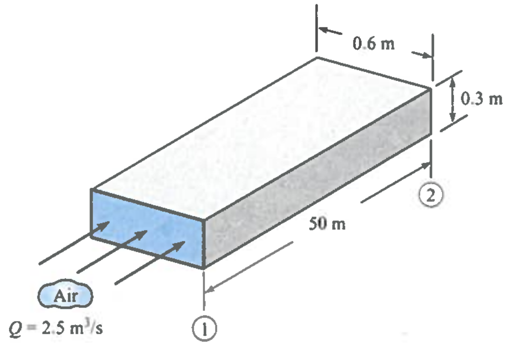
EXAMPLE 10.8

Pressure Drop in an HVAC Duct

Problem Statement

Air ($T = 20°C$ and $p = 101$ kPa absolute) flows at a rate of 2.5 m^3/s in a horizontal, commercial steel, HVAC duct. (Note that HVAC is an acronym for heating, ventilating, and air conditioning.) What is the pressure drop in inches of water per 50 m of duct?



Define the Situation

Air is flowing through a duct.

Assumptions:

- Fully developed flow, meaning that $V_1 = V_2$. Thus, the velocity head terms in the energy equation cancel out.
- No sources of component head loss.

Properties:

- Air (20°C, 1 atm, Table A.2:) $\rho = 1.2$ kg/m^3, $\nu = 15.1 \times 10^{-6}$ m^2/s
- Steel pipe, Table 10.4: $k_s = 0.046$ mm

State the Goal

Find: Pressure drop (inch H_2O) in a length of 50 m.

Generate Ideas and Make a Plan

This is a case 1 problem because flow rate and duct dimensions are known. Thus, the solution is straightforward.

1. Derive an equation for pressure drop by using the energy equation.
2. Calculate parameters needed to find head loss.
3. Calculate head loss by using the Darcy-Weisbach equatio (10.12).
4. Calculate pressure drop Δp by combining steps 1, 2, and 3.

Take Action (Execute the Plan)

1. Energy equation (after term-by-term analysis)

$$p_1 - p_2 = \rho g h_L$$

2. Intermediate calculations

- Flow rate equation

$$V = \frac{Q}{A} = \frac{2.5 \text{ m}^3/\text{s}}{(0.3 \text{ m})(0.6 \text{ m})} = 13.9 \text{ m/s}$$

- Hydraulic diameter

$$D_h = \frac{4 \times \text{section area}}{\text{wetted perimeter}} = \frac{4(0.3 \text{ m})(0.6 \text{ m})}{(2 \times 0.3 \text{ m}) + (2 \times 0.6 \text{ m})} = 0.4$$

- Reynolds number

$$\text{Re} = \frac{VD_h}{\nu} = \frac{(13.9 \text{ m/s})(0.4 \text{ m})}{(15.1 \times 10^{-6} \text{ m}^2/\text{s})} = 368{,}000$$

Thus, flow is turbulent.

- Relative roughness

$$k_s/D_h = (0.000046 \text{ m})/(0.4 \text{ m}) = 0.000115$$

- Resistance coefficient (Moody diagram): $f = 0.015$

3. Darcy-Weisbach equation

$$h_f = f\left(\frac{L}{D_h}\right)\left(\frac{V^2}{2g}\right) = 0.015\left(\frac{50 \text{ m}}{0.4 \text{ m}}\right)\left\{\frac{(13.9 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)}\right\}$$
$$= 18.6 \text{ m}$$

4. Pressure drop (from step 1)

$$p_1 - p_2 = \rho g h_L = (1.2 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(18.6 \text{ m}) = 220 \text{ F}$$

$$\boxed{p_1 - p_2 = 0.883 \text{ inch H}_2\text{O}}$$

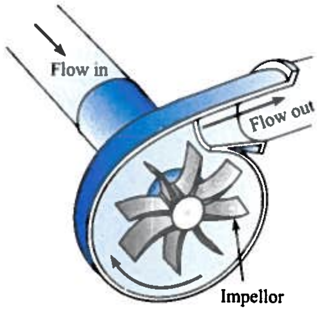
10.10 Pumps and Systems of Pipes

This section explains how to model flow in a network of pipes and how to incorporate performance data for a centrifugal pump. These topics are important because pumps and pipe networks are common.

Modeling a Centrifugal Pump

FIGURE 10.19

A centrifugal pump drives flow with a rotating impellor.



As shown in Fig. 10.19, a **centrifugal pump** is a machine that uses a rotating set of blades sit ated within a housing to add energy to a flowing fluid. The amount of energy that is added represented by the head of the pump h_p, and the rate at which work is done on the flowing flu is $P = \dot{m}gh_p$.

To model a pump in a system, engineers commonly use a graphical solution involving t energy equation and a pump curve. To illustrate this approach, consider flow of water in t system of Fig. 10.20a. The energy equation applied from the reservoir water surface to t outlet stream is

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \sum K_L \frac{V^2}{2g} + \sum \frac{fL}{D}\frac{V^2}{2g}$$

For a system with one size of pipe, this simplifies to

$$h_p = (z_2 - z_1) + \frac{V^2}{2g}\left(1 + \sum K_L + \frac{fL}{D}\right) \quad \text{(10.5}$$

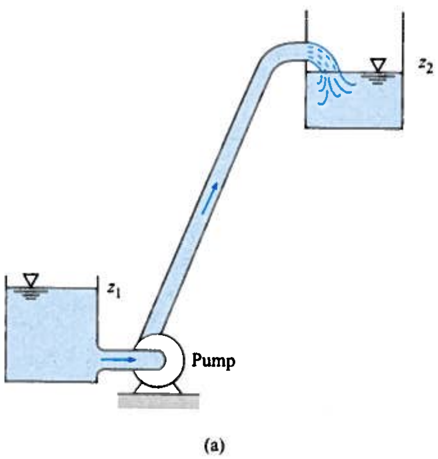
Hence, for any given discharge, a certain head h_p must be supplied to maintain that flow. Thu construct a head-versus-discharge curve, as shown in Fig. 10.20b. Such a curve is called tl **system curve**. Now, a given centrifugal pump has a head-versus-discharge curve that is cha acteristic of that pump. This curve, called a **pump curve**, can be acquired from a pump manı facturer, or it can be measured. A typical pump curve is shown in Fig. 10.20b.

