HOMEWORK MODULE 2 SOLUTIONS

ROY SHEPARD

6.79

$$\frac{p_A}{\gamma_o} + z_A + \frac{\upsilon_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{\upsilon_B^2}{2g}$$

① $$\frac{p_A - p_B}{\gamma_o} + z_A - z_B = \frac{\upsilon_B^2 - \upsilon_A^2}{2g}$$

Let $z_A - z_B = X$
Let y = Distance from B to surface of Mercury.

$$\upsilon_B = \upsilon_A \frac{A_A}{A_B} = \upsilon_A \left(\frac{D_A}{D_B}\right)^2 = \upsilon_A \left(\frac{4}{2}\right)^2 = 4\upsilon_A$$

Manometer: $p_B + \gamma_o y + \gamma_m h - \gamma_o h - \gamma_o y - \gamma_o X = p_A$ [cancel terms with y]

$$\frac{p_A - p_B}{\gamma_o} = \frac{\gamma_m h}{\gamma_o} - h - X = \frac{13.54\gamma_w}{0.90\gamma_w} \cdot h - h - X = 14.04h - X$$

In ①: $14.04h - X + X = \dfrac{16\upsilon_A^2 - \upsilon_A^2}{2g} = \dfrac{15\upsilon_A^2}{2g}$

$$\upsilon_A = \sqrt{\frac{2g(14.04)(h)}{15}} = \frac{\sqrt{2(32.2\text{ ft/s}^2)(14.04)(28\text{ in})}}{15(12\text{ in/ft})} = 11.86\text{ ft/s}$$

$$Q = A_A\upsilon_A = \frac{\pi(4\text{ in})^2}{4} \times \frac{11.86\text{ ft}}{\text{s}} \times \frac{\text{ft}^2}{144\text{ in}^2} = \mathbf{1.035\ ft^3/s}$$

6.82

$$\frac{p_A}{\gamma_o} + z_A + \frac{\upsilon_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{\upsilon_B^2}{2g}$$

① $$\frac{p_A - p_B}{\gamma_o} + z_A - z_B = \frac{\upsilon_B^2 - \upsilon_A^2}{2g}$$

$$\upsilon_B = \upsilon_A \cdot \frac{A_A}{A_B} = \upsilon_A \cdot \frac{0.08840\text{ ft}^2}{0.02333\text{ ft}^2} = 3.789\upsilon_A$$

$$\upsilon_B^2 - \upsilon_A^2 = (3.789\upsilon_A)^2 - \upsilon_A^2 = 13.36\upsilon_A^2$$

$z_A - z_B = -24$ in

Manometer: $p_B + \gamma_o(24\text{ in}) + \gamma_o(6\text{ in}) + \gamma_w(8\text{ in}) - \gamma_o(8\text{ in}) - \gamma_o(6\text{ in}) = p_A$

$p_A - p_B = \gamma_o(16\text{ in}) + \gamma_w(8\text{ in})$

$$\frac{p_A - p_B}{\gamma_o} = 16\text{ in} + \frac{\gamma_w}{\gamma_o}(8\text{ in}) = 16\text{ in} + \frac{62.4\text{ lb/ft}^3}{55.0\text{ lb/ft}^3}(8\text{ in}) = 25.08\text{ in}$$

in ① $25.08\text{ in} - 24.0\text{ in} = 13.36\upsilon_A^2/2g$

$$\upsilon_A = \sqrt{\frac{2g(1.08\text{ in})}{13.36}} = \sqrt{\frac{2(32.2\text{ ft/s}^2)(1.08\text{ in})}{13.36(12\text{ in/ft})}} = 0.659\text{ ft/s}$$

$$Q = A_A\upsilon_A = 0.08840\text{ ft}^2 \times \frac{0.659\text{ ft}}{\text{s}} = \mathbf{0.0582\ ft^3/s}$$

6.91 **To the level of the fluid surface in the tank.**
1.675 m **above the outlet nozzle.**

6.91 To the level of the fluid surface in the tank.
1.675 m above the outlet nozzle.

7.11 $$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}$$ Pt. 1 at well surface. $p_1 = 0$ and $v_1 = 0$; Pt. 2 at tank surface. $v_2 = 0$

$$h_A = \frac{p_2}{\gamma_w} + (z_2 - z_1) + h_L = \frac{40\text{ lb ft}^3\ 144\text{ in}^2}{\text{in}^2\ 62.4\text{ lb ft}^2} + 120\text{ ft} + 10.5\text{ ft} = 222.8\text{ lb ft/lb}$$

$$Q = \frac{745\text{ gal/h}}{60\text{ min/h}} \times \frac{1\text{ ft}^3\text{/s}}{449\text{ gal/min}} = 0.0277\text{ ft}^3\text{/s}$$

a) $$P_A = h_A\gamma_w Q = \frac{222.8\text{ lb}\cdot\text{ft}}{\text{lb}} \times \frac{62.4\text{ lb}}{\text{ft}^3} \times \frac{0.0277\text{ ft}^3}{\text{s}} = \frac{385\text{ lb}\cdot\text{ft}}{\text{lb}}\ \frac{1\text{ hp}}{550\text{ lb}\cdot\text{ft/s}}$$
$$= \mathbf{0.700\ hp}$$

b) $$e_M = \frac{P_A}{P_I} = \frac{0.700\text{ hp}}{1.0\text{ hp}} = 0.700 = \mathbf{70.0\%}$$

7.16 a) $$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}$$ Pt. 1 at lower tank surface. $p_1 = 0$; Pt. 2 at upper tank surface. $v_1 = v_2 = 0$

$$h_A = \frac{p_2}{\gamma_o} + (z_2 - z_1) + h_L = \frac{825\text{ kN m}^3}{\text{m}^2(0.85)(9.81\text{ kN})} + 14.5\text{ m} + 4.2\text{ m} = 117.6\text{ m}$$

$$P_A = h_A\gamma_o Q = (117.6\text{ m})(0.85)\left(\frac{9.81\text{ kN}}{\text{m}^3}\right)\frac{840\text{ L/min}(1\text{ m}^3\text{/s})}{60000\text{ L/min}} = \frac{13.73\text{ kN}\cdot\text{m}}{\text{s}}$$
$$= \mathbf{13.73\ kW}$$

b) $$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_{L_s} = \frac{p_3}{\gamma_o} + z_3 + \frac{v_3^2}{2g}$$ Pt. 3 at pump inlet.

