ME 423: FLUIDS ENGINEERING

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Lecture-03-04 (07/09/2024)
Hydraulics of Pipeline Systems

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Problem

(Example Problem 2.3)

The pipe in Example Problem 2.2 actually connects two reservoirs having a difference in water surface of only 20 ft, so that pipe is clearly incapable of conveying 8 ft^3/s. Now a new pipe has been installed between the reservoirs. If it is made of welded steel and has a diameter of 18 in.

(a) If only pipe friction is considered, what is the new discharge?

(b) If local losses for a sharp-edged entrance, a fully open gate valve near the pipe exit, and the pipe exit itself are also considered, how much does the computed discharge change?

(c) If the gate valve in part (b) were only ¼ open, what would then be the discharge?

Fluid is 60°F with a kinematic viscosity of $\nu = 1.2 \times 10^{-5}$ ft^2/s.

All parts of this problem belong to category 2, since now Q and not h_L is sought.

(a) We are told to assume in this case that

$$z_1 - z_2 = 20\,ft = h_f = f\frac{L}{D}\frac{V^2}{2g}$$

From Table 2.1 for welded steel, we find $e/D = 0.0018/18 = 0.0001$. If the flow is assumed to be in the wholly rough flow zone of the Moody diagram, Fig. 2.2, $f = 0.012$. Hence

$$h_f = 20 = (0.012)\frac{1200}{18/12}\frac{V^2}{2(32.2)}$$

Table 2.1 PIPE ROUGHNESSES

Material	e, mm	e, in
Riveted Steel	0.9 - 9.0	0.035 - 0.35
Concrete	0.30 - 3.0	0.012 - 0.12
Cast Iron	0.26	0.010
Galvanized Iron	0.15	0.006
Asphalted Cast Iron	0.12	0.0048
Commercial or Welded Steel	0.045	0.0018
PVC, Drawn Tubing, Glass	0.0015	0.000 06

and $V = 11.6$ ft/s. Now we must check $Re = VD/\nu = 11.6(18/12)//1.2\text{x}10^{-5} = 1.4\text{x}10^{6}$, which is not in the wholly rough zone; this Re and the value of e/D imply $f = 0.013$. Using 0.013 in place of 0.012 leads to $V = 11.1$ ft/s. The small change in Re will cause no further change in f, so the discharge can now be computed as

$$Q = VA = (11.1)\frac{\pi}{4}\left(\frac{18}{12}\right)^2 = (11.1)(1.77) = 19.6\ ft^3/s$$

(b) In this case

$$20 = \sum h_L = \left(K_{ent.} + f\frac{L}{D} + K_{valve} + K_{exit}\right)\frac{V^2}{2g}$$

The velocity head factors out only because each loss term is associated with the same pipe size, area and velocity. Table 2.5 supplies 0.5 and 0.2 for the entrance and valve loss coefficients; always $K_{exit} = 1.0$. From part (a) we take our first estimate of the friction factor as 0.013, leading to

$$20 = \left(0.5 + 0.013\frac{1200}{18/12} + 0.2 + 1.0\right)\frac{V^2}{2g}$$

and yielding $V = 10.3$ ft/s. Again check $Re = VD/\nu = 10.3(18/12)//1.2\text{x}10^{-5} = 1.3\text{x}10^{6}$, so the initial estimate of f is adequate. Now $Q = (10.3)(1.77) = 18.2$ ft^3/s so the discharge has decreased by 1.4 ft^3/s, a bit under 8%, as a consequence of considering the local losses.

