \)
- Length \( L = 3 \) m = 15.840'
- Steel: \( e = 0.00015', \) \( e/D = 7.5 \times 10^{-5} \)
- Steel: \( F_\text{e}^3 = 24.96 \text{ ft}^3 \)
- Pump efficiency \( \eta_p = 0.80 \) ; Motor eff. \( \eta_m = 0.90 \)
- "Chilled Water"; Assume \( T = 50^\circ F \), so \( V = 1.41 \times 10^{-5} \text{ ft}^2 \)
- \( \rho = 1.94 \text{ lbm/ft}^3 \)

Total Pressure Drop in Pipe:

Energy Eq. (in clean pipe):

\[
\left[ \frac{P_1}{\rho} + \frac{V_1^2}{2} + gZ_1 \right] - \left[ \frac{P_2}{\rho} + \frac{V_2^2}{2} + gZ_2 \right] = h_m + h_\text{clean pipe}
\]

Assume \( Z_1 = Z_2 \); \( V_1 = V_2 \) (mass cons.): \( h_m = h_\text{clean pipe} \)

So \( P_1 - P_2 = \Delta P = \rho \Delta h = \rho \Delta \frac{V^2}{2} \)

- \( \Delta V = \frac{Q}{A} = \frac{24.96 \text{ ft}^3/\text{s}}{\pi (1.41)^2} = 7.945 \text{ ft/s} \)

\( Re = \frac{VD}{\nu} = \frac{7.945 \times 1.41 \times 0.5 \text{ ft/s}}{1.1 \times 10^{-5} \text{ ft/s}} = 1.1 \times 10^6 \); Moody \( w/e/D = 7.5 \times 10^{-5} \)

So gives \( \Delta P = 1.94 \frac{\text{swg}}{\text{ft}^3} \times 0.013 \times 15,840 \times \left( \frac{7.945 \text{ ft/s}}{2} \right)^2 \)

\( = 6.3 \times 10^3 \text{ lbf/ft}^2 \times \frac{\text{ft}^2}{144 \text{ in}^2} = 438 \text{ psi} = \Delta P \)

Energy Addition Rate/Work Done by Pump on Water:

\( W = \frac{d}{\text{hr}} \rightarrow \text{Note } \Delta P \text{ across pump } = \Delta P \text{ from } A \text{ since it's a loop} \)

\( = 24.96 \text{ ft}^3 \times 6.3 \times 10^3 \text{ lbf} / \text{ft}^2 = 1.572 \times 10^5 \text{ lbf}. \frac{\text{lbf} \cdot \text{in}}{\text{in}^2} \times \frac{1 \text{ hp}}{550 \text{ lb} \cdot \text{ft} / \text{sec}} = 286 \text{ hp} \)

Total Power Required (accounting for efficiency of pump and motor):

\( \text{Power} = \frac{W}{\eta_p \cdot \eta_m} = \frac{286 \text{ hp}}{0.8 \cdot 0.9} = 387.2 \text{ hp} \cdot \frac{0.746 \text{ kw}}{\text{hp}} = 276 \text{ kw} \)

- In a day: \(296.24 \text{ kw} \cdot \text{hr} \cdot \frac{12 \text{ c}}{\text{kw} \cdot \text{hr}} = \$853 \text{ daily electricity cost.} \)
The energy relation between the reservoir and the tank is (along the streamline starting from the free surface of the reservoir to the free surface of the tank):

\[
\frac{\Delta p}{\rho} + \frac{V_2^2}{2} + g [H_1 - (H_2 + H_3)] = h_T
\]

where \( V_2 \) is the velocity of the tank free surface.

\[
H_3 = \frac{1}{\sqrt{2}} (L_3 + L_4 + L_5) = \frac{1}{\sqrt{2}} (1.52 + 10 + 1.52) = 10.11 \text{ m}
\]

\( h_T \) is the total loss, which is the combination of the following:

\[
h_T = h_{\text{entrance}} + h_{L_1} + h_{L_2} + h_{L_3} + h_{L_4} + h_{\text{expansion}} + h_{L_4} + h_{\text{contraction}} + h_{L_5} + h_{L_6} + h_{\text{exit}}
\]

The losses are functions of velocity, which can be determined from continuity.

