HOMEWORK MODULE 3 SOLUTIONS

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10.20 **Sudden contraction:** $h_L = K\left(\upsilon_2^2/2g\right)$

$$\frac{D_1}{D_2} = \frac{122.3\text{ mm}}{49.3\text{ mm}} = 2.48$$

$$\upsilon_2 = \frac{Q}{A_2} = \frac{500\text{ L/min}}{1.905\times10^{-3}\text{ m}^2}\times\frac{1\text{ m}^3\text{/s}}{60000\text{ L/min}} = 4.37\text{ m/s};\ K = 0.38\ \text{(Table 10.3)}$$

$$h_L = (0.38)(4.37)^2/2(9.81) = \mathbf{0.371\ m}$$

10.37 Pt. 1 at inlet; Pt. 2 at outlet

$$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} - h_{L_{\text{pipe}}} - h_{L_{\text{bend}}} = \frac{p_2}{\gamma} + z_2 + \frac{\upsilon_2^2}{2g}:\ \upsilon_1 = \upsilon_2;\ \text{assume } z_1 = z_2$$

$$p_1 - p_2 = \gamma\left(h_{L_{\text{pipe}}} + h_{L_{\text{bend}}}\right)$$

Close return bend: $L_e/D = 50,\ f_T = 0.027$ (Table 10.5)

$$\upsilon = \frac{Q}{A} = \frac{12.5\text{ gal/min}}{0.00211\text{ ft}^2}\times\frac{1\text{ ft}^3\text{/s}}{449\text{ gal/min}} = 13.19\text{ ft/s}$$

$$N_R = \frac{\upsilon D\rho}{\mu} = \frac{(13.19)(0.0518)(2.13)}{3.38\times10^{-4}} = 4.31\times10^3$$

$D/\varepsilon = 0.0518/1.5\times10^{-4} = 345$: $f = 0.041$

$$h_{L_{\text{bend}}} = f_T\frac{L_e}{D}\frac{\upsilon^2}{2g} = (0.027)(50)\frac{(13.19)^2}{2(32.2)}\text{ ft} = 3.65\text{ ft}$$

$$h_{L_{\text{tube}}} = f_T\frac{L}{D}\frac{\upsilon^2}{2g} = (0.041)\left[\frac{8.00}{0.0518}\right]\frac{(13.19)^2}{2(32.2)} = 17.12\text{ ft}$$

$$p_1 - p_2 = (68.47)[17.12 + 3.65]/144 = \mathbf{9.87\ psi}$$

10.39 $\upsilon = \dfrac{Q}{A} = \dfrac{0.40\text{ ft}^3\text{/s}}{0.05132\text{ ft}^2} = 7.79$ ft/s: **Tee-flow through run:** $\dfrac{L_e}{D} = 20$

$f_T = 0.018$ (Table 10.5)

$$h_L = f_T\frac{L_e}{D}\frac{\upsilon^2}{2g} = (0.018)(20)\frac{(7.79)^2}{2(32.2)} = \mathbf{0.340\ ft}$$

10.43 **Proposal 1 - Pipe bend:** $\frac{r}{D}=\frac{750\text{ mm}}{49.8\text{ mm}}=15.1;\ \frac{L_e}{D}=40.5$ (Fig. 10.23)

$$\upsilon=\frac{Q}{A}=\frac{750\text{ L/min}}{1.945\times10^{-3}\text{ m}^2}\times\frac{1\text{ m}^3\text{/s}}{60000\text{ L/min}}=6.43\text{ m/s}$$

$$N_R=\frac{\upsilon D\rho}{\mu}=\frac{(6.43)(0.0498)(802)}{1.92\times10^{-3}}=1.34\times10^5:\ \frac{D}{\varepsilon}=\frac{0.0498}{1.5\times10^{-6}}=33200:$$

$f=0.017$; $f_T=0.010$ in zone of complete turbulence

$$h_L=f_T\frac{L_e}{D}\frac{\upsilon^2}{2g}=(0.010)(40.5)\frac{(6.43)^2}{2(9.81)}=\mathbf{0.85\text{ m}}$$

Proposal 2 - Bend + tube: $\frac{r}{D}=\frac{150\text{ mm}}{49.8\text{ mm}}=3.01:\ \frac{L_e}{D}=11.8$

$$\left.\begin{aligned}h_{L_{bend}}&=f_T\frac{L_e}{D}\frac{\upsilon^2}{2g}=(0.010)(11.8)\frac{(6.43)^2}{2(9.81)}=0.248\text{ m}\\ h_{L_{tube}}&=f\frac{L}{D}\frac{\upsilon^2}{2g}=(0.017)\frac{1.20}{0.0498}\frac{(6.43)^2}{2(9.81)}=0.862\text{ m}\end{aligned}\right\}h_{L_{tot}}=1.11\text{ m}$$

10.46

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

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

$$A_1=\frac{\pi D_1^2}{4}=\frac{\pi(0.050\text{ m})^2}{4}=0.001963\text{ m}^2$$

$$A_2=\frac{\pi D_2^2}{4}=\frac{\pi(0.10\text{ m})^2}{4}=0.007854\text{ m}^2$$

$z_1-z_2=-1.20$ m

$$\upsilon_1=\frac{Q}{A_1}=\frac{6.0\times10^{-3}\text{ m}^3\text{/s}}{0.001963\text{ m}^2}=3.056\text{ m/s}:\ \frac{\upsilon_1^2}{2g}=\frac{(3.056)^2}{2(9.81)}=0.476\text{ m}$$

$$\upsilon_2=\frac{Q}{A_2}=\frac{6.0\times10^{-3}}{0.007854}=0.764\text{ m/s}:\ \frac{\upsilon_2^2}{2g}=\frac{(0.764)^2}{2(9.81)}=0.0297\text{ m}$$

Manometer: $p_1+\gamma_w(0.25\text{ m})-\gamma_m(0.35\text{ m})-\gamma_w(1.10\text{ m})=p_2$

$p_1-p_2=\gamma_m(0.35\text{ m})+\gamma_w(1.10-0.25)\text{m}$

$$\frac{p_1-p_2}{\gamma_w}=\frac{\gamma_m(0.35\text{ m})}{\gamma_w}+\frac{\gamma_w(0.85\text{ m})}{\gamma_w}=\frac{132.8(0.35\text{ m})}{9.69}+0.85\text{ m}$$

$$\frac{p_1-p_2}{\gamma_w}=4.80\text{ m}+0.85\text{ m}=5.65\text{ m}$$

Then $h_L=5.65-1.20+0.476-0.0297=4.90$ m

Let $h_L=K\frac{\upsilon_1^2}{2g}$

Then $K=\frac{h_L}{\upsilon_1^2/2g}=\frac{4.90\text{ m}}{0.476\text{ m}}=\mathbf{10.3}$