Table 2.5 Loss Coefficients for Fitting

Fitting	K_L
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Butterfly valve, fully open	0.4
Gate valve, fully open	0.2
3/4 open	1.0
1/2 open	5.6
1/4 open	17.0
Check valve, swing type, fully open	2.3
Check valve, lift type, fully open	12.0
Check valve, ball type, fully open	70.0
Foot valve, fully open	15.0
Elbow, 45°	0.4
Long radius elbow, 90°	0.6
Medium radius elbow, 90°	0.8
Short radius (standard) elbow, 90°	0.9
Close return bend, 180°	2.2
Pipe entrance, rounded, r/D < 0.16	0.1
Pipe entrance, square-edged	0.5
Pipe entrance, re-entrant	0.8

(c) When the gate valve is only 1/4 open, we find from Table 2.5 that the valve loss coefficient has increased from 0.2 to 17.0. The valve loss remains a local loss, but it is no longer in any way a minor loss, since it will cause more head loss than the pipe friction term. Replacing 0.2 in part (b) by 17.0, we recompute and find V = 6.68 ft/s. The new, lower Reynolds number is $Re = 8.4\text{x}10^5$, so the new friction factor is $f = 0.0135$. A re-computation of the velocity gives V = 6.63 ft/s, and so Q = 11.7 $\text{ft}^3\text{/s}$, a decrease of about one third from the discharge in part (b).

Table 2.5 Loss Coefficients for Fitting

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Globe valve, fully open	10.0
Angle valve, fully open	5.0
Butterfly valve, fully open	0.4
Gate valve, fully open	0.2
3/4 open	1.0
1/2 open	5.6
1/4 open	17.0
Check valve, swing type, fully open	2.3
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Foot valve, fully open	15.0
Elbow, 45°	0.4
Long radius elbow, 90°	0.6
Medium radius elbow, 90°	0.8
Short radius (standard) elbow , 90°	0.9
Close return bend, 180°	2.2
Pipe entrance, rounded, r/D < 0.16	0.1
Pipe entrance, square-edged	0.5
Pipe entrance, re-entrant	0.8

Problem

7.132 What pump power (85% efficient) is needed for a flow rate of 0.01 m^3/s in the pipe shown in Fig. P7.132? What is the greatest distance from the left reservoir that the pump can be located?

Vapor pressure of water at 15°C = 1702.4 Pa abs

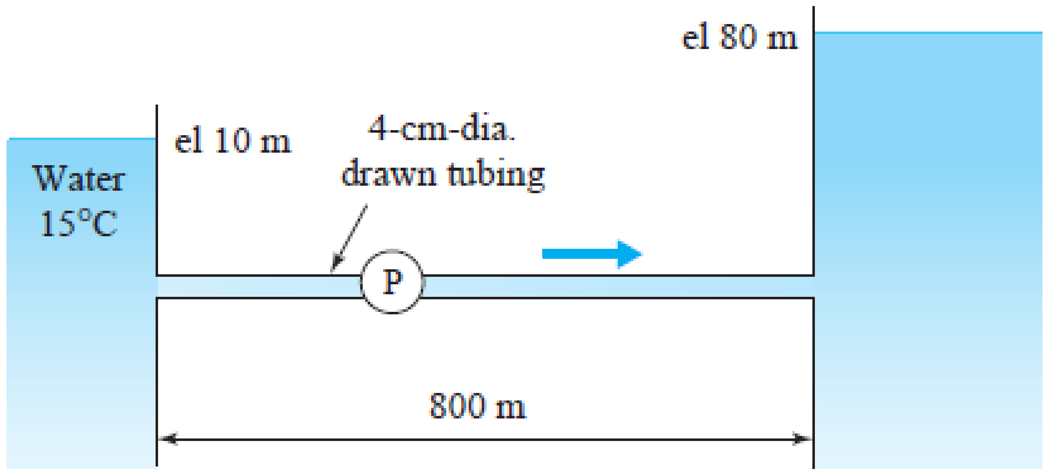

Fig. P7.132

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$$V = \frac{Q}{A} = \frac{0.01}{\pi \times 0.02^2} = 7.96 \text{ m/s} \qquad \mathrm{Re} = \frac{7.96 \times 0.04}{1.14 \times 10^{-6}} = 2.8 \times 10^5$$

$$\frac{e}{D} = \frac{0.0015}{40} = 3.8 \times 10^{-5}$$

$$\therefore f = 0.0145$$

$$H_P = 80 - 10 + \left(0.5 + 1.0 + 0.0145\frac{800}{0.04}\right)\frac{7.96^2}{2\times 9.81} = 1010 \text{ m.}$$

$$\therefore \dot{W}_P = \frac{\gamma Q H_P}{\eta_P} = \frac{9810\times 0.01\times 1010}{0.85} = \underline{117{,}000 \text{ W}}$$

