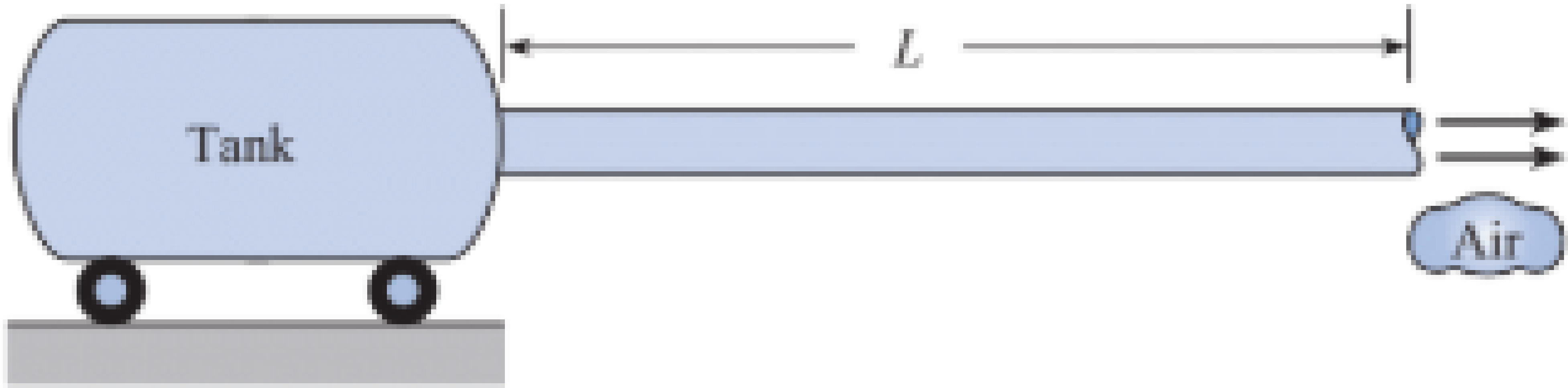
Mech Family

كن أنت التغيير

اللجنة الأكاديمية في قسم الهندسة الميكانيكية

10.6 WILEY PLUS As shown, air (20°C) is flowing from a large tank, through a horizontal pipe, and then discharging to ambient. The pipe length is $L = 50$ m, and the pipe is schedule 40 PVC with a nominal diameter of 1 inch. The mean velocity in the pipe is 10 m/s, and $f = 0.015$. Determine the pressure (in Pa) that needs to be maintained in the tank.



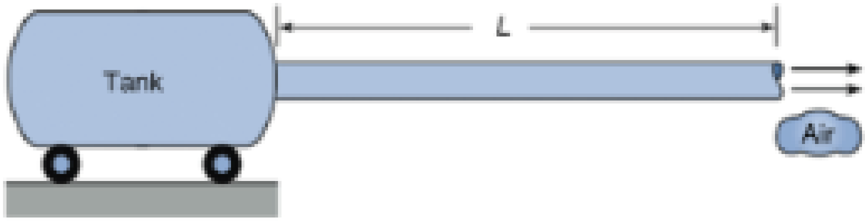
PROBLEM 10.6

10.6: PROBLEM DEFINITION

Situation:

SITUATION

Air is flowing from a large tank to ambient through a horizontal pipe.
Pipe is 25 mm Schedule 40. $D = 0.0266\,\text{m}$.
$V = 10\,\text{m/s}$. $f = 0.015$, $L = 50\,\text{m}$.



Assumptions:
Air has constant density (look up properties at 1 atm).
KE correction factor is $\alpha_2 = 1.0$.

Properties:
Air (20 °C, 1 atm, Table A.3): $\rho = 1.2\,\text{kg/m}^3$.

PLAN

1. Relate pressure in tank to head loss using the energy equation.
2. Describe head loss using the Darcy-Weisbach equation.
3. Combine steps 1 & 2.

SOLUTION

1. Energy eqn. (location 1 inside the tank, location 2 at the pipe exit)

$$\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_t + h_L$$

$$\frac{p_1}{\gamma} + 0 + 0 + 0 = 0 + \frac{V_2^2}{2g} + 0 + h_f \qquad (1)$$

2. Darcy-Weisbach eqn.:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \qquad (2)$$

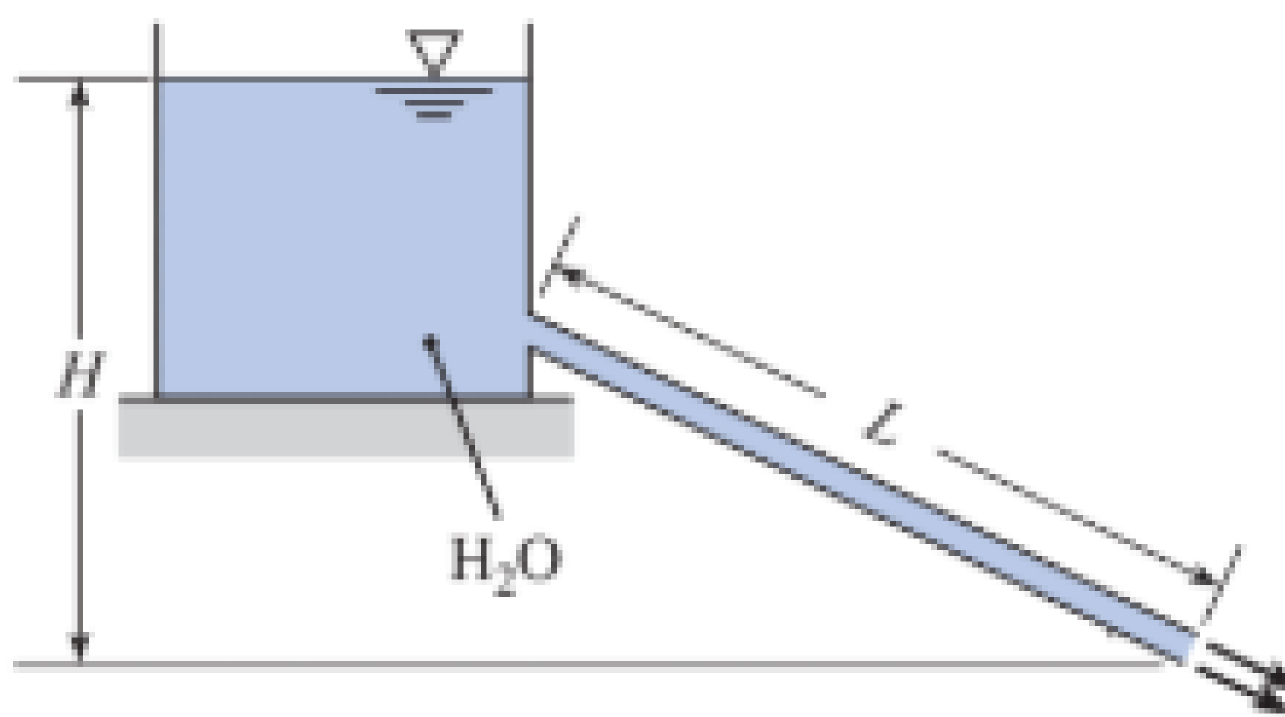
3. Combine Eqs. (1) and (2).

$$\begin{aligned} p_1 &= \gamma \frac{V_2^2}{2g}\left(1 + f\frac{L}{D}\right) = \frac{\rho V_2^2}{2}\left(1 + f\frac{L}{D}\right) \\ &= \frac{(1.2\,\text{kg/m}^3)(10\,\text{m/s})^2}{2}\left(1 + (0.015)\frac{(50\,\text{m})}{(0.0266\,\text{m})}\right) \\ &= 1.75\,\text{kPa-gage} \end{aligned}$$

$$\boxed{p_{\text{tank}} = 1.75\,\text{kPa gage}}$$

REVIEW The constant density assumption is valid because the pressure in the tank is less than 2% of atmospheric pressure.

10.8 As shown, water (15°C) is flowing from a tank through a tube and then discharging to ambient. The tube has an ID of 8 mm and a length of $L = 6$ m, and the resistance coefficient is $f = 0.015$. The water level is $H = 3$ m. Find the exit velocity in m/s. Find the discharge in L/s. Sketch the HGL and the EGL. Assume that the only head loss occurs in the tube.



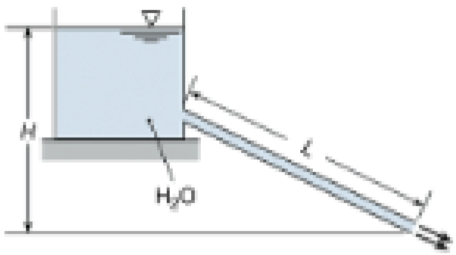
PROBLEM 10.8

10.8: PROBLEM DEFINITION

Situation:

Water is flowing from a tank through a tube & then discharging to ambient.
$D = 0.008\,\text{m}$, $L = 6\,\text{m}$.
$H = 3\,\text{m}$, $f = 0.015$.

Sketch:



Find:

Exit velocity (m/s).
Discharge (L/s).
Sketch the HGL & EGL.

Assumptions:

The only head loss is in the tube.
Turbulent flow so $\alpha_2 = 1.0$.

Properties:

Water (15 °C), Table A.5 (EFM10e), $\rho = 999\,\text{kg/m}^3$ $\nu = 1.14 \times 10^{-6}\,\text{m}^2/\text{s}$.

PLAN

1. Relate H to head loss using the energy equation.
2. Describe head loss using the Darcy-Weisbach equation.
3. Find V by combining steps 1 & 2.
4. Find Q by using the flow rate equation.

SOLUTION

1. Energy eqn. (location 1 at the free surface, location 2 at the pipe exit)

$$\frac{p_1}{\gamma} + \alpha_1\frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \alpha_2\frac{V_2^2}{2g} + z_2 + h_t + h_L$$

$$0 + 0 + H + 0 = 0 + \frac{V_2^2}{2g} + 0 + h_L \quad (1)$$

2. Darcy-Weisbach eqn.:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \quad (2)$$

3. Combine Eqs. (1) and (2):

$$H = \frac{V_2^2}{2g}\left(1 + f\frac{L}{D}\right)$$
$$V_2 = \sqrt{\frac{2gH}{1+f\frac{L}{D}}}$$
$$= \sqrt{\frac{2\,(9.81\text{ m/s}^2)\,(3\text{ m})}{1+0.015\frac{(6\text{ m})}{(0.008\text{ m})}}}$$
$$\boxed{V = 2.19\text{ m/s}}$$

4. Flow rate equation:

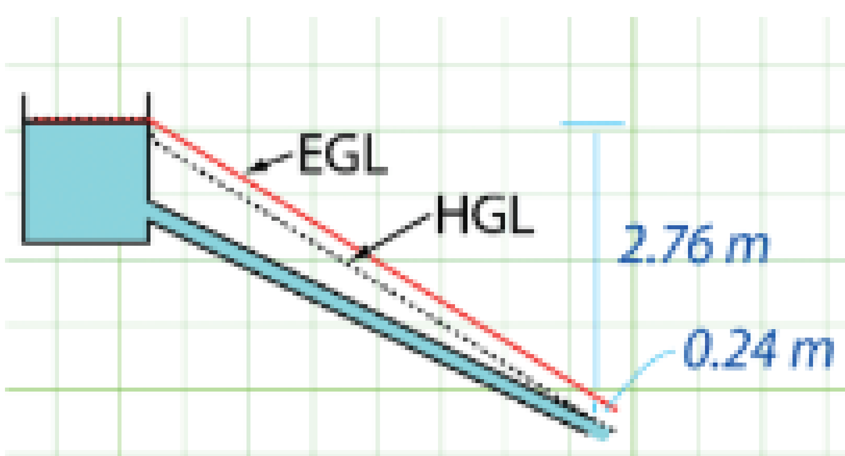
$$Q = VA = V\frac{\pi D^2}{4} = (2.192\text{ m/s})\,\frac{\pi\,(0.008\text{ m})^2}{4}$$
$$\boxed{Q = 0.110\text{ L/s}}$$

5. Sketch HGL & EGL

- Locate the EGL & HGL on free surface of tank.
- Velocity head and head loss:

$$\frac{V^2}{2g} = \frac{(2.192\text{ m/s})^2}{2\,(9.81\text{ m/s}^2)} = 0.24\text{ m}$$
$$h_f = f\frac{L}{D}\frac{V^2}{2g} = 0.015\frac{(6\text{ m})}{(0.008\text{ m})}\frac{(2.192\text{ m/s})^2}{2\,(9.81\text{ m/s}^2)} = 2.76\text{ m}$$

- Locate the EGL and HGL at the end of the pipe. Sketch lines.

