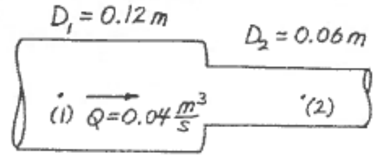
8.62 Water flows at a rate of 0.040 m³/s in a 0.12-m-diameter pipe that contains a sudden contraction to a 0.06-m-diameter pipe. Determine the pressure drop across the contraction section. How much of this pressure difference is due to losses and how much is due to kinetic energy changes?



$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + K_L \frac{V_2^2}{2g}, \text{ where } z_1 = z_2 \quad (1)$$

and

$$V_1 = \frac{Q}{A_1} = \frac{0.04\,\frac{m^3}{s}}{\frac{\pi}{4}(0.12m)^2} = 3.54\,\frac{m}{s}, \quad V_2 = \frac{Q}{A_2} = \frac{0.04\,\frac{m^3}{s}}{\frac{\pi}{4}(0.06m)^2} = 14.1\,\frac{m}{s}$$

Thus, with $\frac{A_2}{A_1} = \left(\frac{D_2}{D_1}\right)^2 = \left(\frac{0.06m}{0.12m}\right)^2 = 0.25$ we obtain from Fig. 8.30

$K_L = 0.40$

Hence, from Eq. (1)

$$p_1 - p_2 = \frac{1}{2}\rho\left[K_L V_2^2 + V_2^2 - V_1^2\right] = \frac{1}{2}\left(999\,\frac{kg}{m^3}\right)\left[0.40\left(14.1\,\frac{m}{s}\right)^2 + \left(14.1\,\frac{m}{s}\right)^2 - \left(3.54\,\frac{m}{s}\right)^2\right]$$

or

$$p_1 - p_2 = 39.7\times10^3\,\frac{N}{m^2} + 93.0\times10^3\,\frac{N}{m^2} = \underline{133\,kPa}$$

This represents a $\underline{39.7\,kPa}$ drop from losses and a $\underline{93.0\,kPa}$ drop due to an increase in kinetic energy.

8.75 Air at standard conditions flows through a horizontal 1 ft by 1.5 ft rectangular wooden duct at a rate of 5000 ft³/min. Determine the head loss, pressure drop, and power supplied by the fan to overcome the flow resistance in 500 ft of the duct.

$$h_L = f\frac{\ell}{D_h}\frac{V^2}{2g}, \text{ where } V = \frac{Q}{A} = \frac{\left(5000\,\frac{ft^3}{min}\right)\left(\frac{1\,min}{60\,s}\right)}{(1\,ft)(1.5\,ft)} = 55.6\,\frac{ft}{s}$$

and $D_h = \frac{4A}{P} = \frac{4(1\,ft)(1.5\,ft)}{2[1\,ft + 1.5\,ft]} = 1.2\,ft$

Also, $Re_h = \frac{VD_h}{\nu} = \frac{\left(55.6\,\frac{ft}{s}\right)(1.2\,ft)}{1.57\times10^{-4}\,\frac{ft^2}{s}} = 4.25\times10^5$ and from Table 8.1

$\varepsilon \approx 0.0006\,ft$ to $0.003\,ft$. Use an "average" $\varepsilon = 0.0018\,ft$ so that $\frac{\varepsilon}{D_h} = \frac{0.0018\,ft}{1.2\,ft} = 0.0015$ Thus, from Fig. 8.20 $f = 0.022$, or

$$h_L = (0.022)\left(\frac{500\,ft}{1.2\,ft}\right)\frac{\left(55.6\,\frac{ft}{s}\right)^2}{2\left(32.2\,\frac{ft}{s^2}\right)} = \underline{440\,ft}$$

For this horizontal pipe $\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$, where $z_1 = z_2$ and $V_1 = V_2$.