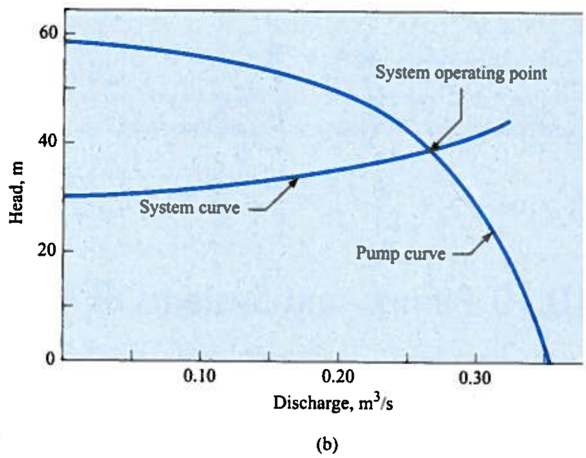
Figure 10.20b reveals that, as the discharge increases in a pipe, the head required for flo also increases. However, the head that is produced by the pump decreases as the dischar increases. Consequently, the two curves intersect, and the operating point is at the point intersection—that point where the head produced by the pump is just the amount needed overcome the head loss in the pipe.

To incorporate performance data for a pump, use the energy equation to derive a systei curve. Then acquire a pump curve from a manufacturer or other source and plot the tw curves together. The point of intersection shows where the pump will operate. This process illustrated in Example 10.9.

FIGURE 10.20

(a) Pump and pipe combination.
(b) Pump and system curves.





EXAMPLE 10.9

Finding a System Operating Point

Define the Situation

- The system diagram is sketched below.
- The pump curve is given in Fig. 10.20b.
- The friction factor is $f = 0.015$.

State the Goal

Calculate the discharge (m^3/s) in the system.

Generate Ideas and Make a Plan

1. Develop an equation for the system curve by applying the energy equation.
2. Plot the given pump curve and the system curve on the same graph.
3. Find discharge Q by finding the intersection of the system and pump curve.

Take Action (Execute the Plan)

Energy equation

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

$$0 + 0 + 200 + h_p = 0 + 0 + 230 + \left(\frac{fL}{D} + K_e + K_b + K_E\right)\frac{V^2}{2g}$$

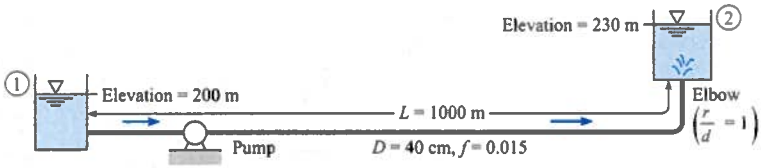
Here $K_e = 0.5$, $K_b = 0.35$, and $K_E = 1.0$. Hence

$$h_p = 30 + \frac{Q^2}{2gA^2}\left[\frac{0.015(1000)}{0.40} + 0.5 + 0.35 + 1\right]$$

$$= 30 + \frac{Q^2}{2 \times 9.81 \times [(\pi/4) \times 0.4^2]^2}(39.3)$$

$$= 30\text{ m} + 127Q^2\text{ m}$$

Now make a table of Q versus h_p (see below) to give values to produce a system curve that will be plotted with the pump curve. When the system curve is plotted on the same graph as the pump curve, it is seen (Fig. 10.20b) that the operating condition occurs at $\boxed{Q = 0.27\text{ m}^3/\text{s}}$.



Q (m^3/s)	$h_p = (30\text{ m} + 127Q^2)$ m
0	30
0.1	31.3
0.2	35.1
0.3	41.4

Pipes in Parallel

Consider a pipe that branches into two parallel pipes and then rejoins, as shown in Fig. 10.21. A problem involving this configuration might be to determine the division of flow in each pipe, given the total flow rate.

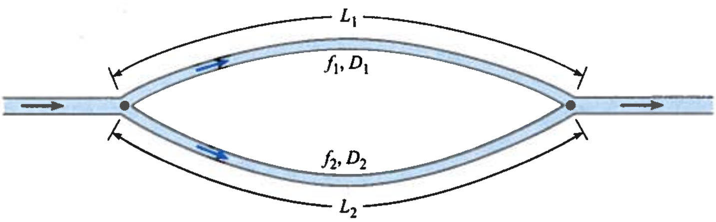


FIGURE 10.21
Flow in parallel pipes.

No matter which pipe is involved, the pressure difference between the two junction poin is the same. Also, the elevation difference between the two junction points is the same. Becau $h_L = (p_1/\gamma + z_1) - (p_2/\gamma + z_2)$, it follows that h_L between the two junction points is the san in both of the pipes of the parallel pipe system. Thus,

$$h_{L_1} = h_{L_2}$$

$$f_1 \frac{L_1}{D_1} \frac{V_1^2}{2g} = f_2 \frac{L_2}{D_2} \frac{V_2^2}{2g}$$

Then

$$\left(\frac{V_1}{V_2}\right)^2 = \frac{f_2 L_2 D_1}{f_1 L_1 D_2} \quad \text{or} \quad \frac{V_1}{V_2} = \left(\frac{f_2 L_2 D_1}{f_1 L_1 D_2}\right)^{1/2}$$

If f_1 and f_2 are known, the division of flow can be easily determined. However, some trial-an error analysis may be required if f_1 and f_2 are in the range where they are functions of th Reynolds number.

Pipe Networks

The most common pipe networks are the water distribution systems for municipalities. The systems have one or more sources (discharges of water into the system) and numerous load one for each household and commercial establishment. For purposes of simplification, th loads are usually lumped throughout the system. Figure 10.22 shows a simplified distributio system with two sources and seven loads.

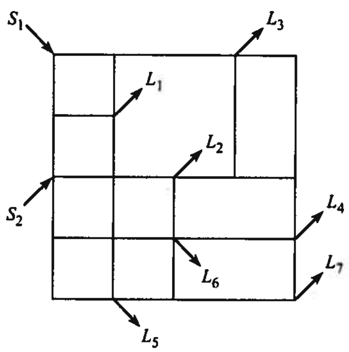


FIGURE 10.22
Pipe network.

The engineer is often engaged to design the original system or to recommend an ecc nomical expansion to the network. An expansion may involve additional housing or comme cial developments, or it may be to handle increased loads within the existing area.

In the design of such a system, the engineer will have to estimate the future loads for th system and will need to have sources (wells or direct pumping from streams or lakes) to satisf the loads. Also, the layout of the pipe network must be made (usually parallel to streets), an pipe sizes will have to be determined. The object of the design is to arrive at a network of pipe that will deliver the design flow at the design pressure for minimum cost. The cost will includ first costs (materials and construction) as well as maintenance and operating costs. The desig process usually involves a number of iterations on pipe sizes and layouts before the optimur design (minimum cost) is achieved.