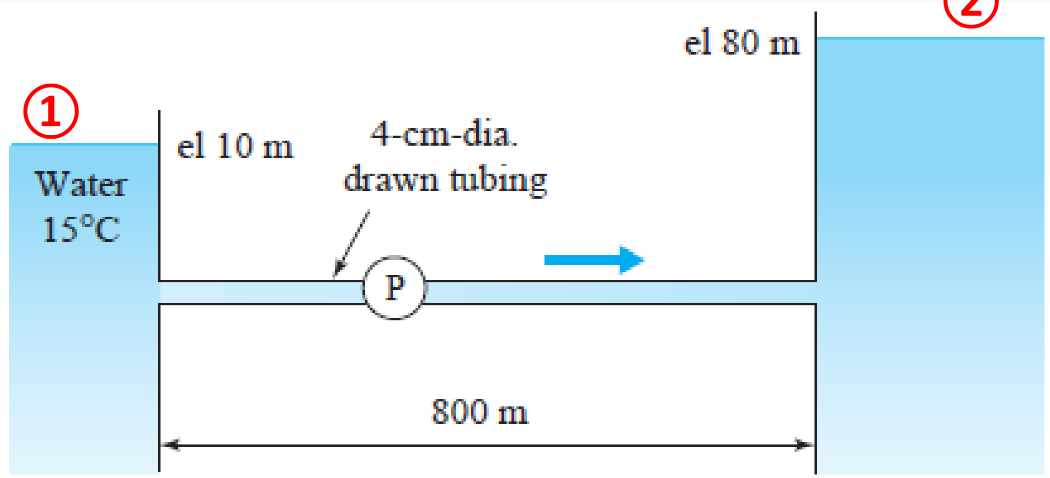

Fig. P7.132

To avoid cavitation, the pressure at the suction side of the pump should be at least equal to the vapor pressure of water.

$$0 = \frac{7.96^2}{2\times 9.81} + \frac{1702 - 101325}{9810} + 0 - 10 + \left(0.5 + 0.0145\frac{L}{0.04}\right)\frac{7.96^2}{2\times 9.81}$$

L = 13.1 m   Ans.

Table 2.5 Loss Coefficients for Fitting

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Globe valve, fully open	10.0
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Elbow, 45°	0.4
Long radius elbow, 90°	0.6
Medium radius elbow, 90°	0.8
Short radius (standard) elbow, 90°	0.9
Close return bend, 180°	2.2
Pipe entrance, rounded, r/D < 0.16	0.1
Pipe entrance, square-edged	0.5
Pipe entrance, re-entrant	0.8

Problem

7.134 What pump power (75% efficient) is needed in the piping system shown in Fig. P7.134? What is the greatest distance from the reservoir that the pump can be located?