10.48 90º Bend. Steel tube; 1 1/4 in OD × 0.083 in wall thickness.
r = 3.25 in. D = 1.084 in = 0.09033 ft.
$D/\varepsilon = 0.09033/1.5 \times 10^{-4} = 602$. Then $f_T = 0.023$ in fully turbulent zone. $A = 6.409 \times 10^{-3}$ ft^2.
Q = 27.5 gal/min = 0.0612 ft^3/s. $v = Q/A$ = (0.0612 ft^3/s)/(0.006409 ft^2) = 9.556 ft/s
$(v^2/2g)$ = (9.556 ft/s)^2/[2(32.2 ft/s^2)] = 1.418 ft. r/D = 3.25 in/1.084 in = 3.00.
L_e/D = 12.5 (Fig.10.27), $K = f_T(L_e/D) = 0.023(12.5) = 0.288$.
$h_L = K(v^2/2g)$ = 0.288(1.418 ft) = **0.408 ft = h_L**

11.5 **Class I;** $\frac{p_A}{\gamma} + z_A + \frac{\upsilon_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{\upsilon_B^2}{2g}$,

Then $p_A = p_B + \gamma_o\left[(z_A - z_B) + \frac{\upsilon_B^2 - \upsilon_A^2}{2g} + h_L\right]$

$\upsilon_A = \frac{Q}{A_A} = \frac{0.015\ \text{m}^3/\text{s}}{1.682\times10^{-2}\ \text{m}^2} = 0.892$ m/s; $\frac{\upsilon_A^2}{2g} = \frac{0.892^2}{2(9.81)}$ m = 0.0405 m

$\upsilon_B = \frac{Q}{A_B} = \frac{0.015}{1.905\times10^{-3}} = 7.87$ m/s; $\frac{\upsilon_B^2}{2g} = \frac{(7.87)^2}{2(9.81)}$ m = 3.16 m

$N_{R_A} = \frac{\upsilon_A D_A}{\nu} = \frac{(0.892)(0.1463)}{2.12\times10^{-5}} = 6.15\times10^3$; $D/\varepsilon = \frac{0.1463}{4.6\times10^{-5}} = 3180$; $f_A = 0.035$

$N_{R_B} = \frac{\upsilon_B D_B}{\nu} = \frac{(7.87)(0.0493)}{2.12\times10^{-5}} = 1.83\times10^4$; $D/\varepsilon = \frac{0.0493}{4.6\times10^{-5}} = 1072$; $f_B = 0.028$

$f_{TB} = 0.019$

$h_L = f_A\frac{180}{0.1463}(0.0405) + 0.37(3.16) + 2(20)(f_{TB})(3.16) + f_B\frac{8}{0.0493}(3.16)$

Friction 6-in   Contr.   Elbows   Friction 2-in

Where $D_1/D_2 = 0.1463/0.0493 = 2.97$; $K = 0.37$, Table 10.3

$h_L = 19.68$ m

$p_A = 12.5\ \text{MPa} + \frac{8.80\ \text{kN}}{\text{m}^2}[4.5 + 3.16 - 0.0405 + 19.68]\text{m} = 12.5\ \text{MPa} + 240\ \text{kPa}$

$\boldsymbol{p_A = 12.74}$ **MPa**

11.5 **Class I;** $\dfrac{p_A}{\gamma} + z_A + \dfrac{v_A^2}{2g} - h_L = \dfrac{p_B}{\gamma} + z_B + \dfrac{v_B^2}{2g}$,

Then $p_A = p_B + \gamma_o\left[(z_A - z_B) + \dfrac{v_B^2 - v_A^2}{2g} + h_L\right]$

$v_A = \dfrac{Q}{A_A} = \dfrac{0.015\text{ m}^3/\text{s}}{1.682\times10^{-2}\text{ m}^2} = 0.892$ m/s; $\dfrac{v_A^2}{2g} = \dfrac{0.892^2}{2(9.81)}$ m = 0.0405 m

$v_B = \dfrac{Q}{A_B} = \dfrac{0.015}{1.905\times10^{-3}} = 7.87$ m/s; $\dfrac{v_B^2}{2g} = \dfrac{(7.87)^2}{2(9.81)}$ m = 3.16 m

$N_{R_A} = \dfrac{v_A D_A}{\nu} = \dfrac{(0.892)(0.1463)}{2.12\times10^{-5}} = 6.15\times10^3$; $D/\varepsilon = \dfrac{0.1463}{4.6\times10^{-5}} = 3180$; $f_A = 0.035$

$N_{R_B} = \dfrac{v_B D_B}{\nu} = \dfrac{(7.87)(0.0493)}{2.12\times10^{-5}} = 1.83\times10^4$; $D/\varepsilon = \dfrac{0.0493}{4.6\times10^{-5}} = 1072$; $f_B = 0.028$

$f_{TB} = 0.019$

$h_L = f_A\dfrac{180}{0.1463}(0.0405) + 0.37(3.16) + 2(20)(f_{TB})(3.16) + f_B\dfrac{8}{0.0493}(3.16)$

Friction 6-in   Contr.   Elbows   Friction 2-in

Where $D_1/D_2 = 0.1463/0.0493 = 2.97$; $K = 0.37$, Table 10.3

$h_L = 19.68$ m

$p_A = 12.5\text{ MPa} + \dfrac{8.80\text{ kN}}{\text{m}^2}[4.5 + 3.16 - 0.0405 + 19.68]\text{m} = 12.5\text{ MPa} + 240\text{ kPa}$

$\boldsymbol{p_A = 12.74}$ **MPa**

11.6 **Class I**

Pts. 1 and 2 at reservoir surfaces: $p_1 = p_2 = 0$; $v_1 = v_2 = 0$

$\dfrac{p_1}{\gamma} + z_1 + \dfrac{v_1^2}{2g} - h_L = \dfrac{p_2}{\gamma} + z_2 + \dfrac{v_2^2}{2g}$: $z_1 - z_2 = h_L$ = sum of 8 losses

Water at 10 C; $\nu = 1.30\times10^{-6}$ m^2/s

3-in pipe: $v_3 = \dfrac{Q}{A_3} = 5.37$ m/s: $\dfrac{v_3^2}{2g} = 1.47$ m: $N_{R_3} = \dfrac{v_3 D_3}{\nu} = 3.48\times10^5$