So far as the fluid mechanics of the problem are concerned, the engineer must determin pressures throughout the network for various conditions—that is, for various combinations o pipe sizes, sources, and loads. The solution of a problem for a given layout and a given set of sources and loads requires that two conditions be satisfied:

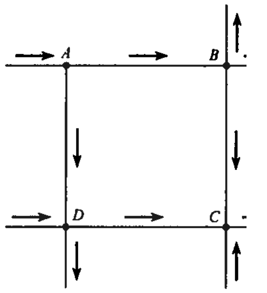
1. The continuity equation must be satisfied. That is, the flow into a junction of the network must equal the flow out of the junction. This must be satisfied for all junctions.
2. The head loss between any two junctions must be the same regardless of the path in the series of pipes taken to get from one junction point to the other. This requirement results because pressure must be continuous throughout the network (pressure cannot have two values at a given point). This condition leads to the conclusion that the algebraic sum of head losses around a given loop must be equal to zero. Here the sign (positive or negative) for the head loss in a given pipe is given by the sense of the flow with respect to the loop, that is, whether the flow has a clockwise or counterclockwise direction.

At one time, these solutions were made by trial-and-error hand computation, but computers have made the older methods obsolete. Even with these advances, however, the engineer charged with the design or analysis of such a system must understand the basic fluid mechanics of the system to be able to interpret the results properly and to make good engineering decisions based on the results. Therefore, an understanding of the original method of solution by Hardy Cross (17) may help you to gain this basic insight. The Hardy Cross method is as follows.

The engineer first distributes the flow throughout the network so that loads at various nodes are satisfied. In the process of distributing the flow through the pipes of the network, the engineer must be certain that continuity is satisfied at all junctions (flow into a junction equals flow out of the junction), thus satisfying requirement 1. The first guess at the flow distribution obviously will not satisfy requirement 2 regarding head loss; therefore, corrections are applied. For each loop of the network, a discharge correction is applied to yield a zero net head loss around the loop. For example, consider the isolated loop in Fig. 10.23. In this loop, the loss of head in the clockwise direction will be given by

$$\begin{aligned}\sum h_{L_c} &= h_{L_{AB}} + h_{L_{BC}} \\ &= \sum kQ_c^n\end{aligned} \qquad (10.51)$$

FIGURE 10.23
A typical loop of a pipe network.



The loss of head for the loop in the counterclockwise direction is

$$\sum h_{L_{cc}} = \sum_{cc} kQ_{cc}^n \qquad (10.52)$$

For a solution, the clockwise and counterclockwise head losses have to be equal, or

$$\sum h_{L_c} = \sum h_{L_{cc}}$$
$$\sum kQ_c^n = \sum kQ_{cc}^n$$

As noted, the first guess for flow in the network will undoubtedly be in error; therefore, a correction in discharge, ΔQ, will have to be applied to satisfy the head loss requirement. If the clockwise head loss is greater than the counterclockwise head loss, ΔQ will have to be applied in the counterclockwise direction. That is, subtract ΔQ from the clockwise flows and add it to the counterclockwise flows:

$$\sum k(Q_c - \Delta Q)^n = \sum k(Q_{cc} + \Delta Q)^n \qquad (10.53)$$

Expand the summation on either side of Eq. (10.53) and include only two terms of the expansion:

$$\sum k(Q_c^n - nQ_c^{n-1}\Delta Q) = \sum k(Q_{cc}^n + nQ_{cc}^{n-1}\Delta Q)$$

Solve for ΔQ:

$$\Delta Q = \frac{\sum kQ_c^n - \sum kQ_{cc}^n}{\sum nkQ_c^{n-1} + \sum nkQ_{cc}^{n-1}} \quad (10.5$$

Thus if ΔQ as computed from Eq. (10.54) is positive, the correction is applied in a cour terclockwise sense (add ΔQ to counterclockwise flows and subtract it from clockwis flows).

A different ΔQ is computed for each loop of the network and applied to the pipes. Sor pipes will have two ΔQs applied because they will be common to two loops. The first set c corrections usually will not yield the final desired result because the solution is approache only by successive approximations. Thus the corrections are applied successively until the co rections are negligible. Experience has shown that for most loop configurations, applying Δ as computed by Eq. (10.54) produces too large a correction. Fewer trials are required to solv for Qs if approximately 0.6 of the computed ΔQ is used.

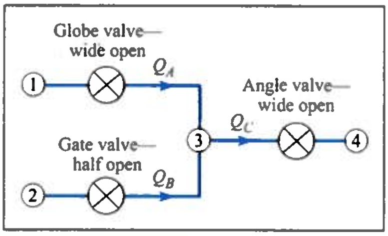
More information on methods of solution of pipe networks is available in references (1 and (19). A search of the Internet under "pipe networks" yields information on software avai able from various sources.

EXAMPLE 10.10

Discharge in a Piping Network

Problem Statement

A simple pipe network with water flow consists of three valves and a junction as shown in the figure. The piezometric head at points 1 and 2 is 1 ft and reduces to zero at point 4. There is a wide-open globe valve in line A, a gate valve half open in line B, and a wide-open angle valve in line C. The pipe diameter in all lines is 2 inches. Find the flow rate in each line. Assume that the head loss in each line is due only to the valves.



Define the Situation

Water flows through a network of pipes.

- $h_1 = h_2 = 1$ ft.
- $h_4 = 0$ ft.
- Pipe diameter (all pipes) is 2/12 ft.

Assumptions: Head loss is due to valves only.

State the Goal

Find the flow rate (in cfs) in each pipe.

Generate Ideas and Make a Plan

1. Let $h_{L,1\to3} = h_{L,2\to3}$.
2. Let $h_{L,2\to4} = 1$ ft.
3. Solve equations using the Hardy Cross approach.

Take Action (Execute the Plan)

The piezometric heads at points 1 and 2 are equal, so

$$h_{L,1\to3} + h_{L,3\to2} = 0$$

The head loss between points 2 and 4 is 1 ft, so

$$h_{L,2\to3} + h_{L,3\to4} = 0$$

Continuity must be satisfied at point 3, so

$$Q_A + Q_B = Q_C$$

The head loss through a valve is given by

$$h_L = K_V \frac{V^2}{2g}$$

$$= K_V \frac{1}{2g}\left(\frac{Q}{A}\right)^2$$

where K_V is the loss coefficient. For a 2-inch pipe, the head loss becomes

$$h_L = 32.6K_vQ^2$$

where h_L is in feet and Q is in cfs.