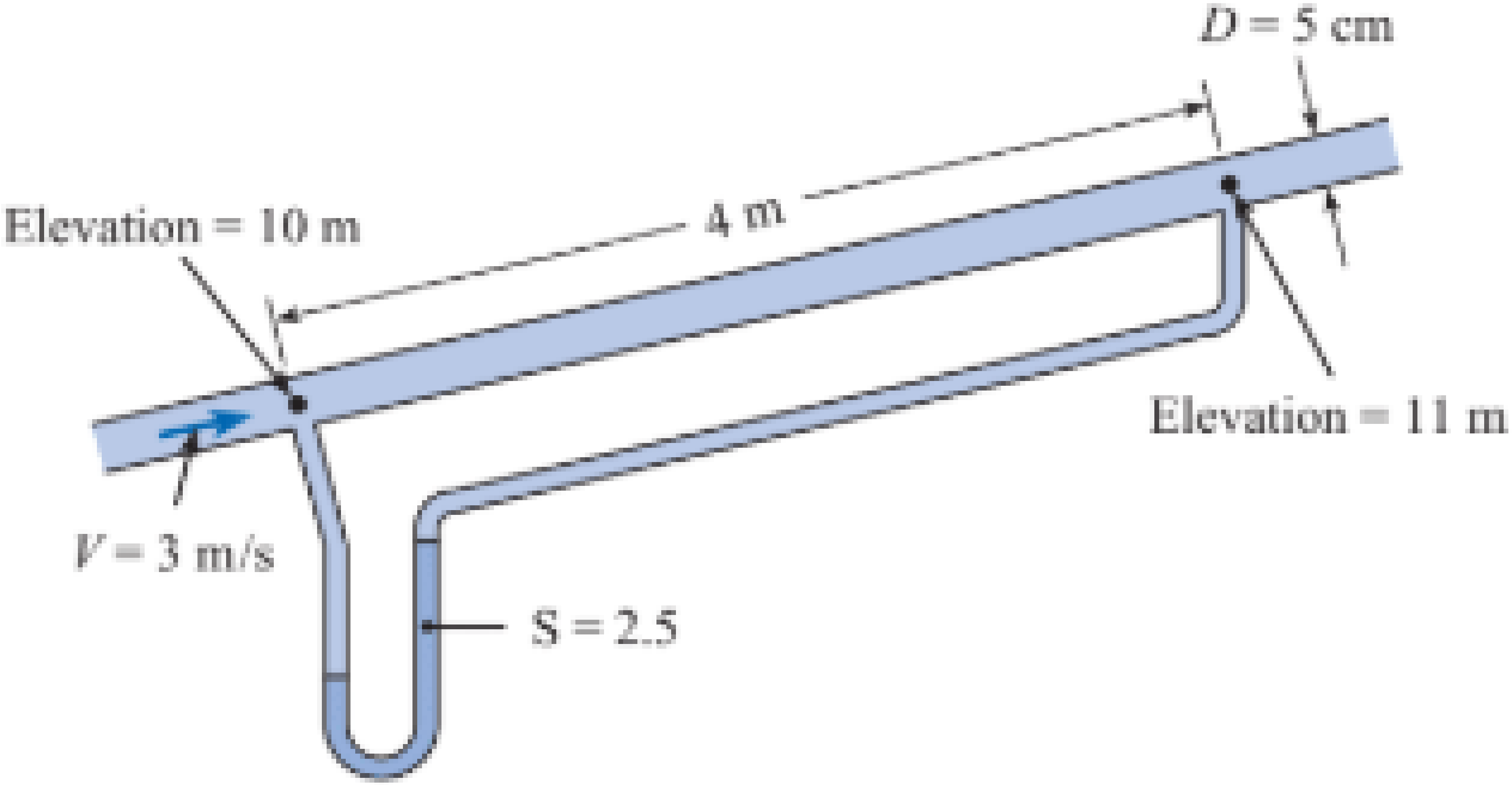


REVIEW Check the turbulent flow assumption.

$$\text{Re} = \frac{VD}{\nu} = \frac{(2.192\text{ m/s})\,(0.008\text{ m})}{(1.14\times10^{-6}\text{ m}^2/\text{s})}$$
$$\text{Re} = 15400 > 3000$$

Thus, the assumption of turbulent flow is valid.

10.9 WILEY PLUS Water flows in the pipe shown, and the manometer deflects 90 cm. What is f for the pipe if $V = 3$ m/s?



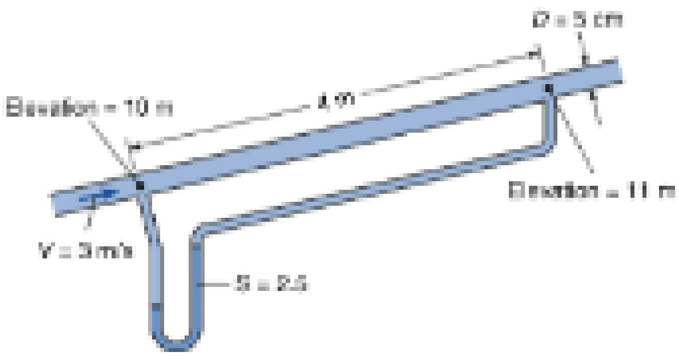
PROBLEM 10.9

10.9: PROBLEM DEFINITION

Situation:

Water flows through a pipe.
$V = 3\,\text{m/s}$, $z_1 = 10\,\text{m}$.
$z_2 = 11\,\text{m}$, $D = 5\,\text{cm}$

Sketch:



Find: Resistance coefficient, f.

SOLUTION

Manometer equation

$$\begin{aligned} h_f &= \Delta h_{\text{manometer}} (\gamma_m/\gamma_{\text{H2O}} - 1) \\ h_f &= (0.90\,\text{m})(2.5 - 1) = 1.35 \text{ m of water} \end{aligned}$$

Darcy Weisbach

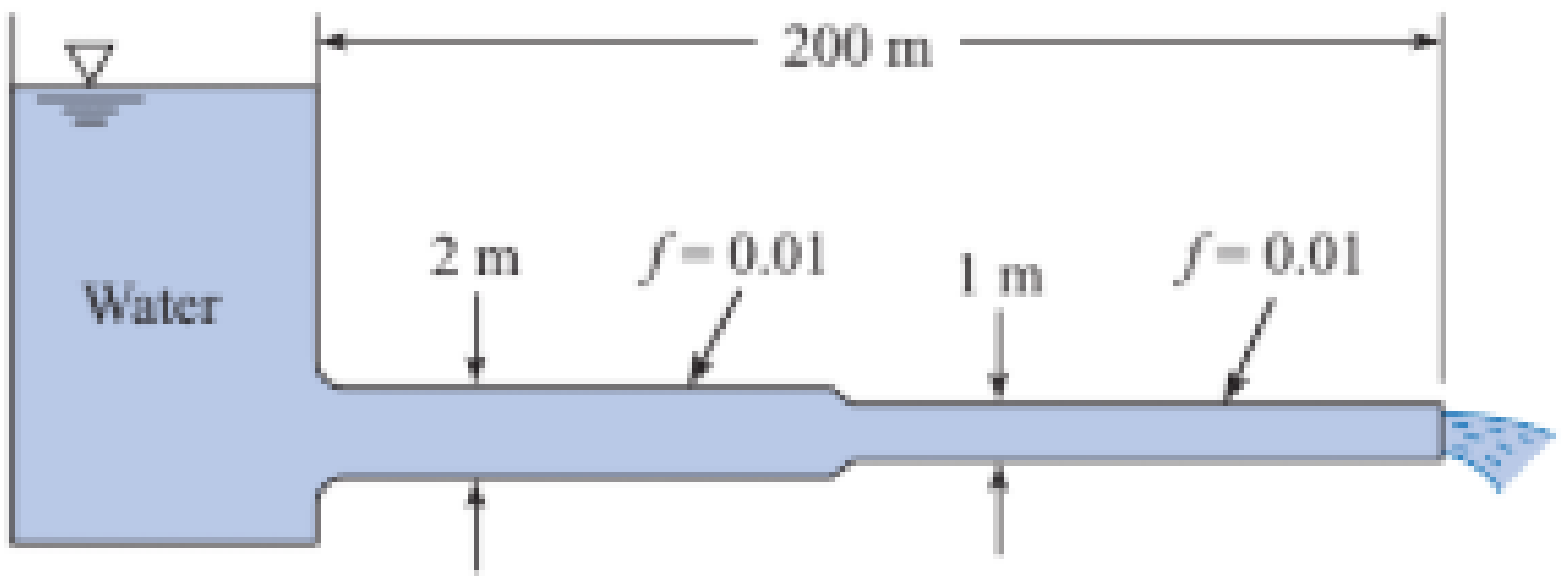
$$h_f = f(L/D)V^2/2g$$

Solve for f

$$\begin{aligned} f &= h_f \left(\frac{D}{L}\right)\left(\frac{2g}{V^2}\right) \\ &= (1.35\,\text{m})\left(\frac{0.05\,\text{m}}{4\,\text{m}}\right)\left(\frac{2\,(9.81\,\text{m/s}^2)}{(3\,\text{m/s})^2}\right) \end{aligned}$$

$$\boxed{f = 0.037}$$

10.22 In the pipe system shown, for a given discharge, the ratio of the head loss in a given length of the 1 m pipe to the head loss in the same length of the 2 m pipe is (a) 2, (b) 4, (c) 16, or (d) 32.



PROBLEM 10.22

10.22: PROBLEM DEFINITION

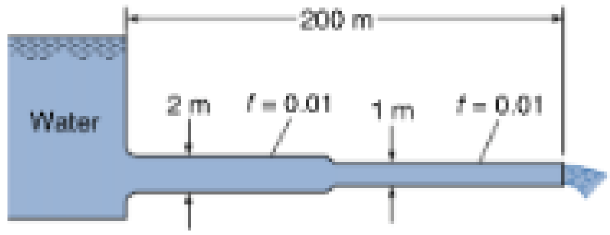
Situation:

Fluid flows out of a tank through a pipe with an abrupt contraction.

$L_1 = L_2 = 100\,\text{m}$, $f = 0.01$.

$D_1 = 2\,\text{m}$, $D_2 = 1\,\text{m}$.

Sketch:



Find:

Ratio of head loss.

$$\frac{h_L\,(\text{1-m pipe})}{h_L\,(\text{2-m pipe})}$$

SOLUTION

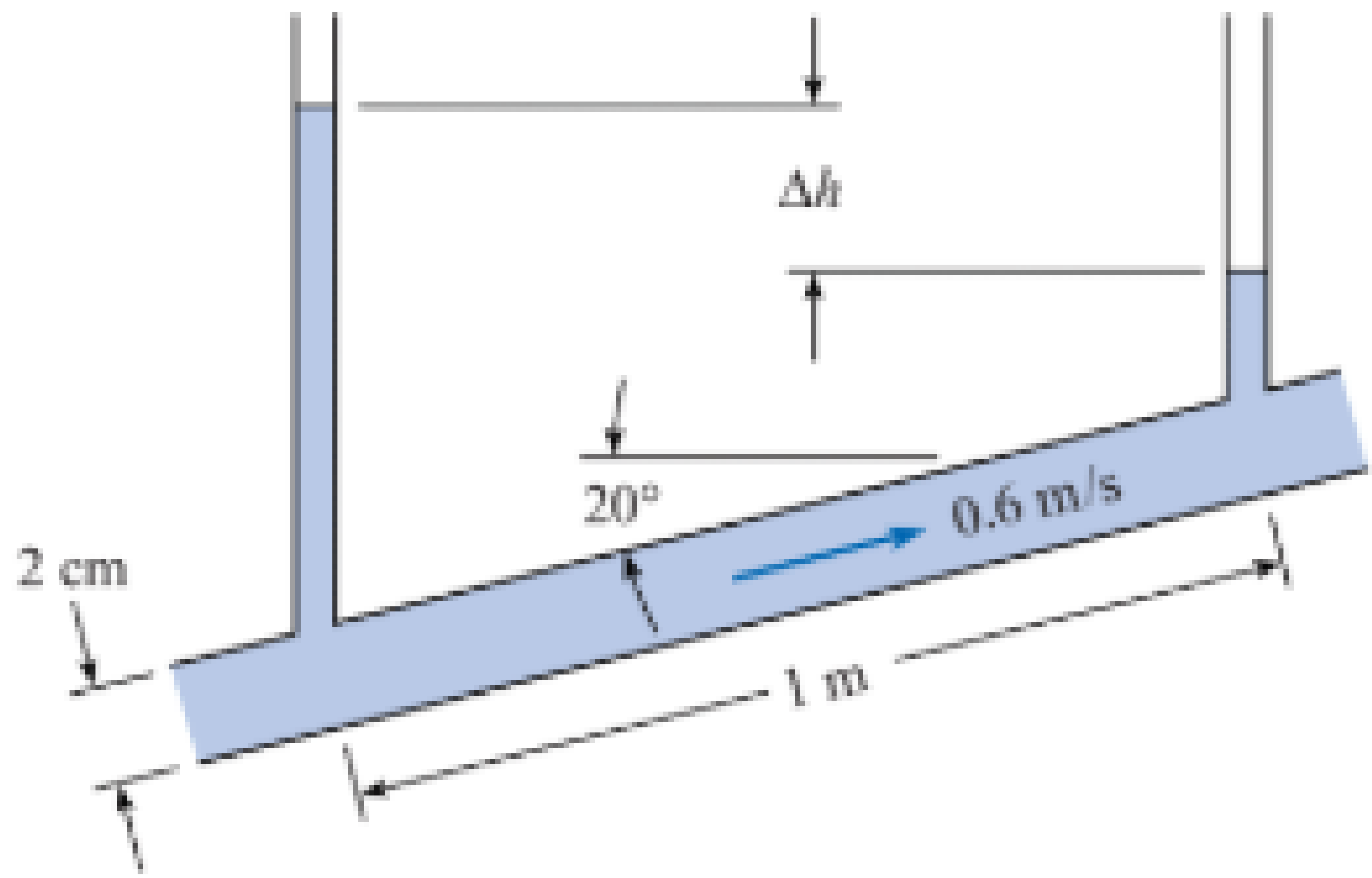
$$\begin{aligned}
h_L &= f\frac{L}{D}\frac{V^2}{2g} \\
\frac{h_L\,(\text{1-m pipe})}{h_L\,(\text{2-m pipe})} &= \left(\frac{f_1 L_1 V_1^2/(D_1)}{f_2 L_2 V_2^2/(D_2)}\right) \\
&= \left(\frac{D_2}{D_1}\right)\left(\frac{V_1^2}{V_2^2}\right) \\
V_1 A_1 &= V_2 A_2 \\
\frac{V_1}{V_2} &= \frac{A_2}{A_1} = \left(\frac{D_2}{D_1}\right)^2 \\
\left(\frac{V_1}{V_2}\right)^2 &= \left(\frac{D_2}{D_1}\right)^4
\end{aligned}$$

Thus

$$\begin{aligned}
\frac{h_L\,(\text{1-m pipe})}{h_L\,(\text{2-m pipe})} &= \left(\frac{D_2}{D_1}\right)\left(\frac{D_2}{D_1}\right)^4 \\
&= \left(\frac{D_2}{D_1}\right)^5 = 2^5 = 32
\end{aligned}$$

Correct choice is (d)

10.29 Glycerine at 20°C flows at 0.6 m/s in the 2-cm commercial steel pipe. Two piezometers are used as shown to measure the piezometric head. The distance along the pipe between the standpipes is 1 m. The inclination of the pipe is 20°. What is the height difference Δh between the glycerine in the two standpipes?