$D_3/\varepsilon = 0.0843/1.2\times10^{-4} = 703$; $f_3 = 0.022$; $F_{T3} = 0.0215$

6-in pipe: $v_6 = \dfrac{Q}{A_6} = 1.57$ m/s: $\dfrac{v_6^2}{2g} = 0.126$ m; $N_{R_6} = \dfrac{v_6 D_6}{\nu} = 1.88\times10^5$

$D_6/\varepsilon = 0.1560/1.2\times10^{-4} = 1300$; $f_6 = 0.0205$; $f_{T6} = 0.0185$

$h_L = 1.0\dfrac{v_3^2}{2g} + f_3\dfrac{100}{0.0843}\dfrac{v_3^2}{2g} + 2(30)f_{T3}\dfrac{v_3^2}{2g} + 160f_{T3}\dfrac{v_3^2}{2g} + 0.43\dfrac{v_3^2}{2g} + f_6\dfrac{300}{0.1560}\dfrac{v_6^2}{2g}$

Entr.   Friction 3-in   Elbows 3-in   Gate valve   Enl.   Friction 6-in

$+ 2(30)f_{T6}\dfrac{v_6^2}{2g} + 1.0\dfrac{v_6^2}{2g}$

Elbows 6-in   Exit

$z_1 - z_2 = \sum h_L = 1.47 + 38.4 + 1.90 + 5.06 + 0.63 + 4.97 + 0.140 + 0.126$

$z_1 - z_2 =$ **52.7 m**

APPLIED FLUID MECHANICS	*II-A & II-B US:* **CLASS II SERIES SYSTEMS**
Objective: Volume flow rate	**Method II-A: No minor losses**
Problem 11.13 (a)	Uses Equation 11-3 to find maximum allowable volume flow rate
Figure 11.18	to maintain desired pressure at point 2 for a given pressure at point 1

System Data:	**US Customary Units**				
Pressure at point 1 =	*20*	psig	*Elevation at point 1 =*	*0*	ft
Pressure at point 2 =	*0*	psig	*Elevation at point 2 =*	*18*	ft
Energy loss: h_L =	*28.45*	Ft			
Fluid Properties:	Turpentine at 77F		May need to compute: $\nu = \eta/\rho$		
Specific weight =	*62.00*	*lb/ft^3*	*Kinematic viscosity =*	*7.37E-06*	*ft^2/s*
Pipe data: Smooth aluminum tube					
Diameter: D =	*0.417*	*ft*			
Wall roughness: ε =	*1.00E-08*	*ft*			
Length: L =	*20*	*ft*	*Results: Maximum values*		
Area: A =	*0.00137*	ft^2	Volume flow rate: Q =	0.0194	ft^3/s Using Eq. 11-3
D/ε =	*4170000*		Velocity: v =	14.23	ft/s

CLASS II SERIES SYSTEMS			*Volume flow rate: Q =*	*0.01107*	*ft^3/s*
Method II-B: Use results of Method IIA;			Given: Pressure p_1 =	20	psig
Include minor losses;			**Pressure p_2 =**	**0.00**	**psig**
then pressure at Point 2 is computed			*NOTE: Should be >*	**0**	**psig**
Additional Pipe Data:			*Adjust estimate for Q until p_2*		
L/D =	480		*is equal or greater than desired.*		
Flow Velocity =	8.11	ft/s	Velocity at point 1 =	8.11	ft/s |--> If velocity is in pipe:
Velocity head =	1.020	ft	Velocity at point 2 =	32.42	ft/s |--> Enter "=B24"
Reynolds No. =	4.59E+04		Vel. head at point 1 =	1.02	ft
Friction factor: f =	0.0212		Vel. head at point 2 =	16.32	ft
Energy losses in Pipe:	K	Qty.			
Pipe: $K_1 = f(L/D)$ =	10.15	1	Energy loss h_{L1} =	10.36	ft Friction
Bend: K_2 =	*0.34*	*1*	Energy loss h_{L2} =	0.35	ft *f_T = 0.01 Assumed*
**Nozzle: K_3 =*	*2.40*	*1*	Energy loss h_{L3} =	2.45	ft
Element 4: K_4 =	*0.00*	*1*	Energy loss h_{L4} =	0.00	ft
Element 5: K_5 =	*0.00*	*1*	Energy loss h_{L5} =	0.00	ft
Element 6: K_6 =	*0.00*	*1*	Energy loss h_{L6} =	0.00	ft
Element 7: K_7 =	*0.00*	*1*	Energy loss h_{L7} =	0.00	ft
Element 8: K_8 =	*0.00*	*1*	Energy loss h_{L8} =	0.00	ft
			Total energy loss h_{Ltot} =	13.15	ft

**Nozzle K_3 restated in terms of velocity head in pipe rather than outlet velocity head.*
$*K_3 = 0.15(v_2/v_1)^2 = 0.15(4)^2 = 2.40$

Nozzle Velocity: $v_N = v_p(A_p/A_N) = v_p(D_p/D_N)^2 = 4.0v_p = 4.0(8.11\ ft/s) = 32.44\ ft/s$

APPLIED FLUID MECHANICS	*II-A & II-B US:* **CLASS II SERIES SYSTEMS**
Objective: Volume flow rate	**Method II-A: No minor losses**
Problem 11.13 (b)	Uses Equation 11-3 to find maximum allowable volume flow rate
Figure 11.18	to maintain desired pressure at point 2 for a given pressure at point 1

System Data:	**US Customary Units**				
Pressure at point 1 =	*80*	psig	*Elevation at point 1 =*	*0*	ft
Pressure at point 2 =	*0*	psig	*Elevation at point 2 =*	*18*	ft
Energy loss: h_L =	*167.81*	ft			
Fluid Properties:	Turpentine at 77F		May need to compute: $\nu = \eta/\rho$		
Specific weight =	*62.00*	*lb/ft³*	*Kinematic viscosity =*	*7.37E-06*	*ft²/s*
Pipe data: Smooth aluminum tube					
Diameter: D =	*0.417*	*ft*			
Wall roughness: ε =	*1.00E-08*	*ft*			
Length: L =	*20*	*ft*	*Results: Maximum values*		
Area: *A* =	*0.00137*	ft²	Volume flow rate: Q =	0.0522	ft³/s Using Eq. 11-3
D/ε =	*4170000*		Velocity: v =	38.20	ft/s