The head loss equation between points 1 and 2 expressed in term of discharge is

$$32.6K_AQ_A^2 - 32.6K_BQ_B^2 = 0$$

or

$$K_AQ_A^2 - K_BQ_B^2 = 0$$

where K_A is the loss coefficient for the wide-open globe valve ($K_A = 10$) and K_B is the loss coefficient for the half-open gate valve ($K_B = 5.6$). The head loss equation between points 2 and 4 is

$$32.6K_BQ_B^2 + 32.6K_CQ_C^2 = 1$$

or

$$K_BQ_B^2 + K_CQ_C^2 = 0.0307$$

where K_C is the loss coefficient for the wide-open angle valve ($K_C = 5$). The two head loss equations and the continuity equation comprise three equations for Q_A, Q_B, and Q_C. However, the equations are nonlinear and require linearization and solution by iteration (Hardy Cross approach). The discharge is written as

$$Q = Q_0 + \Delta Q$$

where Q_0 is the starting value and ΔQ is the change. Then

$$Q^2 \cdot Q_0^2 + 2Q_0\Delta Q$$

where the $(\Delta Q)^2$ term is neglected. The equations in terms of ΔQ become

$$2K_AQ_{0,A}\Delta Q_A - 2K_BQ_{0,B}\Delta Q_B = K_BQ_{0,B}^2 - K_AQ_{0,A}^2$$

$$2K_CQ_{0,C}\Delta Q_C - 2K_BQ_{0,B}\Delta Q_B = 0.0307 - K_BQ_{0,B}^2 - K_CQ_{0,C}^2$$

$$\Delta Q_A + \Delta Q_B = \Delta Q_C$$

which can be expressed in matrix form as

$$\begin{bmatrix} 2K_AQ_{0,A} & -2K_BQ_{0,B} & 0 \\ 0 & 2K_BQ_{0,B} & 2K_CQ_{0,C} \\ 1 & 1 & -1 \end{bmatrix} \begin{Bmatrix} \Delta Q_A \\ \Delta Q_B \\ \Delta Q_C \end{Bmatrix} = \begin{bmatrix} K_BQ_{0,B}^2 - K_AQ_{0,A}^2 \\ 0.0307 - K_BQ_{0,B}^2 - K_CQ_{0,C}^2 \\ 0 \end{bmatrix}$$

The procedure begins by selecting values for $Q_{0,A}$, $Q_{0,B}$, and $Q_{0,C}$. Assume $Q_{0,A} = Q_{0,B}$ and $Q_{0,C} = 2Q_{0,A}$. Then from the head loss equation from points 2 to 4

$$K_BQ_{0,B}^2 + K_CQ_{0,C}^2 = 0.0307$$

$$(K_B + 4K_C)Q_{0,B}^2 = 0.0307$$

$$(5.6 + 4 \times 5)Q_{0,B}^2 = 0.0307$$

$$Q_{0,B} = 0.0346$$

and $Q_{0,A} = 0.0346$ and $Q_{0,C} = 0.0693$. These values are substituted into the matrix equation to solve for the ΔQ's. The discharges are corrected by $Q_0^{new} = Q_0^{old} + \Delta Q$ and substituted into the matrix equation again to yield new ΔQ's. The iterations are continued until sufficient accuracy is obtained. The accuracy is judged by how close the column matrix on the right approaches zero. A table with the results of iterations for this example is shown here.

		Iteration			
	Initial	1	2	3	4
Q_A	0.0346	0.0328	0.0305	0.0293	0.0287
Q_B	0.0346	0.0393	0.0384	0.0394	0.0384
Q_C	0.0693	0.0721	0.0689	0.0687	0.0671

Review the Solution and the Process

Knowledge. This solution technique is called the Newton-Raphson method. This method is useful for nonlinear system of algebraic equations. It can be implemented easily on a computer. The solution procedure for more complex systems is the same.

10.11 Key Knowledge

Classifying Flow in Conduits

- A *conduit* is any pipe, tube, or duct that is filled with a flowing fluid.
- Flow in a conduit is characterized using the Reynolds number based on pipe diameter. This π-group is given by several equivalent formulas

$$\mathrm{Re}_D = \frac{VD}{\nu} = \frac{\rho VD}{\mu} = \frac{4Q}{\pi D\nu} = \frac{4\dot{m}}{\pi D\mu}$$

- To classify a flow as *laminar* or *turbulent*, calculate the Reynolds number

$$\mathrm{Re}_D \leq 2000 \quad \text{laminar flow}$$

$$\mathrm{Re}_D \geq 3000 \quad \text{turbulent flow}$$

- Flow in a conduit can be developing or fully developed
  - *Developing flow* occurs near an entrance or after the flow is disrupted (i.e., downstream of a valve, a bend, an orifice). *Developing flow* means that the velocity profile and wall shear stress are changing with axial location.
  - *Fully developed flow* occurs in straight runs of pipe that are long enough to allow the flow to develop. Fully developed flow means that the velocity profile and the shear stress are constant with axial location x. In fully developed flow, the flow is uniform, and the pressure gradient (dp/dx) is constant.
- To classify a flow at a pipe inlet as developing or fully developed, calculate the *entrance length* (L_e). At any axial location greater than L_e, the flow will be fully developed. The equations for entrance length are

$$\frac{L_e}{D} = 0.05\text{Re}_D \qquad (\text{laminar flow: Re}_D \le 2000)$$

$$\frac{L_e}{D} = 50 \qquad (\text{turbulent flow: Re}_D \ge 3000)$$

- To describe commercial pipe in the NPS system, specify a nominal diameter in inches and a schedule number. The schedule number characterizes the wall thickness. Actual dimensions need to be looked up.

Head Loss (Pipe Head Loss)

- The sum of head losses in a piping system is called *total head loss*. Sources of head loss classify into two categories:
  - *Pipe Head Loss*. Head loss in straight runs of pipe with fully developed flow
  - *Component Head Loss*. Head loss in components and transitions such as valves, elbows, and bends
- To characterize *pipe head loss*, engineers use a π-group called the *friction factor*. The friction factor f gives the ratio of wall shear stress $(4\tau_0)$ to kinetic pressure $(\rho V^2/2)$.
- Pipe head loss has two symbols that are used: h_L or h_f. To predict pipe head loss, apply the Darcy-Weisbach equation (DWE)

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

There are three methods for using the DWE:

- *Method 1 (laminar flow).* Apply the DWE in this form

$$h_f = \frac{32\mu L V}{\gamma D^2}$$

- *Method 2 (laminar or turbulent flow).* Apply the DWE and use a formula for f.

$$f = \frac{64}{\text{Re}} \qquad \text{Laminar flow}$$

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

- *Method 3 (laminar or turbulent flow).* Apply the DWE; and look up f on the Moody diagram.

- The *roughness* of a pipe wall sometimes affects the friction factor
  - *Laminar Flow.* The roughness does not matter; the friction factor f is independent of roughness.
  - *Turbulent Flow.* The roughness is characterized by looking up an equivalent sand roughness height k_s and then finding f as a function of Reynolds number and k_s/D. When the flow is *fully turbulent,* then f is independent of Reynolds number.