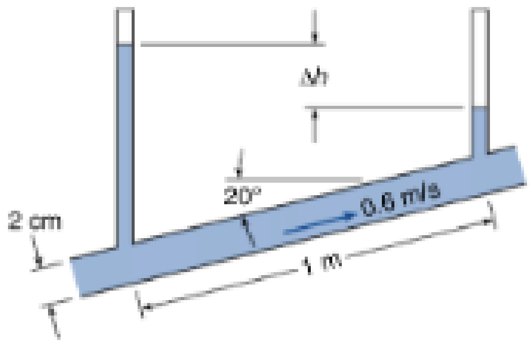
PROBLEM 10.29

10.29: PROBLEM DEFINITION

Situation:

Glycerin flows through a commercial steel pipe connected to two piezometers.
$D = 2\,\text{cm}$, $V = 0.6\,\text{m/s}$.

Sketch:



Find:

Height differential (in m).

Properties:

Glycerin (20 °C), Table A.4, $\mu = 1.41\,\text{N}\cdot\text{s/m}^2$, $\nu = 1.12\times 10^{-3}\,\text{m}^2/\text{s}$.

SOLUTION

Energy equation (apply from one piezometer to the other)

$$\begin{aligned} p_1/\gamma + \alpha_1 V_1^2/2g + z_1 &= p_2/\gamma + \alpha_2 V_2^2/2g + z_2 + h_L \\ p_1/\gamma + z_1 &= p_2/\gamma + z_2 + h_L \\ ((p_1/\gamma) + z_1)) - ((p_2/\gamma) + z_2) &= h_L \\ \Delta h &= h_L \end{aligned}$$

Reynolds number

$$\begin{aligned} \text{Re} &= \frac{VD}{\nu} \\ &= \frac{(0.6)(0.02)}{1.12\times 10^{-3}} \\ &= 10.71 \end{aligned}$$

Since Re < 2000, the flow is laminar. The head loss for laminar flow is

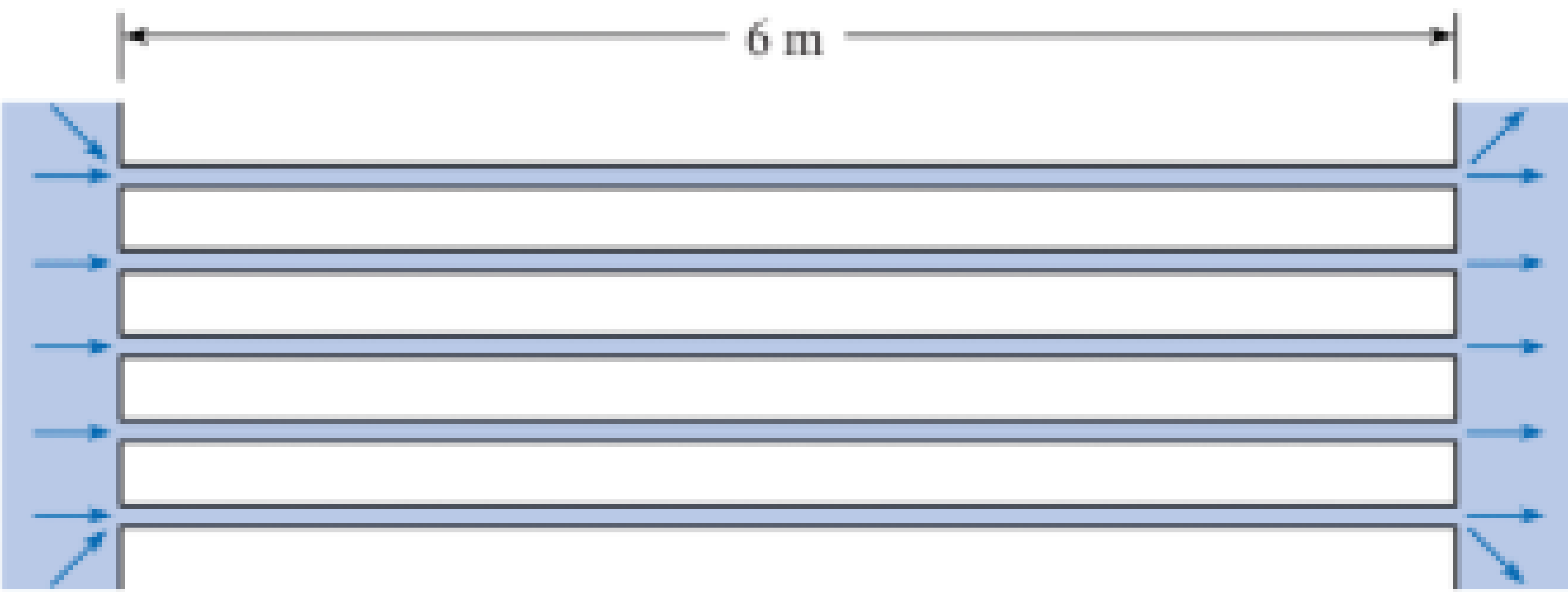
$$\begin{aligned} h_L &= \frac{32\mu LV}{\gamma D^2} \\ &= \frac{(32)(1.41)(1)(0.6)}{12300\times 0.02^2} \\ &= \boxed{5.502\text{ m}} \end{aligned}$$

Energy equation

$$\Delta h = h_L$$

$$\boxed{\Delta h = 5.502 \text{ m}}$$

10.30 Water is pumped through a heat exchanger consisting of tubes 6 mm in diameter and 6 m long. The velocity in each tube is 12 cm/s. The water temperature increases from 20°C at the entrance to 30°C at the exit. Calculate the pressure difference across the heat exchanger, neglecting entrance losses but accounting for the effect of temperature change by using properties at average temperatures.



PROBLEM 10.30

10.30: PROBLEM DEFINITION

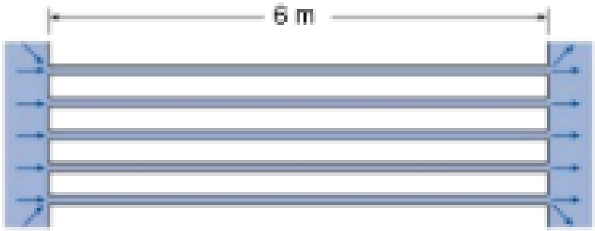
Situation:

Water is pumped through tubes in a heat exchanger

$D = 6\,\text{mm}$, $L = 6\,\text{m}$, $V = 0.12\,\text{m/s}$.

$T_1 = 20\,^\circ\text{C}$, $T_2 = 30\,^\circ\text{C}$.

Sketch:



Find:

Pressure difference across heat exchanger.

Properties:

Water (20 °C), Table A.5: $\nu = 10^{-6}\,\text{m}^2/\text{s}$.

SOLUTION

Reynolds number (based on temperature at the inlet)

$$\text{Re}_{20^\circ} = \frac{VD}{\nu} = \frac{0.12\,\text{m/s} \times 0.006\,\text{m}}{10^{-6}\,\text{m}^2/\text{s}} = 720$$

Since Re ≤ 2000, the flow is laminar. Thus,

$$\Delta p = \frac{32\mu LV}{D^2}$$

Assume linear variation in μ and use the temperature at 25°C. From Table A.5

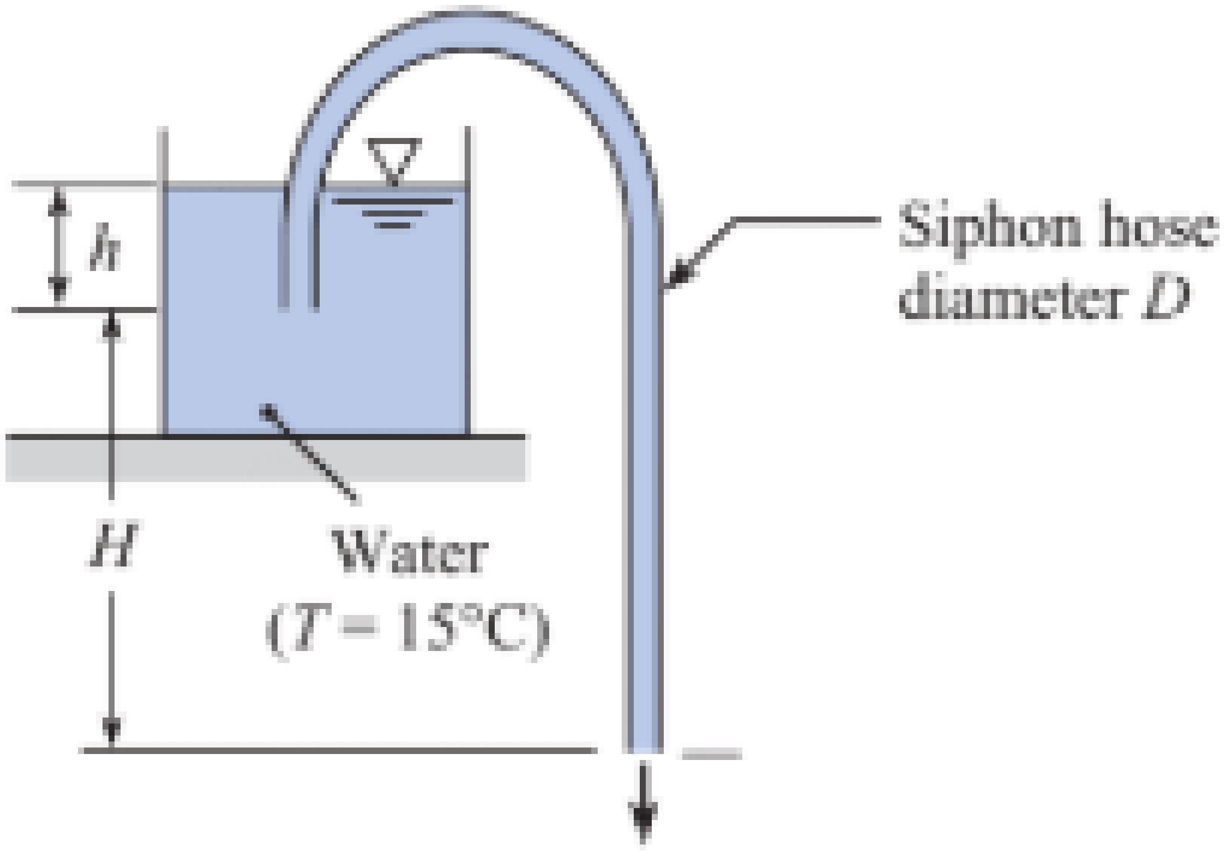
$$\begin{aligned} \mu_{\text{avg.}} &= \mu_{25^\circ} \\ &= 8.91 \times 10^{-4}\,\text{N}\cdot\text{s/m}^2 \end{aligned}$$

and

$$\begin{aligned} \Delta p &= \frac{32\mu LV}{D^2} \\ &= \frac{32 \times 8.91 \times 10^{-4}\,\text{N s/m}^2 \times 6\,\text{m} \times 0.12\,\text{m/s}}{(0.006\,\text{m})^2} = 570\,\text{Pa} \end{aligned}$$

$$\boxed{\Delta p = 570\,\text{Pa}}$$

10.54 A plastic siphon hose of length 7 m is used to drain water (15°C) out of a tank. For a flow rate of 1.5 L/s, what hose diameter is needed? Use $H = 5$ m and $h = 0.5$ m. Assume all head loss occurs in the tube.



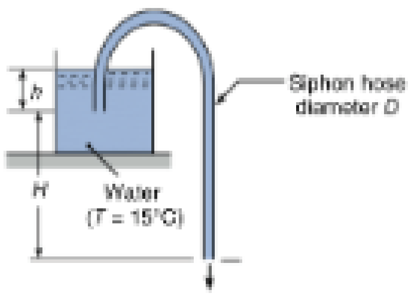
PROBLEMS 10.53, 10.54

10.54: PROBLEM DEFINITION

Situation:

Water is flowing out a plastic siphon hose.
$Q = 0.0015\,\mathrm{m^3/s}$, $H = 5\,\mathrm{m}$.
$h = 0.5\,\mathrm{m}$, $L = 7\,\mathrm{m}$, $k_s = 0$.

Sketch:



Find:

Diameter of hose (meters).

Assumptions:

Steady flow.
Component head loss is zero.
Turbulent flow. Also, $\alpha_2 = 1.0$.

Properties:

Water (15 °C), Table A.5, $\nu = 1.14 \times 10^{-6}\,\mathrm{m^2/s}$.

PLAN Classify this problem as case 3 (D is unknown), then

1. Write the energy eqn., the Darcy-Weisbach eqn., etc. to produce a set of 5 equations with 5 unknowns.
2. Solve the set of equations using a computer program (we used TK Solver).