$$p_3 = \gamma_o\left[(z_1 - z_3) - \frac{v_3^2}{2g} - h_{L_s}\right]$$
$$= \frac{(0.85)(9.81\text{ kN})}{\text{m}^3}\left[-3.0\text{ m} - \frac{(4.53\text{ m/s})^2}{2(9.81\text{ m/s}^2)} - \frac{1.4\text{ N}\cdot\text{m}}{\text{N}}\right] = \mathbf{-45.4\ kPa}$$

$$v_3 = \frac{Q}{A_3} = \frac{840\text{ L/min}(1\text{ m}^3\text{/s})}{60000\text{ L/min}} \cdot \frac{1}{3.090\times10^{-3}\text{ m}^2} = 4.53\text{ m/s}$$

7.22 a) $Q = A_{cyl} \times \frac{\text{stroke}}{\text{time}} = \frac{\pi(5.0\text{ in})^2(1\text{ ft}^2)}{4(144\text{ in}^2)} \times \frac{20\text{ in}}{15\text{ s}}\frac{\text{ft}}{12\text{ in}} = \mathbf{0.01515\ ft^3/s}$

b) $p_{cyl} = \frac{F}{A_{cyl}} = \frac{11000\text{ lb}}{\pi(5.0)^2/(4)\text{ in}^2} = \mathbf{(560\ lb/in^2)}(144\text{ in}^2/\text{ft}^2) = 80672\text{ lb/ft}^2$

c) $$\frac{p_B}{\gamma_o} + z_B + \frac{\upsilon_B^2}{2g} - h_{L_b} = \frac{p_C}{\gamma_o} + z_C + \frac{\upsilon_C^2}{2g}$$

Pt. A at tank surface.
Pt. B at pump outlet.
Pt. C in cylinder.

$$p_B = p_C + \gamma_o\left[(z_C - z_B) + \frac{\upsilon_C^2 - \upsilon_B^2}{2g} + h_{L_b}\right]$$

$$\upsilon_C = \frac{20\text{ in}}{15\text{ s}} \times \frac{\text{ft}}{12\text{ in}} = 0.1111\frac{\text{ft}}{\text{s}};\ \upsilon_B = \frac{Q}{A_B} = \frac{0.01515\text{ ft}^3/\text{s}}{0.000976\text{ ft}^2} = 15.52\text{ ft/s}$$

$$p_B = 560\text{ psig} + 0.90\frac{(62.4\text{ lb})}{\text{ft}^3}\left[10\text{ ft} + \frac{(0.1111^2 - 15.52^2)}{2(32.2)} + 35.0\text{ ft}\right]\frac{1\text{ ft}^2}{144\text{ in}^2}$$

$= \mathbf{576.1\ psig}$

d) $$\frac{p_A}{\gamma_o} + z_A + \frac{\upsilon_A^2}{2g} - h_{L_a} = \frac{p_D}{\gamma_o} + z_D + \frac{\upsilon_D^2}{2g};$$

Pt. D at pump inlet. $p_A = 0, \upsilon_A = 0$

$$p_D = \gamma_o\left[z_A - z_D - \frac{\upsilon_D^2}{2g} - h_{L_a}\right]$$

$\upsilon_D = \upsilon_B = 15.52$ ft/s

$$p_D = \frac{(0.90)(62.4\text{ lb})}{\text{ft}^3}\left[-5.0\text{ ft} - \frac{(15.52\text{ ft/s})^2}{2(32.2\text{ ft/s}^2)} - 11.5\text{ ft}\right]\frac{1\text{ ft}^2}{144\text{ in}^2}$$

$p_D = -4.98$ psig

e) $$\frac{p_A}{\gamma_o} + z_A + \frac{\upsilon_A^2}{2g} + h_A - h_{L_a} - h_{L_b} = \frac{p_C}{\gamma_o} + z_C + \frac{\upsilon_C^2}{2g};\ p_A = 0,\ \upsilon_A = 0$$

$$h_A = \frac{p_C}{\gamma_o} + (z_C - z_A) + \frac{\upsilon_C^2}{2g} + h_{L_a} + h_{L_b} = \frac{80672\text{ lb}\cdot\text{ft}^3}{\text{ft}^2(0.9)(62.4\text{ lb})} + 15\text{ ft} + \frac{(.1111)^2}{2g} + 11.5\text{ ft} + 35\text{ ft}$$

$h_A = 1498$ ft

$$P_A = h_A\gamma_o Q = (1498\text{ ft})(0.90)(62.4\text{ lb/ft}^3)(0.01515\text{ ft}^3/\text{s}) = \frac{1275\text{ ft}\cdot\text{lb/s}}{550} = \mathbf{2.32\ hp}$$

7.30 $\frac{p_1}{\gamma_w}+z_1+\frac{v_1^2}{2g}-h_R-h_L=\frac{p_2}{\gamma_w}+z_2+\frac{v_2^2}{2g}$ | **Pt. 1 at reservoir surface.** $p_1=0, v_1=0$; **Pt. 2 in outlet stream.** $p_2=0$

$$h_L=(z_1-z_2)-\frac{v_2^2}{2g}-h_R$$

$$v_2=\frac{Q}{A_2}=\frac{1000\text{ gal/min}}{0.3472\text{ ft}^2}\times\frac{1\text{ ft}^3/\text{s}}{449\text{ gal/min}}=6.41\text{ ft/s}$$

$$h_L=165\text{ ft}-\frac{(6.41\text{ ft/s})^2}{2(32.2\text{ ft/s}^2)}-146.4\text{ ft}=17.9\text{ ft}=\mathbf{17.9\ ft\text{-}lb/lb}$$

$$h_R=\frac{P_R}{\gamma_w Q}=\frac{37.0\text{ hp}(550\text{ ft}\cdot\text{lb/s})}{1\text{ hp}(62.4\text{ lb/ft}^3)(2.227\text{ ft}^3/\text{s})}=146.4\text{ ft}$$

