CHAPTER EIGHT

REYNOLDS NUMBER, LAMINAR FLOW, TURBULENT FLOW, AND ENERGY LOSSES DUE TO FRICTION

8.1 $\upsilon = \dfrac{Q}{A} = \dfrac{0.20\ \text{ft}^3/\text{s}}{\pi(4.0\ \text{in})^2/4} \times \dfrac{144\ \text{in}^2}{\text{ft}^2} = 2.29$ ft/s; $D = 4.0$ in(1 ft/12 in) = 0.333 ft

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(2.29)(0.333)(1.26)(1.94)}{7.5 \times 10^{-3}} = \textbf{249 Laminar}$$

(7.5×10^{-3} from App. D)

8.2 Let $N_R = 4000 = \upsilon D/\nu$: $\nu = 4.38 \times 10^{-6}$ ft²/s—App. A; $D = (2/12)$ft

$$\upsilon = \frac{N_R \nu}{D} = \frac{4000(4.38 \times 10^{-6})}{2/12} = 0.105 \frac{\text{ft}}{\text{s}} \times \frac{0.3048\ \text{m}}{\text{ft}} = 0.03204 \frac{\text{m}}{\text{s}}$$

8.3 Let $N_R = 2000 = \upsilon D\rho/\mu$

$$\upsilon_{max} = \frac{N_R \mu}{D\rho} = \frac{2000(4.0 \times 10^{-2})}{(0.10)(0.895)(1000)} = 0.894\ \text{m/s}$$

$$Q = A\upsilon = \frac{\pi(0.10\ \text{m})^2}{4} \times 0.894\ \text{m/s} = \mathbf{7.02 \times 10^{-3}\ m^3/s}$$

8.4 $\upsilon = Q/A = \dfrac{0.25\ \text{ft}^3/\text{s}}{0.02333\ \text{ft}^2} = 10.72$ ft/s; $D = 0.1723$ ft

a) $N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(10.72)(0.1723)}{1.21 \times 10^{-5}} = \mathbf{1.53 \times 10^5}$ (ν from App. A)

b) $N_R = \dfrac{\upsilon D\rho}{\mu} = \dfrac{(10.72)(0.1723)(1.53)}{6.60 \times 10^{-6}} = \mathbf{4.28 \times 10^5}$ (ρ, μ from App. B)

c) $N_R = \dfrac{\upsilon D\rho}{\mu} = \dfrac{(10.72)(0.1723)(1.86)}{1.36 \times 10^{-2}} = \mathbf{253}$ (ρ, μ from App. B)

d) $N_R = \dfrac{\upsilon D\rho}{\nu} = \dfrac{(10.72)(0.1723)(0.87)(1.94)}{9.5 \times 10^{-5}} = \mathbf{3.28 \times 10^4}$ (μ from App. D)

8.5 $N_R = \dfrac{\upsilon D\rho}{\mu} = \dfrac{QD\rho}{A\mu} = \dfrac{QD\rho}{\frac{\pi D^2}{4}\mu} = \dfrac{4Q\rho}{\pi\mu D}$: $D_{min} = \dfrac{4Q\rho}{\pi\mu N_R} = \dfrac{4Q}{\pi N_R \nu}$

$Q = 4.0\ \text{L/min} \times \dfrac{1\ \text{m}^3/\text{s}}{60000\ \text{L/min}} = 6.667 \times 10^{-5}$ m³/s: Let $N_R = 2000$

a) $D_{min} = \dfrac{4(6.667 \times 10^{-5})}{\pi(2000)(\nu)} = \dfrac{4.244 \times 10^{-8}}{\nu} = \dfrac{4.244 \times 10^{-8}}{6.56 \times 10^{-7}} = 0.0647 \text{ m} = 64.7 \text{ mm}$

3-in Type K copper tube—$D = 73.8$ mm

b) $D_{min} = \dfrac{4.244 \times 10^{-8}(680)}{2.87 \times 10^{-4}} = 0.101$ m; **5-in tube,** $D = 122$ mm

c) $D_{min} = \dfrac{4.244 \times 10^{-8}(790)}{1.8 \times 10^{-3}} = 0.0186$ m; $\dfrac{3}{4}$-in tube, $D = 18.9$ mm

d) $D_{min} = \dfrac{4.244 \times 10^{-8}(906)}{1.07 \times 10^{-1}} = 3.59 \times 10^{-4}$ m; $\dfrac{1}{8}$-in tube, $D = 4.57$ mm

Smallest listed

8.6 $N_R = \dfrac{\upsilon D \rho}{\mu}$; $\mu = \dfrac{\upsilon D \rho}{N_R} = \dfrac{(2.97)(0.0779)(890)}{5 \times 10^4} = 4.12 \times 10^{-3}$ Pa·s

$\upsilon = \dfrac{Q}{A} = \dfrac{8.50 \text{ L/min}}{4.768 \times 10^{-3} \text{ m}^2} \times \dfrac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 2.97$ m/s

From App. D, oil must be heated to **100°C** for SAE 10 oil.

8.7

	Auto. Hydraulic Oil	Medium Hydraulic Oil
At 212°F	$N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(10)(0.4011)}{7.85 \times 10^{-5}} = \mathbf{5.11 \times 10^4}$ **turb.**	$N_R = \dfrac{10(0.4011)}{7.85 \times 10^{-5}} = \mathbf{5.11 \times 10^4}$ **turb.**
At 104°F	$N_R = \dfrac{(10)(0.4011)}{4.30 \times 10^{-4}} = \mathbf{9328}$ **turb.**	$N_R = \dfrac{10(0.4011)}{7.21 \times 10^{-4}} = \mathbf{5563}$ **turb.**

8.8 $N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(3.06)(0.0475)}{1.30 \times 10^{-6}} = \mathbf{1.12 \times 10^5}$ **Turbulent**

$\upsilon = \dfrac{Q}{A} = \dfrac{325 \text{ L/min}}{1.772 \times 10^{-3} \text{ m}^2} \times \dfrac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.06$ m/s

8.9 $N_R = \dfrac{\upsilon D \rho}{\mu} = \dfrac{(0.899)(0.0243)(860)}{3.95 \times 10^{-4}} = \mathbf{4.76 \times 10^4}$ **Turbulent**

$\upsilon = \dfrac{Q}{A} = \dfrac{25 \text{ L/min}}{4.636 \times 10^{-4} \text{ m}^2} \times \dfrac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.899$ m/s

8.10 $N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(1.78)(0.0134)}{3.60 \times 10^{-7}} = \mathbf{6.62 \times 10^4}$ **Turbulent**

$\upsilon = \dfrac{Q}{A} = \dfrac{15.0 \text{ L/min}}{1.407 \times 10^{-4} \text{ m}^2} \times \dfrac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.78$ m/s

8.11 $N_R = \frac{\upsilon D}{\nu} = \frac{(8.59)(1.563)}{1.40\times10^{-5}}$ = **9.59 × 10⁵**

$\upsilon = \frac{Q}{A} = \frac{16.5 \text{ ft}^3\text{/s}}{1.920 \text{ ft}^2} = 8.59 \text{ ft/s}$

8.12 $\upsilon = \frac{Q}{A} = \frac{0.40 \text{ gal}}{\text{hr}} \times \frac{\text{ft}^3}{7.48 \text{ gal}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{1}{2.029\times10^{-5} \text{ ft}^2} = 0.732 \text{ ft/s}$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.732)(0.00508)(0.88)(1.94)}{6.2\times10^{-3}}$ = **1.02 Laminar**

8.13 $N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.732)(0.00508)(0.88)(1.94)}{1.90\times10^{-4}}$ = **33.4 Laminar**

Note: sg of oil may be slightly lower at 160°F.