SOLUTION

1. Governing equations:

- Flow rate equation:

$$Q = V\left(\frac{\pi D^2}{4}\right) \tag{1}$$

- Energy equation (section 1 on water surface, section 2 at exit plane)

$$\begin{aligned}\frac{p_1}{\gamma} + \alpha_1\frac{V_1^2}{2g} + z_1 + h_p &= \frac{p_2}{\gamma} + \alpha_2\frac{V_2^2}{2g} + z_2 + h_t + h_L \\ 0 + 0 + (H + h) + 0 &= 0 + \frac{V_2^2}{2g} + 0 + h_f \end{aligned} \tag{2}$$

- Darcy-Weisbach:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{3}$$

- Swamee-Jain:

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2} \tag{4}$$

- Reynolds number:

$$\mathrm{Re} = \frac{VD}{\nu} \tag{5}$$

3. Solution of Eqs. (1) to (5):

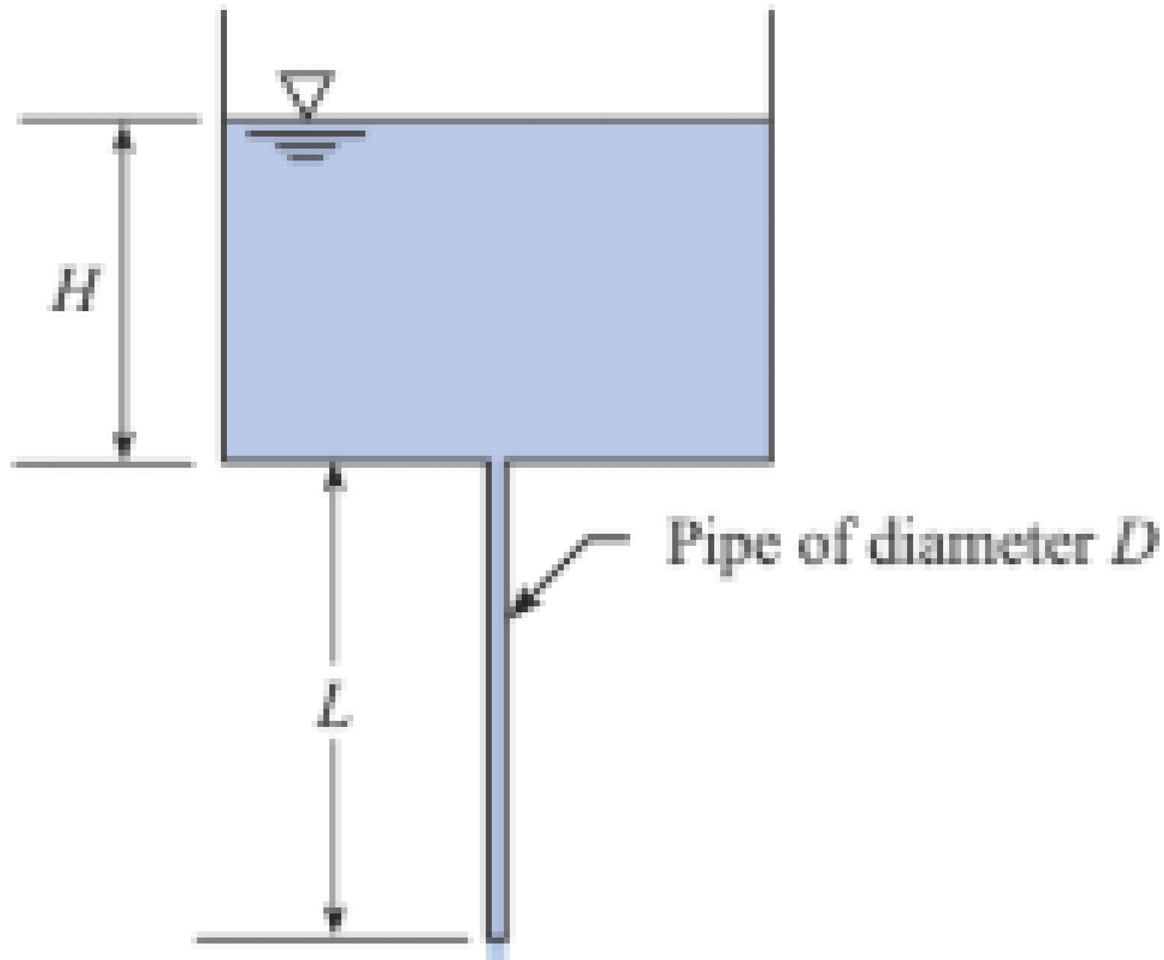
$$\begin{aligned} h_f &= 4.715\,\mathrm{m} \\ \mathrm{Re} &= 75900 \\ f &= 0.0189 \\ V &= 3.92\,\mathrm{m/s} \end{aligned}$$

$$\boxed{D = 0.022\,\mathrm{m}}$$

REVIEW

- Notice that the turbulent flow assumption is valid because $\mathrm{Re} > 2300$.
- An easy way to solve case 2 and case 3 problems is to acquire a computer program that can solve coupled, non-linear equations.
- Notice that most of the elevation head $(5.5\,\mathrm{m})$ is converted to head loss $(4.72\,\mathrm{m})$.

10.56 As shown, water (15°C) is draining from a tank through a galvanized iron pipe. The pipe length is $L = 2$ m, the tank depth is $H = 1$ m, and the pipe is a 0.5 inch NPS schedule 40. Calculate the velocity in the pipe. Neglect component head loss.



PROBLEMS 10.55, 10.56

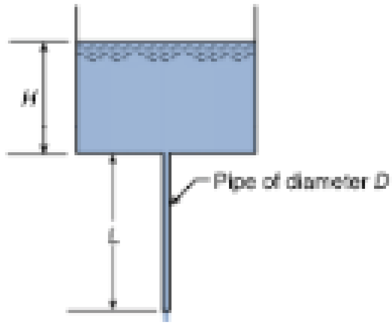
10.56: PROBLEM DEFINITION

Situation:

Water is draining out of a tank through a galvanized iron pipe.

$L = 2\,\text{m}$, $H = 1\,\text{m}$, $k_s = 0.15 \times 10^{-3}\,\text{m}$

The pipe is 15 mm schedule 40 NPS, $D = 0.0158\,\text{m}$.



Find:

Velocity in the pipe (m/s).

Assumptions:

Steady flow.

Component head loss is zero.

Turbulent flow, so $\alpha_2 = 1.0$.

Properties:

Water (15 °C), Table A.5, $\nu = 1.14 \times 10^{-6}\,\text{m}^2/\,\text{s}$.

PLAN

Classify this problem as case 2 (V is unknown), then

1. Write the energy eqn., the Darcy-Weisbach eqn., etc. to produce a set of 4 equations with 4 unknowns.
2. Solve the set of equations using a computer program (we used TK Solver).

SOLUTION

1. Governing equations:

- Energy equation (section 1 on water surface, section 2 at exit plane)

$$\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_t + h_L$$

$$0 + 0 + (H + L) + 0 = 0 + \frac{V_2^2}{2g} + 0 + h_f \qquad (1)$$

- Darcy-Weisbach:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \qquad (2)$$

- Swamee-Jain:

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{\text{Re}^{0.9}}\right)\right]^2} \tag{3}$$

- Reynolds number:

$$\text{Re} = \frac{VD}{\nu} \tag{4}$$

2. Solution of Eqs. (1) to (4):

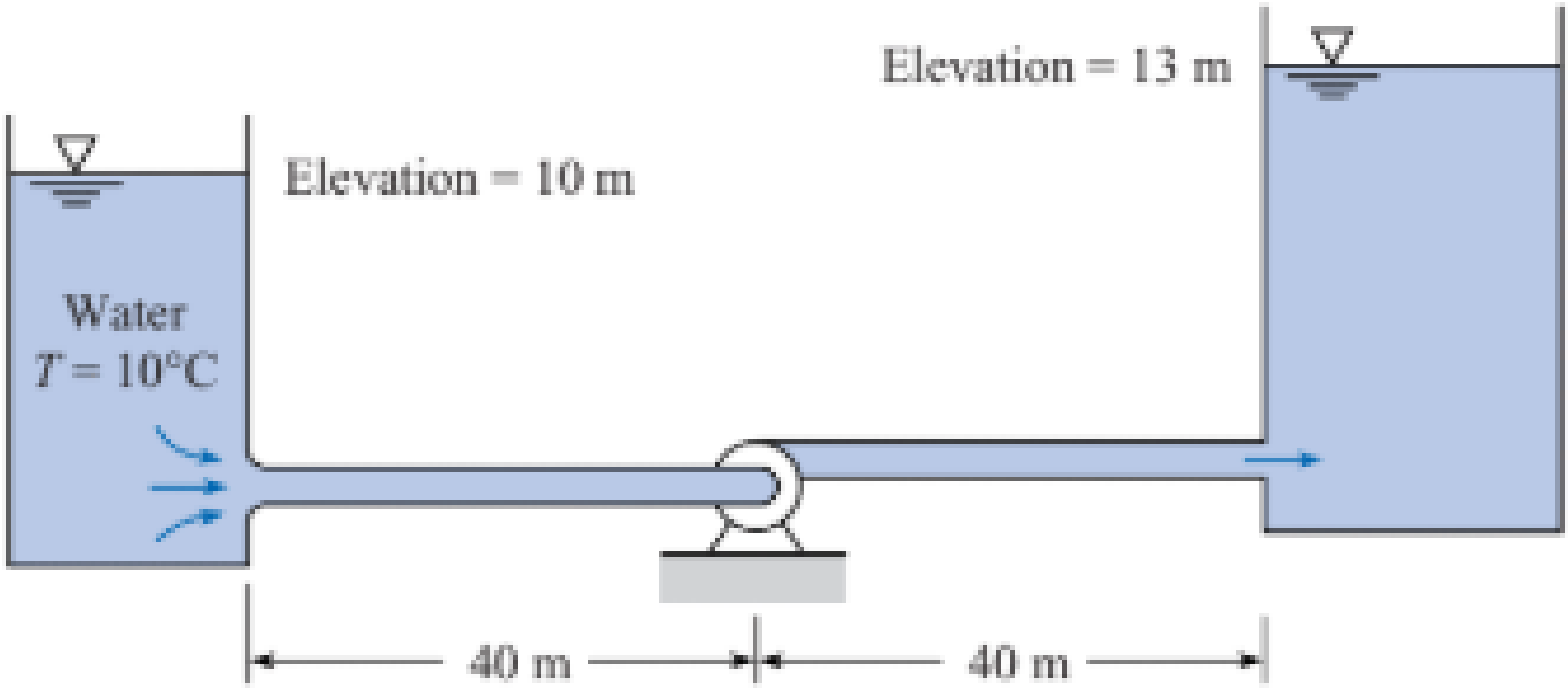
$$\begin{aligned} h_f &= 2.50\,\text{m} \\ \text{Re} &= 43600 \\ f &= 0.039 \end{aligned}$$

$$\boxed{V = 3.15\,\text{m/s}}$$

REVIEW

1. Notice that the turbulent flow assumption is valid because Re > 2300.
2. An easy way to solve case 2 and case 3 problems is to acquire a computer program that can solve coupled, nonlinear equations.

10.63 WILEY PLUS If the flow of 0.10 m^3/s of water is to be maintained in the system shown, what power must be added to the water by the pump? The pipe is made of steel and is 15 cm in diameter.



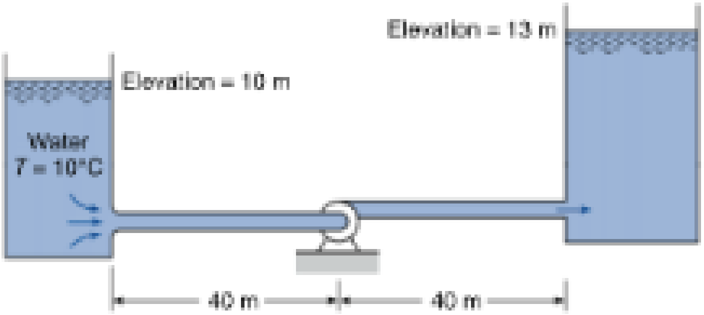
PROBLEM 10.63

10.63: PROBLEM DEFINITION

Situation:

Water is pumped between reservoirs through a steel pipe.
$Q = 0.1\,\text{m}^3/\,\text{s},\ D = 15\,\text{cm}.$

Sketch:



Find:

Power that is supplied to the system by the pump.

Properties:

From Table 10.4: $k_s = 0.046$ mm.
Water (10 °C), Table A.5: $\nu = 1.3 \times 10^{-6}\,\text{m}^2/\,\text{s}$, $\gamma = 9810\,\text{N}/\,\text{m}^3$.

SOLUTION

Flow rate equation

$$\begin{aligned} V &= \frac{Q}{A} \\ &= \frac{0.1\,\text{m}^3/\,\text{s}}{(\pi/4) \times (0.15\,\text{m})^2} \\ &= 5.66\ \text{m/s} \\ \frac{V^2}{2g} &= 1.63\ \text{m} \\ \frac{k_s}{D} &= \frac{0.0046}{15} = 0.0003 \end{aligned}$$

Reynolds number

$$\begin{aligned} \text{Re} &= \frac{VD}{\nu} = \frac{5.66\,\text{m}/\,\text{s} \times 0.15\,\text{m}}{1.3 \times 10^{-6}\,\text{m}^2/\,\text{s}} \\ &= 6.4 \times 10^5 \end{aligned}$$

Resistance coefficient (from the Moody diagram, Fig. 10.14 in EFM10e)

$$f = 0.016$$

Energy equation (between the reservoir surfaces), with a K_e and K_E

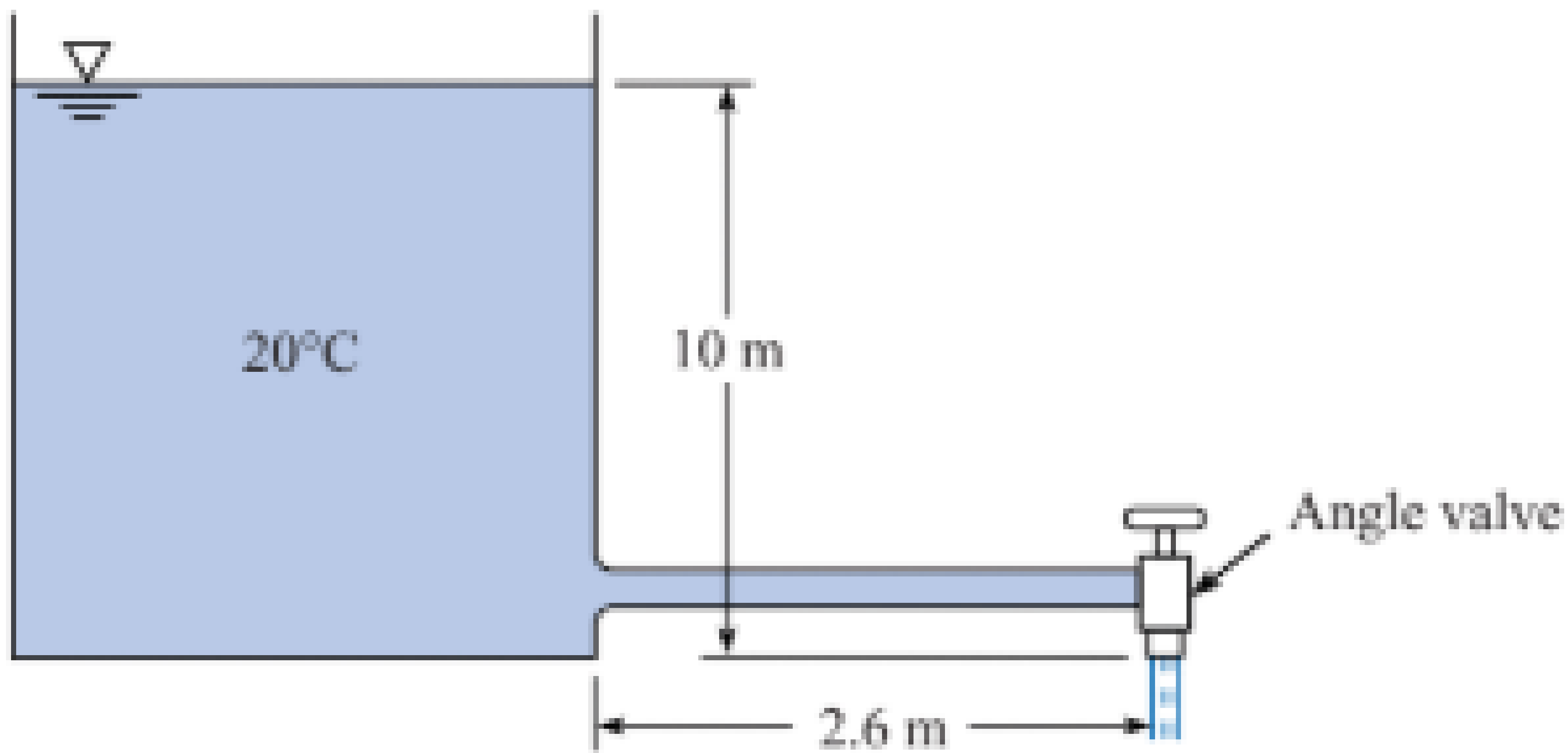
$$
\begin{aligned}
\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p &= \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + \sum h_L \\
&\quad \text{assume the two KE terms are equal and thus cancel, so} \\
h_p &= z_2 - z_1 + \frac{V^2}{2g}\left(K_e + f\frac{L}{D} + K_E\right) \\
&= 13\,\mathrm{m} - 10\,\mathrm{m} + 1.63\,\mathrm{m} \times \left(0.1 + 0.016 \times \frac{80\,\mathrm{m}}{0.15\,\mathrm{m}} + 1\right) \\
&= 3 + 15.7 = 18.7 \mathrm{~m}
\end{aligned}
$$