CLASS II SERIES SYSTEMS			*Volume flow rate: Q =*	*0.02781*	*ft³/s*
Method II-B: Use results of Method IIA;			Given: Pressure p_1 =	80	psig
Include minor losses;			**Pressure p_2 =**	**0.01**	**psig**
then pressure at Point 2 is computed			*NOTE: Should be >*	**0**	**psig**
Additional Pipe Data:			*Adjust estimate for Q until p_2*		
L/D =	480		*is equal or greater than desired.*		
Flow Velocity =	20.36	ft/s	Velocity at point 1 =	20.36	ft/s |--> If velocity is in pipe:
Velocity head =	6.439	ft	Velocity at point 2 =	81.45	ft/s |--> Enter "=B24"
Reynolds No. =	1.15E+05		Vel. head at point 1 =	6.44	ft
Friction factor: *f* =	0.0173		Vel. head at point 2 =	103.02	ft
Energy losses in Pipe:	*K*	Qty.			
Pipe: $K_1 = f(L/D)$ =	8.32	1	Energy loss h_{L1} =	53.57	ft Friction
Bend: K_2 =	*0.34*	*1*	Energy loss h_{L2} =	2.19	ft *f_T = 0.01 Assumed*
**Nozzle: K_3 =*	*2.40*	*1*	Energy loss h_{L3} =	15.45	ft
Element 4: K_4 =	*0.00*	*1*	Energy loss h_{L4} =	0.00	ft
Element 5: K_5 =	*0.00*	*1*	Energy loss h_{L5} =	0.00	ft
Element 6: K_6 =	*0.00*	*1*	Energy loss h_{L6} =	0.00	ft
Element 7: K_7 =	*0.00*	*1*	Energy loss h_{L7} =	0.00	ft
Element 8: K_8 =	*0.00*	*1*	Energy loss h_{L8} =	0.00	ft
			Total energy loss h_{Ltot} =	71.21	ft

**Nozzle K_3 restated in terms of velocity head in pipe rather than outlet velocity head.*
$^*K_3 = 0.15(v_2/v_1)^2 = 0.15(4)^2 = 2.40$

Nozzle Velocity: $v_N = v_p(A_p/A_N) = v_p(D_p/D_N)^2 = 4.0v_p = 4.0(20.36\ ft/s) = 32.44\ ft/s$

11.14 **Class II** Pt. 1 at surface of tank A; Pt. 2 in stream outside pipe. $\upsilon_1 = 0$, $p_2 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{\upsilon_2^2}{2g} : \frac{p_1}{\gamma} + (z_1 - z_2) = \frac{\upsilon_2^2}{2g} + h_L$$

$$\frac{150 \text{ kN/m}^2}{8.07 \text{ kN/m}^3} - 5 \text{ m} = \boxed{13.59 \text{ m} = \frac{\upsilon_2^2}{2g} + h_L} \quad \text{I} \qquad \textbf{Method IIC}$$

$$h_L = \underbrace{0.50\frac{\upsilon_2^2}{2g}}_{\text{Entrance}} + \underbrace{160 f_T \frac{\upsilon_2^2}{2g}}_{\text{Valve}} + \underbrace{2(18) f_T \frac{\upsilon_2^2}{2g}}_{\text{Bends}} + \underbrace{f \frac{30 \text{ mm}}{0.0498 \text{ m}} \frac{\upsilon_2^2}{2g}}_{\text{Friction}} = (2.46 + 602f)\frac{\upsilon_2^2}{2g}$$

$$r/D = \frac{300 \text{ mm}}{49.8 \text{ mm}} = 6.02 \rightarrow \frac{L_e}{D} = 18 \text{ (Fig. 10.23)}$$

$$D/\varepsilon = \frac{0.0498 \text{ m}}{1.5 \times 10^{-6} \text{ m}} = 33200$$

$f_T = 0.010$ (Approx.)

In Eq. I:

$$13.59 \text{ m} = \frac{\upsilon_2^2}{2g} + (2.46 + 602f)\frac{\upsilon_2^2}{2g} = (3.46 + 602f)\frac{\upsilon_2^2}{2g}$$

$$\upsilon = \sqrt{\frac{2g(13.59 \text{ m})}{3.46 + 602f}} = \sqrt{\frac{2(9.81)(13.59)}{3.46 + 602f}} = \sqrt{\frac{266.6}{3.46 + 602f}}$$

Try $f = 0.02$

$$\upsilon = \sqrt{\frac{266.6}{3.46 + 602(0.02)}} = 4.15 \text{ m/s}; \; N_R = \frac{\upsilon D \rho}{\eta} = \frac{(4.15)(0.0498)(823)}{1.64 \times 10^{-3}} = 1.04 \times 10^5$$

New $f = 0.018$; $\upsilon = 4.32$ m/s; $N_R = 1.08 \times 10^5$; New $f = 0.018$ **No change**

$Q = A\upsilon = (1.945 \times 10^{-3} \text{ m}^2)(4.32 \text{ m/s}) = 8.40 \times 10^{-3} \text{ m}^3\text{/s}$

11.15 **Class II with 2 pipes:** Pts. **A** and **B** at tank surfaces. **Method IIC**

$$\frac{p_A}{\gamma} + z_A + \frac{\upsilon_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{\upsilon_B^2}{2g} : \; z_A - z_B = h_L = 10 \text{ m}: \quad p_A = p_B = 0; \; \upsilon_A = \upsilon_B = 0$$

$$h_L = \underbrace{1.0\frac{\upsilon_3^2}{2g}}_{\text{Entrance}} + \underbrace{2(30)\, f_{3T}\frac{\upsilon_3^2}{2g}}_{\text{Elbows}} + \underbrace{f_3 \frac{55}{0.08432}\frac{\upsilon_3^2}{2g}}_{\text{Friction}} + \underbrace{0.45\frac{\upsilon_3^2}{2g}}_{\text{Enlarge.}} \Bigg\} \text{ Based on 3-in pipe; } f_{3T} = 0.022$$

$$\frac{D_2}{D_1} = \frac{0.156}{0.0843} = 1.85$$

$$+ \underbrace{f_6 \frac{30}{0.156}\frac{\upsilon_6^2}{2g}}_{\text{Friction}} + \underbrace{30 f_{6T}\frac{\upsilon_6^2}{2g}}_{\text{Elbow}} + \underbrace{45 f_{6T}\frac{\upsilon_6^2}{2g}}_{\text{Valve}} + \underbrace{1.0\frac{\upsilon_6^2}{2g}}_{\text{Exit}} \Bigg\} \text{ Based on 6-in pipe; } f_{6T} = 0.019$$

$$h_L = (2.77 + 652 f_3)\frac{\upsilon_3^2}{2g} + (2.43 + 192 f_6)\frac{\upsilon_6^2}{2g}$$

$$\text{But } \upsilon_3 = \upsilon_6 \frac{A_6}{A_3} = \upsilon_6 \left(\frac{D_6}{D_3}\right)^2 = \upsilon_6 \left(\frac{0.156}{0.0843}\right)^2 = 3.42\upsilon_6; \; \upsilon_3^2 = 11.73\upsilon_6^2$$

$$h_L = (2.77 + 652f_3)\frac{11.73\upsilon_6^2}{2g} + (2.43 + 192f_6)\frac{\upsilon_6^2}{2g} = (34.9 + 7646f_3 + 192f_6)\frac{\upsilon_6^2}{2g}$$