8.14 $N_R = \frac{\upsilon D\rho}{\mu};\ \upsilon = \frac{N_R\mu}{D\rho} = \frac{(4000)(4.01\times10^{-5})}{(0.2423)(1.56)}$ = **0.424 ft/s**

$Q = A\upsilon = 4.609\times10^{-2} \text{ ft}^2 \times 0.424 \text{ ft/s}$ = **1.96×10^{-2} ft³/s**

8.15 $\upsilon = \frac{Q}{A} = \frac{45 \text{ L/min}}{2.812\times10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3\text{/s}}{60000 \text{ L/min}} = 2.67 \text{ m/s}$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(2.67)(0.01892)(0.89)(1000)}{8\times10^{-3}}$ = **5.61 × 10³ Turbulent**

Note: μ from App. D.

8.16 $N_R = \frac{\upsilon D\rho}{\mu} = \frac{(2.67)(0.01892)(890)}{3.0}$ = **15.0** very low—**Laminar**

8.17 $\upsilon = \frac{Q}{A} = \frac{45 \text{ L/min}}{1.772\times10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3\text{/s}}{60000 \text{ L/min}} = 0.423 \text{ m/s}$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.423)(0.0475)(890)}{8\times10^{-3}}$ = **2237 Critical Zone**

8.18 $N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.423)(0.0475)(890)}{3.0}$ = **5.97** very low—**Laminar**

8.19 $\upsilon = \frac{Q}{A} = \frac{1.65 \text{ gal/min}}{2.509\times10^{-4} \text{ ft}^2} \times \frac{1 \text{ ft}^3\text{/s}}{449 \text{ gal/min}} = 14.65 \text{ ft/s}$

$N_R = \frac{\upsilon D}{\nu} = \frac{(14.65)(0.01788)}{2.37\times10^{-4}}$ = **1105 Laminar**

8.20 $N_R = \frac{\upsilon D}{\nu} = \frac{(14.65)(0.01788)}{4.20\times10^{-5}}$ = **6237 Turbulent**

Changing from laminar flow, through critical zone, into turbulent flow could cause erratic performance. Also, $\upsilon = 14.65$ ft/s is quite high, causing large pressure drops through the system.

8.21 $A = \dfrac{Q}{\upsilon} = \dfrac{500 \text{ gal/min}}{10.0 \text{ ft/s}} \times \dfrac{1 \text{ ft}^3\text{/s}}{449 \text{ gal/min}} = 0.1114 \text{ ft}^2 \Rightarrow$ 5-in Sch. 40 pipe

$A = 0.1390 \text{ ft}^2, D = 0.4026 \text{ ft}$

Actual $\upsilon = \dfrac{Q}{A} = \dfrac{(500/499)\text{ft}^3\text{/s}}{0.1390 \text{ ft}^2} = 8.01 \text{ ft/s}$

$N_R = \dfrac{\upsilon D \rho}{\mu} = \dfrac{(8.01)(0.4026)(2.13)}{3.38 \times 10^{-4}} = \mathbf{2.12 \times 10^4}$

8.22 $\upsilon_1 = \dfrac{N_R \nu}{D} = \dfrac{2000(1.21 \times 10^{-5} \text{ ft}^2\text{/s})}{0.0621 \text{ ft}} = 0.3897 \text{ ft/s}$

For $N_R = 4000$, $\upsilon_2 = 2(0.3897 \text{ ft/s}) = 0.7794 \text{ ft/s}$

$Q_1 = A\upsilon_1 = (3.027 \times 10^{-3} \text{ ft}^2)(0.3897 \text{ ft/s})$

$= 1.180 \times 10^{-3} \text{ ft}^3\text{/s} \times \dfrac{449 \text{ gal/min}}{1 \text{ ft}^3\text{/s}}$

Q_1 = 0.530 gal/min—Lower Limit

$Q_2 = 2Q_1$ = 1.060 gal/min—Upper Limit

8.23 (See Prob. 8.22)

$\upsilon_1 = \dfrac{N_R \nu}{D} = \dfrac{(2000)(3.84 \times 10^{-6})}{0.0621} = 0.1237 \text{ ft/s}; \ \upsilon_2 = 2\upsilon_1 = 0.2473 \text{ ft/s}$

$Q_1 = A\upsilon_1 = (3.027 \times 10^{-3} \text{ ft}^2)(0.1237 \text{ ft/s}) \times \dfrac{449 \text{ gal/min}}{1 \text{ ft}^3\text{/s}} = 0.1681 \text{ gal/min}$

$Q_2 = 2Q_1$ = 0.3362 gal/min

8.24 $\upsilon = 1.30 \text{ cs} \times \dfrac{1.076 \times 10^{-5} \text{ ft}^2\text{/s}}{1 \text{ cs}} = 1.40 \times 10^{-5} \text{ ft}^2\text{/s}$

$Q = 45 \text{ gal/min} \times \dfrac{1 \text{ ft}^3\text{/s}}{449 \text{ gal/min}} = 0.1002 \text{ ft}^3\text{/s}$

$\upsilon = \dfrac{Q}{A} = \dfrac{0.1002 \text{ ft}^3\text{/s}}{6.842 \times 10^{-3} \text{ ft}^2} = 14.65 \text{ ft/s}$

$N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(14.65)(0.0933)}{1.40 \times 10^{-5}} = \mathbf{9.78 \times 10^4}$

8.25 $\nu = 17.0 \text{ cs} \times \dfrac{10^{-6} \text{ m}^2\text{/s}}{1 \text{ cs}} = 1.7 \times 10^{-5} \text{ m}^2\text{/s}$

$\upsilon = \dfrac{Q}{A} = \dfrac{215 \text{ L/min}}{5.017 \times 10^{-4} \text{ m}^2} \times \dfrac{1 \text{ m}^3\text{/s}}{60000 \text{ L/min}} = 7.142 \text{ m/s}$

$N_R = \dfrac{\upsilon D}{\nu} = \dfrac{(7.142)(0.0253)}{1.70 \times 10^{-5}} = 1.06 \times 10^4$

8.26 $\nu = 1.20 \text{ cs} \times \dfrac{10^{-6}\text{ m}^2/\text{s}}{1\text{ cs}} = 1.20 \times 10^{-6}\text{ m}^2/\text{s}$

$$\upsilon = \frac{Q}{A} = \frac{200\text{ L/min}}{3.835\times10^{-4}\text{m}^2}\times\frac{1\text{ m}^3/\text{s}}{60000\text{ L/min}} = 8.69\text{ m/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(8.69)(0.0221)}{1.20\times10^{-6}} = \mathbf{1.60 \times 10^5}$$

8.27 $\dfrac{p_1}{\gamma_o} + z_1 + \dfrac{\upsilon_1^2}{2g} - h_L = \dfrac{p_2}{\gamma_o} + z_2 + \dfrac{\upsilon_2^2}{2g}:\ \upsilon_1 = \upsilon_2$

$$p_1 - p_2 = \gamma_o\left[z_2 - z_1 + h_L\right]$$

$$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.64)(0.0243)(0.86)(1000)}{1.70\times10^{-2}} = 787\text{ (Laminar)};\ f = \frac{64}{N_R} = 0.0813$$

$$h_L = f\ \frac{L}{D}\frac{\upsilon^2}{2g} = 0.0813\times\frac{60}{0.0243}\times\frac{(0.64)^2}{2(9.81)} = 4.19\text{ m}$$

$$\boldsymbol{p_1 - p_2} = (0.86)(9.82\text{ kN/m}^3)\left[-60\text{ m} + 4.19\text{ m}\right] = -471\text{ kN/m}^2 = \mathbf{-471\ kPa}$$

