8.35

8.35 Gasoline flows in a smooth pipe of 40-mm diameter at a rate of 0.001 m^3/s. If it were possible to prevent turbulence from occurring, what would be the ratio of the head loss for the actual turbulent flow compared to that if it were laminar flow?

Let $(\ )_t$ denote the turbulent flow and $(\ )_\ell$ the laminar flow.

Thus, $h_{Lt} = f_t \frac{\ell}{D}\frac{V^2}{2g}$ and $h_{L\ell} = f_\ell \frac{\ell}{D}\frac{V^2}{2g}$ (1)

where

$$V = V_t = V_\ell = \frac{Q}{A} = \frac{0.001\,\frac{m^3}{s}}{\frac{\pi}{4}(0.04m)^2} = 0.796\,\frac{m}{s}$$

From Table 1.5 $\rho = 680\,\frac{kg}{m^3}$ and $\mu = 3.1\times10^{-4}\,\frac{N\cdot s}{m^2}$ so that

$$Re = \frac{\rho V D}{\mu} = \frac{(680\frac{kg}{m^3})(0.796\frac{m}{s})(0.04m)}{3.1\times10^{-4}\,\frac{N\cdot s}{m^2}} = 6.98\times10^4$$

Hence, from Fig. 8.10, for a smooth pipe $f_t = 0.0192$

while for laminar flow $f_\ell = \frac{64}{Re} = \frac{64}{6.98\times10^4} = 9.16\times10^{-4}$

Thus, from Eq. (1)

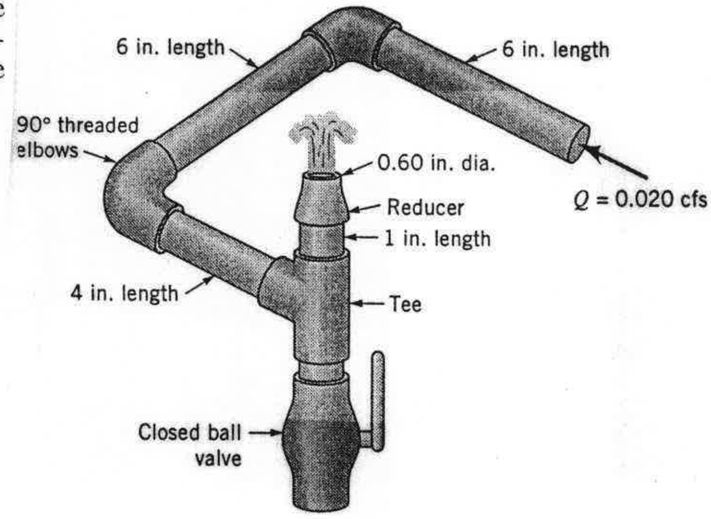
$$\frac{h_{Lt}}{h_{L\ell}} = \frac{f_t}{f_\ell} = \frac{0.0192}{9.16\times10^{-4}} = \underline{\underline{21.0}}$$

8.35

Master Typing Sheet
10% reduction
8 1/2 x 11 trim size

8.51

8.51 Water flows steadily through the 0.75-in.-diameter galvanized iron pipe system shown in **Video V8.13** and Fig. P8.51 at a rate of 0.020 cfs. Your boss suggests that friction losses in the straight pipe sections are negligible compared to losses in the threaded elbows and fittings of the system. Do you agree or disagree with your boss? Support your answer with appropriate calculations.



■ FIGURE P8.51

Major loss $= f\,\frac{\ell}{D}\frac{V^2}{2g}$ where

$\ell = (6+6+4+1)\,in. = 17\,in.$, $D = 0.75\,in.$

and

$$V = \frac{Q}{A} = \frac{0.02\,\frac{ft^3}{s}}{\frac{\pi}{4}(0.75/12)^2\,ft^2} = 6.52\,\frac{ft}{s}$$

Thus, with

$$Re = \frac{VD}{\nu} = \frac{6.52\,\frac{ft}{s}\left(\frac{0.75}{12}ft\right)}{1.21\times10^{-5}\,\frac{ft^2}{s}} = 3.37\times10^4 \text{ and}$$

$$\frac{\varepsilon}{D} = \frac{0.0005\,ft}{\left(\frac{0.75}{12}ft\right)} = 8\times10^{-3}$$ (see Table 8.1) we obtain (see Fig. 8.10)

$$f = 0.038 \text{ so that } f\,\frac{\ell}{D}\frac{V^2}{2g} = 0.038\,\frac{17\,in.}{0.75\,in.}\frac{V^2}{2g} = 0.861\,\frac{V^2}{2g} \qquad (1)$$