Solve for υ_6

$$\upsilon_6 = \sqrt{\frac{2gh_L}{(34.9 + 7646f_3 + 192f_6)}} = \sqrt{\frac{2(9.81)(10)}{34.9 + 7646f_3 + 192f_6}}$$

$$= \sqrt{\frac{196.2}{34.6 + 7646f_3 + 192f_6}}$$

Iterate for both f_3 and f_6:

$$\frac{D_3}{\varepsilon} = \frac{0.0843\text{ m}}{1.2\times10^{-4}\text{ m}} = 703:\; N_{R_3} = \frac{\upsilon_3 D_3}{\nu} = \frac{\upsilon_3(0.0843)}{6.56\times10^{-7}} = 1.29\times10^5(\upsilon_3)$$

$$\frac{D_6}{\varepsilon} = \frac{0.1560}{1.2\times10^{-4}} = 1300:\; N_{R_6} = \frac{\upsilon_6 D_6}{\nu} = \frac{\upsilon_6(0.156)}{6.56\times10^{-7}} = 2.38\times10^5(\upsilon_6)$$

Try $f_3 = f_6 = 0.02$

$$\upsilon_6 = \sqrt{\frac{196.2}{34.9 + 7646(0.02) + 192(0.02)}} = 1.012\text{ m/s}$$

$\upsilon_3 = 3.42\,\upsilon_6 = 3.46$ m/s

$N_{R_3} = 1.29\times10^5(3.46) = 4.46\times10^5 \rightarrow$ New $f_3 = 0.0195$

$N_{R_6} = 2.38\times10^5(1.012) = 2.41\times10^5 \rightarrow$ New $f_6 = 0.020$

$$\upsilon_6 = \sqrt{\frac{196.2}{34.9 + 7646(0.0195) + 192(0.02)}} = \mathbf{1.022\text{ m/s}}$$

$\upsilon_3 = 3.42\,\upsilon_6 =$ **3.50 m/s**

$N_{R_3} = 1.29\times10^5(3.50) = 4.20\times10^5 \rightarrow f_3 = 0.0195$ **No change**

$N_{R_6} = 2.38\times10^5(1.02) = 2.43\times10^5 \rightarrow f_6 = 0.020$ **No change**

$$Q = A_6\upsilon_6 = \frac{\pi(0.156\text{ m})^2}{4} \times 1.02\text{ m/s} = \mathbf{1.95\times10^{-2}\text{ m}^3\text{/s}}$$

Practice problems for any class

11.21 **Class I** Pt. 1 at tank surface, Pt. 2 in stream outside pipe: $p_1 = p_2 = 0$; $\upsilon_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{\upsilon_2^2}{2g}: \quad \boxed{z_1 - z_2 = \frac{\upsilon_2^2}{2g} + h_L} \quad \text{①}$$

$$\upsilon_2 = \frac{Q}{A_2} = \frac{1500\text{ L/min}}{6.38\times10^{-3}\text{m}^2}\,\frac{1\text{ m}^3\text{/s}}{60000\text{ L/min}} = 3.92\text{ m/s}: \frac{\upsilon_2^2}{2g} = \frac{(3.92)^2}{2(9.81)} = 0.782\text{ m}$$

$f_T = 0.018$

$$h_L = 0.5\frac{\upsilon_2^2}{2g} + f_T(160)\frac{\upsilon_2^2}{2g} + f_T(30)\frac{\upsilon_2^2}{2g} = \frac{\upsilon_2^2}{2g}[0.5 + 190 f_T] = 0.782[0.5 + 190(0.018)]$$

$$= 3.07\text{ m}$$

In Eq. ①

$$z_1 - z_2 = \frac{\upsilon_2^2}{2g} + h_L = 0.782 + 3.07 = 3.85\text{ m}$$

But $h = z_1 - z_2 - 0.5$ m $= 3.85$ m $- 0.5$ m $=$ **3.35 m**

11.22 **Class I** Pt. 1 at collector tank surface. Pt. 2 at pump inlet. $p_1 = 0$, $\upsilon_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{\upsilon_2^2}{2g}: \quad \boxed{p_2 = \gamma\left[(z_1 - z_2) - h_L - \frac{\upsilon_2^2}{2g}\right]} \quad \text{①}$$

$$Q = 30\text{ gal/min} \times \frac{1\text{ ft}^3\text{/s}}{449\text{ gal/min}}\ 1 = 0.0668\text{ ft}^3\text{/s} \qquad f_T = 0.019 \text{ for 2-in pipe}$$

$$\upsilon_2 = \frac{Q}{A_2} = \frac{0.0668\text{ ft}^3\text{/s}}{0.02333\text{ ft}^2} = 2.86\text{ ft/s}; \frac{\upsilon_2^2}{2g} = \frac{(2.86)^2}{2(32.2)} = 0.127\text{ ft}$$

$$h_L = 0.5\frac{\upsilon_2^2}{2g} + 1.85\frac{\upsilon_2^2}{2g} + f\frac{10.0\text{ ft}}{0.1723\text{ ft}}\frac{\upsilon_2^2}{2g} + f_T(8)\frac{\upsilon_2^2}{2g} = \frac{\upsilon_2^2}{2g}(2.50 + 58.0f)$$

Entrance Filter Friction Valve

$$N_R = \frac{\upsilon D\rho}{\eta} = \frac{(2.86)(0.1723)(0.92)(1.94)}{3.6\times10^{-5}} = 2.45\times10^4: \ \frac{D}{\varepsilon} = \frac{0.1723}{1.5\times10^{-4}} = 1149$$