Head Loss (Component Head Loss)

- To characterize the head loss in a component, engineers use a π-group called the *minor loss coefficient*, K, which gives the ratio of head loss to velocity head. Values of K, which come from experimental studies, are tabulated in engineering references. Each component has a specific value of K, which is looked up. The head loss for a component is

$$h_L = K_{\text{component}} \frac{V^2}{2g}$$

- The *total head loss* in a pipe is given by

$$\text{Overall (total) head loss} = \sum (\text{Pipe head losses}) + \sum (\text{Component head losses})$$

$$h_L = \sum_{\text{pipes}} f \frac{L}{D} \frac{V^2}{2g} + \sum_{\text{components}} K \frac{V^2}{2g}$$

Additional Useful Results

- Noncircular conduits can be analyzed using the hydraulic diameter D_h or the hydraulic radius (R_h). To analyze a noncircular conduit, apply the same equations that are used for round conduits and replace D with D_h in the formulas. The equations for D_h and R_h are

$$D_h = 4R_h = \frac{4 \times \text{section area}}{\text{wetted perimeter}}$$

- To find the operating point of a centrifugal pump in a system, the traditional approach is a graphical solution. One plots a system curve that is derived using the energy equation, and one plots the head versus flow rate curve of the centrifugal pump. The intersection of these two curves gives the operating point of the system.
- The analysis of pipe networks is based on the continuity equation being satisfied at each junction and the head loss between any two junctions being independent of pipe path between the two junctions. A series of equations based on these principles are solved iteratively to obtain the flow rate in each pipe and the pressure at each junction in the network.

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PROBLEMS

PLUS Problem available in *WileyPLUS* at instructor's discretion.

GO Guided Online (GO) Problem, available in *WileyPLUS* at instructor's discretion.

Notes on Pipe Diameter for Chapter 10 Problems

When a pipe diameter is given using the label "NPS" or "nominal," find the dimensions using Table 10.1 on p. 363 of §10.2. Otherwise, assume the specified diameter is an inside diameter (ID).

Classifying Flow (§10.1)

10.1 PLUS Kerosene (20°C) flows at a rate of 0.02 m^3/s in a 17.7-cm-diameter pipe. Would you expect the flow to be laminar or turbulent? Calculate the entrance length.

10.2 PLUS A compressor draws 0.3 m^3/s of ambient air (20°C) in from the outside through a round duct that is 10 m long and 150 mm in diameter. Determine the entrance length and establish whether the flow is laminar or turbulent.

10.3 Design a lab demo for laminar flow. Specify the diameter and length for a tube that carries SAE 10W-30 oil at 38°C so that the system demonstrates laminar flow, and fully developed flow, with a discharge of $Q = 0.1$ L/s.

Darcy-Weisbach Equation (§10.3)

10.4 Using §10.3 and other resources, answer the following questions. Strive for depth, clarity, and accuracy while also combining sketches, words, and equations in ways that enhance the effectiveness of your communication.

a. What is pipe head loss? How is pipe head loss related to total head loss?

b. What is the friction factor f? How is f related to wall shear stress?

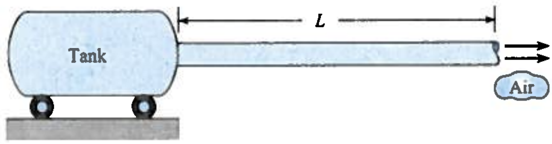
c. What assumptions need to be satisfied to apply the Darcy-Weisbach equation?

10.5 PLUS For each case that follows, apply the Darcy-Weisbach equation from Eq. (10.12) in §10.3 to calculate the head loss in a pipe. Apply the grid method to carry and cancel units.

a. Water flows at a rate of 20 gpm and a mean velocity of 180 ft/min in a pipe of length 200 feet. For a resistance coefficient of $f = 0.02$, find the head loss in feet.

b. The head loss in a section of PVC pipe is 0.8 m, the resistance coefficient is $f = 0.012$, the length is 15 m, and the flow rate is 1 cfs. Find the pipe diameter in meters.

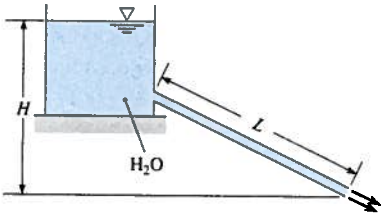
10.6 PLUS As shown, air (20°C) is flowing from a large tank, through a horizontal pipe, and then discharging to ambient. The pipe length is $L = 50$ m, and the pipe is schedule 40 PVC with a nominal diameter of 1 inch. The mean velocity in the pip is 10 m/s, and $f = 0.015$. Determine the pressure (in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



PROBLEM 10.6

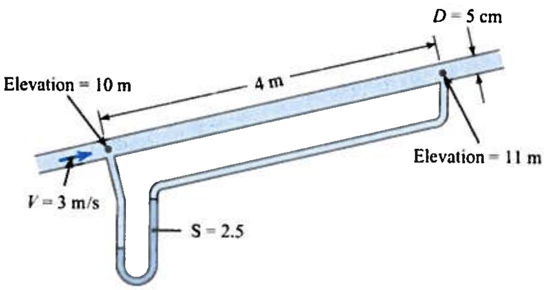
10.7 PLUS Water (15°C) flows through a garden hose (ID = 22 mn with a mean velocity of 2 m/s. Find the pressure drop for a section of hose that is 20 meters long and situated horizontally. Assume that $f = 0.012$.

10.8 GO 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

10.9 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

Laminar Flow in Pipes (§10.5)

10.10 Using §10.5 and other resources, answer the questions that follow. Strive for depth, clarity, and accuracy while also combining sketches, words, and equations in ways that enhance the effectiveness of your communication.

a. What are the main characteristics of laminar flow?

b. What is the meaning of each variable that appears in Eq. (10.27) in §10.5?

c. In Eq. (10.33) of §10.5, what is the meaning of h_f?

10.11 GO A fluid ($\mu = 10^{-2}$ N · s/m^2; $\rho = 800$ kg/m^3) flows with a mean velocity of 4 cm/s in a 10 cm smooth pipe.

a. What is the value of Reynolds number?

b. What is the magnitude of the maximum velocity in the pipe?

c. What is the magnitude of the friction factor f?

d. What is the shear stress at the wall?

e. What is the shear stress at a radial distance of 25 mm from the center of the pipe?

10.12 PLUS Water (15°C) flows in a horizontal schedule 40 p that has a nominal diameter of 0.5 in. The Reynolds number Re = 1000. Work in SI units.

a. What is mass flow rate?