Thus, $p_1 - p_2 = \gamma h_L = \left(7.65\times10^{-2}\,\frac{lb}{ft^3}\right)(440\,ft) = 33.7\,\frac{lb}{ft^2} = \underline{0.234\,psi}$

$$\mathcal{P} = \gamma Q h_L = Q(p_1 - p_2) = \left(5000\,\frac{ft^3}{min}\right)\left(\frac{1\,min}{60\,s}\right)\left(33.7\,\frac{lb}{ft^2}\right) = \left(2810\,\frac{ft\cdot lb}{s}\right)\left[\frac{1\,hp}{\left(550\,\frac{ft\cdot lb}{s}\right)}\right]$$

or

$\mathcal{P} = \underline{5.11\,hp}$

8.77

8.77 The pressure at section (2) shown in Fig. P8.77 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.

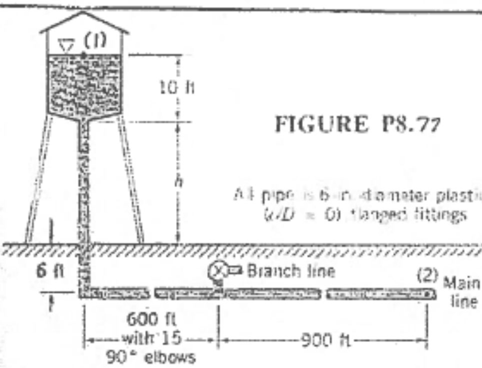


FIGURE P8.77

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

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

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 $Re=\frac{VD}{\nu}=\frac{(5.09\frac{ft}{s})(\frac{6}{12}ft)}{1.21\times10^{-5}\frac{ft^2}{s}}=2.10\times10^5$ we obtain

$f=0.0155$ (see Fig. 8.20)

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.

8.84

8.84 Water at 40 °F flows through the coils of the heat exchanger as shown in Fig. P8.84 at a rate of 0.9 gal/min. Determine the pressure drop between the inlet and outlet of the horizontal device.

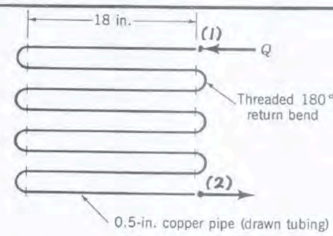


FIGURE P8.84

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

$$V=V_1=V_2=\frac{Q}{A}=\frac{\left(0.9\frac{gal}{min}\right)\left(231\frac{in.^3}{gal}\right)\left(\frac{1\,ft^3}{1728\,in.^3}\right)\left(\frac{1\,min}{60\,s}\right)}{\frac{\pi}{4}\left(\frac{0.5}{12}ft\right)^2}=1.47\frac{ft}{s}$$

Thus,

$$p_1-p_2=\left(f\frac{\ell}{D}+\Sigma K_L\right)\frac{1}{2}\rho V^2, \text{ with } \ell=8\left(\frac{18}{12}ft\right)=12\,ft \quad (1)$$

and $\Sigma K_L=7(1.5)=10.5$ (see Table 8.2)

Also, from Table 8.1 $\frac{\varepsilon}{D}=(0.000005\,ft/(0.5/12\,ft))=1.2\times10^{-4}$

and $Re=\frac{VD}{\nu}=\frac{\left(1.47\frac{ft}{s}\right)\left(\frac{0.5}{12}ft\right)}{1.66\times10^{-5}\frac{ft^2}{s}}=3690$ (see Table B.1 for ν)

Hence, from Fig. 8.20

$f=0.041$

and from Eq. (1)

$$p_1-p_2=\left(0.041\left(\frac{12\,ft}{\frac{0.5}{12}ft}\right)+10.5\right)\left(\frac{1}{2}\right)\left(1.94\frac{slugs}{ft^3}\right)\left(1.47\frac{ft}{s}\right)^2$$

or

$$p_1-p_2=46.8\frac{lb}{ft^2}=\underline{\underline{0.325\,psi}}$$

8.93 Water flows from the nozzle attached to the spray tank shown in Fig. P8.93. Determine the flowrate if the loss coefficient for the nozzle (based on upstream conditions) is 0.75 and the friction factor for the rough hose is 0.11.