8.28 $\dfrac{p_1}{\gamma_w} + z_1 + \dfrac{\upsilon_1^2}{2g} - h_L = \dfrac{p_2}{\gamma_w} + z_2 + \dfrac{\upsilon_2^2}{2g}:\ \upsilon_1 = \upsilon_2;\ z_1 = z_2:\ p_1 - p_2 = \gamma_w h_L$

$$\upsilon = \frac{Q}{A} = \frac{12.9\text{ L/min}}{1.407\times10^{-4}\text{ m}^2}\times\frac{1\text{ m}^3/\text{s}}{60000\text{ L/min}} = 1.528\text{ m/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(1.528)(0.0134)}{3.83\times10^{-7}} = 5.35\times10^4\text{ (turbulent)}$$

$D/\varepsilon = 0.0134/1.50 \times 10^{-6} = 8933$; Then $f = 0.0205$

$$h_L = f\ \frac{L}{D}\frac{\upsilon^2}{2g} = (0.0205)\cdot\frac{45}{0.0134}\cdot\frac{(1.528)^2}{2(9.81)} = 8.19\text{ m}$$

$$\boldsymbol{p_1 - p_2} = \gamma_w h_L = 9.56\text{ kN/m}^3 \times 8.19\text{ m} = 78.3\text{ kN/m}^2 = \mathbf{78.3\ kPa}$$

8.29 Let $N_R = 2000$; $f = 64/N_R = 0.032$; $N_R = \dfrac{\upsilon D\rho}{\mu}$

$$\upsilon = \frac{N_R\mu}{D\rho} = \frac{(2000)(8.3\times10^{-4})}{(0.3355)(0.895)(1.94)} = 2.85\text{ ft/s}$$

$$h_L = f\ \frac{L}{D}\frac{\upsilon^2}{2g} = (0.032)\cdot\frac{100}{0.3355}\cdot\frac{(2.85)^2}{2(32.2)}\text{ ft} = 1.20\text{ ft} = \mathbf{1.20\ ft{\cdot}lb/lb}$$

8.30 $\frac{p_A}{\gamma_o} + z_A + \frac{\upsilon_A^2}{2g} - h_L = \frac{p_B}{\gamma_o} + z_B + \frac{\upsilon_B^2}{2g}$: $\upsilon_A = \upsilon_B$

$p_B = p_A + \gamma_o[z_A - z_B - h_L]$

$\upsilon = \frac{N_R\mu}{D\rho} = \frac{(800)(4\times10^{-4})}{(0.2557)(0.90)(1.94)} = 0.717$ ft/s

$h_L = f\ \frac{L}{D}\frac{\upsilon^2}{2g} = \frac{64}{800}\cdot\frac{5000}{0.2557}\cdot\frac{(0.717)^2}{2(32.2)} = 12.5$ ft

$p_B = 50$ psig + (0.90)(62.4 lb/ft^3)[−20 ft − 12.5 ft] $\frac{1\ \text{ft}^2}{144\ \text{in}^2}$ = **37.3 psig**

8.31 $\frac{p_1}{\gamma_b} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma_b} + z_2 + \frac{\upsilon_2^2}{2g}$: $z_1 = z_2$: $\upsilon_1 = \upsilon_2$: $p_1 - p_2 = \gamma_b h_L = \gamma_b f\ \frac{L}{D}\frac{\upsilon^2}{2g}$

$\upsilon = \frac{Q}{A} = \frac{20\ \text{L/min}}{4.636\times10^{-4}\ \text{m}^2} \times \frac{1\ \text{m}^3/\text{s}}{60000\ \text{L/min}} = 0.719$ m/s

$\rho = \frac{\gamma}{g} = \frac{8.62\ \text{kN}}{\text{m}^3} \times \frac{\text{s}^2}{9.81\ \text{m}} \times \frac{10^3\ \text{N}}{\text{kN}} \times \frac{1\ \text{kg}\cdot\text{m/s}^2}{\text{N}} = 879\ \text{kg/m}^3$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.719)(0.0243)(879)}{3.95\times10^{-4}} = 3.89 \times 10^4$

$D/\varepsilon = 0.0243/4.6 \times 10^{-5} = 528$; Then $f = 0.027$

$p_1 - p_2 = 8.62\ \text{kN/m}^3 \times 0.027 \times \frac{100}{0.0243} \times \frac{(0.719)^2}{2(9.81)}\text{m} = 25.2\ \text{kN/m}^2 =$ **25.2 kPa**

8.32 From Prob. 8.31, $p_1 - p_2 = \gamma_w h_L$; $h_L = p_1 - p_2/\gamma_w$

$h_L = \frac{(1035 - 669)\text{kN/m}^2}{9.81\ \text{kN/m}^3} = 37.3\ \text{m} = f\ \frac{L}{D}\frac{\upsilon^2}{2g}$

$f = \frac{h_L D 2g}{L\upsilon^2} = \frac{(37.3)(0.03388)(2)(9.81)}{(30)(4.16)^2} = 0.048$

$\upsilon = \frac{Q}{A} = \frac{225\ \text{L/min}}{9.017\times10^{-4}\ \text{m}^2} \times \frac{1\ \text{m}^3/\text{s}}{60000\ \text{L/min}} = 4.16$ m/s

$N_R = \frac{\upsilon D}{\nu} = \frac{(4.16)(0.03388)}{1.30\times10^{-6}} = 1.08\times10^5$: Then $\frac{D}{\varepsilon} = 55$ for $f = 0.048$

$\varepsilon = D/55 = 0.03388/55 =$ **6.16×10^{-4} m**

8.33 $$\frac{p_1}{\gamma_w}+z_1+\frac{\upsilon_1^2}{2g}-h_L=\frac{p_2}{\gamma_w}+z_2+\frac{\upsilon_2^2}{2g}$$

$$h=z_1-z_2=h_L+\frac{\upsilon_2^2}{2g}$$

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

Pt. 1 at tank surface. $p_1 = 0$, $\upsilon_1 = 0$
Pt. 2 in outlet stream. $p_2 = 0$
$D = 0.5054$ ft
$A = 0.2006$ ft^2

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

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

8.34 From Prob. 8.31, $p_1-p_2=\gamma_w h_L=\gamma_w f\ \frac{L}{D}\frac{\upsilon^2}{2g}$

$$\upsilon=\frac{Q}{A}=\frac{15.0\ \text{ft}^3/\text{s}}{\pi(1.50\ \text{ft})^2/4}=8.49\ \text{ft/s}$$

$$N_R=\frac{\upsilon D}{\nu}=\frac{(8.49)(1.50)}{1.40\times10^{-5}}=9.09\times10^5;\ \frac{D}{\varepsilon}=\frac{1.50}{4\times10^{-4}}=3750;\ f=0.0158$$

$$p_1-p_2=\gamma_w\ f\ \frac{L}{D}\frac{\upsilon^2}{2g}=\frac{62.4\ \text{lb}}{\text{ft}^3}\times0.0158\times\frac{5280\ \text{ft}}{1.50\ \text{ft}}\times\frac{(8.49)^2\ \text{ft}^2/\text{s}^2}{2(32.2\ \text{ft/s}^2)}\times\frac{1\ \text{ft}^2}{144\ \text{in}^2}=\mathbf{30.5\ psi}$$