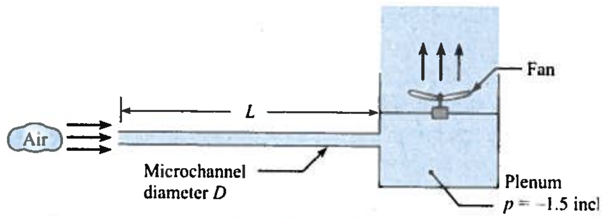
b. What is the magnitude of the friction factor f?

c. What is the head loss per meter of pipe length?

d. What is the pressure drop per meter of pipe length

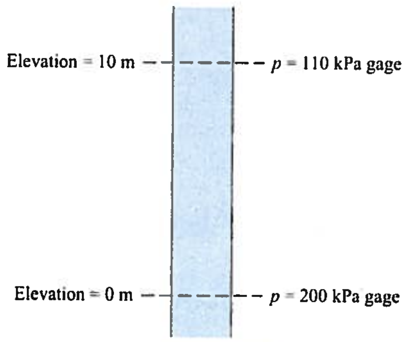
10.13 Flow of a liquid in a smooth 2.5 cm pipe yields a head of 2 m per meter of pipe length when the mean velocity is 0.5 Calculate f and the Reynolds number. Prove that doubling the flow rate will double the head loss. Assume fully developed flc

10.14 PLUS As shown, a round tube of diameter 0.5 mm and length 750 mm is connected to plenum. A fan produces a negative gage pressure of −1.5 inch H_2O in the plenum and draws air (20°C) into the microchannel. What is the mean velocity of air in the microchannel? Assume that the only head loss is in the tube.



PROBLEM 10.14

10.15 Liquid ($\gamma = 10$ kN/m^3) is flowing in a pipe at a steady rate, but the direction of flow is unknown. Is the liquid movin upward or moving downward in the pipe? If the pipe diamete 8 mm and the liquid viscosity is 3.0×10^{-3} N · s/m^2, what is t magnitude of the mean velocity in the pipe?

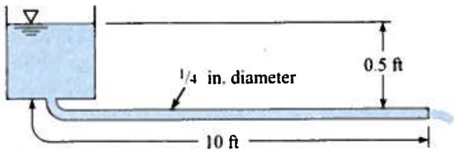


PROBLEM 10.15

10.16 PLUS Oil (S = 0.97, $\mu = 10^{-2}$ lbf-s/ft^2) is pumped throu a nominal 1 in., schedule 80 pipe at the rate of 0.004 cfs. What the head loss per 100 ft of level pipe?

10.17 PLUS A liquid ($\rho = 1000$ kg/m^3; $\mu = 10^{-1}$ N · s/2 m^2; $\nu = 10^{-4}$ m^2/s) flows uniformly with a mean velocity of 1.5 m, in a pipe with a diameter of 100 mm. Show that the flow is laminar. Also, find the friction factor f and the head loss per meter of pipe length.

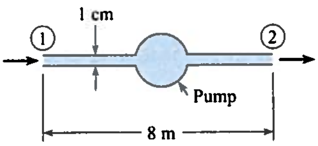
10.18 WILEY GO Kerosene (S = 0.80 and T = 68°F) flows from the tank shown and through the 1/4 in.-diameter (ID) tube. Determine the mean velocity in the tube and the discharge. Assume the only head loss is in the tube.



PROBLEM 10.18

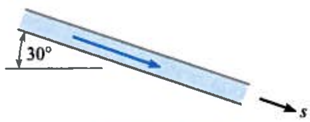
10.19 WILEY PLUS Oil (S = 0.94; μ = 0.048 N · s/m^2) is pumped through a horizontal 5 cm pipe. Mean velocity is 0.5 m/s. What is the pressure drop per 10 m of pipe?

10.20 WILEY PLUS As shown, SAE 10W-30 oil is pumped through an 8 m length of 1-cm-diameter drawn tubing at a discharge of 7.85 × 10^{-4} m^3/s. The pipe is horizontal, and the pressures at points 1 and 2 are equal. Find the power necessary to operate the pump, assuming the pump has an efficiency of 100%. Properties of SAE 10W-30 oil: kinematic viscosity = 7.6 × 10^{-5} m^2/s; specific weight = 8630 N/m^3.



PROBLEM 10.20

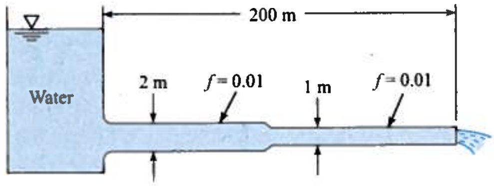
10.21 WILEY PLUS Oil (S = 0.80; μ = 10^{-2} lbf-s/ft^2; ν = 0.0057 ft^2/s) flows downward in the pipe, which is 0.10 ft in diameter and has a slope of 30° with the horizontal. Mean velocity is 3 ft/s. What is the pressure gradient (dp/ds) along the pipe?



PROBLEM 10.21

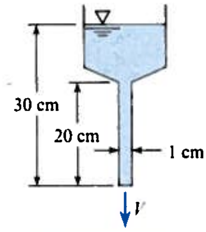
10.22 WILEY PLUS In the pipe system shown, for a given discharge, the ratio of the head loss in a given length of the 1 m pipe to the head loss in the same length of the 2 m pipe is (a) 2, (b) 4, (c) 16, or (d) 32.

10.23 Glycerine (T = 68°F) flows in a pipe with a 6-in. diameter at a mean velocity of 1.5 ft/s. Is the flow laminar or turbulent? Plot the velocity distribution across the flow section, in 0.5-in. increments of radius.



PROBLEM 10.22

10.24 WILEY PLUS Glycerine (T = 20°C) flows through a funnel as shown. Calculate the mean velocity of the glycerine exiting the tube. Assume the only head loss is due to friction in the tube.



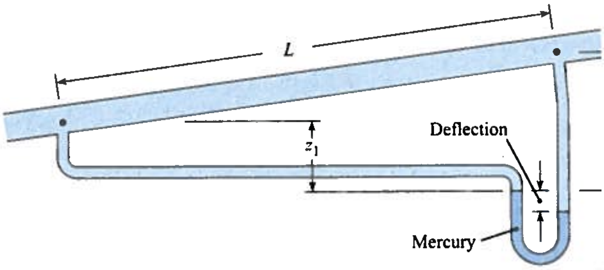
PROBLEM 10.24

10.25 What nominal size of steel pipe should be used to carry 0.2 cfs of castor oil at 90°F a distance of 0.5 mi with an allowable pressure drop of 10 psi (μ = 0.085 lbf-s/ft^2)? Assume S = 0.85.

10.26 WILEY GO Velocity measurements are made in a 30-cm pipe. The velocity at the center is found to be 1.5 m/s, and the velocit distribution is observed to be parabolic. If the pressure drop is found to be 1.9 kPa per 100 m of pipe, what is the kinematic viscosity ν of the fluid? Assume that the fluid's specific gravity is 0.80.