Also,

$$\text{Minor loss} = \sum K_L \frac{V^2}{2g} = \left[\underbrace{2(1.5)}_{90^\circ\text{ elbow}} + \underbrace{2}_{\text{tee}} + \underbrace{0.15}_{\text{reducer}}\right]\frac{V^2}{2g} = 5.15\,\frac{V^2}{2g} \qquad (2)$$

reducer with $\frac{A_2}{A_1} = \left(\frac{0.6\,in.}{0.75\,in.}\right)^2 = 0.64$ (see Fig. 8.14)

Thus, from Eqs. (1) and (2):

$$\frac{\text{major loss}}{\text{minor loss}} = \frac{0.861\,\frac{V^2}{2g}}{5.15\,\frac{V^2}{2g}} = 0.167 = 16.7\%$$

Probably <u>disagree</u> with boss because pipe friction is about 17% of other losses.

8.59

8.59 The pressure at section (2) shown in Fig. P8.59 is not to fall below 60 psi when the flowrate from the tank varies from 0 to 1.0 cfs and the branch line is shut off. Determine the minimum height, h, of the water tank under the assumption that **(a)** minor losses are negligible, **(b)** minor losses are not negligible.

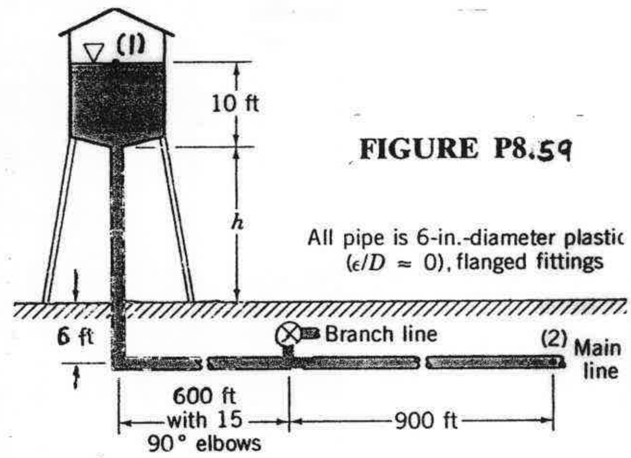


FIGURE P8.59

All pipe is 6-in.-diameter plastic ($\varepsilon/D \approx 0$), flanged fittings

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+\left(f\frac{\ell}{D}+\Sigma K_L\right)\frac{V^2}{2g}, \text{ where } p_1=0,\ V_1=0,\ z_1=16\,ft+h,$$

and $z_2=0$ Thus, with $V=V_2$

$$16+h=\frac{p_2}{\gamma}+\frac{V^2}{2g}+\left(f\frac{\ell}{D}+\Sigma K_L\right)\frac{V^2}{2g}.$$ Note: h must be no less than that with $p_{2\,min}=60\,psi$ and $Q_{max}=1\,cfs$, or

$$V_2=V=\frac{Q}{A_2}=\frac{1\frac{ft^3}{s}}{\frac{\pi}{4}\left(\frac{6}{12}ft\right)^2}=5.09\frac{ft}{s}$$

Hence,

$$h=-16\,ft+\frac{\left(60\frac{lb}{in^2}\right)\left(144\frac{in^2}{ft^2}\right)}{62.4\frac{lb}{ft^3}}+\left(1+f\left(\frac{h+6+600+900}{\frac{6}{12}}\right)+\Sigma K_L\right)\frac{\left(5.09\frac{ft}{s}\right)^2}{2\left(32.2\frac{ft}{s^2}\right)}$$

or

$$h=122.5+\left(1+f\left(\frac{1506+h}{0.5}\right)+\Sigma K_L\right)(0.402)\ \ ft, \text{ where } h\sim ft \qquad (1)$$

With $\frac{\varepsilon}{D}=0$ and $Re=\frac{VD}{\nu}=\frac{\left(5.09\frac{ft}{s}\right)\left(\frac{6}{12}ft\right)}{1.21\times10^{-5}\frac{ft^2}{s}}=2.10\times10^5$ we obtain