8.35 $$Q=1500\ \text{gal/min}\times\frac{1\ \text{ft}^3/\text{s}}{449\ \text{gal/min}}=3.34\ \text{ft}^3/\text{s}$$

$$\upsilon_A=\frac{Q}{A_A}=\frac{3.34\ \text{ft}^3/\text{s}}{0.5479\ \text{ft}^2}=6.097\ \text{ft/s};\ \frac{\upsilon_A^2}{2g}=\frac{(6.097)^2}{2(32.2)}=0.577\ \text{ft}$$

a) $$\frac{p_1}{\gamma_w}+z_1+\frac{\upsilon_1^2}{2g}-h_{L_s}=\frac{p_A}{\gamma_w}+z_A+\frac{\upsilon_A^2}{2g}$$ **Pt. 1 at tank surface. $p_1 = 0$, $\upsilon_1 = 0$**

$$z_1-z_A=h=\frac{p_A}{\gamma_w}+\frac{\upsilon_A^2}{2g}+h_L$$

$$N_R=\frac{\upsilon_A D}{\nu}=\frac{(6.097)(0.835)}{1.21\times10^{-5}}=4.21\times10^5;\ \frac{D}{\varepsilon}=\frac{0.835}{1.5\times10^{-4}}=5567;\ f=0.0155$$

$$h_L=f\ \frac{L}{D}\frac{\upsilon^2}{2g}=(0.0155)\times\frac{45}{0.835}\times0.577\ \text{ft}=0.482\ \text{ft}$$

$$h=\frac{5.0\ \text{lb}\cdot\text{ft}^3}{\text{in}^2\,62.4\ \text{lb}}\frac{144\ \text{in}^2}{\text{ft}^2}+0.577+0.482=\mathbf{12.60\ ft}$$

b) $$\frac{p_A}{\gamma}+z_A+\frac{\upsilon_A^2}{2g}-h_{L_d}+h_A=\frac{p_B}{\gamma}+z_B+\frac{\upsilon_B^2}{2g}$$

$$\upsilon_B=\frac{Q}{A_B}=\frac{3.34\text{ ft}^3/\text{s}}{0.3472\text{ ft}^2}=9.62\text{ ft/s}$$

$$h_A=\frac{p_B-p_A}{\gamma_w}+(z_B-z_A)+\frac{\upsilon_B^2-\upsilon_A^2}{2g}+h_{L_d}=\frac{(85-5)\text{ lb ft}^3\,(144\text{ in}^2)}{\text{in}^2(62.4\text{ lb})\text{ft}^2}+25$$

$$+\frac{(9.62^2-6.097^2)\text{ft}^2/\text{s}^2}{2(32.2\text{ ft/s}^2)}+89.9=300.4\text{ ft}$$

$$N_{R_B}=\frac{\upsilon_B D_B}{\nu}=\frac{(9.62)(0.6651)}{1.21\times10^{-5}}=5.29\times10^5$$

$$D/\varepsilon=\frac{0.6651}{1.5\times10^{-4}}=4434;\ f=0.016$$

$$h_{L_d}=f\frac{L}{D}\frac{\upsilon^2}{2g}=(0.016)\times\frac{2600}{0.6651}\times\frac{(9.62)^2}{2(32.2)}=89.9\text{ ft}$$

$$P_A=h_A\gamma_w Q=300.4\text{ ft}\times\frac{62.4\text{ lb}}{\text{ft}^3}\times\frac{3.34\text{ ft}^3}{\text{s}}\frac{\text{hp}}{550\text{ ft}\cdot\text{lb/s}}=\mathbf{113.8\ hp}$$

8.36 $$\frac{p_1}{\gamma}+z_1+\frac{\upsilon_1^2}{2g}+h_A-h_L=\frac{p_2}{\gamma}+z_2+\frac{\upsilon_2^2}{2g}$$

Pt. 1 at well surface ($p_1 = 0$ psig).
Pt. 2 at tank surface.
$\upsilon_1 = \upsilon_2 = 0$

$$h_A=\frac{p_2}{\gamma_w}+(z_2-z_1)+h_L$$

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

$$\upsilon=\frac{Q}{A}=\frac{0.0277\text{ ft}^3/\text{s}}{0.0060\text{ ft}^2}=4.61\text{ ft/s}\ \textbf{in pipe}$$

$$N_R=\frac{\upsilon D}{\nu}=\frac{(4.61)(0.0874)}{1.21\times10^{-5}}=3.33\times10^4;\ \frac{D}{\varepsilon}=\frac{0.0874}{1.5\times10^{-4}}=583;\ f=0.0275$$

$$h_L=f\frac{L}{D}\frac{\upsilon^2}{2g}=(0.0275)\frac{140}{0.0874}\times\frac{(4.61)^2}{2(32.2)}\text{ ft}=14.54\text{ ft}$$

$$h_A=\frac{(40\text{ lb})\text{ft}^3(144\text{ in}^2)}{\text{in}^2(62.4\text{ lb})\text{ft}^2}+120+14.54=226.8\text{ ft}$$

$P_A = h_A\gamma Q = (226.8\text{ ft})(62.4\text{ lb/ft}^3)(0.0277\text{ ft}^3/\text{s})/550\text{ ft·lb/s/hp} =$ **0.713 hp**

8.37 $$\frac{p_1}{\gamma_w}+z_1+\frac{\upsilon_1^2}{2g}-h_L=\frac{p_2}{\gamma_w}+z_2+\frac{\upsilon_2^2}{2g}$$

Pt. 1 at tank surface. $\upsilon_1 = 0$
Pt. 2 in outlet stream. $p_2 = 0$

$$p_1=\gamma_w\left[(z_2-z_1)+\frac{\upsilon_2^2}{2g}+h_L\right]$$

$$\upsilon_2=\frac{Q}{A_2}=\frac{75\text{ gal/min}}{0.01414\text{ ft}^2}\times\frac{1\text{ ft}^3/\text{s}}{449\text{ gal/min}}=11.8\text{ ft/s}:\ \frac{\upsilon^2}{2g}=\frac{(11.8)^2}{2(32.2)}=2.167\text{ ft}$$

$$N_R=\frac{\upsilon D}{\nu}=\frac{(11.8)(0.1342)}{1.21\times10^{-5}}=1.31\times10^5:\ \frac{D}{\varepsilon}=\frac{0.1342}{1.5\times10^{-4}}=895:f=0.0225$$

$$h_L=f\ \frac{L}{D}\frac{\upsilon^2}{2g}=(0.0225)\frac{300}{0.1342}\ (2.167\text{ ft})=109.0\text{ ft}$$

$$p_1=\frac{62.4\text{ lb}}{\text{ft}^3}[-3\text{ ft}+2.167\text{ ft}+109.0\text{ ft}]\frac{1\text{ ft}^2}{144\text{ in}^2}=\mathbf{46.9\ psi}$$

8.38 $$\frac{p_1}{\gamma}+z_1+\frac{\upsilon_1^2}{2g}+h_A-h_L=\frac{p_2}{\gamma}+z_2+\frac{\upsilon_2^2}{2g}$$

Pt. 1 at tank surface. $p_1 = 0$; $\upsilon_1 = 0$
Pt. 2 in hose at nozzle.
Pt. 3 in hose at pump outlet.
$\upsilon_3 = \upsilon_2$

a) $$h_A=\frac{p_2}{\gamma}+(z_2-z_1)+\frac{\upsilon_2^2}{2g}+h_L$$

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

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

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

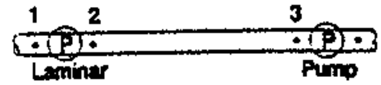
$$h_A=\frac{140\text{ kN/m}^2}{(1.10)(9.81\text{ kN/m}^3)}+7.3\text{ m}+0.530+37.86\text{ m}=58.67\text{ m}$$