$f = 0.0265$

$h_L = (0.127\text{ ft})[2.50 + 58.0(0.0265)] = 0.513$ ft

In Eq. ①:

$$p_2 = (0.92)\ \frac{62.4\text{ lb}}{\text{ft}^3}\ [3.0 - 0.513 - 0.127]\frac{\text{ft ft}^2}{144\text{ in}^2} = \mathbf{0.94\ psig}$$

11.23 **Class I** Pt. 1 at collector tank surface; Pt. 3 at upper tank surface. $p_1 = p_3 = 0,\ \upsilon_1 = \upsilon_3 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{\upsilon_1^2}{2g} - h_L + h_A = \frac{p_3}{\gamma} + z_3 + \frac{\upsilon_3^2}{2g}:\ h_A = (z_3 - z_1) + h_L = 19.0\text{ ft} + h_L$$

$$h_L = \underbrace{h_{L_{\text{suct.}}} + h_{L_{\text{disch.}}} = 0.513\text{ ft}}_{\text{From Prob. 11.22}} + \underbrace{f_{dT}(100)\frac{\upsilon_d^2}{2g}}_{\text{Ch. valve}} + \underbrace{f_d\frac{18\text{ ft}}{0.115\text{ ft}}\frac{\upsilon_2^2}{2g}}_{\text{Friction}} + \underbrace{1.0\frac{\upsilon_d^2}{2g}}_{\text{Exit}}$$

$$\upsilon_d = \frac{Q}{A_d} = \frac{0.0668\text{ ft}^3/\text{s}}{0.01039\text{ ft}^2} = 6.43\text{ ft/s}:\quad \frac{\upsilon_d^3}{2g} = \frac{(6.43)^2}{2(32.2)} = 0.642\text{ ft}$$

$$N_{R_d} = \frac{\upsilon_d D\rho}{\eta} = \frac{(6.43)(0.115)(0.92)(1.94)}{3.6\times10^{-5}} = 3.67\times10^4:$$

$$\frac{D}{\varepsilon} = \frac{0.115}{1.5\times10^{-4}} = 767 \rightarrow f = 0.0265;\ f_{dT} = 0.022$$

$h_L = 0.513$ ft + (0.022)(100)(0.642) + (0.0265)(157)(0.642) + 1.0(0.642) = 5.24 ft

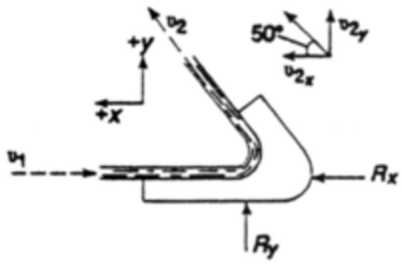
$h_A = 19.0$ ft + h_L = 19.0 + 5.24 = 24.24 ft

$$\text{Power} = P_A = h_A\gamma Q = (24.24\text{ ft})(0.92)\left(\frac{62.4\ lb}{\text{ft}^3}\right)\left(\frac{0.0668\text{ ft}^3}{\text{s}}\right)\frac{1\text{ hp}}{550\text{ ft-lb/s}}\ 2 = 0.169\text{ hp}$$

APPLIED FLUID MECHANICS		*III-A & III-B US:* **CLASS III SERIES SYSTEMS**	
Objective: Minimum pipe diameter		*Method III-A:* *Uses Equation 11-8 to compute the*	
Problem 11.24		*minimum size of pipe of a given length*	
Figure 11.24 – Return System from upper tank		*that will flow a given volume flow rate of fluid*	
System Data: **SI Metric Units**		*with a limited pressure drop. (No minor losses)*	
Pressure at point 1 =	*0* psig	*Fluid Properties: Coolant – Given properties*	
Pressure at point 2 =	*0* psig	*Specific weight =*	*57.41*lb/ft^3
Elevation at point 1 =	*9* ft	*Kinematic Viscosity =*	*2.02E-05*ft^2/s
Elevation at point 2 =	*0* ft	**Intermediate Results in Eq. 11-8:**	
Allowable Energy Loss: $h_{L\,=}$	12.00 ft	L/gh$_L$ =	0.134576
Volume flow rate: Q =	*0.-6682* ft^3/s	Argument in bracket:	1.37E-09
Length of pipe: L =	*39* ft	**Final Minimum Diameter:**	
Pipe wall roughness: ε =	*1.50E-04* ft	Minimum diameter: *D* =	0.1059ft

CLASS III SERIES SYSTEMS			*Specified pipe diameter: D =*	*0.115* ft-min std sz
Method III-B: Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.			5-in Sch 40 steel pipe	
			If velocity is in the pipe, enter "=B23" for value	
			Velocity at point 1 =	*0.00* ft/s
Additional Pipe Data:			Velocity at point 2 =	*6.43* ft/s
Flow area: A =	0.01039 ft^2		Vel. head at point 1 =	0.000 ft
Relative roughness: D/ε =	767		Vel. head at point 2 =	0.643 ft
L/D =	339		*Results:*	
Flow Velocity =	6.43 ft/s		*Given pressure at point 1 =*	0 psig
Velocity head =	0.643 ft		*Desired pressure at point 2 =*	0 psig
Reynolds No. =	3.67E+04		*Actual pressure at point 2 =*	*0.49 psig*
Friction factor: f =	0.0261		*(Compare actual with desired pressure at point 2)*	
Energy losses in Pipe:	K	Qty.		
Pipe Friction: $K_1 = f(L/D)$ =	8.84	1	Energy loss h_{L1} =	5.68 ft
Entrance-Square edge: K_2 =	*0.50*	*1*	Energy loss h_{L2} =	0.32 ft
Elbows: K_3 =	*0.66*	*2*	Energy loss h_{L3} =	0.85 ft f_T = 0.022
Tee-flow thru run: K_4 =	*0.44*	*1*	Energy loss h_{L4} =	0.28 ft f_T = 0.022
Element 5: K_5 =	*0.00*	*1*	Energy loss h_{L5} =	0.00 ft
Element 6: K_6 =	*0.00*	*1*	Energy loss h_{L6} =	0.00 ft
Element 7: K_7 =	*0.00*	*1*	Energy loss h_{L7} =	0.00 ft
Element 8: K_8 =	*0.00*	*1*	Energy loss h_{L8} =	0.00 ft
			Total energy loss h_{Ltot} =	7.13 ft

16.6 $Q = A\upsilon = (2.95\ \text{in}^2)(22.0\ \text{ft/s})(1\ \text{ft}^2/144\ \text{in}^2)$
$= 0.451\ \text{ft}^3/\text{s}$



$R_x = \rho Q\left(\upsilon_{2_x} - \upsilon_{1_x}\right) = \rho Q[\upsilon_2 \cos 50° - (-\upsilon_1)]$