7.35 $\frac{p_1}{\gamma}+z_1+\frac{v_1^2}{2g}-h_{L_{1-6}}+h_A-h_R=\frac{p_6}{\gamma}+z_6+\frac{v_6^2}{2g}$: $p_1=p_6=0,\ v_1=0$

$$h_R=(z_1-z_6)-\frac{v_6^2}{2g}-h_{L_{1-6}}+h_A$$

$$z_1-z_6=-1.0\text{ ft}$$

$$v_6=\frac{Q}{A_6}=\frac{0.390\text{ ft}^3/\text{s}}{0.03326\text{ ft}^2}=11.72\text{ ft/s}=v_3=v_4=v_5$$

$$\frac{v_6^2}{2g}=\frac{(11.72)^2}{2(32.2)}=2.13\text{ ft}$$

$$h_{L_{1-6}}=2.80+28.50+3.50=34.8\text{ ft}$$

$$P_A=h_A\gamma Q;\ h_A=\frac{P_A}{\gamma Q}=\frac{12496\text{ ft}\cdot\text{lb/s}}{(58.03\text{ lb/ft}^3)(0.390\text{ ft}^3/\text{s})}=552.5\text{ ft}$$

$$h_R=-1.0-2.13-34.8+552.5=514.5\text{ ft}$$

$$P_R=h_R\gamma Q=\frac{(514.5\text{ ft})(58.03\text{ lb/ft}^3)(0.390\text{ ft}^3/\text{s})}{550\text{ ft}\cdot\text{lb/s/hp}}=\mathbf{21.16\ hp}$$

7.36 $\frac{p_1}{\gamma}+z_1+\frac{v_1^2}{2g}-h_{L_{1-2}}=\frac{p_2}{\gamma}+z_2+\frac{v_2^2}{2g}$: $p_1=0,\ v_1=0$

$$p_2=\gamma\left[(z_1-z_2)-\frac{v_2^2}{2g}-h_{L_{1-2}}\right]$$

$$v_2=\frac{Q}{A_2}=\frac{0.390\text{ ft}^3/\text{s}}{0.05132\text{ ft}^2}=7.59\text{ ft/s}$$

$$\frac{v_2^2}{2g}=\frac{(7.59)^2}{2(32.2)}=0.896\text{ ft}$$

$$p_2=58.03\frac{\text{lb}}{\text{ft}^3}[-4.0\text{ ft}-0.896\text{ ft}-2.80\text{ ft}]\frac{1\text{ ft}^2}{144\text{ in}^2}=\mathbf{-3.10\ psig}$$

7.37 $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_{L_{1-3}} + h_A = \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g}$: $p_1 = 0$, $v_1 = 0$

$$p_3 = \gamma\left[(z_1 - z_3) - \frac{v_3^2}{2g} - h_{L_{1-3}}\right] + h_A = 58.03\frac{\text{lb}}{\text{ft}^3}[-4.0 - 2.13 - 2.80 + 552.5]\frac{\text{ft}\cdot\text{ft}^2}{144\,\text{in}^2}$$

$\boldsymbol{p_3 = 219.1}$ **psig**

7.38 $\frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g} - h_{L_{3-4}} = \frac{p_4}{\gamma} + z_4 + \frac{v_4^2}{2g}$: $v_3 = v_4$, $z_3 = z_4$

$$p_4 = p_3 - \gamma h_{L_{3-4}} = 219.1\ \text{psig} - 58.03\ \frac{\text{lb}}{\text{ft}^3}\ (28.5\ \text{ft})\ \frac{1\,\text{ft}^2}{144\,\text{in}^2} = 207.6\ \text{psig}$$

7.39 $\frac{p_5}{\gamma} + z_5 + \frac{v_5^2}{2g} - h_{L_{5-6}} = \frac{p_6}{\gamma} + z_6 + \frac{v_6^2}{2g}$: $v_5 = v_6$, $p_6 = 0$

$$p_5 = \gamma\left[(z_6 - z_5) + h_{L_{5-6}}\right] = 58.03\frac{\text{lb}}{\text{ft}^3}[-1.0\ \text{ft} + 3.50\ \text{ft}]\frac{1\,\text{ft}^2}{144\,\text{in}^2} = 1.01\ \text{psig}$$

7.40 For $Q = 175$ gal/min, Fig. 6.3 suggests using either a 2 ½-in or 3-in Schedule 40 steel pipe for the suction line. The given 3-in pipe is satisfactory. However, noting that the pressure at the inlet to the pump is −3.10 psig, a larger pipe may be warranted to decrease the energy losses in the suction line and increase the pump inlet pressure. See Chapters 9–13, especially Section 13.10 on net positive suction head (NPSH).

Fig. 6.3 suggests either a 2-in or 2 ½-in pipe for the discharge line. The given 2 ½-in pipe size is satisfactory.