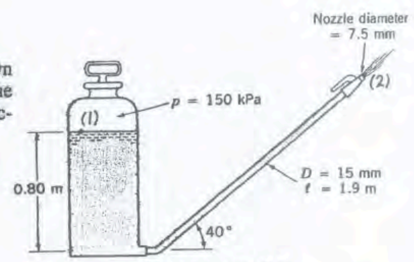


FIGURE P8.93

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+\left(f\frac{\ell}{D}+K_L\right)\frac{V^2}{2g}, \text{ where } p_1=150\,kPa,\ p_2=0, \quad (1)$$

$z_1=0.8\,m$, $z_2=\ell\sin40°=(1.9\,m)\sin40°=1.22\,m$, $V_1=0$,

$V=\frac{Q}{A}$, and $V_2=\frac{Q}{A_2}=\left(\frac{A}{A_2}\right)V=\left(\frac{D}{D_2}\right)^2V=\left(\frac{15\,mm}{7.5\,mm}\right)^2V=4V$

Thus, with $f=0.11$ and $K_L=0.75$ Eq. (1) gives

$$\frac{150\times10^3\frac{N}{m^2}}{9.80\times10^3\frac{N}{m^3}}+0.8\,m=1.22\,m+\left(4^2+0.11\left(\frac{1.9\,m}{0.015\,m}\right)+0.75\right)\frac{V^2}{2\left(9.81\frac{m}{s^2}\right)}$$

or

$V=3.09\frac{m}{s}$

Thus, $Q=AV=\frac{\pi}{4}(0.015\,m)^2\left(3.09\frac{m}{s}\right)=\underline{\underline{5.46\times10^{-4}\frac{m^3}{s}}}$

8.97

8.97 The pump shown in Fig. P8.97 delivers a head of 250 ft to the water. Determine the power that the pump adds to the water. The difference in elevation of the two ponds is 200 ft.

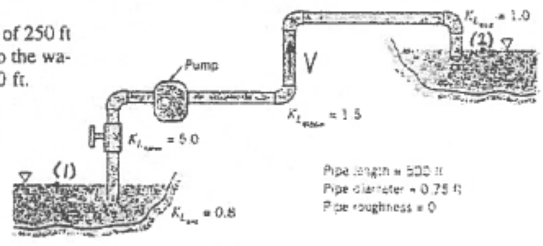


FIGURE P8.97

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_L + h_p = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

where $p_1 = p_2 = 0$, $V_1 = V_2 = 0$, $z_1 = 0$, $z_2 = 200\ ft$, $h_p = 250\ ft$

Thus,

$$-f\frac{\ell}{D}\frac{V^2}{2g} - \sum_i K_{L_i}\frac{V^2}{2g} + h_p = z_2 \quad \text{so that with } \sum_i K_{L_i}\frac{V^2}{2g} = (0.8 + 4(1.5) + 5.0 + 1)\frac{V^2}{2g} = 12.8\frac{V^2}{2g}$$

$$\left[-f\left(\frac{500}{0.75}\right) - 12.8\right]\frac{V^2}{2(32.2)} + 250 = 200$$

or

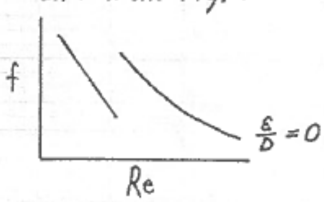
(1) $$(667f + 12.8)V^2 = 3220$$

Also, $$Re = \frac{\rho V D}{\mu} = \frac{(1.94\ \frac{slugs}{ft^3})\ V\ (0.75\ ft)}{2.34 \times 10^{-5}\ \frac{lb \cdot s}{ft^2}}$$

or

(2) $$Re = 6.22 \times 10^4\ V$$

and from Fig. 8.20:

(3) 

Trial and error solution. Assume $f = 0.02 \xrightarrow{(1)} V = 11.1\ \frac{ft}{s} \xrightarrow{(2)} Re = 6.9 \times 10^5$
$\xrightarrow{(3)} f = 0.012 \neq 0.02$

Assume $f = 0.012 \xrightarrow{(1)} V = 12.4\ \frac{ft}{s} \xrightarrow{(2)} Re = 7.7 \times 10^5 \xrightarrow{(3)} f = 0.0121 \approx 0.012$

Thus, $V = 12.4\ \frac{ft}{s}$ and

$$\dot{W}_s = \gamma Q h_p = (62.4\ \tfrac{lb}{ft^3})\ \tfrac{\pi}{4}(0.75\ ft)^2(12.4\ \tfrac{ft}{s})(250\ ft) = 8.55 \times 10^4\ \tfrac{ft \cdot lb}{s}$$

$$= 8.55 \times 10^4\ \frac{ft \cdot lb}{s} \times 1\ \frac{hp}{550\ \frac{ft \cdot lb}{s}} = \underline{\underline{155\ hp}}$$

Alternatively, we could replace Eq. (3) (the Moody chart) by Eq 8.35

(con't)

8.97 (con't)

(the Colebrook equation) and obtain V as follows.