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

b) $$\frac{p_3}{\gamma}+z_3+\frac{\upsilon_3^2}{2g}-h_L=\frac{p_2}{\gamma}+z_2+\frac{\upsilon_2^2}{2g}:\ p_3=p_2+[(z_2-z_3)+h_L]\gamma$$

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

8.39 $Q = 1200 \text{ L/min} \times 1 \text{ m}^3\text{/s}/60000 \text{ L/min} = 0.02 \text{ m}^3\text{/s}$



$$\upsilon = \frac{Q}{A} = \frac{0.02 \text{ m}^3\text{/s}}{1.682\times10^{-2} \text{ m}^2} = 1.189 \text{ m/s}$$

a) $$p_2 - p_3 = \gamma_o h_L = \gamma_o f \frac{L}{D}\frac{\upsilon^2}{2g}$$

$$N_R = \frac{\upsilon D\rho}{\mu} = \frac{1.189(0.1463)(930)}{0.15} = 1079 \text{ Laminar}$$

$$p_2 - p_3 = \gamma_o h_L = (0.93)(9.81 \text{ kN/m}^3)\left(\frac{64}{1079}\right)\left(\frac{3200}{0.1463}\right)\frac{(1.189)^2}{2(9.81)} \text{ m} = \mathbf{853 \text{ kPa}}$$

b) $$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} + h_A - h_L = \frac{p_3}{\gamma} + z_3 + \frac{\upsilon_3^2}{2g}: \; p_1 = p_3,\; \upsilon_1 = \upsilon_3,\; z_1 = z_3$$

$$h_A = h_L = \frac{853 \text{ kN/m}^2}{(0.93)(9.81 \text{ kN/m}^3)} = 93.5 \text{ m}$$

$$P_A = h_A\gamma Q = (93.5 \text{ m})(0.93)(9.81 \text{ kN/m}^3)(0.02 \text{ m}^3\text{/s}) = 17.1 \text{ kN·m/s} = \mathbf{17.1 \text{ kW}}$$

8.40 At 100°C, $\mu = 7.9 \times 10^{-3}$ Pa·s

a) With pumping stations 3.2 km apart:

$$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(1.189)(0.1463)(930)}{7.9\times10^{-3}} = 2.05 \times 10^4 \text{ turbulent}$$

$D/\varepsilon = 0.1463 \text{ m}/4.6 \times 10^{-5} \text{ m} = 3180; f = 0.026$

$$h_A = h_L = f\frac{L}{D}\frac{\upsilon^2}{2g} = (0.026)\frac{3200}{0.1463}\frac{(1.189)^2}{2(9.81)} \text{ m} = 40.98 \text{ m}$$

$$P_A = h_A\gamma Q = (40.98)(0.93)(9.81)(0.02) = \mathbf{7.48 \text{ kW}}$$

b) Let $h_L = 93.5$ m (from Prob. 9.13): $h_L = f\dfrac{L}{D}\dfrac{\upsilon^2}{2g}$

$$L = \frac{h_L D(2g)}{f\upsilon^2} = \frac{(93.5 \text{ m})(0.1463 \text{ m})(2)(9.81 \text{ m/s}^2)}{(0.026)(1.189 \text{ m/s})^2} = 8682 \text{ m} = \mathbf{8.68 \text{ km}}$$

8.41 $\frac{p_1}{\gamma_w} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{\upsilon_B^2}{2g}$

$p_B = \gamma_w\left[(z_1 - z_B) - \frac{\upsilon_B^2}{2g} - h_L\right]$

Pt. 1 at tank surface. $p_1 = 0$, $\upsilon_1 = 0$

$Q = \frac{900 \text{ L/min } 1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.015 \text{ m}^3/\text{s}$

$\upsilon = \frac{Q}{A} = \frac{0.015 \text{ m}^3/\text{s}}{7.538\times10^{-3} \text{ m}^2} = 1.99 \text{ m/s}$

$N_R = \frac{\upsilon D}{\nu} = \frac{(1.99)(0.098)}{1.30\times10^{-6}} = 1.50\times10^5 : \frac{D}{\varepsilon} = \frac{0.098}{1.5\times10^{-6}} = 65333 : f = 0.0165$

$h_L = f\,\frac{L}{D}\frac{\upsilon^2}{2g} = (0.0165)\frac{80.5}{0.098}\times\frac{(1.99)^2}{2(9.81)} = 2.735 \text{ m}$

$p_B = 9.81 \text{ kN/m}^3\left[12 - \frac{(1.99)^2}{2(9.81)} - 2.735\right]\text{m}$ = **89.9 kPa**

8.42 $Q = 50 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.1114 \text{ ft}^3/\text{s}: \upsilon = \frac{Q}{A} = \frac{0.1114 \text{ ft}^3/\text{s}}{0.0060 \text{ ft}^2} = 18.56 \text{ ft/s}$

$\frac{p_1}{\gamma_w} + z_1 + \frac{\upsilon_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{\upsilon_2^2}{2g} : \; p_1 = 0,\ \upsilon_1 = \upsilon_2 = 0$

$h_A = \frac{p_2}{\gamma_w} + (z_2 - z_1) + h_L$

$N_R = \frac{\upsilon D}{\nu} = \frac{(18.56)(0.0874)}{1.21\times10^{-5}} = 1.34\times10^5 : \frac{D}{\varepsilon} = \frac{0.0874}{1.5\times10^{-4}} = 583 : f = 0.0243$

$h_L = f\,\frac{L}{D}\frac{\upsilon^2}{2g} = (0.0243)\frac{225}{0.0874}\times\frac{(18.56)^2}{2(32.2)} \text{ ft} = 335 \text{ ft}$

$h_A = \frac{(40 \text{ lb})\text{ft}^3}{\text{in}^2 \; 62.4 \text{ lb}}\times\frac{144 \text{ in}^2}{\text{ft}^2} + 220 \text{ ft} + 335 \text{ ft} = 647 \text{ ft}$

$P_A = h_A\gamma_w Q = (647 \text{ ft})(62.4 \text{ lb/ft}^3)(0.1114 \text{ ft}^3/\text{s})/550 =$ **8.18 hp**

(b) Increase the pipe size to 1 1/2-in Schedule 40. Results: $\upsilon = 7.88$ ft/s; $N_R = 8.74\times10^4$; $D/\varepsilon = 895$; $f = 0.0232$; Then, $h_L = 37.5$ ft; $h_A = 349.8$ ft; **Power = P_A = 4.42 hp.**

8.43 $\frac{p_1}{\gamma_o} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{\upsilon_2^2}{2g} : \; p_1 - p_2 = \gamma_o h_L$

$\upsilon = \frac{Q}{A} = \frac{60 \text{ gal/min}}{0.01414 \text{ ft}^2}\times\frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 9.45 \text{ ft/s}$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(9.45)(0.1342)(0.94)(1.94)}{8.5\times10^{-3}} = 272$ Laminar

$h_L = f\,\frac{L}{D}\frac{\upsilon^2}{2g} = \frac{64}{272}\times\frac{40}{0.1342}\times\frac{(9.45)^2}{2(32.2)} \text{ ft} = 97.23 \text{ ft}$

$p_1 - p_2 = \gamma_o h_L = (0.94)\frac{(62.4 \text{ lb})}{\text{ft}^3}(97.23 \text{ ft})\frac{1 \text{ ft}^2}{144 \text{ in}^2}$ = **39.6 psi**