$f=0.0155$ (see Fig. 8.10)

a) Neglect minor losses ($\Sigma K_L=0$):

From Eq. (1)

$$h=122.5+\left(1+(0.0155)\left(\frac{1506+h}{0.5}\right)\right)(0.402)$$

or $\underline{\underline{h=143\ ft}}$

b) Include minor losses:

$$\Sigma K_L=K_{L_{entrance}}+15K_{L_{elbow}}+K_{L_{tee}}=0.5+15(0.3)+0.2=5.2$$

(see Table 8.2, assume flanged fittings)

Thus, from Eq. (1)

$$h=122.5+\left(1+(0.0155)\left(\frac{1506+h}{0.5}\right)+5.2\right)(0.402)$$

or

$\underline{\underline{h=146\ ft}}$

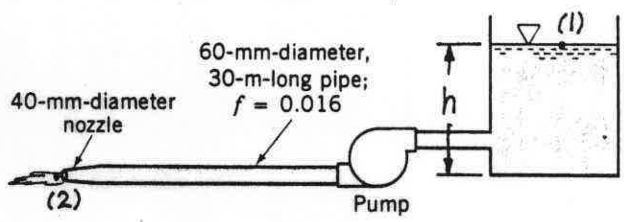
Note: For this case minor losses are not very important.

8.54

55

8.81

8.81 The pump shown in Fig. P8.81 adds 25 kW to the water and causes a flowrate of 0.04 m^3/s. Determine the flowrate expected if the pump is removed from the system. Assume $f = 0.016$ for either case and neglect minor losses.



■ FIGURE P8.81

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + f\frac{\ell}{D}\frac{V^2}{2g}, \text{ where } p_1 = p_2 = 0,\ z_1 = h,\ z_2 = 0,$$

$$V_1 = 0,\quad V_2 = \frac{Q}{A_2} = \frac{0.04\,\frac{m^3}{s}}{\frac{\pi}{4}(0.04m)^2} = 31.8\,\frac{m}{s},\quad V = \frac{Q}{A} = \frac{0.04\,\frac{m^3}{s}}{\frac{\pi}{4}(0.06m)^2} = 14.15\,\frac{m}{s}$$

Thus,

$$h + h_p = \frac{(31.8\,\frac{m}{s})^2}{2(9.81\,\frac{m}{s^2})} + 0.016\left(\frac{30m}{0.06m}\right)\frac{(14.15\,\frac{m}{s})^2}{2(9.81\,\frac{m}{s^2})} = 133.2\,m$$

but,

$$h_p = \frac{P}{\gamma Q} = \frac{25\times10^3\,\frac{N\cdot m}{s}}{(9.80\times10^3\,\frac{N}{m^3})(0.04\,\frac{m^3}{s})} = 63.8\,m$$

Hence,

$$h = 133.2m - 63.8\,m = 69.5m$$

Without the pump $h_p = 0$ and $z_1 = \frac{V_2^2}{2g} + f\frac{\ell}{D}\frac{V^2}{2g}$ where $h = 69.5m = z_1$

and

$$V_2 = \frac{AV}{A_2} = \left(\frac{D}{D_2}\right)^2 V \text{ or } V_2 = \left(\frac{60mm}{40mm}\right)^2 V = 2.25V$$

Thus,

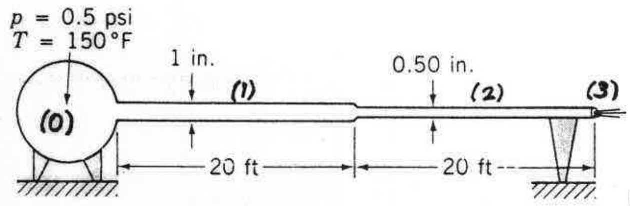
$$69.5\,m = \frac{(2.25V)^2 + 0.016\left(\frac{30m}{0.06m}\right)V^2}{2(9.81\,\frac{m}{s^2})} \quad \text{or } V = 10.22\,\frac{m}{s}$$

so that

$$Q = AV = \frac{\pi}{4}(0.06m)^2(10.22\,\frac{m}{s}) = \underline{\underline{0.0289\,\frac{m^3}{s}}}$$

8.82

8.82 Air, assumed incompressible, flows through the two pipes shown in Fig. P8.82 Determine the flowrate if minor losses are neglected and the friction factor in each pipe is 0.020. Determine the flowrate if the 0.5-in.-diameter pipe were replaced by a 1-in.-diameter pipe. Comment on the assumption of incompressibility.