From Eq. (1),

$V = \left[3220/(667f + 12.8)\right]^{1/2}$, which when combined with Eq. (2) gives

(4) $\quad Re = 6.22 \times 10^4 \left[3220/(667f + 12.8)\right]^{\frac{1}{2}} = 3.53 \times 10^6/(667f + 12.8)^{\frac{1}{2}}$

Also, the Colebrook equation with $\varepsilon/D = 0$ is

(5) $\quad \frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{2.51}{Re\sqrt{f}}\right)$

By combining Eqs (4) and (5) we obtain a single equation involving only f:

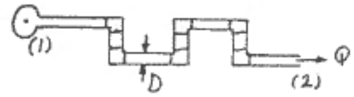
$$\frac{1}{\sqrt{f}} = -2.0 \log\left[\frac{2.51(667f + 12.8)^{1/2}}{3.53 \times 10^6 \sqrt{f}}\right]$$

Using a compute root-finding program to solve Eq (6) gives

$f = 0.0123$, consistent with the above trial and error method.

8.100

8.100 A certain process requires 2.3 cfs of water to be delivered at a pressure of 30 psi. This water comes from a large-diameter supply main in which the pressure remains at 60 psi. If the galvanized iron pipe connecting the two locations is 200 ft long and contains six threaded 90° elbows, determine the pipe diameter. Elevation differences are negligible.



$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \left(f\frac{\ell}{D} + \Sigma K_L\right)\frac{V^2}{2g}$, where $p_2 = 30\,psi$, $p_1 = 60\,psi$,

$z_1 = z_2$, $V_1 = 0$, $V_2 = V = \frac{Q}{A} = \frac{2.3\,\frac{ft^3}{s}}{\frac{\pi}{4}D^2} = \frac{2.93}{D^2}\,\frac{ft}{s}$, with $D \sim ft$

Thus,

$$p_1 - p_2 = \left(f\frac{\ell}{D} + \Sigma K_L\right)\frac{1}{2}\rho V^2$$

or

$$(60-30)\frac{lb}{in.^2}\left(144\frac{in.^2}{ft^2}\right) = \left(1 + f\left(\frac{200\,ft}{D}\right) + 6(1.5) + 0.5\right)\left(\frac{2.93}{D^2}\frac{ft}{s}\right)^2\left(\frac{1}{2}\right)\left(1.94\frac{slugs}{ft^3}\right)$$

where we have used

$$\Sigma K_L = 6K_{L_{elbow}} + K_{L_{entrance}} = 6(1.5) + 0.5$$

Thus,

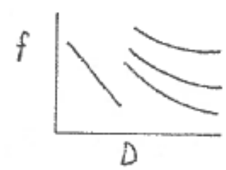
$$49.4 = \left(1 + \frac{19.0f}{D}\right)\frac{1}{D^4} \qquad (1)$$

Also, $Re = \frac{VD}{\nu} = \frac{\left(\frac{2.93}{D^2}\right)D}{\nu} = \frac{2.93\,\frac{ft^2}{s}}{1.21\times10^{-5}\frac{ft^2}{s}D}$ or $Re = 2.42\times10^5\,\frac{1}{D}$ (2)

and from Table 8.1

$$\frac{\varepsilon}{D} = \frac{0.0005\,ft}{D} \qquad (3)$$

Finally, from Fig. 8.20:



(4)

Trial and error solution of Eqs. (1), (2), (3), and (4) for f, D, $\frac{\varepsilon}{D}$, and Re.

Normally it is easiest to guess a value of f, calculate D, etc. In this case (because of minor losse), Eq.(1) is not easy to use in this fashion. Thus, assume D, calculate f (Eq.(1)), Re (Eq.(2)), and $\frac{\varepsilon}{D}$ (Eq.(3)). Look up f in Fig. 8.20 (Eq.(4)) and compare with that from Eq.(1).