Let \( V_1 \) be the velocity in pipes with diameter \( D_1 \):

\[
\left(\frac{\pi D_1^2}{4}\right) V_1 = \left(\frac{\pi D_2^2}{4}\right) V_2 \quad , \quad V_2 = 4 \text{ cm/s} = 0.04 \text{ m/s}
\]

\[
\Rightarrow V_1 = \left(\frac{D_2}{D_1}\right)^2 V_2 = \left(\frac{4}{0.1}\right)^2 \times 0.04 = 64 \text{ m/s}
\]

Let \( V_5 \) be the velocity in the big pipe with diameter \( D_5 \):

\[
\left(\frac{\pi D_5^2}{4}\right) V_5 = \left(\frac{\pi D_2^2}{4}\right) V_2
\]

\[
\Rightarrow V_5 = \left(\frac{D_5}{D_2}\right)^2 V_2 = \left(\frac{4}{0.02}\right)^2 \times 0.04 = 16 \text{ m/s}
\]
Thus

\[ h_{\text{extreme}} = k \frac{V_i^2}{2} = 0.5 \times \frac{64^2}{2} = 1024 \text{ (m/s)}^2 \]  \( \text{(1)} \)

\[ h_{L1} = f \left( \frac{L_1}{D_1} \right) \frac{V_i^2}{2} \]

\[ Re = \frac{D_1 V_i}{\nu} = \frac{0.1 \times 64}{1 \times 10^{-6}} = 6.4 \times 10^6 \]

\[ \frac{e_i}{D_1} = \frac{0.15 \times 10^{-3}}{0.1} = 0.015 \approx 0.02 \]

\[ f = \text{From Fig. 8.12, we have } f = 0.023 \]

\[ h_{L1} = 0.023 \times \frac{2}{0.1} \times \frac{64^2}{2} = 942 \text{ (m/s)}^2 \]  \( \text{(1)} \)

\[ h_{L2} = f \frac{L_2}{D_1} \frac{V_i^2}{2} = 0.023 \times \frac{1.5^2}{0.1} \times \frac{64^2}{2} = 716 \text{ (m/s)}^2 \]  \( \text{(1)} \)

\[ h_{esp} = f \left( \frac{e_i}{D_1} \right) \frac{V_i^2}{2} = 0.023 \times 30 \times \frac{64^2}{2} = 1413 \text{ (m/s)}^2 \]  \( \text{(1)} \)

\[ L_2 = \text{Up to 30} \]

\[ h_{esp} = \frac{V_i^2}{2} \]

\[ \beta R = \left( \frac{A_s}{A_1} \right)^2 = (\frac{D_2}{D_1})^2 = (\frac{0.2}{0.1})^2 = 0.25 \]

\[ k_e = 0.6 \]

\[ h_{esp} = 0.6 \times \frac{64^2}{2} = 229 \text{ (m/s)}^2 \]  \( \text{(1)} \)
\[ h_{LV} = f \frac{L_y}{D_y} \frac{V_s^2}{2} \]

\[ \text{Re}_{D_y} = \frac{D_y V_y}{\nu} = \frac{0.2 \times 16}{10^{-6}} = 3.2 \times 10^6 \]

\[ \frac{e_y}{D_y} = \frac{0.046 \times 10^{-3}}{0.2} = 0.0023 \approx 0.002 \]

\[ f' = 0.016 \]

\[ h_{LV} = 0.016 \times \frac{10}{0.2} \times \frac{16^2}{2} = 102 \text{ (m/s)}^2 \quad (1) \]

\[ h_{cont} = K_c \frac{V_i^2}{2} \]

\[ AR = 0.25 \]

\[ K_c = 0.4 \]

\[ h_{cont} = 0.4 \times \frac{64^2}{2} = 819 \text{ (m/s)}^2 \quad (1) \]

\[ h_{L5} = f \left( \frac{L_5}{D_1} \right) \frac{V_i^2}{2} = h_{L5} = 716 \text{ (m/s)}^2 \quad (1) \]

\[ h_{L6} = f \frac{L_6}{D_1} \frac{V_i^2}{2} = 0.023 \times \frac{5}{0.1} \times \frac{64^2}{2} = 2355 \text{ (m/s)}^2 \quad (1) \]

\[ h_{exit} = K_c \frac{V_i^2}{2} = 1 \times \frac{64^2}{2} = 2048 \text{ (m/s)}^2 \quad (1) \]
Combine the above terms together,

\[ \Delta p = \left[ \frac{1}{2} \rho v_z^2 - \rho g \left( H_1 - (H_2 + H_3) \right) + \rho h_T \right] \rho \]

\[ h_T = 1024 + 942 + 716 + 1413 + 716 \]
\[ + 1229 + 102 + 819 + 716 + 1413 \]
\[ + 2355 + 2048 \]
\[ = 13493 \text{ (m/s}^2 \text{)} \]

\[ \Rightarrow [\Delta p] = 999 \times \left[ \frac{1}{2} \times 0.04^2 - 9.8 \times (5 - (4 + 1.11)) + 13493 \right] \]
\[ = \boxed{1.36 \times 10^7 \text{ Pa}} \]