7.42 $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L + h_A = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ **Pt. 1 at creek surface.** $p_1 = 0, v_1 = 0$ **Pt. 2 at tank surface.** $v_2 = 0$

$$h_A = \frac{p_2}{\gamma} + (z_2 - z_1) + h_L = \frac{30\ \text{lb}}{\text{in}^2}\ \frac{\text{ft}^3}{62.4\ \text{lb}}\ \frac{144\ \text{in}^2}{\text{ft}^2} + 220\ \text{ft} + 15.5\ \text{ft} = 304.7\ \text{ft}$$

$$P_A = h_A\gamma Q = 304.7\ \text{ft} \times \frac{62.4\ \text{lb}}{\text{ft}^3} \times \frac{40\ \text{gal/min}}{449\ \text{gal/min}}\ \frac{(1\ \text{ft}^3/\text{s})\text{hp}}{550\ \text{ft}\cdot\text{lb/s}} = \mathbf{3.08\ hp}$$

7.44 $\dfrac{p_1}{\gamma_o}+z_1+\dfrac{v_1^2}{2g}-h_R=\dfrac{p_2}{\gamma}+z_2+\dfrac{v_2^2}{2g}; \quad z_1=z_2$

$$h_R=\frac{p_1-p_2}{\gamma_o}+\frac{v_1^2-v_2^2}{2g}$$

Manometer: $p_1+\gamma_o y+\gamma_o(38.5\text{ in})-\gamma_m(38.5\text{ in})-\gamma_o y=p_2$

$$p_1-p_2=\gamma_m(38.5\text{ in})-\gamma_o(38.5\text{ in})$$

$$\frac{p_1-p_2}{\gamma_o}=\frac{\gamma_m}{\gamma_o}(38.5\text{ in})-38.5\text{ in}=\frac{13.54\gamma_w}{0.9\gamma_w}(38.5\text{ in})-38.5\text{ in}$$

$$\frac{p_1-p_2}{\gamma_o}=540.7\text{ in}\times\frac{1\text{ ft}}{12\text{ in}}=45.06\text{ ft}$$

$$v_1=\frac{Q}{A_1}=\frac{135\text{ gal/min}}{0.01227\text{ ft}^2}\times\frac{1\text{ ft}^3/\text{s}}{449\text{ gal/min}}=\frac{0.3007\text{ ft}^3/\text{s}}{0.01227\text{ ft}^2}=24.50\text{ ft/s}$$

$$v_2=\frac{Q}{A_2}=\frac{0.3007\text{ ft}^3/\text{s}}{0.02944\text{ ft}^2}=10.21\text{ ft/s}$$

$$h_R=45.06\text{ ft}+\frac{(24.5^2-10.21^2)\text{ft}^2/\text{s}^2}{2(32.2\text{ ft/s}^2)}=52.76\text{ ft}$$

$$P_R=h_R\gamma Q=(52.76\text{ ft})(0.90)(62.4\text{ lb/ft}^3)(0.3007\text{ ft}^3/\text{s})=891.0\text{ ft·lb/s}$$

$$P_R=891.0\text{ ft·lb/s}\times\frac{1\text{ hp}}{550\text{ ft}\cdot\text{lb/s}}=\mathbf{1.62\text{ hp}}$$

8.33 $\frac{p_1}{\gamma_w}+z_1+\frac{v_1^2}{2g}-h_L=\frac{p_2}{\gamma_w}+z_2+\frac{v_2^2}{2g}$

$h=z_1-z_2=h_L+\frac{v_2^2}{2g}$

$v=\frac{Q}{A}=\frac{2.50\text{ ft}^3/\text{s}}{0.2006\text{ ft}^2}=12.46\text{ ft/s}$

Pt. 1 at tank surface. $p_1=0$, $v_1=0$
Pt. 2 in outlet stream. $p_2=0$
$D=0.5054$ ft
$A=0.2006$ ft^2

$N_R=\frac{vD}{\nu}=\frac{(12.46)(0.5054)}{9.15\times10^{-6}}=6.88\times10^5$: $\frac{D}{\varepsilon}=\frac{0.5054}{1.5\times10^{-4}}=3369$: $f=0.0165$

$h=f\frac{L}{D}\frac{v^2}{2g}+\frac{v^2}{2g}=0.0165\times\frac{550}{0.5054}\times\frac{(12.46)^2}{2(32.2)}+\frac{(12.46)^2}{2(32.2)}=$ **45.7 ft**

8.38 $\frac{p_1}{\gamma}+z_1+\frac{v_1^2}{2g}+h_A-h_L=\frac{p_2}{\gamma}+z_2+\frac{v_2^2}{2g}$

Pt. 1 at tank surface. $p_1=0$; $v_1=0$
Pt. 2 in hose at nozzle.
Pt. 3 in hose at pump outlet.
$v_3=v_2$

a) $h_A=\frac{p_2}{\gamma}+(z_2-z_1)+\frac{v_2^2}{2g}+h_L$

$v=\frac{Q}{A}=\frac{95\text{ L/min}}{\pi(0.025\text{ m})^2/4}\times\frac{1\text{ m}^3/\text{s}}{60000\text{ L/min}}=3.23\text{ m/s}$: $\frac{v^2}{2g}=\frac{(3.23)^2}{2(9.81)}=0.530\text{ m}$

$N_R=\frac{vD\rho}{\eta}=\frac{(3.23)(0.025)(1100)}{2.0\times10^{-3}}=4.44\times10^4$: $f=0.021$ (smooth)

$h_L=f\frac{L}{D}\frac{v^2}{2g}=(0.021)\frac{85}{0.025}(0.530)\text{m}=37.86\text{ m}$

$h_A=\frac{140\text{ kN/m}^2}{(1.10)(9.81\text{ kN/m}^3)}+7.3\text{ m}+0.530+37.86\text{ m}=58.67\text{ m}$

$P_A=h_A\gamma Q=(58.67\text{ m})(1.10)(9.81\text{ kN/m}^3)(95/60000)\text{m}^3/\text{s}=1.00\text{ kN·m/s}=$ **1.00 kW**

b) $\frac{p_3}{\gamma}+z_3+\frac{v_3^2}{2g}-h_L=\frac{p_2}{\gamma}+z_2+\frac{v_2^2}{2g}$: $p_3=p_2+[(z_2-z_3)+h_L]\gamma$

$p_3=140\text{ kPa}+(1.10)(9.81\text{ kN/m}^3)[8.5\text{ m}+37.86\text{ m}]=$ **640 kPa**