Power equation

$$
\begin{aligned}
P &= Q\gamma h_p \\
&= 0.10\,\mathrm{m}^3/\mathrm{s} \times 9810\,\mathrm{N}/\mathrm{m}^3 \times 18.7\,\mathrm{m} \\
&= 18,345 \mathrm{~W}
\end{aligned}
$$

$$
\boxed{P = 18.3\,\mathrm{kW}}
$$

10.65 Water flows from a tank through a 2.6-m length of galvanized iron pipe 26 mm in diameter. At the end of the pipe is an angle valve that is wide open. The tank is 2 m in diameter. Calculate the time required for the level in the tank to change from 10 m to 2 m. *Hint:* Develop an equation for dh/dt where h is the level and t if time. Then solve this equation numerically.



PROBLEM 10.65

10.65: PROBLEM DEFINITION

Situation:

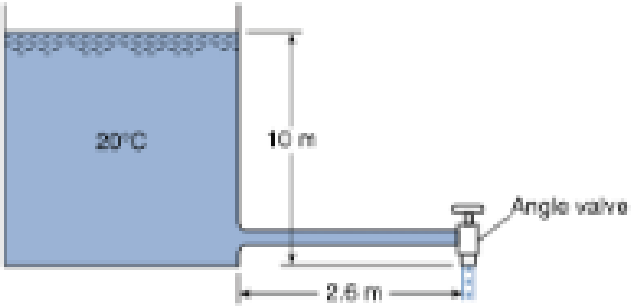
Water exits a tank through a short galvanize iron pipe.

$D_{\text{tank}} = 2\,\text{m}$, $D_{\text{pipe}} = 26\,\text{mm}$.

$L_{\text{pipe}} = 2.6\,\text{m}$, $z_1 = 10\,\text{m}$.

Fully open angle valve: $K_v = 5.0$.

Sketch:



Find:

Time required for the water level in tank to drop from 10 m to 2 m.

Assumptions:

The pipe entrance is smooth: $K_e \approx 0$

The kinetic energy correction factor in the pipe is $\alpha_2 = 1.0$

PLAN

Apply the energy equation from the top of the tank (location 1) to the exit of the angle valve (location 2).

SOLUTION

Energy equation

$$h = \alpha_2 \frac{V^2}{2g} + \frac{V^2}{2g}(K_e + K_v + f\frac{L}{D})$$

Term by term analysis

$$\begin{aligned} \alpha_2 &= 1.0 \\ K_e &\approx 0,\ K_v = 5.0 \\ L/D &= 2.6/0.026 = 100.0 \end{aligned}$$

Combine equation and express V in terms of h

$$V = \sqrt{\frac{2gh}{6 + 100 \times f}}$$

Sand roughness height

$$\frac{k_s}{D} = \frac{0.15}{26} = 5.8 \times 10^{-3}$$

Reynolds number

$$\text{Re} = \frac{V \times 0.026}{10^{-6}} = 2.6 \times 10^4 V$$

Rate of decrease of height

$$\frac{dh}{dt} = -\frac{Q}{A} = -\frac{D_{pipe}^2}{D_{\tan k}^2} V = -\frac{0.000531}{3.14} V = -0.000169V$$

A program was written to first find V iteratively for a given h using the Swamee-Jain equation for the friction factor. Then a new h was found by

$$h_n = h_{n-1} - 0.000169V\Delta t$$

where Δt is the time step. The result was 1424 s or 23.7 minutes.

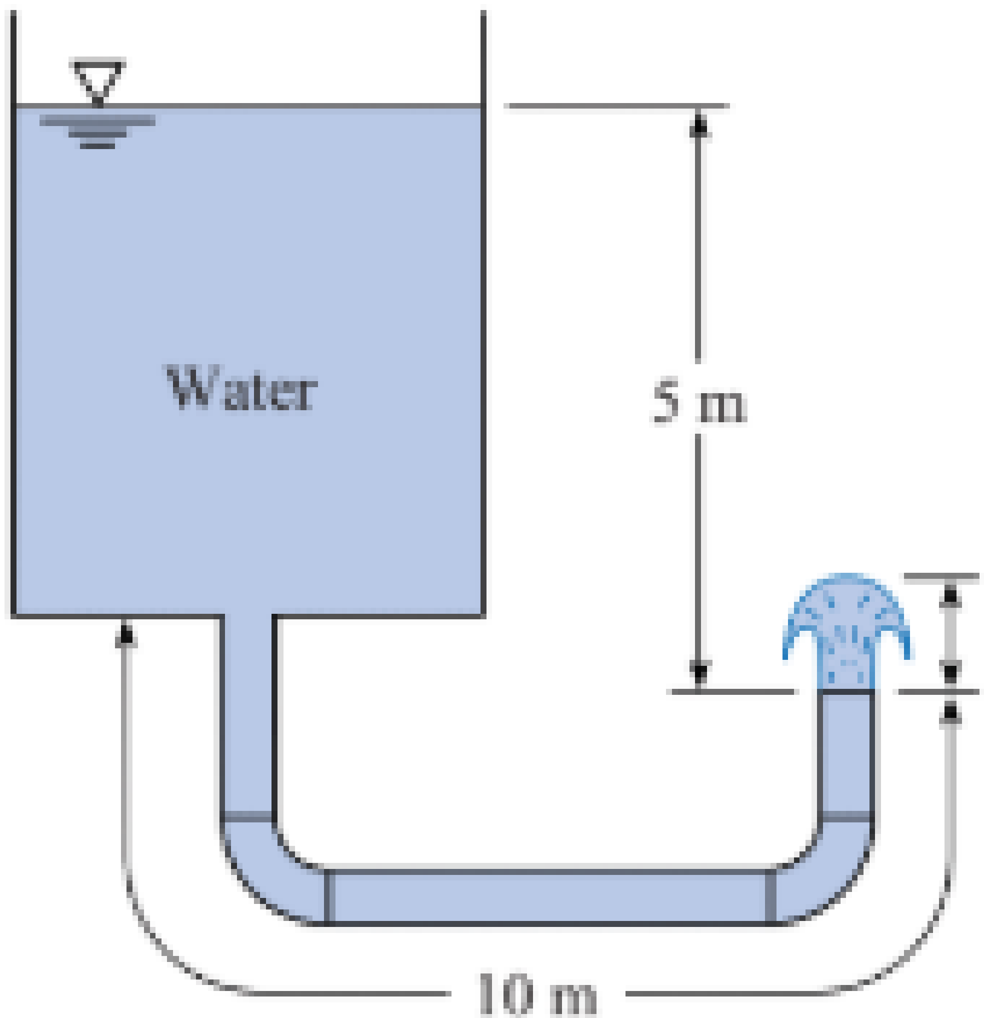
$$\boxed{t = 23.7\,\text{min}}$$

REVIEW

1. When valves are tested to evaluate K_{valve} the pressure taps are usually connected to pipes both upstream and downstream of the valve. Therefore, the head loss in this problem may not actually be $5V^2/2g$.

2. The velocity exiting the valve will probably be highly non-uniform; therefore, this solution should be considered as an approximation only.

10.66 A tank and piping system are shown. The galvanized pipe diameter is 1.5 cm, and the total length of pipe is 10 m. The two 90° elbows are threaded fittings. The vertical distance from the water surface to the pipe outlet is 5 m. Find (a) the exit velocity of the water and (b) the height (h) the water jet would rise on exiting the pipe. The water temperature is 20°C.

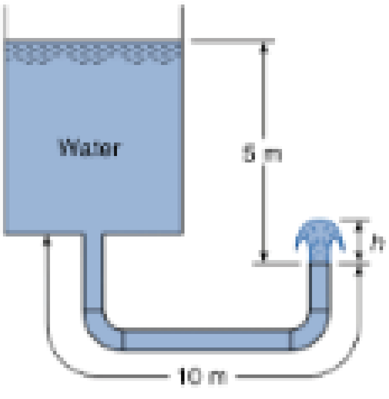


PROBLEM 10.66

10.66: PROBLEM DEFINITION

Situation:

Water drains from a tank, passes through a pipe and then jets upward.
$D = 1.5\,\text{cm}$, $L = 10\,\text{m}$, $\Delta z = 5\,\text{m}$.
Two 90° elbows in pipe.



Find:

(a) Exit velocity of water (m/ s).
(b) Height of water jet (cm).

Assumptions:

The pipe is galvanized iron.
The water temperature is 20°C so $\nu = 10^{-6}\ \text{m}^2/\text{s}$.
Relative roughness $k_s/D = .015/1.5 = 0.01$. Start iteration at $f = 0.035$.
Turbulent, so $\alpha_2 = 1.0$

Properties:

From Table 10.4 $k_s = 0.15$ mm $= 0.015$ cm.
From Table 10.5 $K_b = 0.9$ and $K_e = 0.5$.

PLAN

Apply the energy equation from the water surface in the tank to the pipe outlet.

SOLUTION

Energy equation

$$
\begin{aligned}
\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 &= \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + \sum h_L \\
0 + 0 + 5 &= 0 + \alpha_2 \frac{V_2^2}{2g} + 0 + (K_e + 2K_b + f\frac{L}{D})\frac{V_2^2}{2g} \\
5 &= \left(\frac{V_2^2}{2g}\right)\left(1 + 0.5 + 2 \times 0.9 + .035 \times \frac{10\,\text{m}}{0.015\,\text{m}}\right) \\
5 &= \left(\frac{V_2^2}{2 \times 9.81}\right)(26.6) \\
V_2 &= 1.920\ \text{m/s}
\end{aligned}
$$

Reynolds number

$$\begin{aligned} \mathrm{Re} &= VD/\nu \\ &= 1.92 \times 0.015/10^{-6} \\ &= 2.88 \times 10^4. \end{aligned}$$

Resistance coefficient (new value)

$$\begin{aligned} f &= \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2} \\ &= \frac{0.25}{\left[\log_{10}\left(\frac{0.01}{3.7} + \frac{5.74}{28800^{0.9}}\right)\right]^2} \\ &= 0.0404 \end{aligned}$$

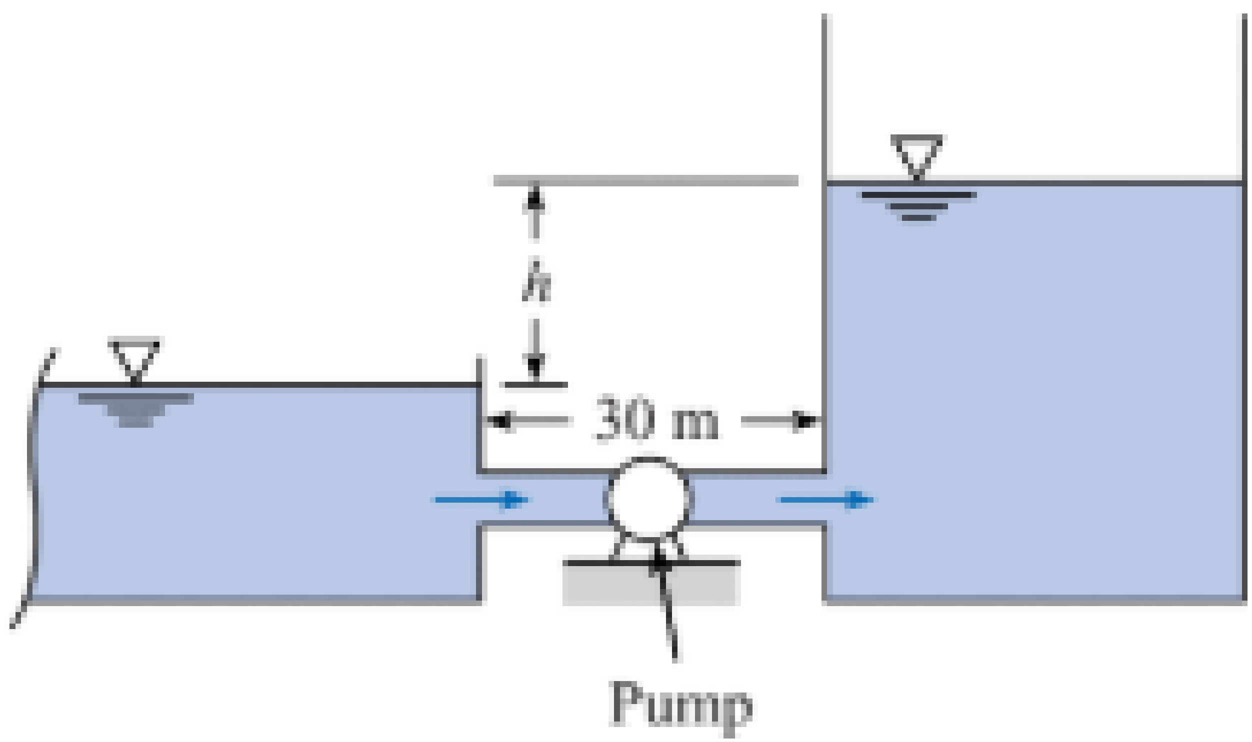
Recalculate V_2 with this new value of f

$$\boxed{V_2 = 1.80 \text{ m/s}}$$

Energy equation (from the pipe outlet to the top of the water jet)

$$\begin{aligned} h &= \frac{V^2}{2g} \\ &= \frac{(1.80 \text{ m/ s})^2}{2 \times 9.81 \text{ m/ s}^2} \\ &= 0.1650 \text{ m} \\ & \boxed{h = 16.5\text{cm}} \end{aligned}$$

10.67 A pump is used to fill a tank from a reservoir as shown. The head provided by the pump is given by $h_p = h_0(1 - (Q^2/Q^2_{max}))$ where h_0 is 50 meters, Q is the discharge through the pump, and Q_{max} is 2 m^3/s. Assume $f = 0.018$ and the pipe diameter is 90 cm. Initially the water level in the tank is the same as the level in the reservoir. The cross-sectional area of the tank is 100 m^2. How long will it take to fill the tank to a height, h, of 40 m?