Assume $D = 0.4\,ft$. Thus, $f = 0.00557$, $Re = 6.05\times10^5$, $\frac{\varepsilon}{D} = 0.00125$ or from Fig. 8.20 $f = 0.021 \neq 0.00557$

Assume $D = 0.5\,ft$; $f = 0.0551$, $Re = 4.84\times10^5$, $\frac{\varepsilon}{D} = 0.001$ or $f = 0.0203 \neq 0.0551$

Assume $D = 0.45\,ft$; $f = 0.0243$, $Re = 5.38\times10^5$, $\frac{\varepsilon}{D} = 0.00111$ or $f = 0.0205 \neq 0.0243$

Assume $D = 0.44\,ft$; $f = 0.0197$, $Re = 5.50\times10^5$, $\frac{\varepsilon}{D} = 0.00114$ or $f = 0.0205 \neq 0.0197$

After enough trials obtain $D = \underline{\underline{0.442\,ft}}$

Note: If Fig. 8.20 (Eq.(4)) is replaced by the Colebrook equation, 8.100 (con't)

this problem can be solved as follows.

Thus, from Eq. (1),

$f = (49.4D^5 - D)/19$ so that with the Colebrook equation (Eq. 8.35), when combined with Eqs. (2) and (3), gives

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

or

$$\left[\frac{19}{(49.4D^5 - D)}\right]^{1/2} = -2.0 \log\left[\frac{0.0005}{3.7\,D} + \frac{2.51\,D\,\sqrt{19}}{2.42 \times 10^5\,(49.4\,D^5 - D)^{1/2}}\right] \qquad (5)$$

Using a computer root-finding routine gives the solution to Eq. (5) as $D = 0.442$ ft which is the same as that obtained by the trial and error method above.

8.110 The flowrate between tank A and tank B shown in Fig. P8.110 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.

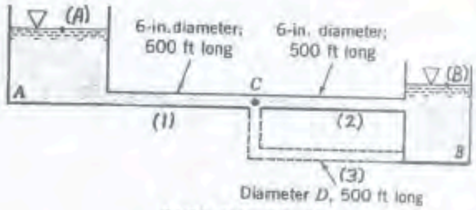


FIGURE P8.110

With the single pipe: $\frac{p_A}{\gamma}+\frac{V_A^2}{2g}+z_A=\frac{p_B}{\gamma}+\frac{V_B^2}{2g}+z_B+f_1\frac{l_1}{D_1}\frac{V_1^2}{2g}+f_2\frac{l_2}{D_2}\frac{V_2^2}{2g}$ (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, $z_A=f_1\frac{(l_1+l_2)}{D_1}\frac{V_1^2}{2g}$, 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,

$z_A=h_{L_1}+h_{L_2}=f_1\frac{l_1}{D_1}\frac{V_1^2}{2g}+f_2\frac{l_2}{D_2}\frac{V_2^2}{2g}$ (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,

$z_A=h_{L_1}+h_{L_3}=f_1\frac{l_1}{D_1}\frac{V_1^2}{2g}+f_3\frac{l_3}{D_3}\frac{V_3^2}{2g}$, 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

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

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

8.123 Water flows through the orifice meter shown in Fig. P8.123 at a rate of 0.10 cfs. If $d = 0.1$ ft, determine the value of h.

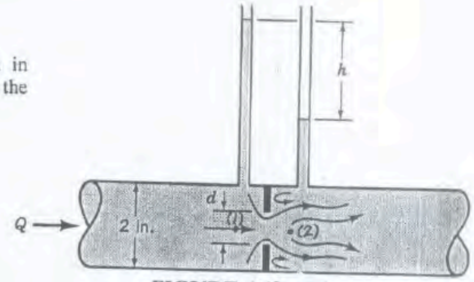


FIGURE P8.123

$$Q = C_o A_o \sqrt{\frac{2(p_1 - p_2)}{\rho(1-\beta^4)}}, \text{ where } \beta = \frac{d}{D} = \frac{0.1\,ft}{\frac{2}{12}\,ft} = 0.6,\ p_1 - p_2 = \gamma h = \rho g h \quad (1)$$