8.44 $$\frac{p_A}{\gamma}+z_A+\frac{v_A^2}{2g}+h_A-h_L=\frac{p_B}{\gamma}+z_B+\frac{v_B^2}{2g}$$

$$h_A=\frac{p_B-p_A}{\gamma}+z_B-z_A+\frac{v_B^2-v_A^2}{2g}+h_L$$

$$v_A=\frac{Q}{A_A}=\frac{0.50\text{ ft}^3/\text{s}}{0.06868\text{ ft}^2}=7.28\text{ ft/s}:\quad v_B=\frac{Q}{A_B}=\frac{0.50}{0.03326}=15.03\text{ ft/s}$$

$$N_{R_B}=\frac{v_B D\rho}{\eta}=\frac{(15.03)(0.2058)(1.026)(1.94)}{4.0\times10^{-5}}=1.54\times10^5$$

$$\frac{D}{\varepsilon}=\frac{0.2058}{1.5\times10^{-4}}=1372:\ f=0.020$$

$$h_L=f\ \frac{L}{D}\frac{v^2}{2g}=(0.020)\frac{80}{0.2058}\times\frac{(15.03)^2}{2(32.2)}\text{ ft}=27.28\text{ ft}$$

$$h_A=\frac{[25.0-(-3.50)]\text{lb ft}^3\ 144\text{ in}^2}{\text{in}^2(1.026)(62.4\text{ lb})\text{ ft}^2}+80\text{ ft}+\frac{(15.03)^2-(7.28)^2\text{ft}^2/\text{s}^2}{2(32.2\text{ ft/s}^2)}+27.28\text{ ft}=174.1\text{ ft}$$

$$P_A=h_A\gamma Q=(174.1\text{ ft})(1.026)(62.4\text{ lb/ft}^3)(0.50\text{ ft}^3/\text{s})/550=\mathbf{10.13\ hp}$$

8.46 $$\frac{p_1}{\gamma_w}+z_1+\frac{v_1^2}{2g}-h_L=\frac{p_2}{\gamma_w}+z_2+\frac{v_2^2}{2g}$$

Pt. 1 at pump outlet in pipe.

Pt. 2 at reservoir surface. $p_2=0,\ v_2=0$

$$v=\frac{Q}{A}=\frac{4.00\text{ ft}^3/\text{s}}{0.3472\text{ ft}^2}=11.52\text{ ft/s}$$

$$p_1=\gamma_w\left[(z_2-z_1)-\frac{v_1^2}{2g}+h_L\right]$$

$$N_R=\frac{vD}{\nu}=\frac{(11.52)(0.6651)}{1.21\times10^{-5}}=6.33\times10^5:\ \frac{D}{\varepsilon}=\frac{0.6651}{1.5\times10^{-4}}=4434:f=0.0155$$

$$h_L=f\ \frac{L}{D}\frac{v^2}{2g}=(0.0155)\cdot\frac{2500}{0.6651}\cdot\frac{(11.52)^2}{2(32.2)}\text{ ft}=120.1\text{ ft}$$

$$p_1=\frac{62.4\text{ lb}}{\text{ft}^3}\left[210-\frac{(11.52)^2}{2(32.2)}+120.1\right]\frac{\text{ft}\cdot1\text{ ft}^2}{144\text{ in}^2}=\mathbf{142.1\ psi}$$

8.49 $\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}$

Pt. 1 at tank surface. $p_1 = 0, v_1 = 0$
Pt. 2 in outlet stream from 3-in pipe. $p_2 = 0$
$Q = \frac{300\ \text{gal/min} \cdot 1\ \text{ft}^3/\text{s}}{449\ \text{gal/min}} = 0.668\ \text{ft}^3/\text{s}$
oil- App. C

$$h_A = (z_2 - z_1) + \frac{v_2^2}{2g} + h_L$$

$$v_4 = \frac{Q}{A_4} = \frac{0.668\ \text{ft}^3/\text{s}}{0.08840\ \text{ft}^2} = 7.56\ \text{ft/s}$$

$$v_3 = \frac{Q}{A_3} = \frac{0.668\ \text{ft}^3/\text{s}}{0.05132\ \text{ft}^2} = 13.02\ \text{ft/s} = v_2$$

$$h_L = h_{L_3} + h_{L_4} = f_3 \frac{L_3}{D_3}\frac{v_3^2}{2g} + f_4 \frac{L_4}{D_4}\frac{v_4^2}{2g}$$

$$N_{R_3} = \frac{v_3 D_3}{\nu} = \frac{(13.02)(0.2557)}{2.15\times10^{-3}} = 1548\ \text{(Laminar)}: f_3 = \frac{64}{N_R} = 0.0413$$

$$N_{R_4} = \frac{v_4 D_4}{\nu} = \frac{(7.56)(0.3355)}{2.15\times10^{-3}} = 1180\ \text{(Laminar)}: f_4 = \frac{64}{N_R} = 0.0543$$

$$h_L = 0.0413 \cdot \frac{75}{0.2557}\cdot\frac{(13.02)^2}{2(32.2)} + 0.0543\cdot\frac{25}{0.3355}\cdot\frac{(7.56)^2}{2(32.2)} = 35.5\ \text{ft}$$

$$h_A = 1.0\ \text{ft} + \frac{(13.02)^2}{2(32.2)}\ \text{ft} + 35.5\ \text{ft} = 39.1\ \text{ft}$$

$$P_A = h_A\gamma_o Q = (39.1\ \text{ft})(0.890)\frac{(62.4\ \text{lb})}{\text{ft}^3}\frac{(0.668\ \text{ft}^3)}{\text{s}}\frac{1\ \text{hp}}{550\ \text{ft}\cdot\text{lb/s}} = \mathbf{2.64\ hp}$$

8.62 Heavy fuel oil at 77°F; $\rho = 1.76$ slugs/ft^3
$\eta = 2.24 \times 10^{-3}$ lb-s/ft^2
$v = 12$ ft/s; $D = 0.5054$ ft

$$N_R = \frac{vD\rho}{\eta} = \frac{(12.0)(0.5054)(1.76)}{2.24\times10^{-3}} = 4.77\times10^3$$