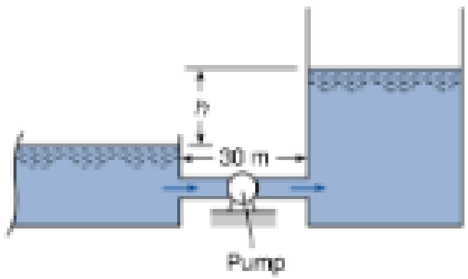


PROBLEM 10.67

10.67: PROBLEM DEFINITION

Situation:

A pump operates between a reservoir and a tank.
$h_p = h_o(1 - Q^2/Q^2_{\max})$, $h_o = 50\,\mathrm{m}$.
$Q_{\max} = 2\,\mathrm{m}^3/\mathrm{s}$, $f = 0.018$.
$D = 90\,\mathrm{cm}$, $A_{\mathrm{tank}} = 100\,\mathrm{m}^2$.



Find:

Time to fill tank to 40 meters.

Properties:

From Table 10.5: $K_e = 0.5$ and $K_E = 1.0$.

PLAN

Apply the energy equation from the reservoir water surface to the tank water surface. The head losses will be due to entrance, pipe resistance, and exit.

SOLUTION

Energy equation

$$\begin{aligned}
\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p &= \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \sum h_L \\
0 + 0 + z_1 + h_p &= 0 + 0 + z_2 + (K_e + f\frac{L}{D} + K_E)\frac{V^2}{2g} \\
h_p &= (z_2 - z_1) + \left(0.5 + \left(0.018 \times \frac{30}{0.9}\right) + 1.0\right)\frac{V^2}{2g} \\
h_p &= h + (2.1)\frac{V^2}{2g}
\end{aligned}$$

But the head supplied by the pump is $h_o(1 - (Q^2/Q^2_{\max}))$ so

$$\begin{aligned}
h_o\left(1 - \frac{Q^2}{Q^2_{\max}}\right) &= h + 1.05\frac{V^2}{g} \\
50\left(1 - \frac{Q^2}{4}\right) &= h + 1.05\frac{Q^2}{gA^2} \\
50 - 12.5Q^2 &= h + 1.05\frac{Q^2}{gA^2}
\end{aligned}$$

Area

$$A = (\pi/4)D^2 = (\pi/4)(0.9^2) = 0.63\,\mathrm{m}^2$$

So

$$\begin{aligned} 50 - 12.5Q^2 &= h + 0.270Q^2 \\ 50 - h &= 127.77Q^2 \\ \sqrt{50 - h} &= 3.57Q \end{aligned}$$

The discharge into the tank and the rate of water level increase is related by

$$Q = A_{\text{tank}}\frac{dh}{dt}$$

so

$$\sqrt{50 - h} = 3.57A_{\text{tank}}\frac{dh}{dt}$$

or

$$dt = 3.57A_{\text{tank}}(50 - h)^{-1/2}dh$$

Integrating

$$t = 2 \times 3.57A_{\text{tank}}(50 - h)^{1/2} + C$$

when $t = 0$, $h = 0$ and $A_{\text{tank}} = 100$ m^2 so

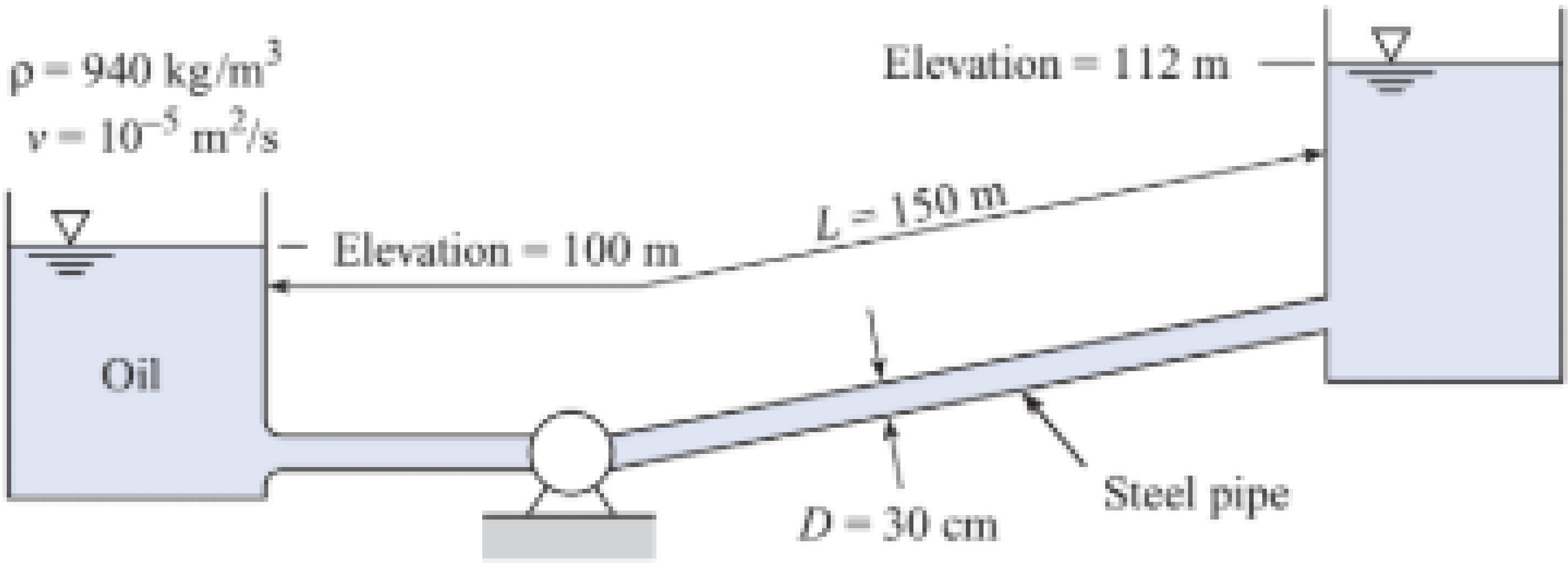
$$t = 714(7.071 - (50 - h)^{1/2})$$

When $h = 40$ m

$$t = 2791 \text{ s}$$

$$\boxed{t = 46.5 \text{ min}}$$

10.69 What power must the pump supply to the system to pump the oil from the lower reservoir to the upper reservoir at a rate of 0.20 m^3/s? Sketch the HGL and the EGL for the system.



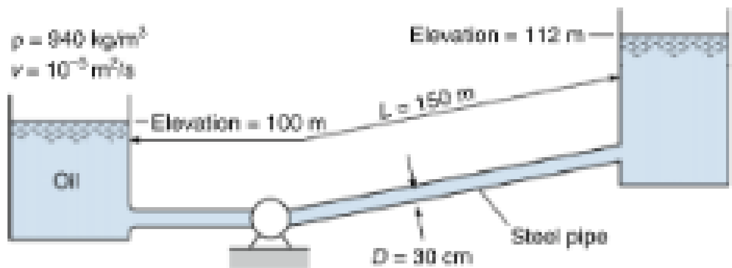
PROBLEM 10.69

10.69: PROBLEM DEFINITION

Situation:

Oil is pumped from a lower reservoir to an upper reservoir through a steel pipe.
$D = 30\,\text{cm}$, $Q = 0.20\,\text{m}^3/\text{s}$.
$z_1 = 100\,\text{m}$, $z_2 = 112\,\text{m}$, $L = 150\,\text{m}$.

Sketch:



Find:

(a) Pump power.
(b) Sketch an EGL and HGL.

Properties:

$\rho = 940\,\text{kg}/\text{m}^3$, $\nu = 10^{-5}\,\text{m}^2/\text{s}$.
From Table 10.4 $k_s = 0.046$ mm

PLAN

Apply the energy equation between reservoir surfaces .

SOLUTION

Energy equation

$$
\begin{aligned}
\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p &= \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + \sum h_L \\
100 + h_p &= 112 + \frac{V^2}{2g}(K_e + f\frac{L}{D} + K_E) \\
h_p &= 12 + \left(\frac{V^2}{2g}\right)\left(0.03 + f\frac{L}{D} + 1\right)
\end{aligned}
$$

Flow rate equation

$$
\begin{aligned}
V &= \frac{Q}{A} \\
&= \frac{0.2\,\text{m}^3/\text{s}}{(\pi/4) \times (0.30\,\text{m})^2} \\
&= 2.83\ \text{m/s} \\
\frac{V^2}{2g} &= 0.408\ \text{m}
\end{aligned}
$$

Reynolds number

$$\begin{aligned}
\text{Re} &= \frac{VD}{\nu} \\
&= \frac{2.83\,\text{m/s} \times 0.30\,\text{m}}{10^{-5}\,\text{m}^2/\text{s}} \\
&= 8.5 \times 10^4 \\
\frac{k_s}{D} &= \frac{4.6 \times 10^{-5}\,\text{m}}{0.3\,\text{m}} \\
&= 1.5 \times 10^{-4}
\end{aligned}$$

Resistance coefficient (from the Moody diagram, Fig. 10.14 in EFM10e)

$$f = 0.019$$

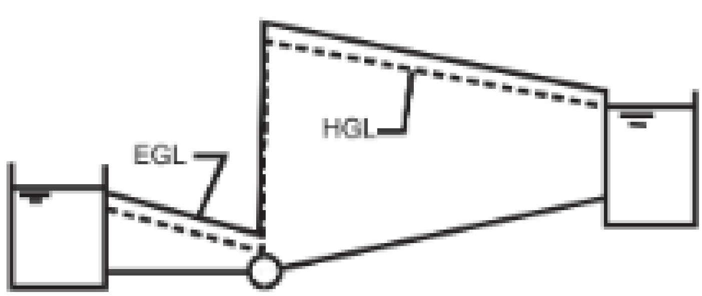
Then

$$\begin{aligned}
h_p &= 12\,\text{m} + 0.408\,\text{m}(0.03 + (0.019 \times \frac{150\,\text{m}}{0.3\,\text{m}}) + 1.0) \\
&= 16.3\ \text{m}
\end{aligned}$$

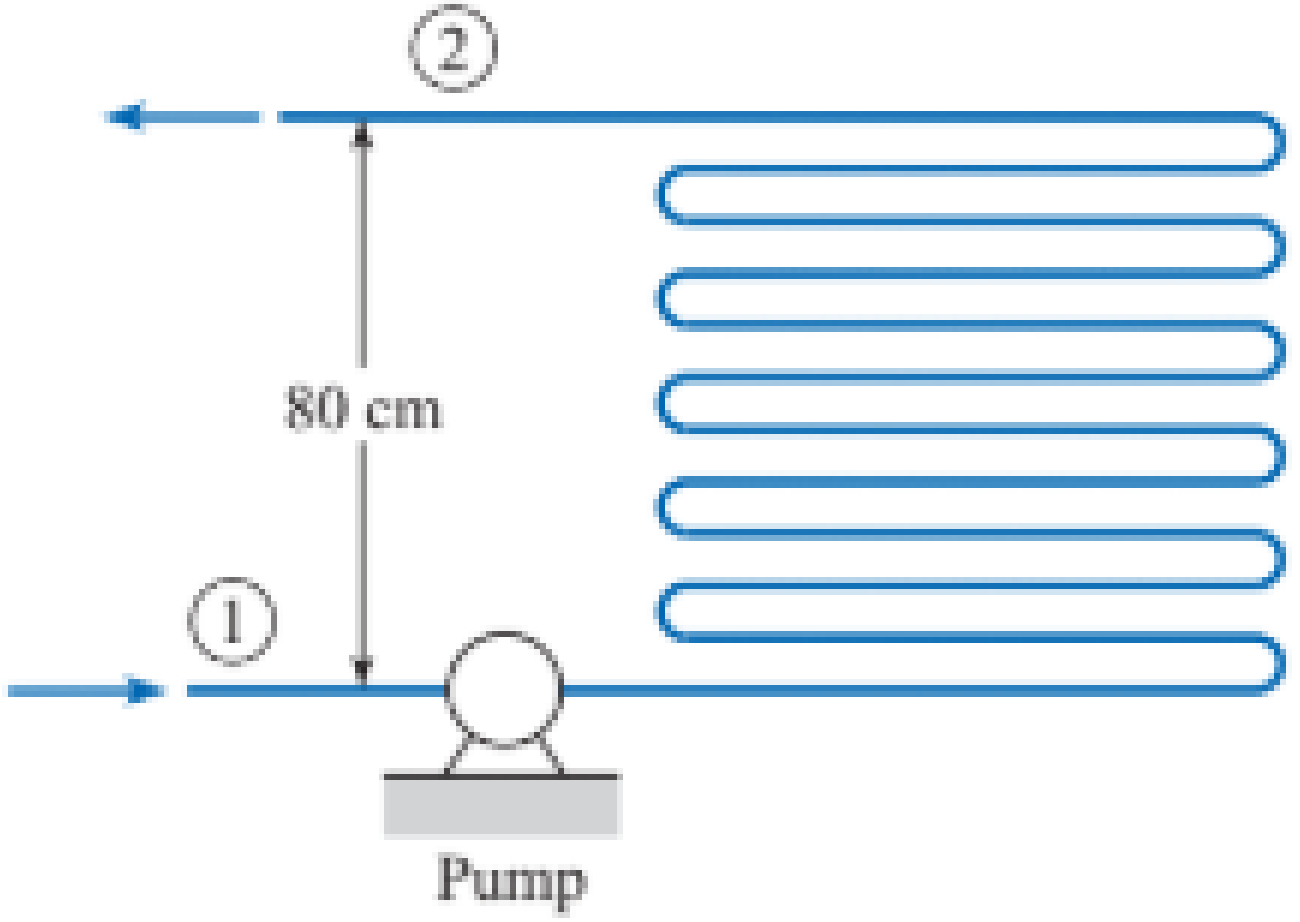
Power equation

$$\begin{aligned}
P &= Q\gamma h_p \\
&= 0.20\,\text{m}^3/\text{s} \times (940\,\text{kg/m}^3 \times 9.81\,\text{m/s}^2) \times 16.3\,\text{m} = 30100\,\text{W}
\end{aligned}$$

$$\boxed{P = 30.1\,\text{kW}}$$



10.74 The heat exchanger shown consists of 10 m of drawn tubing 2 cm in diameter with 19 return bends. The flow rate is 3×10^{-4} m^3/s. Water enters at 20°C and exits at 80°C. The elevation difference between the entrance and the exit is 0.8 m. Calculate the pump power required to operate the heat exchanger if the pressure at 1 equals the pressure at 2. Use the viscosity corresponding to the average temperature in the heat exchanger.