$R_x = \rho Q[\upsilon_2 \cos 50° + \upsilon_1]$; but $\upsilon_2 = \upsilon_1$

$R_x = \rho Q\upsilon_1[\cos 50° + 1]$

$$R_x = \frac{1.88\ \text{lb}\cdot\text{s}^2}{\text{ft}^4} \times \frac{0.451\ \text{ft}^3}{\text{s}} \times \frac{22.0\ \text{ft}}{\text{s}} \times 1.643$$

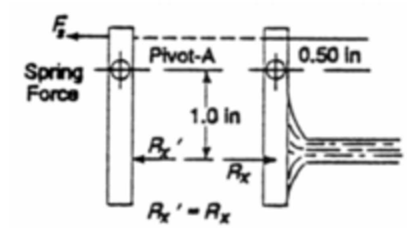
$= \mathbf{30.6\ lb}$

$R_y = \rho Q\left(\upsilon_{2_y} - \upsilon_{1_y}\right) = \rho Q[\upsilon_2 \sin 50° - 0] = (1.88)(0.451)(22 \sin 50°) = \mathbf{14.3\ lb}$

16.11 $Q = 100\ \text{gal/min} \times \dfrac{1\ \text{ft}^3/\text{s}}{449\ \text{gal/min}} = 0.223\ \text{ft}^3/\text{s}$: $\upsilon_1 = \dfrac{Q}{A} = \dfrac{0.223\ \text{ft}^3/\text{s}}{0.0060\ \text{ft}^2} = 37.1\ \text{ft/s}$

Assume all fluid strikes vane and is deflected perpendicular to incoming stream.

$R_x = \rho Q\left(\upsilon_{2_x} - \upsilon_{1_x}\right) = \rho Q[0 - (-\upsilon_1)] = \rho Q\upsilon_1$



$$R_x = \frac{1.94\ \text{lb}\cdot\text{s}^2}{\text{ft}^4} \times \frac{0.223\ \text{ft}^3}{\text{s}} \times \frac{37.1\ \text{ft}}{\text{s}} = 16.0\ \text{lb}$$

R_x is force exerted by vane on water

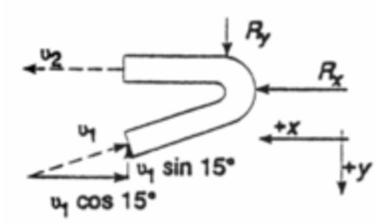
R_x' is force exerted by water on vane

$\Sigma M_A = 0 = F_S(0.5\ \text{in}) - R_x'(1.0\ \text{in})$

$F_S = R_x' \dfrac{1.0}{0.5} = 2R_x' = 2(16.0\ \text{lb}) = \mathbf{32.0\ lb}$

16.20 $Q = A\upsilon = (3.142 \times 10^{-2}\ \text{m}^2)(30\ \text{m/s}) = 0.943\ \text{m}^3/\text{s}$

a. **x-direction:**



$R_x = \rho Q\left(\upsilon_{2_x} - \upsilon_{1_x}\right) = \rho Q(\upsilon_2 - (-\upsilon_1 \cos 15°))$

$R_x = \rho Q\upsilon(1 + \cos 15°) = 1.966\rho Q\upsilon$

$$R_x = (1.966)\left(\frac{1000\ \text{kg}}{\text{m}^3}\right)\left(\frac{0.943\ \text{m}^3}{\text{s}}\right)\left(\frac{30\ \text{m}}{\text{s}}\right)$$

$R_x = 55.6 \times 10^3\ \text{kg·m/s}^2 = 55.6\ \text{kN}$ = Force of car on water. ←

Force on car = 55.6 kN →

y-direction:

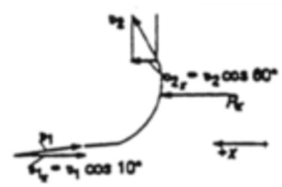
$R_y = \rho Q\left(\upsilon_{2_y} - \upsilon_{1_y}\right) = \rho Q(0 - (-\upsilon_1 \sin 15°)) = \rho Q\upsilon \sin 15°$

$R_y = (1000)(0.943)(30)(0.259) = 7.32 \times 10^3\ \text{kg·m/s}^2 = 7.32\ \text{kN}$ = Force on water ↓

Force on car = 7.32 kN ↑

b. Because the inlet jet acts at an angle to the *x*-*y* directions, we compute its components:
$\upsilon_{1x} = \upsilon_1 \cos(15°) = (30 \text{ m/s})(0.966) = 28.98$ m/s: $\upsilon_{1y} = \upsilon_1 \sin(15°) = 30 \text{ m/s})(0.259)$
$= 7.76$ m/s
Only υ_{1x} is affected by the moving vane. Then $\upsilon_{elx} = \upsilon_{1x} - 12 \text{ m/s} = 16.98$ m/s.
$\upsilon_{e1y} = \upsilon_{1y} = 7.76$ m/s. The magnitude of the resultant effective velocity is:
$\left|\upsilon_{e1y}\right| = \sqrt{(16.98)^2 + (7.76)^2} = 18.67$ m/s
The total effective mass flow rate into the vane, M_e, is,
$M_e = \rho Q_e = \rho A \upsilon_{e1} = (1000 \text{ kg/m}^3)(3.142 \times 10^{-2} \text{ m}^2)(18.67 \text{ m/s}) = 586.6$ kg/s
The velocity, υ_{e1}, acts at an angle α, with respect to the horizontal, where
$\alpha = \text{Tan}^{-1}(7.76)/16.98) = 24.58°$
Only the component of υ_{e1} acting parallel to the vane is maintained as the jet travels around the vane.
This component is computed using β, the difference between α and the angle of the vane inlet.
$\beta = 24.58° - 15° = 9.58°$
Then, $\upsilon_{e1(\text{par})} = (\upsilon_{e1})\cos(9.58°) = (18.67 \text{ m/s})(0.986) = 18.41$ m/s
This velocity remains undiminished as the jet travels around the vane.
Then $\upsilon_{e2} = 18.41$ m/s to the left.
Force in *x*-direction: $R_x = M_e(\Delta\upsilon_{ex}) = M_e(\upsilon_{e2x} - \upsilon_{e1x}) = (586.6 \text{ kg/s})[18.41 - (-16.98)]$m/s
$= \mathbf{20.76\ kN}$
Force in *y*-direction: $R_y = M_e(\Delta\upsilon_{ey}) = M_e(\upsilon_{e2y} - \upsilon_{e1y}) = (586.6 \text{ kg/s})[0 - (-7.76)]$m/s
$= \mathbf{4.55\ kN}$