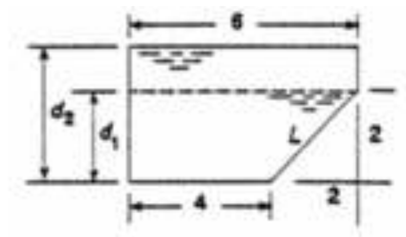
$$D/\varepsilon = \frac{0.5054}{1.5\times10^{-4}} = 3369; \boldsymbol{f = 0.0388}$$

14.6 $d = d_1 = 2.0$ in; $L = \sqrt{2^2 + 2^2} = 2.828$ in

$A = (4)(2) + \frac{1}{2}(2)(2) = 10 \text{ in}^2$

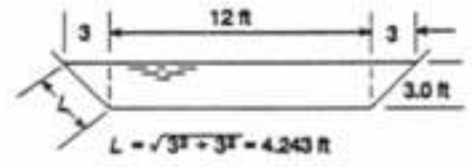
$WP = 4 + 2 + 2.828 = 8.828$ in

$R = A/WP =$ **1.133 in**



14.15 a. **Depth = 3.0 ft:**

$$A = (3)(12) + 2\left[\frac{1}{2}(3)(3)\right] = 45 \text{ ft}^2$$



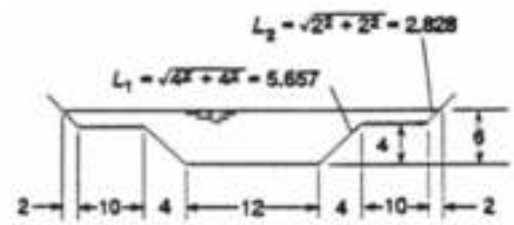
$WP = 12 + 2(4.243) = 20.485$ ft

$R = A/WP = 45/20.485 = 2.197$ ft

$$Q = \frac{1.49}{0.04}(45)(2.197)^{2/3}(0.00015)^{1/2} = \mathbf{34.7\ ft^3/s}$$

b. **Depth = 6.0 ft:**

$$A = (4)(12) + 2\left[\frac{1}{2}(4)(4)\right] + (2)(40) + 2\left[\frac{1}{2}(2)(2)\right]$$



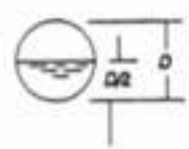
$A = 148 \text{ ft}^2$

$WP = 2(2.828) + 2(10) + 2(5.657) + 12 = 48.97$ ft

$R = A/WP = 148/48.97 = 3.022$ ft

$$Q = \frac{1.49}{0.04}(148)(3.022)^{2/3}(0.00015)^{1/2} = \mathbf{141.1\ ft^3/s}$$

14.21 $Q = 500 \text{ gal/min} \times \dfrac{1 \text{ ft}^3\text{/s}}{449 \text{ gal/min}} = 1.114 \text{ ft}^3\text{/s}$



$$AR^{2/3} = \frac{nQ}{1.49S^{1/2}} = \frac{(0.013)(1.114)}{(1.49)(0.001)^{1/2}} = 0.307$$

$$A = \pi D^2/8;\ WP = \pi D/2;\ R = \frac{A}{WP} = \frac{\pi D^2}{8}\,\frac{2}{\pi D} = \frac{D}{4}$$

$$AR^{2/3} = \frac{\pi D^2}{8}\left[\frac{D}{4}\right]^{2/3} = \frac{\pi D^2(D)^{2/3}}{8(4)^{2/3}} = \frac{\pi(D)^{8/3}}{8(2.52)} = 0.156(D)^{8/3} = 0.307$$

$$\text{Then } D = \left[\frac{0.307}{0.156}\right]^{3/8} = \mathbf{1.29\ ft}$$

14.36

$Q = 1.25\ \text{ft}^3/\text{s}$; $\upsilon = 2.75$ **ft/s**; $A = Q/\upsilon = 0.4545\ \text{ft}^2$ **(All)**

Rectangle: $y = \sqrt{\dfrac{A}{2.0}} = \sqrt{\dfrac{0.4545}{2}} = \mathbf{0.4767\ ft}$; $\mathbf{b} = 2y = \mathbf{0.9535\ ft}$

$$R = y/2 = 0.4767\ \text{ft}/2 = 0.2384\ \text{ft}$$

$$S = \left[\frac{nQ}{1.49\,AR^{2/3}}\right]^2 = \left[\frac{(0.015)(1.25)}{(1.49)(0.4545)R^{2/3}}\right]^2 = \left[\frac{0.02768}{R^{2/3}}\right]^2 = \left[\frac{0.02768}{(0.2384)^{2/3}}\right]^2 = \mathbf{0.00519}$$

$$y_h = \frac{A}{T} = \frac{2y^2}{2y} = y = 0.4767\ \text{ft};\ N_F = \frac{\upsilon}{\sqrt{gy_h}} = \frac{2.75}{\sqrt{(32.2)(0.4767)}} = \mathbf{0.702} < 1.0\ \textbf{Subcritical}$$

Triangle: $y = \sqrt{A} = \sqrt{0.4545} = \mathbf{0.674\ ft}$; $R = 0.354y = 0.2387\ \text{ft}$

$$S = \left[\frac{0.02768}{(0.2387)^{2/3}}\right]^2 = \mathbf{0.00518}$$

$$y_h = \frac{A}{T} = \frac{y^2}{2y} = \frac{y}{2} = 0.337\ \text{ft};\ N_F = \frac{2.75}{\sqrt{(32.2)(0.337)}} = \mathbf{0.835} < 1.0\ \textbf{Subcritical}$$

Trapezoid: $y = \sqrt{\dfrac{A}{1.73}} = \sqrt{\dfrac{0.4545}{1.73}} = \mathbf{0.5126\ ft}$; $R = y/2 = 0.2563\ \text{ft}$

$$S = \left[\frac{0.02768}{(0.2563)^{2/3}}\right]^2 = \mathbf{0.00471};$$

$$y_h = \frac{A}{T} = \frac{A}{2.309y} = \frac{0.4545}{2.309(0.5126)} = 0.3841\ \text{ft}$$

$$N_F = \frac{2.75}{\sqrt{(32.2)(0.3841)}} = \mathbf{0.782} < 1.0\ \textbf{Subcritical}$$