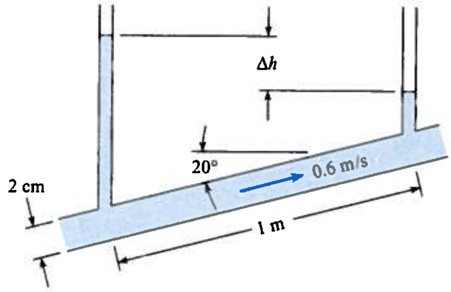
10.27 WILEY GO The velocity of oil (S = 0.8) through the 5-cm smooth pipe is 1.2 m/s. Here L = 12 m, z_1 = 1 m, z_2 = 2 m, and the manometer deflection is 10 cm. Determine the flow directio the resistance coefficient f, whether the flow is laminar or turbulent, and the viscosity of the oil.

10.28 The velocity of oil (S = 0.8) through the 2 in. smooth pip is 5 ft/s. Here L = 30 ft, z_1 = 2 ft, z_2 = 4 ft, and the manometer deflection is 4 in. Determine the flow direction, the resistance coefficient f, whether the flow is laminar or turbulent, and the viscosity of the oil.



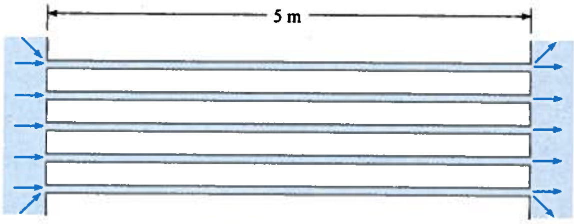
PROBLEMS 10.27, 10.28

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

10.30 PLUS 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

Turbulent Flow in Pipes (§10.6)

10.31 PLUS Use Figure 10.14, Table 10.3, and Table 10.4 (in §10.6) to assess the following statements as True or False:

- **a.** If k_s/D is 0.05 or larger, and the flow is turbulent, the value of f is not dependent on Re_D.
- **b.** For smooth pipes and turbulent flow, f depends on k_s/D and not Re_D.
- **c.** For laminar flow, f is always given by $f = 64/\mathrm{Re}_D$.
- **d.** If $\mathrm{Re}_D = 2 \times 10^7$ and $k_s/D = 0.00005$, then $f = 0.012$.
- **e.** If $\mathrm{Re}_D = 1000$ and the pipe is smooth, $f = 0.04$.
- **f.** The sand roughness height k_s for wrought iron is 0.002 mm.

10.32 PLUS Water (70°F) flows through a nominal 4-in., schedule 40, PVC pipe at the rate of 1 cfs. What is the resistance coefficient f? Use the Swamee-Jain Eq. (10.39) in §10.6.

10.33 PLUS Water at 20°C flows through a 2-cm ID smooth brass tube at a rate of 0.003 m^3/s. What is f for this flow? Use Swamee-Jain Eq. (10.39) in §10.6.

10.34 Water (10°C) flows through a 25-cm smooth pipe at a of 0.05 m^3/s. What is the resistance coefficient f?

10.35 PLUS What is f for the flow of water at 10°C through a 1(cast-iron pipe with a mean velocity of 4 m/s?

10.36 GO A fluid ($\mu = 10^{-2}$ N · s/m²; $\rho = 800$ kg/m³) flow with a mean velocity of 500 mm/s in a 100-mm-diameter sm pipe. Answer the following questions relating to the given flo conditions.

- **a.** What is the magnitude of the maximum velocity in the
- **b.** What is the magnitude of the resistance coefficient
- **c.** What is the shear velocity?
- **d.** What is the shear stress at a radial distance of 25 m from the center of the pipe?
- **e.** If the discharge is doubled, will the head loss per le of pipe also be doubled?

10.37 PLUS Water (20°C) flows in a 16-cm cast-iron pipe at a rate of 0.1 m^3/s. For these conditions, determine or estimate t following:

- **a.** Reynolds number
- **b.** Friction factor f (use Swamee-Jain Eq. (10.39) in §1(
- **c.** Shear stress at the wall, τ_0

10.38 In a 4-in. uncoated cast-iron pipe, 0.02 cfs of water flo at 60°F. Determine f from Fig. 10.14.

10.39 PLUS Determine the head loss in 900 ft of a concrete pipe with a 6 in. diameter ($k_s = 0.0002$ ft) carrying 3.0 cfs of fluid. The properties of the fluid are $\nu = 3.33 \times 10^{-3}$ ft²/s anc $\rho = 1.5$ slug/ft³.

10.40 PLUS Points A and B are 1.5 km apart along a 15-cm n steel pipe ($k_s = 4.6 \times 10^{-5}$ m). Point B is 20 m higher than A. With a flow from A to B of 0.03 m^3/s of crude oil (S = 0.82) a 10°C ($\mu = 10^{-2}$ N · s/m²), what pressure must be maintained A if the pressure at B is to be 300 kPa?

10.41 A pipe can be used to measure the viscosity of a fluid. liquid flows in a 1.5-cm smooth pipe 1 m long with an averag velocity of 4 m/s. A head loss of 50 cm is measured. Estimate kinematic viscosity.

10.42 GO For a 40-cm pipe, the resistance coefficient f was found to be 0.06 when the mean velocity was 3 m/s and the kinematic viscosity was 10^{-5} m²/s. If the velocity were double would you expect the head loss per meter of length of pipe to double, triple, or quadruple?

10.43 GO Water (50°F) flows with a speed of 5 ft/s through a horizontal run of PVC pipe. The length of the pipe is 100 ft, and the pipe is schedule 40 with a nominal diameter of 2.5 inches. Calculate (a) the pressure drop in psi, (b) the head loss in feet, and (c) the power in horsepower needed to overcome the head loss.

10.44 Water (10°C) flows with a speed of 2 m/s through a horizontal run of PVC pipe. The length of the pipe is 50 m, and the pipe is schedule 40 with a nominal diameter of 2.5 inches. Calculate (a) the pressure drop in kilopascals, (b) the head loss in meters, and (c) the power in watts needed to overcome the head loss.

10.45 WILEY PLUS Air flows in a 3-cm smooth tube at a rate of 0.015 m^3/s. If $T = 20°C$ and $p = 110$ kPa absolute, what is the pressure drop per meter of length of tube?

10.46 Points A and B are 3 mi apart along a 24-in. new cast-iron pipe carrying water ($T = 50°F$). Point A is 30 ft higher than B. The pressure at B is 20 psi greater than that at A. Determine the direction and rate of flow.

10.47 WILEY PLUS Air flows in a 1-in. smooth tube at a rate of 30 cfm. If $T = 80°F$ and $p = 15$ psia, what is the pressure drop per foot of length of tube?