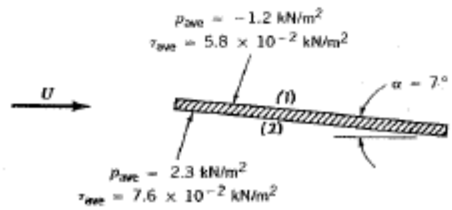
Also, $V = \frac{Q}{\frac{\pi}{4}D^2} = \frac{0.10\,\frac{ft^3}{s}}{\frac{\pi}{4}\left(\frac{2}{12}\,ft\right)^2} = 4.58\,\frac{ft}{s}$ so that

$$Re = \frac{VD}{\nu} = \frac{(4.58\,\frac{ft}{s})(\frac{2}{12}\,ft)}{1.21\times10^{-5}\,\frac{ft^2}{s}} = 6.31\times10^4$$ Hence, from Fig. 8.41, $C_o = 0.616$

Therefore, from Eq. (1):

$$0.10\,\frac{ft^3}{s} = (0.616)\frac{\pi}{4}(0.1\,ft)^2\sqrt{\frac{2\rho(32.2\,\frac{ft}{s^2})h}{\rho(1-0.6^4)}} \quad \text{or} \quad h = \underline{\underline{5.77\,ft}}$$

9.4 The average pressure and shear stress acting on the surface of the 1-m-square flat plate are as indicated in Fig. P9.4. Determine the lift and drag generated. Determine the lift and drag if the shear stress is neglected. Compare these two sets of results.



■ FIGURE P9.4

Since $\int p\, dA = p_{ave} A$ and $\int \tau_w\, dA = \tau_{ave} A$ it follows that

$\mathcal{D} = -p_1 A_1 \sin\alpha + p_2 A_2 \sin\alpha + \tau_1 A_1 \cos\alpha + \tau_2 A_2 \cos\alpha$

or with $A_1 = A_2 = 1\,m^2$ and $\alpha = 7°$,

$$\mathcal{D} = A_1 \sin\alpha\,(p_2 - p_1) + A_1 \cos\alpha\,(\tau_1 + \tau_2)$$
$$= (1m^2)\sin 7°\,(2.3-(-1.2))\,\frac{kN}{m^2} + (1m^2)\cos 7°\,(5.8\times10^{-2} + 7.6\times10^{-2})\,\frac{kN}{m^2}$$
$$= 0.427\,kN + 0.133\,kN = \underline{0.560\,kN}$$

Note, if shear stress is neglected $\mathcal{D} = \underline{0.427\,kN}$ (ie, $\tau_1 = \tau_2 = 0$)

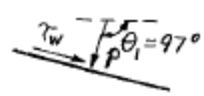
Also, $\mathcal{L} = -p_1 A_1 \cos\alpha + p_2 A_2 \cos\alpha - \tau_1 A_1 \sin\alpha - \tau_2 A_2 \sin\alpha$

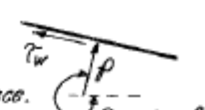
or

$$\mathcal{L} = A_1 \cos\alpha\,(p_2 - p_1) - A_1 \sin\alpha\,(\tau_1 + \tau_2)$$
$$= (1m^2)\cos 7°(2.3-(-1.2))\,\frac{kN}{m^2} - (1m^2)\sin 7°\,(5.8\times10^{-2} + 7.6\times10^{-2})\,\frac{kN}{m^2}$$
$$= 3.47\,kN - 0.0163\,kN = \underline{3.45\,kN}$$

Note, if shear stress is neglected $\mathcal{L} = \underline{3.47\,kN}$

Note: If the general expressions $\mathcal{D} = \int p \cos\theta\, dA + \int \tau_w \sin\theta\, dA$ and $\mathcal{L} = -\int p \sin\theta\, dA + \int \tau_w \cos\theta\, dA$ are use, be careful about the signs involved. On the upper surface $\theta_1 = 97°$ and p and τ_w are positive as indicated in the figure. On the lower surface $\theta_2 = 277°$ and p and τ_w are positive as indicated in the lower figure.





For example, with this notation $\tau_w < 0$ on the lower surface.

$$\mathcal{L} = -(-1.2\,\frac{kN}{m^2})\sin 97°(1m^2) - (2.3\,\frac{kN}{m^2})\sin 277°(1m^2)$$
$$+ (5.8\times10^{-2}\,\frac{kN}{m^2})\cos 97°(1m^2) + (-7.6\times10^{-2}\,\frac{kN}{m^2})\cos 277°(1m^2)$$
$$= 3.45\,kN\text{, as obtained above.}$$