Semicircle: $A = \dfrac{y^2}{2}$; $y = \sqrt{2A} = \sqrt{2(0.4545)} = \mathbf{0.5379\ ft}$

$$R = y/2 = 0.269\ \text{ft};\ S = \left[\frac{0.02768}{(0.269)^{2/3}}\right]^2 = \mathbf{0.00441}$$

$$y_h = \frac{A}{T} = \frac{y^2}{2(2y)} = \frac{y}{4} = 0.4225\ \text{ft}$$

$$N_F = \frac{2.75}{\sqrt{(32.2)(0.4225)}} = 0.746 < 1.0\ \textbf{Subcritical}$$

14.42 Trapezoidal channel

$z =$ 0.75 $\quad n = 0.013$

$Q =$ 0.80 ft³/s $\quad b = 3.000$ ft

y(ft)	A(ft²)	V(ft/s)	T(ft)	Y_h(ft)	N_F	E(ft)	
0.05	**0.152**	**5.267**	**3.08**	**0.049**	**4.177**	**0.481**	**Given y**
0.1	0.308	2.602	3.15	0.098	1.467	0.205	
0.1288	**0.399**	**2.006**	**3.19**	**0.125**	**1.000**	**0.191**	**Critical depth**
0.20	0.630	1.270	3.30	0.191	0.512	0.225	
0.25	0.797	1.004	3.38	0.236	0.364	0.266	
0.30	0.968	0.827	3.45	0.280	0.275	0.311	
0.40	1.320	0.606	3.60	0.367	0.176	0.406	
0.4770	**1.602**	**0.499**	**3.72**	**0.431**	**0.134**	**0.481**	**Alternate depth**
0.50	1.688	0.474	3.75	0.450	0.125	0.503	
0.60	2.070	0.386	3.90	0.531	0.093	0.602	
0.70	2.468	0.324	4.05	0.609	0.073	0.702	
0.80	2.880	0.278	4.20	0.686	0.059	0.801	
0.90	3.308	0.242	4.35	0.760	0.049	0.901	
1.00	3.750	0.213	4.50	0.833	0.041	1.001	
1.065	4.046	0.198	4.60	0.880	0.037	1.066	
1.10	4.208	0.190	4.65	0.905	0.035	1.101	
1.20	4.680	0.171	4.80	0.975	0.031	1.200	
1.30	5.168	0.155	4.95	1.044	0.027	1.300	
1.40	5.670	0.141	5.10	1.112	0.024	1.400	
1.50	6.188	0.129	5.25	1.179	0.021	1.500	

Slopes at given depth and alternate depth

y(ft)	R(ft)	S	
0.05	0.0486	0.264	Slope for given depth
0.477	0.3820	0.000152	Slope for alternate depth

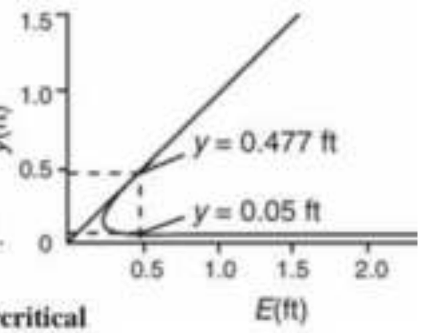
Problem 14.42 Procedure: Refer to Table 14.2 for geometry of a trapezoidal channel.

a) For given Q, b, z, and y: Compute A, T using equations in Table 14.2.
Compute $N_F = v/\sqrt{gy_h} = Q/\left(A\sqrt{gy_h}\right)$.
Iterate values of y until $N_F = 1.000$. See spreadsheet: $\mathbf{y_c = 0.1288}$ **ft.**

b) Minimum specific energy: $E = y + v^2/2g = y + Q^2/(2gA^2)$
From spreadsheet, with $y = y_c = 0.1288$ ft: $\mathbf{E_{min} = 0.191}$ **ft.**

c) Specific energy versus y: See spreadsheet using equation in b).

d) Specific energy for y = 0.05 ft: $E = 0.481$ ft from spreadsheet.
Iterate on y to find alternate depth for which $E = 0.481$ ft.
See spreadsheet: $\mathbf{y_{alt} = 0.4770}$ **ft.**



e) Velocity $= v = Q/A$, $N_F = v/\sqrt{gy_h} = Q/\left(A\sqrt{gy_h}\right)$.
See spreadsheet
For y = **0.05 ft:** v = **5.267 ft/s,** N_F = **4.177. Supercritical**
For y = **0.4770 ft:** v = **0.499 ft/s,** N_F = **0.134. Subcritical.**

f) Compute $WP = b + 2y\sqrt{1+z^2}$ (See Table 14.2). Compute $R = A/WP$.
Compute S: $\left[\dfrac{nQ}{AR^{2/3}}\right]^2$
See spreadsheet: For y = 0.05 ft, $S = 0.264$. For y = 0.4770 ft, $S = 0.000152$.