■ FIGURE P8.82

$$\frac{p_0}{\gamma}+\frac{V_0^2}{2g}+z_0=h_{L_1}+h_{L_2}+\frac{p_3}{\gamma}+\frac{V_3^2}{2g}+z_3\,,\quad \text{where } V_0=0,\ z_0=z_2,\ p_3=0, \qquad (1)$$

$V_2=V_3$, $h_{L_1}=f_1\frac{\ell_1}{D_1}\frac{V_1^2}{2g}$, $h_{L_2}=f_2\frac{\ell_2}{D_2}\frac{V_2^2}{2g}$, and $V_1=V_2\frac{A_2}{A_1}=V_2\left(\frac{D_2}{D_1}\right)^2=\left(\frac{0.5\text{ in.}}{1.0\text{ in.}}\right)^2V_2$
$=0.25V_2$

Thus, Eq. (1) becomes

$$\frac{p_0}{\gamma}=f_1\frac{\ell_1}{D_1}\frac{(0.25V_2)^2}{2g}+f_2\frac{\ell_2}{D_2}\frac{V_2^2}{2g}+\frac{V_2^2}{2g}$$

or

$$p_0=\frac{1}{2}\rho V_2^2\left[f_1\frac{\ell_1}{D_1}(0.25)^2+f_2\frac{\ell_2}{D_2}+1\right] \qquad (2)$$

With $p_0=\rho_0RT_0$ or $\rho_0=\frac{p_0}{RT_0}=\frac{\left(0.5\frac{\text{lb}}{\text{in.}^2}+14.7\frac{\text{lb}}{\text{in.}^2}\right)\left(144\frac{\text{in.}^2}{\text{ft}^2}\right)}{\left(1716\frac{\text{ft}\cdot\text{lb}}{\text{slug}\cdot{}^\circ\text{R}}\right)(150+460)^\circ\text{R}}=0.00209\ \frac{\text{slug}}{\text{ft}^3}$

and $f_1=f_2=0.020$ Eq. (2) gives

$$\left(0.5\frac{\text{lb}}{\text{in.}^2}\right)\left(144\frac{\text{in.}^2}{\text{ft}^2}\right)=\frac{1}{2}\left(0.00209\frac{\text{slug}}{\text{ft}^3}\right)V_2^2\left[(0.020)\left(\left(\frac{20\text{ ft}}{\frac{1}{12}\text{ ft}}\right)(0.25)^2+\left(\frac{20\text{ ft}}{\frac{1}{24}\text{ ft}}\right)\right)+1\right]$$

or $V_2=79.5\ \frac{\text{ft}}{\text{s}}$ Thus, $Q=A_2V_2=\frac{\pi}{4}\left(\frac{1}{24}\text{ft}\right)^2\left(79.5\frac{\text{ft}}{\text{s}}\right)=\underline{\underline{0.108\ \frac{\text{ft}^3}{\text{s}}}}$

If both pipes were 1 in. diameter, then $V_1=V_2$ and Eq. (1) becomes

$$p_0=\frac{1}{2}\rho V_2^2\left[f_1\frac{\ell_1}{D_1}+f\frac{\ell_2}{D_2}+1\right] \quad \text{or with } f_1=f_2,\ \ell_1=\ell_2, \text{ and } D_1=D_2$$

$$p_0=\frac{1}{2}\rho V_2^2\left[f_2\frac{(2\ell_2)}{D_2}+1\right]$$

Hence,

$$\left(0.5\frac{\text{lb}}{\text{in.}^2}\right)\left(144\frac{\text{in.}^2}{\text{ft}^2}\right)=\frac{1}{2}\left(0.00209\frac{\text{slug}}{\text{ft}^3}\right)V_2^2\left[0.02\left(\frac{40\text{ ft}}{\frac{1}{12}\text{ ft}}\right)+1\right]$$

or

$V_2=80.6\ \frac{\text{ft}}{\text{s}}$ Thus, $Q=A_2V_2=\frac{\pi}{4}\left(\frac{1}{12}\text{ft}\right)^2\left(80.6\frac{\text{ft}}{\text{s}}\right)=\underline{\underline{0.440\ \frac{\text{ft}^3}{\text{s}}}}$