16.29 $R_x = M(\Delta\upsilon_2) = M(\upsilon_{2x} - \upsilon_{1x})$: Where $M = \rho A \upsilon$
$A = \pi D^2/4 = \pi(0.0075 \text{ m})^2/4 = 4.418 \times 10^{-5} \text{ m}^2$
$M = \rho A \upsilon = (1000 \text{ kg/m}^3)(4.418 \times 10^{-5} \text{ m}^2)(25 \text{ m/s}) = 1.105$ kg/s
$\upsilon_{1x} = \upsilon_1 \cos(10°) = (25 \text{ m/s})(0.985) = 24.62$ m/s;
$\upsilon_{1y} = \upsilon_1 \sin(10°) = (25 \text{ m/s})(0.174) = 4.34$ m/s
$\upsilon_2 = \upsilon = 25$ m/s;
$\upsilon_{2x} = \upsilon_2 \cos(60°) = (25 \text{ m/s})(0.5) = 12.5$ m/s; $\upsilon_{2y} = \upsilon_2 \sin(60°)$
$= (25 \text{ m/s})(0.0866) = 21.65$ m/s



Force in the *x*-direction: $R_x = M(\Delta\upsilon_x) = M(\upsilon_{2x} - \upsilon_{1x})$
$= (1.105 \text{ kg/s})[12.5 - (-24.62)]\text{m/s} = \mathbf{41.0\ N}$
Force in the *y*-direction: $R_y = M(\Delta\upsilon_y) = M(\upsilon_{2y} - \upsilon_{1y})$
$= (1.105 \text{ kg/s})[21.65 - 4.34]\text{m/s} = \mathbf{19.1\ N}$

CHAPTER THIRTEEN

PUMP SELECTION AND APPLICATION

13.1 to 13.14: Answers to questions in text.

13.15 **Affinity laws** relate the manner in which capacity, head and power vary with either speed or impeller diameter.

13.16 $Q_2 = Q_1 \dfrac{N_2}{N_1} = Q_1 \dfrac{0.5N_1}{N_1} = 0.5Q_1$: Capacity cut in half.

13.17 $h_{a_2} = h_{a_1}\left(\dfrac{N_2}{N_1}\right)^2 = h_{a_1}\left(\dfrac{0.5N_1}{N_1}\right)^2 = 0.25h_{a_1}$: h_a divided by 4.

13.18 $P_2 = P_1\left(\dfrac{N_2}{N_1}\right)^3 = P_1\left(\dfrac{0.5N_1}{N_1}\right)^3 = 0.125P_1$: P divided by 8.

13.19 $Q_2 = Q_1 \dfrac{D_2}{D_1} = Q_1 \dfrac{0.75D_1}{D_1} = 0.75Q_1$: 25% reduction.

13.20 $h_{a_2} = h_{a_1}\left(\dfrac{D_2}{D_1}\right)^2 = h_{a_1}\left(\dfrac{0.75D_1}{D_1}\right)^2 = 0.5625h_{a_1}$: 44% reduction.

13.21 $P_2 = P_1\left(\dfrac{D_2}{D_1}\right)^3 = P_1\left(\dfrac{0.75D_1}{D_1}\right)^3 = 0.422P_1$: 58% reduction.

13.22 $1\frac{1}{2} \times 3 \quad 6$

6 in casing-size of largest impeller

3 in nominal suction connection size

$1\frac{1}{2}$ in nominal discharge connection size

13.23 $1\frac{1}{2} \times 3 \quad 10$

13.24 $1\frac{1}{2} \times 3 \quad 6$

13.25 Q = 230 gal/min; P = 22 hp; e = 53%; $NPSH_R$ = 10.1 ft

13.26 At $h_a = 248$ ft, $e_{max} = 57\%$: $Q = 165$ gal/min; $P = 17.0$ hp; $NPSH_R = 7.5$ ft

13.27 From Problem 13.26, $h_{a_1} = 248$ ft: Let $h_{a_2} = 1.15\, h_{a_1} = 285$ ft
Then $Q_2 = 65$ gal/min; $P_2 = 8.5$ hp;$e_2 = 44\%$; $NPSH_R = 5.5$ ft (approximate values)

13.28

	6 in	7 in	8 in	9 in	10 in
h_a	120 ft	195 ft	248 ft	320 ft	390 ft
Q	90 gal/min	130 gal/min	165 gal/min	210 gal/min	245 gal/min
e_{max}	52%	55%	57%	58%	58.7%(Est)

13.29 $NPSH_R$ increases.

13.30 Throttling valves dissipate energy from fluid that was delivered by pump. When a lower speed is used to obtain a lower capacity, power required to drive pump decreases as the cube of the speed. Variable speed control is often more precise and it can be automatically controlled.

13.31 As fluid viscosity increases, capacity and efficiency decrease, power required increases.

13.32 Total capacity doubles.

13.33 The same capacity is delivered but the head capability increases to the sum of the ratings of the two pumps.

13.34
a. Rotary or 3500 rpm centrifugal
b. Rotary
c. Rotary
d. Reciprocating
e. Rotary or high speed centrifugal
f. 1750 rpm centrifugal
g. 1750 rpm centrifugal or mixed flow
h. Axial flow

13.35 $Q = 350$ gal/min; $H = 550$ ft; $D = 12$ in; $N = 3560$ rpm

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{3560\sqrt{350}}{(550)^{0.75}} = \mathbf{586};\ D_s = \frac{DH^{1/4}}{\sqrt{Q}} = \frac{(12)(550)^{0.25}}{\sqrt{350}} = \mathbf{3.1}$$

Point in Fig. 13.53 lies in **radial flow** centrifugal region.

13.36 $Q = 2525$ gal/min; $H = 200$ ft; $D = 15$ in; $N = 1780$ rpm

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{1780\sqrt{2525}}{(200)^{0.75}} = \mathbf{1682};\ D_s = \frac{DH^{1/4}}{\sqrt{Q}} = \frac{15(200)^{0.25}}{\sqrt{2525}} = \mathbf{1.12}$$

Point in Figure 13.34 lies in **radial flow** centrifugal region.

13.37 $$N_s = \frac{N\sqrt{Q}}{H^{3/4}}:\ N = \frac{N_s H^{3/4}}{\sqrt{Q}} = \frac{(5000)(40)^{0.75}}{\sqrt{10000}} = \mathbf{795\ rpm}$$