PROBLEM 10.74

10.74: PROBLEM DEFINITION

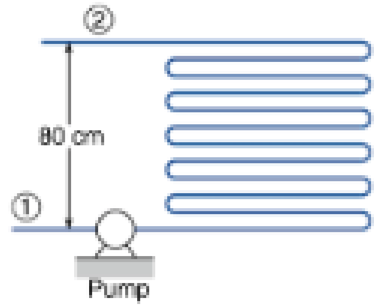
Situation:

Water flows through a heat exchanger.

$L = 10\,\text{m}$, $D = 2\,\text{cm}$, $Q = 3.4 \times 10^{-4}\,\text{m}^3/\text{s}$.

$T_1 = 20\,^\circ\text{C}$, $T_2 = 80\,^\circ\text{C}$, $\Delta z = 0.8\,\text{m}$, $p_1 = p_2$.

Sketch:



Find:

Pump power required.

Assumptions:

K =2 × K for smooth bends of 90°, $r/d \approx 1$, $K_b \approx 2 \times 0.35 = 0.7$

Properties can be found at the average temperature in the heat exchanger.

Smooth tubes ($k_s = 0.0\,\text{m}$)

Properties:

Water (50 °C), Table A.5: $\nu = 5.53 \times 10^{-7}$ m²/s, $\rho = 998\,\text{kg/m}^3$, $\gamma = 9693\,\text{N/m}^3$.

SOLUTION

Energy equation (section 1 at inlet, section 2 at exit)

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

Since $V_1 = V_2$ and $p_1 = p_2$

$$h_p = h_L + (z_2 - z_1)$$

Velocity

$$V = \frac{Q}{A} = \frac{3 \times 10^{-4}\,\text{m}^3/\text{s}}{\pi/4 \times (0.02\,\text{m})^2} = 0.955 \text{ m/s}$$

Reynolds number and resistance coefficient

$$\begin{aligned} \text{Re} &= \frac{VD}{\nu} = \frac{0.955\,\text{m/s} \times (0.02\,\text{m})}{5.53 \times 10^{-7}\,\text{m}^2/\text{s}} = 34539 \\ f &= 0.022 \end{aligned}$$

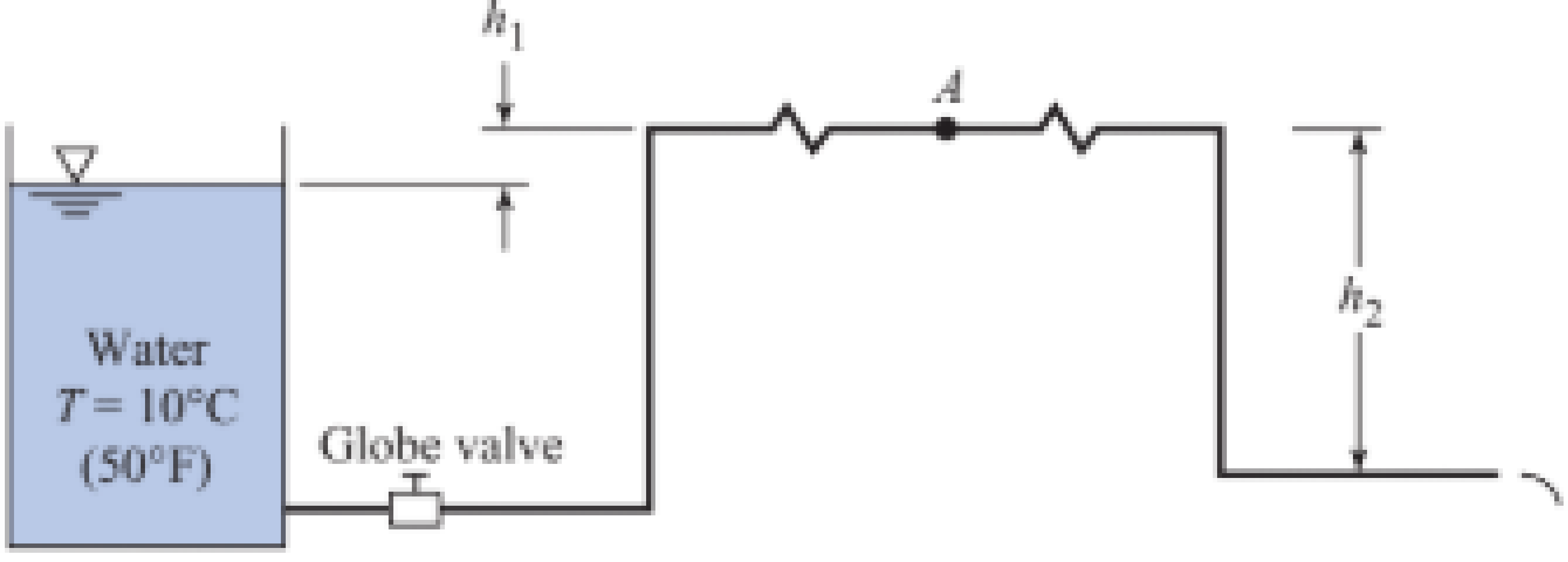
Head loss

$$h_L = \left(f\frac{L}{D} + 19K_b\right)\frac{V^2}{2g} = \left(0.022\frac{10\,\mathrm{m}}{0.02\,\mathrm{m}} + 19\times 0.7\right)\frac{(0.955\,\mathrm{m/\,s})^2}{2\times 9.81\,\mathrm{m/\,s^2}}$$
$$= 1.13\ \mathrm{m}$$

Final calculations

$$h_p = z_2 - z_1 + h_L = 0.8 + 1.13 = 1.93\ \mathrm{m}$$
$$P = \gamma h_p Q = 9693\,\mathrm{N/\,m^3}\times 1.93\,\mathrm{m}\times 3\times 10^{-4}$$
$$\boxed{P = 5.61\mathrm{W}}$$

10.80 The 12-cm galvanized-steel pipe shown is 800 m long and discharges water into the atmosphere. The pipeline has an open globe valve and four threaded elbows; $h_1 = 3$ m and $h_2 = 15$ m. What is the discharge, and what is the pressure at A, the midpoint of the line?



PROBLEM 10.80

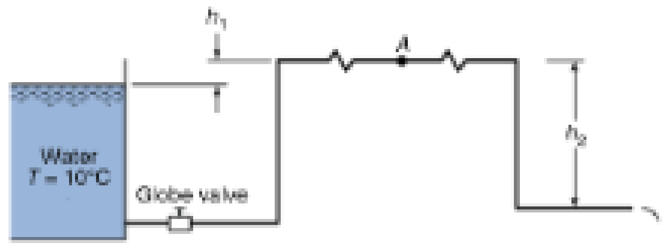
10.80: PROBLEM DEFINITION

Situation:

A steel pipe discharges into the atmosphere.

$D = 12\,\text{cm}$, $L = 800\,\text{m}$, $z_1 = 12\,\text{m}$.

Sketch:



Find:

Discharge (m^3/s).

Pressure at point A.

Assumptions:

Water temperature is 10 °C.

Properties:

Water (10 °C), Table A.5: $\nu = 1.31 \times 10^{-6}\ \text{m}^2/\text{s}$.

From Table 10.5: $K_v = 10, K_b = 0.9,\ K_e = 0.5$.

SOLUTION

Energy equation

$$\begin{aligned}
\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 &= \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \sum h_L \\
0 + 12 + 0 &= 0 + 0 + \frac{V_2^2}{2g}(1 + K_e + K_v + 4K_b + f \times \frac{L}{D})
\end{aligned}$$

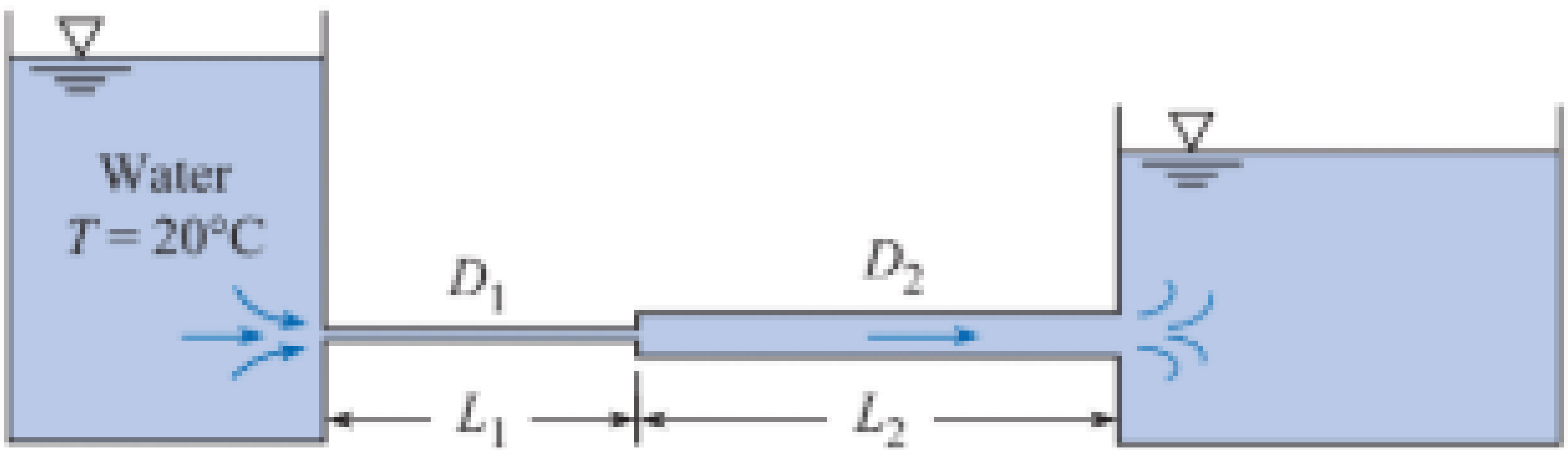
Using a pipe diameter of 10 cm and assuming $f = 0.025$

$$\begin{aligned}
24g &= V^2(1 + 0.5 + 10 + 4(0.9) + 0.025 \times \frac{800\,\text{m}}{0.12\,\text{m}}) \\
V^2 &= 24g/265.1 = 1.0668\ \text{m}^2/\text{s}^2 \\
V &= 1.138\ \text{m/s} \\
Q &= VA \\
&= 1.138\,\text{m/s} \times \pi/4 \times (0.12\,\text{m})^2 \\
& \boxed{Q = 0.0129\text{m}^3/\text{s}} \\
\text{Re} &= 1.138 \times 0.12/1.31 \times 10^{-6} = 1.04 \times 10^5
\end{aligned}$$

From Fig. 10.8 $f \approx 0.025$

$$\begin{aligned}
\frac{p_A}{\gamma} + \frac{V^2}{2g} + z_A &= \frac{p_B}{\gamma} + \frac{V^2}{2g} + z_B + \sum h_L \\
\frac{p_A}{\gamma} + 15 &= \frac{V^2}{2g}(2K_b + f \times \frac{L}{D}) \\
\frac{p_A}{\gamma} &= \frac{1.067\,\mathrm{m}^2/\,\mathrm{s}^2}{2g}(2 \times 0.9 + 0.025 \times \frac{400\,\mathrm{m}}{0.12\,\mathrm{m}}) - 15\,\mathrm{m} = -9.38\ \mathrm{m} \\
p_A &= 9810\,\mathrm{N}/\,\mathrm{m}^3 \times (-9.38\,\mathrm{m}) \\
& \boxed{p_A = -92.0\ \mathrm{kPa}}
\end{aligned}$$

10.82 Both pipes in the system shown have an equivalent sand roughness k_s of 0.10 mm and a flow rate of 0.1 m^3/s, with $D_1 = 12$ cm, $L_1 = 60$ m, $D_2 = 24$ cm, and $L_2 = 120$ m. Determine the difference in the water-surface elevation between the two reservoirs.