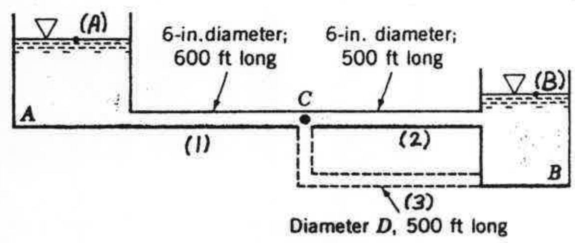
Since $p=\rho RT$ it follows that

$$\frac{\rho_3}{\rho_0}=\frac{\left(\frac{p_3}{RT_3}\right)}{\left(\frac{p_0}{RT_0}\right)}=\frac{p_3}{p_0}\frac{T_0}{T_3}$$ If we assume $T_3=T_0$ (it probably will not be, but it should be a reasonable approximation), then

$$\frac{\rho_3}{\rho_0}\approx\frac{p_3}{p_0}=\frac{14.7\text{ psi}}{(0.5+14.7)\text{ psi}}=0.967$$ The flow is nearly incompressible.

8.89

8.89 The flowrate between tank A and tank B shown in Fig. P8.89 is to be increased by 30% (i.e., from Q to $1.30Q$) by the addition of a second pipe (indicated by the dotted lines) running from node C to tank B. If the elevation of the free surface in tank A is 25 ft above that in tank B, determine the diameter, D, of this new pipe. Neglect minor losses and assume that the friction factor for each pipe is 0.02.



■ FIGURE P8.89

With the single pipe: $\frac{p_A}{\gamma} + \frac{V_A^2}{2g} + z_A = \frac{p_B}{\gamma} + \frac{V_B^2}{2g} + z_B + f_1 \frac{\ell_1}{D_1}\frac{V_1^2}{2g} + f_2 \frac{\ell_2}{D_2}\frac{V_2^2}{2g}$ (1)

where $p_A = p_B = 0$, $V_A = V_B = 0$, $z_A = 25\ ft$, $z_B = 0$,

and $V_1 = V_2$ (since $D_1 = D_2$).

Thus, $z_A = f_1 \frac{(\ell_1 + \ell_2)}{D_1}\frac{V_1^2}{2g}$, or $25\ ft = (0.02)\frac{(600+500)ft}{(\frac{6}{12}ft)} \frac{V_1^2}{2(32.2\frac{ft}{s^2})}$

or $V_1 = 6.05\frac{ft}{s}$ Hence, $Q = A_1V_1 = \frac{\pi}{4}(\frac{6}{12}ft)^2(6.05\frac{ft}{s}) = 1.188\frac{ft^3}{s}$

With the second pipe $Q = 1.30(1.188\frac{ft^3}{s}) = 1.54\frac{ft^3}{s}$

Thus, $Q_1 = 1.54\frac{ft^3}{s} = Q_2 + Q_3$ or $V_1 = \frac{Q_1}{A_1} = \frac{1.54\frac{ft^3}{s}}{\frac{\pi}{4}(\frac{6}{12}ft)^2} = 7.84\frac{ft}{s}$

For fluid flowing from A to B through pipes 1 and 2,

$z_A = h_{L_1} + h_{L_2} = f_1\frac{\ell_1}{D_1}\frac{V_1^2}{2g} + f_2\frac{\ell_2}{D_2}\frac{V_2^2}{2g}$ (see Eq. (1))

or

$$25\ ft = (0.02)\frac{600\ ft}{(\frac{6}{12}ft)}\frac{(7.84\frac{ft}{s})^2}{2(32.2\frac{ft}{s^2})} + (0.02)\frac{500\ ft}{(\frac{6}{12}ft)}\frac{V_2^2}{2(32.2\frac{ft}{s^2})}$$

Hence, $V_2 = 2.60\frac{ft}{s}$

and $Q_2 = A_2V_2 = \frac{\pi}{4}(\frac{6}{12}ft)^2(2.60\frac{ft}{s}) = 0.511\frac{ft^3}{s}$