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

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

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

$$N_{R_B} = \frac{\upsilon_B D \rho}{\mu} = \frac{(15.03)(0.2058)(1.026)(1.94)}{4.0 \times 10^{-5}} = 1.54 \times 10^5$$

$$\frac{D}{\varepsilon} = \frac{0.2058}{1.5 \times 10^{-4}} = 1372: \ f = 0.020$$

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

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

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

8.45 $N_R = \frac{\upsilon D \rho}{\mu} = \frac{QD\rho}{A\mu} = \frac{QD\rho}{\frac{\pi D^2}{4}\mu} = \frac{4Q\rho}{\pi D \mu}: \ D_{min} = \frac{4Q\rho}{\pi N_R \mu}$

$$D_{min} = \frac{4(0.90\ \text{ft}^3/\text{s})(1.24)(1.94\ \text{lb}\cdot\text{s}^2/\text{ft}^4)}{\pi(300)(5.0 \times 10^{-2}\ \text{lb}\cdot\text{s}/\text{ft}^2)} = 0.184\ \text{ft}$$

2 1/2-in Type K Copper Tube: $D = 0.2029$ ft: $A = 0.03234\ \text{ft}^2$

$$\upsilon = \frac{Q}{A} = \frac{0.90\ \text{ft}^3/\text{s}}{0.03234\ \text{ft}^2} = 27.8\ \text{ft/s}$$

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(27.8)(0.2029)(1.24)(1.94)}{5.0 \times 10^{-2}} = 272$$

$$p_1 - p_2 = \gamma_g h_L = \gamma_g f \frac{L}{D}\frac{\upsilon^2}{2g} = (1.24)(62.4)\frac{64}{272} \times \frac{55}{0.2029} \times \frac{(27.8)^2}{2(32.2)}\frac{\text{lb}}{\text{ft}^2}\frac{1\ \text{ft}^2}{144\ \text{in}^2}$$

= **411 psi**

8.46 $\frac{p_1}{\gamma_w} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{\upsilon_2^2}{2g}$

Pt. 1 at pump outlet in pipe.
Pt. 2 at reservoir surface. $p_2 = 0, \upsilon_2 = 0$

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

$$p_1 = \gamma_w \left[(z_2 - z_1) - \frac{\upsilon_1^2}{2g} + h_L \right]$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(11.52)(0.6651)}{1.21 \times 10^{-5}} = 6.33 \times 10^5: \ \frac{D}{\varepsilon} = \frac{0.6651}{1.5 \times 10^{-4}} = 4434: f = 0.0155$$

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

$p_1 = \frac{62.4\ \text{lb}}{\text{ft}^3}\left[210 - \frac{(11.52)^2}{2(32.2)} + 120.1\right]\frac{\text{ft}\cdot 1\ \text{ft}^2}{144\ \text{in}^2} =$ **142.1 psi**

8.47 $\frac{p_0}{\gamma_w}+z_0+\frac{\upsilon_0^2}{2g}+h_A=\frac{p_1}{\gamma_w}+z_1+\frac{\upsilon_1^2}{2g}$

Pt. 0 at pump inlet.
Pt. 1 at pump outlet.
Assume $z_0=z_1, \upsilon_0=\upsilon_1$

$$h_A=\frac{p_1-p_0}{\gamma_w}=\frac{[142.1-(-2.36)]\text{lb}}{(62.4\text{ lb/ft}^3)(\text{in}^2)(1\text{ ft}^2/144\text{ in}^2)}$$

$h_A=333.5$ ft·lb/lb

$$P_A=h_A\gamma Q=\frac{333.5\text{ ft}\cdot\text{lb}}{\text{lb}}\cdot\frac{62.4\text{ lb}}{\text{ft}^3}\cdot\frac{4.00\text{ ft}^3}{\text{s}}\cdot\frac{1\text{ hp}}{550\text{ ft}\cdot\text{lb/s}}=\mathbf{151\ hp}$$

8.48 $\frac{p_A}{\gamma_g}+z_A+\frac{\upsilon_A^2}{2g}-h_L=\frac{p_B}{\gamma}+z_B+\frac{\upsilon_B^2}{2g}$

$\upsilon=\frac{Q}{A}=\frac{4.25\text{ ft}^3/\text{s}}{0.5479\text{ ft}^2}=7.76$ ft/s
Assume sg = 0.68
μ From App. D.

$p_A=p_B+\gamma_g[(z_B-z_A)+h_L]$

$$N_R=\frac{\upsilon D\rho}{\mu}=\frac{(7.76)(0.8350)(1.32)}{7.2\times10^{-6}}=1.19\times10^6$$

$$\frac{D}{\varepsilon}=\frac{0.8350}{1.5\times10^{-4}}=5567;\ f=0.0145$$

$$h_L=f\ \frac{L}{D}\frac{\upsilon^2}{2g}=0.0145\cdot\frac{3200}{0.8350}\times\frac{(7.76)^2}{2(32.2)}=51.9\text{ ft}$$

$$p_A=40.0\text{ psig}+\frac{42.4\text{ lb}}{\text{ft}^3}[85+51.9]\frac{\text{ft}\cdot1\text{ ft}^2}{144\text{ in}^2}=80.3\text{ psig}$$

8.49 $\frac{p_1}{\gamma_o}+z_1+\frac{\upsilon_1^2}{2g}+h_A-h_L=\frac{p_2}{\gamma_o}+z_2+\frac{\upsilon_2^2}{2g}$

Pt. 1 at tank surface. $p_1=0, \upsilon_1=0$
Pt. 2 in outlet stream from 3-in pipe. $p_2=0$
$Q=\frac{300\text{ gal/min}\cdot1\text{ ft}^3/\text{s}}{449\text{ gal/min}}=0.668\text{ ft}^3/\text{s}$
oil- App. C

$$h_A=(z_2-z_1)+\frac{\upsilon_2^2}{2g}+h_L$$

$$\upsilon_4=\frac{Q}{A_4}=\frac{0.668\text{ ft}^3/\text{s}}{0.08840\text{ ft}^2}=7.56\text{ ft/s}$$

$$\upsilon_3=\frac{Q}{A_3}=\frac{0.668\text{ ft}^3/\text{s}}{0.05132\text{ ft}^2}=13.02\text{ ft/s}=\upsilon_2$$

$$h_L=h_{L_3}+h_{L_4}=f_3\frac{L_3}{D_3}\frac{\upsilon_3^2}{2g}+f_4\frac{L_4}{D_4}\frac{\upsilon_4^2}{2g}$$

$$N_{R_3}=\frac{\upsilon_3D_3}{\nu}=\frac{(13.02)(0.2557)}{2.15\times10^{-3}}=1548\text{ (Laminar)}: f_3=\frac{64}{N_R}=0.0413$$

$$N_{R_4}=\frac{\upsilon_4D_4}{\nu}=\frac{(7.56)(0.3355)}{2.15\times10^{-3}}=1180\text{ (Laminar)}: f_4=\frac{64}{N_R}=0.0543$$

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

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

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

8.50 $\frac{p_1}{\gamma_o} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{\upsilon_2^2}{2g}$: $\upsilon_1 = \upsilon_2$

$p_1 - p_2 = \gamma_o[(z_2 - z_1) + h_L]$

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(3.65)(0.0189)(930)}{3.31\times10^{-2}} = 1938$ (Laminar): $f = \frac{64}{N_R} = 0.0330$