Vapor pressure of water at 15°C = 1702.4 Pa abs

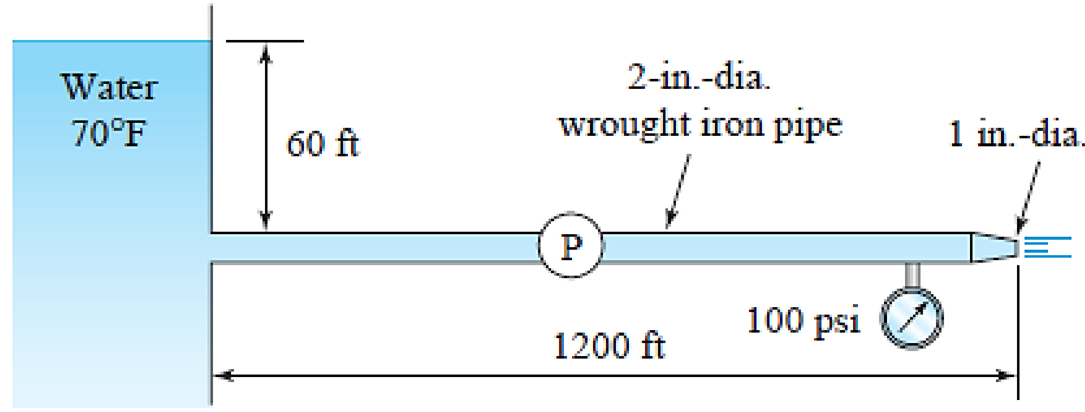

Fig. P7.134

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Energy across nozzle (neglect losses): $\dfrac{V_1^2}{2g}+\dfrac{690\times10^3}{9810}=\dfrac{V_2^2}{2g}=\dfrac{(4V_1)^2}{2g}$

$\therefore V_1 = 9.6\ \text{m/s}$ $\quad \text{Re}=\dfrac{9.6\times0.05}{1.007\times10^{-6}}=4.8\times10^5$ $\quad \dfrac{e}{D}=\dfrac{0.000045}{0.05}=0.0009$

$\therefore f = 0.02$

(1 psi = 6.89 kPa)

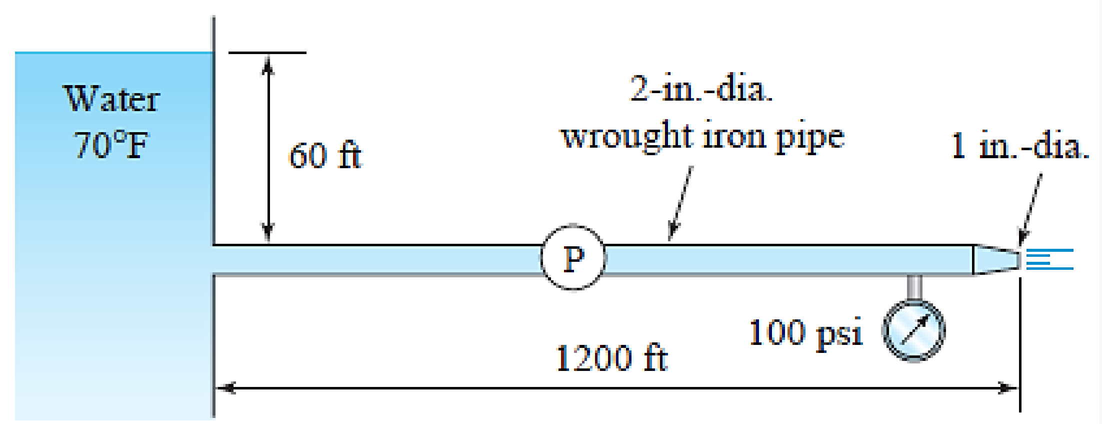

Fig. P7.134

$$H_P = \frac{(4\times 9.6\ \ )^2}{19.62} - 18 + \left(0.5 + 0.02\frac{360}{0.05}\right)\frac{9.6^2}{19.62} = 677.2 \text{ m}$$

$$\therefore \dot{W}_P = \frac{\gamma Q H_P}{\eta_P} = \frac{9810\times(\pi\times(0.025)^2\times 9.6)\times 677.2}{0.75} = 166.97\times 10^3 \text{ W or } \underline{166.97 \text{ kW}}$$

To avoid cavitation, the pressure at the suction side of the pump should be at least equal to the vapor pressure of water.

$$0 = \frac{9.6^2}{2\times 9.81} + \frac{1702 - 101325}{9810} - 18 + \left(0.5 + 0.02\frac{L}{0.05}\right)\frac{9.6^2}{2\times 9.81}$$

$L = 11.2$ m   Ans.

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Fitting	K_L
Globe valve, fully open	10.0
Angle valve, fully open	5.0
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