Thus, $Q_3 = Q_1 - Q_2 = 1.54\frac{ft^3}{s} - 0.511\frac{ft^3}{s} = 1.03\frac{ft^3}{s}$

For fluid flowing from A to B through pipes 1 and 3,

$z_A = h_{L_1} + h_{L_3} = f_1\frac{\ell_1}{D_1}\frac{V_1^2}{2g} + f_3\frac{\ell_3}{D_3}\frac{V_3^2}{2g}$, where $V_3 = \frac{Q_3}{A_3} = \frac{1.03\frac{ft^3}{s}}{\frac{\pi}{4}D_3^2} = \frac{1.31}{D_3^2}$

Thus,

$$25\ ft = (0.02)\frac{600\ ft}{(\frac{6}{12}ft)}\frac{(7.84\frac{ft}{s})^2}{2(32.2\frac{ft}{s^2})} + (0.02)\frac{500\ ft}{D_3}\frac{(\frac{1.31}{D_3^2})^2}{2(32.2\frac{ft}{s^2})}$$

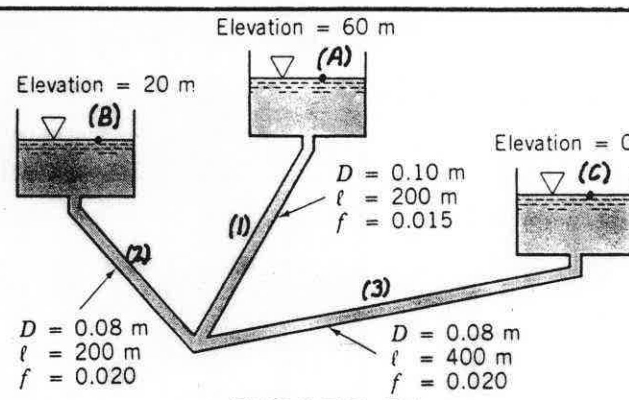
or

$\underline{\underline{D_3 = 0.662\ ft}}$

Note: With the parameters given, the solution is quite sensitive to roundoff errors in the calculations

8.92

8.92 The three water-filled tanks shown in Fig. P8.92 are connected by pipes as indicated. If minor losses are neglected, determine the flowrate in each pipe.



■ **FIGURE P8.92**

Assume the fluid flows from A to B and A to C. Thus, $Q_1 = Q_2 + Q_3$

or $\frac{\pi}{4}(0.1m)^2 V_1 = \frac{\pi}{4}(0.08m)^2 V_2 + \frac{\pi}{4}(0.08m)^2 V_3$

Thus, $V_1 = 0.64 V_2 + 0.64 V_3$ (1)

For fluid flowing from A to B with $p_A = p_B = 0$ and $V_A = V_B = 0$,

$z_A = z_B + f_1 \frac{\ell_1}{D_1}\frac{V_1^2}{2g} + f_2 \frac{\ell_2}{D_2}\frac{V_2^2}{2g}$

or

$$60m - 20m = (0.015)\left(\frac{200m}{0.1m}\right)\frac{V_1^2}{2(9.81\frac{m}{s^2})} + (0.020)\left(\frac{200m}{0.08m}\right)\frac{V_2^2}{2(9.81\frac{m}{s^2})}$$

Hence,

$40 = 1.529 V_1^2 + 2.55 V_2^2$ (2)

Similarly, for fluid flowing from A to C with $p_A = p_C = 0$ and $V_A = V_C = 0$,

$z_A = z_C + f_1 \frac{\ell_1}{D_1}\frac{V_1^2}{2g} + f_3 \frac{\ell_3}{D_3}\frac{V_3^2}{2g}$

or

$$60m = (0.015)\left(\frac{200m}{0.1m}\right)\frac{V_1^2}{2(9.81\frac{m}{s^2})} + (0.020)\left(\frac{400m}{0.08m}\right)\frac{V_3^2}{2(9.81\frac{m}{s^2})}$$

Hence,

$60 = 1.529 V_1^2 + 5.10 V_3^2$ (3)

Solve Eqs. (1), (2), and (3) for V_1, V_2, and V_3. From Eqs. (1) and (3):

$60 = 1.529(0.64)^2(V_2+V_3)^2 + 5.10 V_3^2$, or $95.8 = (V_2+V_3)^2 + 8.14 V_3^2$ (4)

Subtract Eq. (2) from Eq. (3):