$h_L = f\,\frac{L}{D}\frac{\upsilon^2}{2g} = (0.0330)\frac{17.5}{0.0189}\cdot\frac{(3.65)^2}{2(9.81)} = 20.76$ m

$p_1 - p_2 = 9.12$ kN/m^3[−1.88 m + 20.76 m] = **172 kPa**

8.51 $p_1 - p_2 = \gamma_g[(z_2 - z_1) + h_L]$ (From 9.24)

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.701)(0.0738)(1258)}{0.960}$

$N_R = 67.8$ (Laminar): $f = \frac{64}{N_R} = 0.944$

$h_L = f\,\frac{L}{D}\frac{\upsilon^2}{2g} = (0.944)\cdot\frac{25.8}{0.0738}\cdot\frac{(0.701)^2}{2(9.81)} = 8.27$ m

$p_1 - p_2 = 12.34$ kN/m^3[0.68 m + 8.27 m] = **110 kPa**

$Q = \frac{180\text{ L/min}\cdot 1\text{ m}^3\text{/s}}{60000\text{ L/min}} = 0.003\text{ m}^3\text{/s}$

$\upsilon = \frac{Q}{A} = \frac{0.003}{4.282\times10^{-3}} = 0.701\text{ m/s}$

NOTE: For problems 8.52 through 8.62 the objective is to compute the value of the friction factor, f, from the Swamee-Jain equation (8-7) from Section 8.8, shown below:

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\varepsilon)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2} \qquad (8\text{–}7)$$

For each problem, the calculation of the Reynolds number and the relative roughness are shown followed by the result of the calculation for f.

8.52 Water at 75°C; $\nu = 3.83\times10^{-7}$ m^2/s

$\upsilon = \frac{Q}{A} = \frac{12.9\text{ L/min}}{60000\text{ L/min}}\cdot\frac{1\text{ m}^3\text{/s}}{1.407\times10^{-4}\text{ m}^2} = 1.528$ m/s

$N_R = \frac{\upsilon D}{\mu} = \frac{(1.528)(0.0134)}{3.83\times10^{-7}} = 5.34\times10^4$

$D/\varepsilon = 0.0134/1.5\times10^{-6} = 8933$; $f =$ **0.0209**

8.53 Benzene at 60°C: $\rho = 0.88(1000) = 880$ kg/m^3; $\mu = 3.95\times10^{-4}$ Pa·s

$\upsilon = \frac{Q}{A} = \frac{20\text{ L/min}}{60000\text{ L/min}}\cdot\frac{1\text{ m}^3\text{/s}}{4.636\times10^{-4}\text{ m}^2} = 0.719$ m/s

$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(0.719)(0.0243)(880)}{3.95\times10^{-4}} = 3.89\times10^4$

$D/\varepsilon = 0.0243/4.6\times10^{-5} = 528$; $f =$ **0.0273**

8.54 Water at 80°F: $\nu = 9.15 \times 10^{-6}$ ft²/s

$D = 0.512$ ft; $A = 0.2056$ ft²

$$\upsilon = \frac{Q}{A} = \frac{2.50\ \text{ft}^3/\text{s}}{0.2056\ \text{ft}^2} = 12.16\ \text{ft/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(12.16)(0.512)}{9.15\times10^{-6}} = 6.80 \times 10^5;\ D/\varepsilon = \frac{0.512}{4\times10^{-4}} = 1280$$

$f =$ **0.0191**

8.55 Water at 50°F: $\nu = 1.40 \times 10^{-5}$ ft²/s

$$D = 18\ \text{in}(1\ \text{ft}/12\ \text{in}) = 1.50\ \text{ft};\ A = \frac{\pi D^2}{4} = 1.767\ \text{ft}^2$$

$$\upsilon = \frac{Q}{A} = \frac{15.0\ \text{ft}^3/\text{s}}{1.767\ \text{ft}^2} = 8.49\ \text{ft/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(8.49)(1.50)}{1.40\times10^{-5}} = 9.09 \times 10^5;\ D/\varepsilon = \frac{1.50}{4\times10^{-4}} = 3750$$

$f =$ **0.0155**

8.56 Water at 60°F: $\nu = 1.21 \times 10^{-5}$ ft²/s

$$\upsilon = \frac{Q}{A} = \frac{1500\ \text{gal/min}}{0.5479\ \text{ft}^2} \times \frac{1\ \text{ft}^3/\text{s}}{449\ \text{gal/min}} = 6.097\ \text{ft/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(6.097)(0.835)}{1.21\times10^{-5}} = 4.21 \times 10^5;\ D/\varepsilon = \frac{0.835}{1.5\times10^{-4}} = 5567$$

$f =$ **0.0156**

8.57 $A = \pi D^2/4 = \pi(0.025)^2/4 = 4.909 \times 10^{-4}$ m²

$$\upsilon = \frac{Q}{A} = \frac{95\ \text{L/min}}{4.909\ \text{ft}^2 \times 10^{-4}\ \text{m}^2} \times \frac{1\ \text{m}^3/\text{s}}{60000\ \text{L/min}} = 3.23\ \text{m/s}$$

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(3.23)(0.025)(1.10)(1000)}{2.0\times10^{-3}} = 4.44 \times 10^4;\ D/\varepsilon = \text{Smooth [Large } D/\varepsilon]$$

$f =$ **0.0213**

8.58 Crude oil (sg = 0.93) at 100°C

$\rho = (0.93)(1000\ \text{kg/m}^3) = 930\ \text{kg/m}^3$; $\mu = 7.8 \times 10^{-3}$ Pa·s

$$\upsilon = \frac{Q}{A} = \frac{1200\ \text{L/min}}{1.682\times10^{-2}\ \text{m}^2} \times \frac{1\ \text{m}^3/\text{s}}{60000\ \text{L/min}} = 1.19\ \text{m/s}$$

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(1.19)(0.1463)(9.30)}{7.8\times10^{-3}} = 2.07 \times 10^4$$

$$D/\varepsilon = \frac{0.1463}{4.6 \times 10^{-5}} = 3180;\ f = \mathbf{0.0264}$$

8.59 Water at 65°C; $\nu = 4.39 \times 10^{-7}$ m²/s

$D = 0.0409$ m

$$N_R = \frac{\upsilon D}{\nu} = \frac{(10)(0.0409)}{4.39 \times 10^{-7}} = 9.32 \times 10^5$$

$$D/\varepsilon = \frac{0.0409}{4.6 \times 10^{-5}} = 889; \boldsymbol{f = 0.0206}$$

8.60 Propyl alcohol at 25°C; $\rho = 802$ kg/m³

$\mu = 1.92 \times 10^{-3}$ Pa·s

$$\upsilon = \frac{Q}{A} = \frac{0.026\ \text{m}^3/\text{s}}{4.282 \times 10^{-3}\ \text{m}^2} = 6.07\ \text{m/s}$$

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(6.07)(0.0738)(802)}{1.92 \times 10^{-3}} = 1.87 \times 10^5$$

$$D/\varepsilon = \frac{(0.0738)}{1.5 \times 10^{-6}} = 49200; \boldsymbol{f = 0.0159}$$

8.61 Water at 70°F; $\nu = 1.05 \times 10^{-5}$ ft²/s

$$\upsilon = \frac{Q}{A} = \frac{3.0\ \text{ft}^3/\text{s}}{0.7854\ \text{ft}^2} = 3.82\ \text{ft/s}$$

$$N_R = \frac{\upsilon D}{\nu} = \frac{(3.82)(1.00)}{1.05 \times 10^{-5}} = 3.64 \times 10^5$$

$$D/\varepsilon = \frac{1.00}{4.0 \times 10^{-4}} = 2500; \boldsymbol{f = 0.0175}$$