15.4 $Q = 25$ gal/min $\times$ 1 ft^3/sec/449 gal/min = 0.0557 ft ^{3}/sec

$v = Q/A = 0.0557$ ft ^{3}/sec/0.545 ft^2 = 0.1022 ft/sec

pipe $N_R = \dfrac{vD\rho}{\eta} = \dfrac{(0.1022)(0.833)(0.83)(1.94)}{2.5 \times 10^{-6}} = 5.5 \times 10^4$

(a) $d/D = 1.0/10.0 = 0.10$; $C = 0.595$ (Fig. 15.7)

(b) $d/D = 7.0/10.0 = 0.70$; $C = 0.620$

Solve for $p_1 - p_2$ from Eq. (15.5)

$$Q = CA_1\left[\frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1}\right]^{1/2}; \text{ Then } Q^2 = C^2 A_1^2\left[\frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1}\right]$$

$$p_1 - p_2 = \frac{\gamma Q^2[(A_1/A_2)^2 - 1]}{2g\ C^2 A_1^2}$$

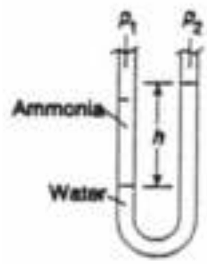
(a) For $d = 1.0$ in, $A_2 = 0.00545$ ft ^{2}; $A_1/A_2 = 0.545/0.00545 = 100$

$$p_1 - p_2 = \frac{\gamma Q^2[(A_1/A_2)^2 - 1]}{2g\ C^2 A_1^2} = \frac{(0.83)(62.4)(0.0557)^2[(100)^2 - 1]}{2(32.2)(0.595)^2(0.545)^2} = 238 \text{ lb/ft}^2$$

For Manometer

$p_1 + \gamma_A h - \gamma_w h = p_2$

$p_1 - p_2 = \gamma_w h - \gamma_A h = h(\gamma_w - \gamma_A)$



$h = \dfrac{p_1 - p_2}{\gamma_w - \gamma_A}$ But $\gamma_A = (0.83)(62.4$ lb/ft $^3) = 51.8$ lb/ft ^{3}

$$h = \frac{p_1 - p_2}{62.4 - 51.8} = \frac{p_1 - p_2}{10.6 \text{ lb/ft}^3} = \frac{238 \text{ lb/ft}^2}{10.6 \text{ lb/ft}^3} = \mathbf{22.4 \text{ ft}}$$

(b) For $d = 7.0$ in, $A_2 = \dfrac{\pi(7.0)^2 \text{ in}^2}{4} \times \dfrac{\text{ft}^2}{144 \text{ in}^2} = 0.267$ ft ^{2}

$A_1/A_2 = 0.545/0.267 = 2.04$

$$p_1 - p_2 = \frac{\gamma Q^2[(A_1/A_2)^2 - 1]}{2g\ C^2 A_1^2} = \frac{(0.83)(62.4)(0.0557)^2[(2.04)^2 - 1]}{2(32.2)(0.620)^2(0.545)^2} = 0.0694 \text{ lb/ft}^2$$

$$h = \frac{p_1 - p_2}{10.6} = \frac{0.0694 \text{ lb/ft}^2}{10.6 \text{ lb/ft}^3} = \mathbf{0.00655 \text{ ft}}$$

An orifice size between 1.0 in and 7.0 in would be preferred to give a more convenient manometer deflection.

15.9 Flow nozzle — Design: Install in 5 1/2 inch Type K copper tube; $D_1 = 4.805$ in; $A_1 = 0.1259$ ft^2
Specify the throat diameter d. **NOTE:** *Multiple solutions possible.*
Fluid: Linseed oil at 77°F; $= 58.0$ lb/ft^3; $= 3.84 \times 10^{4}$ ft^2/s
Use mercury manometer with scale range 0 8 inHg
Range of flow rate: $Q_{min} = 700$ gpm $= 1.559$ ft^3/s; $Q_{max} = 1000$ gpm $= 2.227$ ft^3/s
Velocity in pipe: $_{1\ min} = Q_{min}/A_1 = 12.38$ ft/s; $_{1\ max} = Q_{max}/A_1 = 17.69$ ft/s
Reynolds No.: $N_{R\ min} = \ _{1\ min} D_1/ \ = 1.29 \times 10^4$; $N_{R\ max} = \ _{1\ max} D_1/ \ = 1.84 \times 10^4$
From Figure 15 5: $C_{min} = 0.955$; $C_{max} = 0.961$

a) Use Eq. (15-6) and solve for A_2 from which we can obtain the throat diameter d

$$A_2 = \frac{A_1}{\left[\frac{BhC^2}{\ _1^2} + 1\right]^{1/2}}$$

Where $B = 2g[(\ _g/\ _{l.o}) \quad 2(32.2)[844.9/58.0) \quad 1] = 873.7$

Let $h = 8.0$ in $= 0.667$ ft when $\ = \ _{1\ max} = 17.69$ ft/s and $C = 0.961$

$$A_2 = \frac{0.1259}{\left[\frac{(873.7)(0.667)(0.961)^2}{(17.69)^2} + 1\right]^{1/2}} = 0.07635\ \text{ft}^2 = \ d^2/4$$

Then $d = (4A_2/\ )^{1/2} = [(4)(0.07635)/\ ]^{1/2} = 0.3118$ ft $=$ **3.741 in = Throat diameter**

b) Use Eq. (15-6) and solve for h to determine the manometer reading when $Q = Q_{min}$.

$$h = \frac{(\ _1/C)^2[(A_1/A_2)^2 \quad 1]}{B}$$

For $_1 = \ _{1\ min} = 12.38$ ft/s and $C = 0.955$,

$$h = \frac{(\ _1/C)^2[(A_1/A_2)^2 \quad 1}{B} = \frac{[(12.38/0.955)^2[(0.1259/0.07635)^2 \quad 1]}{873.73} = 0.3306\ \text{ft} = \mathbf{3.97\ in}$$

Summary: Nozzle throat diameter $= d = 3.741$ in
When $Q = 1000$ gpm, $h = 8.00$ in manometer deflection
When $Q = 700$ gpm, $h = 3.97$ in manometer deflection

15.15 Pitot-static tube carrying air at atmospheric pressure and 80°F. $\gamma_a = 0.0736$ lb/ft^3.
$h = 0.24$ inH$_2$O; $h = (0.24$ in$)(1.0$ ft$/12$ in$) = 0.02$ ft; $\gamma_g = \gamma_w = 62.4$ lb/ft^3
Find flow velocity υ.

$$\upsilon = \sqrt{2gh(\gamma_w - \gamma_a)/\gamma_a} = \sqrt{2(32.2\ \text{ft}^2/\text{s})(0.02\ \text{ft})(62.4 - 0.0736)/0.0736} = 33.0\ \text{ft/s}$$