$60 - 40 = 5.10 V_3^2 + 2.55 V_2^2$ or $V_2 = \sqrt{2V_3^2 - 7.84}$ (5)

Thus, from Eqs. (4) and (5): $8.14 V_3^2 + \left(\sqrt{2V_3^2 - 7.84} + V_3\right)^2 - 95.8 = 0$

This can be simplified to

$2V_3\sqrt{2V_3^2 - 7.84} = 103.6 - 11.14 V_3^2$ Square both sides and (6)

rearrange to give $V_3^4 - 19.63 V_3^2 + 92.5 = 0$ which can be solved by the quadratic formula to give

$V_3^2 = \frac{19.63 \pm \sqrt{19.63^2 - 4(92.5)}}{2} = 11.77$ or 7.86 Thus $V_3 = 3.43\frac{m}{s}$

or $V_3 = 2.80\frac{m}{s}$

(con't)

8.92 (con't)

Note: The value $V_3 = 3.43\,\frac{m}{s}$ is not a solution of the original equations, Eqs. (1), (2), and (3). With this value the right hand side of Eq. (6) is negative (i.e. $103.6 - 11.14V_3^2 = 103.6 - 11.14(3.43)^2 = -24.5$). As seen from the left hand side of Eq. (6), this cannot be. This extra root was introduced by squaring Eq. (6).

Thus, $Q_3 = A_3V_3 = \frac{\pi}{4}(0.08\,m)^2(2.80\,\frac{m}{s}) = \underline{\underline{0.0141\,\frac{m^3}{s}}}$

Also, from Eq. (3):

$60 = 1.529\,V_1^2 + 5.10\,(2.80)^2$ or $V_1 = 3.62\,\frac{m}{s}$

or $Q_1 = A_1V_1 = \frac{\pi}{4}(0.10\,m)^2(3.62\,\frac{m}{s}) = \underline{\underline{0.0284\,\frac{m^3}{s}}}$

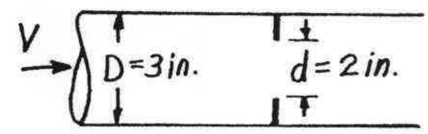
and from Eq. (1):

$3.62 = 0.64\,V_2 + 0.64(2.80)$ or $V_2 = 2.86\,\frac{m}{s}$

or $Q_2 = A_2V_2 = \frac{\pi}{4}(0.08\,m)^2(2.86\,\frac{m}{s}) = \underline{\underline{0.0143\,\frac{m^3}{s}}}$

8.99

8.99 A 2-in.-diameter orifice plate is inserted in a 3-in.-diameter pipe. If the water flowrate through the pipe is 0.70 cfs, determine the pressure difference indicated by a manometer attached to the flow meter.



$$Q = C_o A_o \sqrt{\frac{2(p_1 - p_2)}{\rho(1-\beta^4)}}\,, \quad \text{where } \beta = \frac{d}{D} = \frac{2\text{ in.}}{3\text{ in.}} = \frac{2}{3}\,, \quad Q = 0.70\,\frac{ft^3}{s}\,, \text{ and}$$

$$A_o = \frac{\pi}{4}d$$

Also,

$$Re = \frac{VD}{\nu}\,, \quad \text{where } V = \frac{Q}{\frac{\pi}{4}D^2} = \frac{0.7\,\frac{ft^3}{s}}{\frac{\pi}{4}\left(\frac{3}{12}\,ft\right)^2} = 14.26\,\frac{ft}{s}$$

Thus,

$$Re = \frac{\left(14.26\,\frac{ft}{s}\right)\left(\frac{3}{12}\,ft\right)}{1.21\times10^{-5}\,\frac{ft^2}{s}} = 2.95\times10^5$$

Hence, from Fig. 8.23: $C_o = 0.608$

so that,

$$0.7\,\frac{ft^3}{s} = (0.608)\frac{\pi}{4}\left(\frac{2}{12}\,ft\right)^2\sqrt{\frac{2(p_1 - p_2)}{\left(1.94\,\frac{slugs}{ft^3}\right)\left(1-\left(\frac{2}{3}\right)^4\right)}}$$

or

$$p_1 - p_2 = 2170\,\frac{lb}{ft^2} = \underline{\underline{15.1\,\frac{lb}{in.^2}}}$$