8.62 Heavy fuel oil at 77°F; $\rho = 1.76$ slugs/ft³

$\mu = 2.24 \times 10^{-3}$ lb·s/ft²

$\upsilon = 12$ ft/s; $D = 0.5054$ ft

$$N_R = \frac{\upsilon D \rho}{\mu} = \frac{(12.0)(0.5054)(1.76)}{2.24 \times 10^{-3}} = 4.77 \times 10^3$$

$$D/\varepsilon = \frac{0.5054}{1.5 \times 10^{-4}} = 3369; \boldsymbol{f = 0.0388}$$

Hazen-Williams Formula

8.63 $Q = 1.5$ ft³/s, $L = 550$ ft, $D = 0.5/2$ ft, $A = 0.2056$ ft²

$R = D/4 = 0.128$ ft, $C_h = 140$

$$h_L = L\left[\frac{Q}{1.32 A C_h R^{0.63}}\right]^{1.852}$$

$$h_L = 550\left[\frac{1.50}{(1.32)(0.2056)(140)(0.128)^{0.63}}\right]^{1.852} = \mathbf{15.22\ ft}$$

8.64 $Q = 1000 \text{ L/min} \times \dfrac{1 \text{ m}^3\text{/s}}{60000 \text{ L/min}} = 0.0167 \text{ m}^3\text{/s}; L = 45 \text{ m}$

4-in type K copper tube; $D = 97.97 \text{ mm} = 0.09797 \text{ m}, A = 7.538 \times 10^{-3} \text{ m}^2$

$R = D/4 = 0.0245 \text{ m}, C_h = 130$

$$h_L = L\left[\frac{Q}{0.85AC_hR^{0.63}}\right]^{1.852}$$

$$= 45\left[\frac{0.0167}{0.85(7.538\times10^{-3})(130)(0.0245)^{0.63}}\right]^{1.852}$$

$h_L = \mathbf{2.436 \text{ m}}$

8.65 $Q = 7.50 \text{ ft}^3\text{/s}; L = 5280 \text{ ft}, D = 18 \text{ in} = 1.50 \text{ ft}, A = 1.767 \text{ ft}^2$

$R = D/4 = 0.375 \text{ ft}; C_h = 100$

$$h_L = 5280\left[\frac{7.50}{(1.32)(1.767)(100)(0.375)^{0.63}}\right]^{1.852} = \mathbf{28.51 \text{ ft}}$$

8.66 $Q = 1500 \text{ gal/min} \times \dfrac{1 \text{ ft}^3\text{/s}}{449 \text{ gal/min}} = 3.341 \text{ ft}^3\text{/s}; L = 1500 \text{ ft}$

$D = 10.02 \text{ in} = 0.835 \text{ ft}; A = 0.5479 \text{ ft}^2$

$C_h = 100; R = D/4 = 0.2088$

$$h_L = 1500\left[\frac{3.341}{(1.32)(0.5479)(100)(0.2088)^{0.63}}\right]^{1.852}$$

$h_L = \mathbf{31.38 \text{ ft}}$

8.67 $Q = 900 \text{ L/min} \times \dfrac{1 \text{ m}^3\text{/s}}{60000 \text{ L/min}} = 0.015 \text{ m}^3\text{/s}; L = 80 \text{ m}$

$D = 97.97 \text{ mm} = 0.09797 \text{ m}; A = 7.538 \times 10^{-3} \text{ m}^2$

$R = D/4 = 0.0245 \text{ m}; C_h = 130$

$$h_L = 80\left[\frac{0.015}{(0.85)(7.538\times10^{-3})(130)(0.0245)^{0.63}}\right]^{1.852} = \mathbf{3.56 \text{ m}}$$

8.68 $Q = 0.20 \text{ ft}^3\text{/s}; D = 2.469 \text{ in} = 0.2058 \text{ ft}; A = 0.03326 \text{ ft}^2$

$C_h = 100; R = D/4 = 0.0515 \text{ ft}$

$\upsilon = Q/A = 6.01 \text{ ft/s (OK)}$

$$h_L = 80\left[\frac{0.20}{(1.32)(0.03326)(100)(0.0515)^{0.63}}\right]^{1.852} = \mathbf{8.35 \text{ ft}}$$

8.69 $Q = 2.0\ \text{ft}^3/\text{s};\ L = 2500\ \text{ft}$

a) 8-in Schedule 40 steel pipe; $D = 0.6651$ ft; $A = 0.3472\ \text{ft}^2$
$R = D/4 = 0.1663$ ft; $C_h = 100$

$$h_L = 2500\left[\frac{2.0}{(1.32)(0.3472)(100)(0.1663)^{0.63}}\right]^{1.852} = \mathbf{61.4\ ft}$$

b) Cement lined 8-in ductile iron pipe
$D = 8.23$ in $= 0.686$ ft; $A = 0.3694\ \text{ft}^2$; $C_h = 140$
$R = D/4 = 0.1715$ ft

$$h_L = 2500\left[\frac{2.0}{(1.32)(0.3694)(140)(0.1715)^{0.63}}\right]^{1.852} = \mathbf{28.3\ ft}$$

8.70 Specify a new Schedule 40 steel pipe size. Use $C_h = 130$

$$Q = 300\ \text{gal/min} \times \frac{1\ \text{ft}^3/\text{s}}{449\ \text{gal/min}} = 0.668\ \text{ft}^3/\text{s}$$

$s = 10\ \text{ft}/1200\ \text{ft} = 0.00833$ ft/ft

$$D = \left[\frac{2.31(0.668)}{(130)(0.00833)^{0.54}}\right]^{0.380} = 0.495\ \text{ft}$$

6-in Schedule 40 steel pipe; $D = 0.5054$ ft

Actual h_L for 6-in pipe

$D = 0.5054$ ft; $R = D/4 = 0.1264$ ft
$A = 0.2006\ \text{ft}^2$

$$h_L = L\left[\frac{Q}{1.32AC_hR^{0.63}}\right]^{1.852}$$

$$h_L = 1200\left[\frac{0.668}{(1.32)(0.2006)(130)(0.1264)^{0.63}}\right]^{1.852} = \mathbf{9.05\ ft}$$

8.71 **From 8.70**
$Q = 0.668\ \text{ft}^3/\text{s}$
$D = 0.5054$ ft $= 6.065$ in; $A = 0.2006\ \text{ft}^2$
$R = D/4 = 0.1264$ ft; $C_h = 100$

$$h_L = 1200\left[\frac{0.668}{1.32(0.2006)(100)(0.1264)^{0.63}}\right]^{1.852}$$

$h_L =$ **14.72 ft**

8.72 $Q = 100$ gal/min × 1 ft^3/s/449 gal/min = 0.2227 ft^3/s
$L = 1000$ ft; $C_h = 130$ (New steel)

a) 2-in pipe: $D = 2.067$ in = 0.1723 ft; $A = 0.02333$ ft^2
$R = D/4 = 0.0431$ ft

$$h_L = 1000\ \text{ft}\left[\frac{0.2227}{(1.32)(0.02333)(130)(0.0431)^{0.63}}\right]^{1.852}$$

h_L = **186 ft**

b) 3-in pipe; $D = 3.068$ in = 0.2557 ft; $A = 0.05132$ ft^2
$R = D/4 = 0.0639$ ft

$$h_L = 1000\left[\frac{0.2227}{(1.32)(0.05132)(130)(0.0639)^{0.63}}\right]^{1.852}$$

h_L = **27.27 ft**