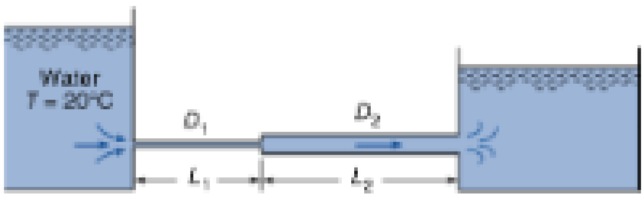
PROBLEM 10.82

10.82: PROBLEM DEFINITION

Situation:

A system with two pipe sizes connects two reservoirs.
$k_s = 0.1\,\text{mm}$, $Q = 0.1\,\text{m}^3/\text{s}$.
$D_1 = 12\,\text{cm}$, $L_1 = 60\,\text{m}$.
$D_2 = 24\,\text{cm}$, $L_2 = 120\,\text{m}$.

Sketch:



Find:

Difference in water surface between two reservoirs.

Properties:

Water (20°C), Table A.5: $\nu = 10^{-6}\ \text{m}^2/\text{s}$.

SOLUTION

$$\begin{aligned}
\frac{k_s}{D_{12}} &= \frac{0.1}{120} = 0.00083 \\
\frac{k_s}{D_{24}} &= \frac{0.1}{240} = 0.00042 \\
V_{12} &= \frac{Q}{A_{12}} = \frac{0.1\,\text{m}^3/\text{s}}{\pi/4 \times (0.12\,\text{m})^2} = 8.842\ \text{m/s} \\
V_{24} &= 2.210\ \text{m/s} \\
\text{Re}_{12} &= \frac{VD}{\nu} = \frac{8.842\,\text{m/s} \times 0.12\,\text{m}}{10^{-6}\,\text{m}^2/\text{s}} = 1.06 \times 10^6 \\
\text{Re}_{24} &= \frac{2.210\,\text{m/s} \times 0.24\,\text{m}}{10^{-6}\,\text{m}^2/\text{s}} = 5.37 \times 10^5
\end{aligned}$$

Resistance Coefficient (from the Moody diagram, Fig. 10.8)

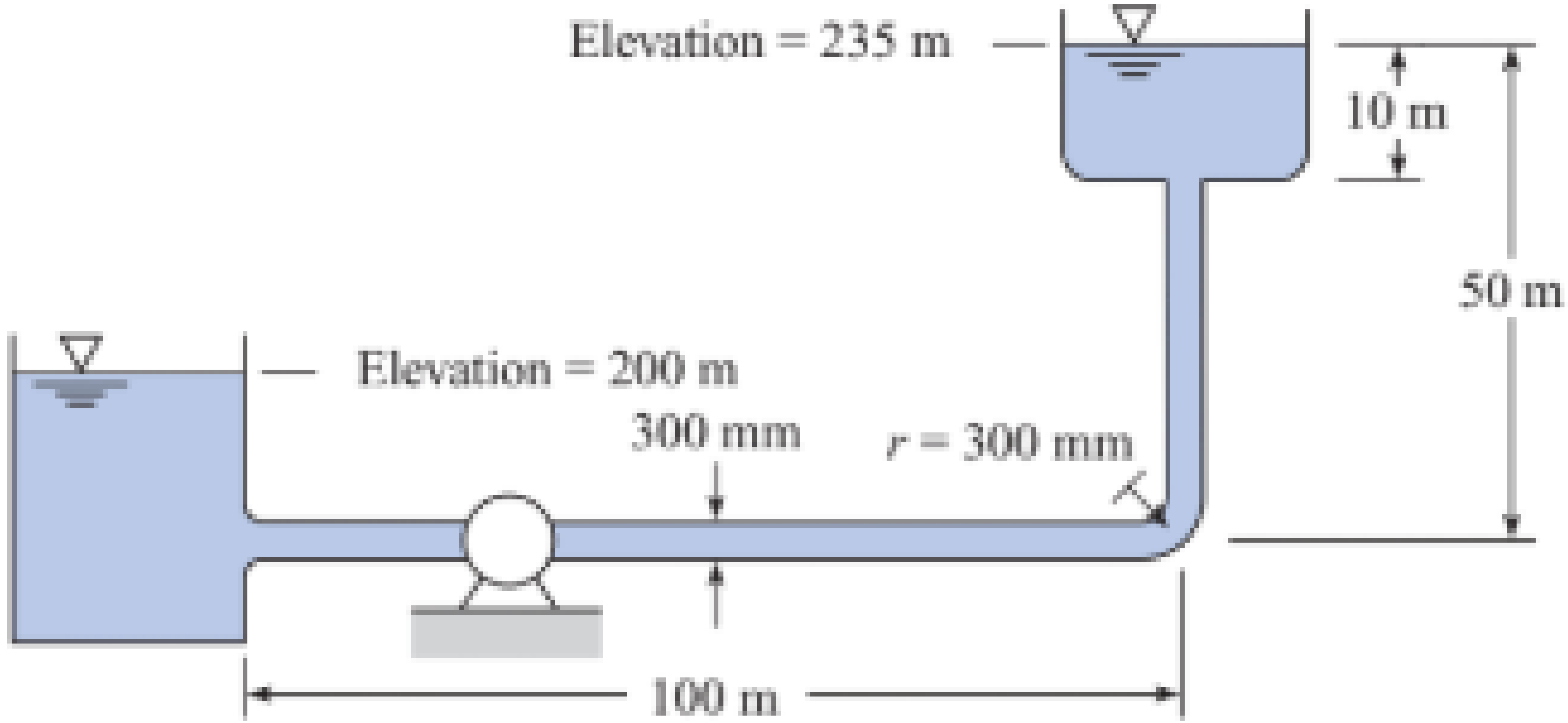
$$\begin{aligned}
f_{12} &= 0.0190 \\
f_{24} &= 0.0170
\end{aligned}$$

Energy equation

$$z_1 - z_2 = \sum h_L$$

$$
\begin{aligned}
z_1 - z_2 &= \frac{V_{12}^2}{2g}(0.5 + 0.019 \times \frac{60}{0.12}) \\
&+ \frac{V_{24}^2}{2g}\left(1 + 0.017 \times \frac{120\,\mathrm{m}}{0.24\,\mathrm{m}}\right) + \frac{(V_{12} - V_{24})^2}{2g} \\
z_1 - z_2 &= \left(\frac{(8.842\,\mathrm{m/\,s})^2}{2 \times 9.81\,\mathrm{m/\,s^2}}\right)(10.0) \\
&+ \left(\frac{(2.210\,\mathrm{m/\,s})^2}{2 \times 9.81\,\mathrm{m/\,s^2}}\right)(9.5) + \frac{(8.842\,\mathrm{m/\,s} - 2.210\,\mathrm{m/\,s})^2}{2 \times 9.81} \\
&\boxed{z_1 - z_2 = 44.5\ \mathrm{m}}
\end{aligned}
$$

10.90 What power must be supplied by the pump to the flow if water ($T = 20°C$) is pumped through the 300-mm steel pipe from the lower tank to the upper one at a rate of $0.4\ m^3/s$?

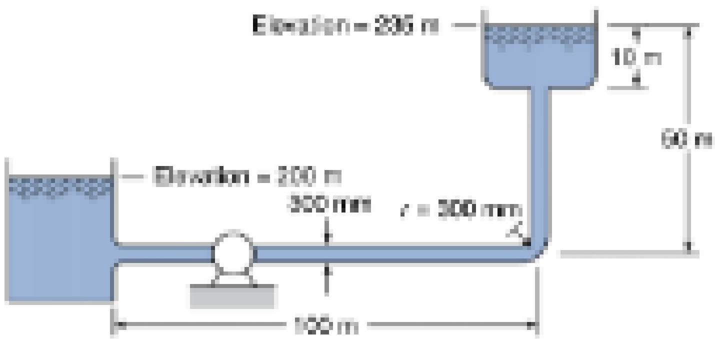


PROBLEM 10.90

10.90: PROBLEM DEFINITION

Situation:

Water is pumped through a steel pipe from one tank to another.
$D = 300\,\text{mm}$, $L = 140\,\text{m}$, $Q = 0.4\,\text{m}^3/\,\text{s}$.
$z_1 = 200\,\text{m}$, $z_2 = 235\,\text{m}$, Elbow radius is 300 mm.



Find:

The pump power.

Assumptions:

Pipe entrance is well-rounded: $r/D > 0.2$.

Properties:

From Table 10.5: $K_e = 0.03$; $K_b = 0.35$; $K_E = 1.0$.
Water (20 °C), Table A.5: $\nu = 10^{-6}\ \text{m}^2/\text{s}$.
From Table 10.4: $k_s = 0.046$ mm.

PLAN

Apply the energy equation from the water surface in the lower reservoir to the water surface in the upper reservoir.

SOLUTION

Energy equation

$$\begin{aligned}
\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p &= \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \sum h_L \\
0 + 0 + 200\ \text{m} + h_p &= 0 + 0 + 235\ \text{m}\ + \frac{V_2^2}{2g}(K_e + K_b + K_E + f\frac{L}{D})
\end{aligned}$$

Flow rate equation

$$\begin{aligned}
V &= \frac{Q}{A} \\
&= \frac{0.4\,\text{m}^3/\,\text{s}}{(\pi/4) \times (0.3\,\text{m})^2} \\
&= 5.66\ \text{m/s} \\
\frac{V^2}{2g} &= 1.63\ \text{m}
\end{aligned}$$

Reynolds number

$$\begin{aligned}
\text{Re} &= \frac{VD}{\nu} \\
&= \frac{5.66\,\text{m/s} \times 0.3\,\text{m}}{10^{-6}\,\text{m}^2/\text{s}} \\
&= 1.70 \times 10^{6} \\
\frac{k_s}{D} &\approx 0.00015
\end{aligned}$$

Resistance coefficient (from the Moody diagram)

$$f = 0.015$$

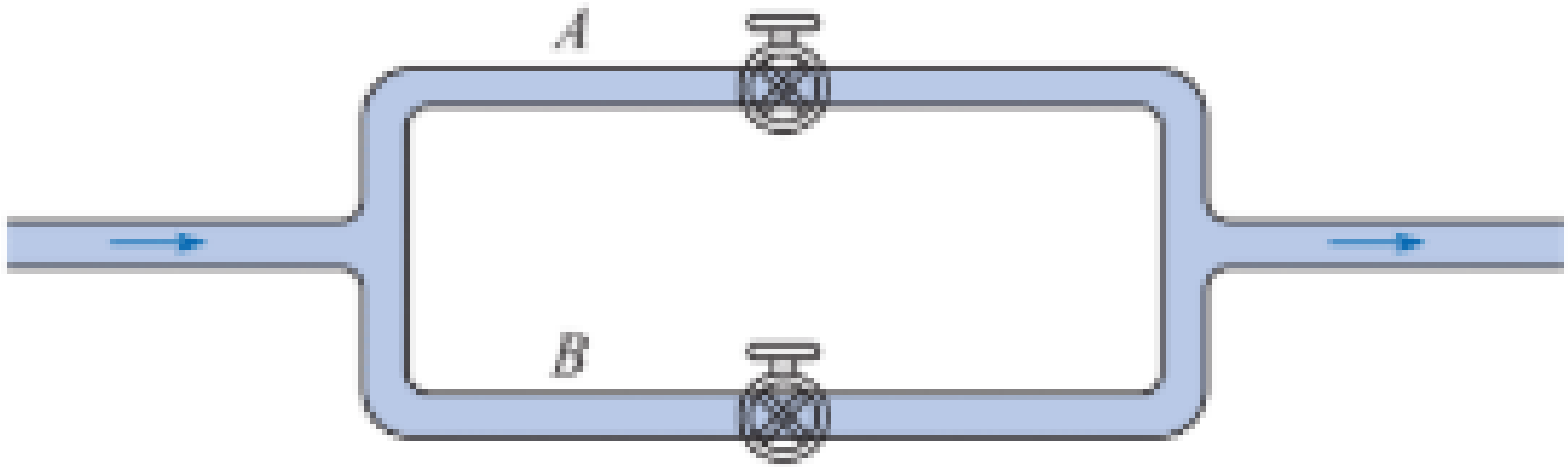
So

$$\begin{aligned}
f\frac{L}{D} &= 0.015 \times \frac{140\,\text{m}}{0.3\,\text{m}} = 7 \\
h_p &= 235\,\text{m} - 200\,\text{m} + 1.63\,\text{m}(0.03 + 0.35 + 1 + 7) \\
&= 47.9\,\text{m}
\end{aligned}$$

Power equation

$$\begin{aligned}
P &= Q\gamma h_p \\
&= 0.4\,\text{m}^3/\text{s} \times 9,790\,\text{N/m}^3 \times 47.9\,\text{m} \\
& \boxed{P = 188\ \text{kW}}
\end{aligned}$$

10.95 A flow is divided into two branches as shown. A gate valve, half open, is installed in line *A*, and a globe valve, fully open, is installed in line *B*. The head loss due to friction in each branch is negligible compared with the head loss across the valves. Find the ratio of the velocity in line *A* to that in line *B* (include elbow losses for threaded pipe fittings).



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diameter. Assume f is the same in both pipes. What is the division of the flow of water at 10°C if the flow rate will be 1.2 m^3/s?

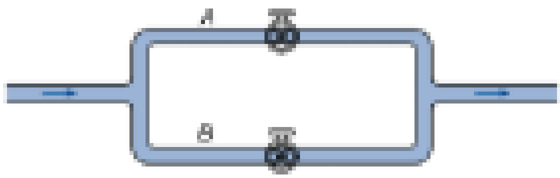
10.95: PROBLEM DEFINITION

Situation:

Two pipes are connected in parallel.

Line A has a half open gate valve, line B a fully open globe valve.

Sketch:



Find:

Ratio of velocity in line A to B.

Assumptions:

Head loss due to friction is negligible.

Properties:

From Table 10.5: $K_{vA} = 5.6$, $K_{vB} = 10$, $K_b = 0.9$.

SOLUTION

$$\begin{aligned}
\sum h_{L,B} &= \sum h_{L,A} \\
h_{L,\text{globe}} + 2h_{L,\text{elbow}} &= h_{L,\text{gate}} + 2h_{L,\text{elbow}} \\
10\frac{V_B^2}{2g} + 2\left(0.9\frac{V_B^2}{2g}\right) &= 5.6\frac{V_A^2}{2g} + 2\left(0.9\frac{V_A^2}{2g}\right) \\
11.8\frac{V_B^2}{2g} &= 7.4\frac{V_A^2}{2g}
\end{aligned}$$

$$\boxed{\frac{V_A}{V_B} = 1.26}$$