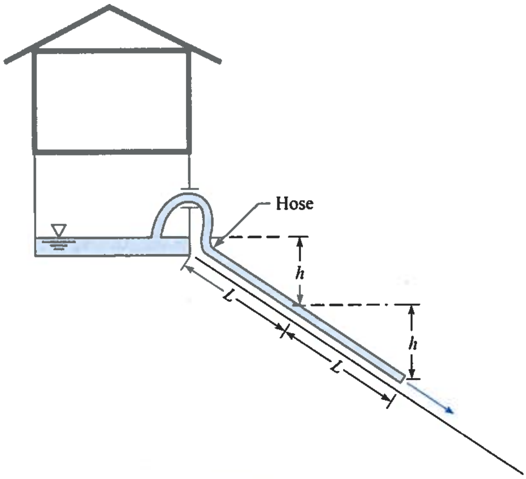
10.48 WILEY PLUS Water is pumped through a vertical 10-cm new steel pipe to an elevated tank on the roof of a building. The pressure on the discharge side of the pump is 1.6 MPa. What pressure can be expected at a point in the pipe 110 m above the pump when the flow is 0.02 m^3/s? Assume $T = 20°C$.

10.49 WILEY GO The house located on a hill as shown is flooded by a broken waterline. The frantic owners siphon water out of the basement window and down the hill in the backyard, with one hose, of length L, and thus an elevation difference of h to drive the siphon. Water drains from the siphon, but too slowly for the desperate home owners. They reason that with a larger head difference, they can generate more flow. So they get another hose, same length as the first, and connect the 2 hoses for total length $2L$. The backyard has a constant slope, so that a hose length of $2L$ correlates to a head difference of $2h$.

a. Assume no head loss, and calculate whether the flow rate doubles when the hose length is doubled from Case 1 (length L and height h) to Case 2 (length $2L$ and height $2h$).

b. Assume $h_L = 0.025(L/D)(V^2/2g)$, and calculate the flow rate for Cases 1 and 2, where $D = 1$ in., $L =$ 50 ft., and $h = 20$ ft. How much of an improvement in flow rate is accomplished in Case 2 as compared to Case 1?

c. Both the husband and wife of this couple took fluid mechanics in college. They review with new appreciation the energy equation and the form of the head loss term and realize that they should use a larger diameter hose. Calculate the flow rate for Case 3, where $L =$ 50 ft., $h = 20$ ft, and $D = 2$ in. Use the same expression for h_L as in part (b). How much of an improvement in flow rate is accomplished in Case 3 as compared to Case 1 in part (b)?



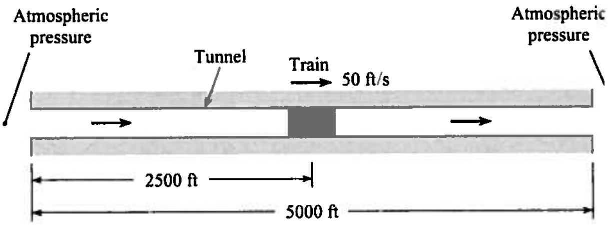
PROBLEM 10.49

10.50 A train travels through a tunnel as shown. The train and tunnel are circular in cross section. Clearance is small, causing all air (60°F) to be pushed from the front of the train and discharged from the tunnel. The tunnel is 10 ft in diameter and is concrete. The train speed is 50 fps. Assume the concrete is very rough ($k_s = 0.05$ ft).

a. Determine the change in pressure between the front and rear of the train that is due to *pipe friction* effects.

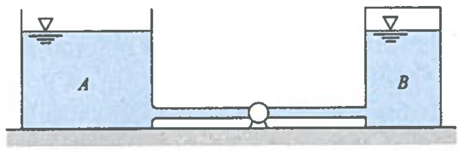
b. Sketch the energy and hydraulic grade lines for the train position shown.

c. What power is required to produce the air flow in the tunnel?



PROBLEM 10.50

10.51 Water (60°F) is pumped from a reservoir to a large, pressurized tank as shown. The steel pipe is 4 in. in diameter an 300 ft long. The discharge is 1 cfs. The initial water levels in the tanks are the same, but the pressure in tank B is 10 psig, and tank A is open to the atmosphere. The pump efficiency is 90%. Find the power necessary to operate the pump for the given conditions.



PROBLEM 10.51

Solving Turbulent Flow Problems (§10.7)

10.52 WILEY PLUS Using the information at the beginning of §10.7, classify each problem given below as case 1, case 2, or case 3. For each of your choices, state your rationale.

a. Problem 10.51

b. Problem 10.54

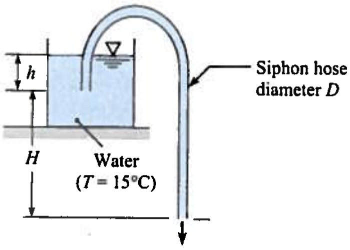
c. Problem 10.57

10.53 A plastic siphon hose with $D = 1.2$ cm and $L = 5.5$ m is used to drain water (15°C) out a tank. Calculate the velocity in the tube for the two situations given below. Use $H = 3$ m and $h = 1$ m.

a. Assume the Bernoulli equation applies (neglect all head loss).

b. Assume the component head loss is zero, and the pipe head loss is nonzero.

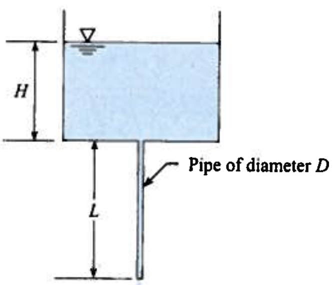
10.54 WILEY GO A plastic siphon hose of length 7 m is used to drain water (15°C) out of a tank. For a flow rate of 1.5 L/s, what hose diameter is needed? Use $H = 5$ m and $h = 0.5$ m. Assume all head loss occurs in the tube.



PROBLEMS 10.53, 10.54

10.55 WILEY PLUS As shown, water (70°F) is draining from a tank through a galvanized iron pipe. The pipe length is $L = 10$ ft, the tank depth is $H = 4$ ft, and the pipe is 1-in. NPS schedule 40. Calculate the velocity in the pipe and the flow rate. Neglect component head loss.

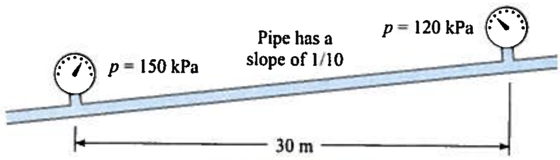
10.56 As shown, water (15°C) is draining from a tank through a galvanized iron pipe. The pipe length is $L = 2$ m, the tank depth is $H = 1$ m, and the pipe is a 0.5 inch NPS schedule 40. Calculate the velocity in the pipe. Neglect component head loss.



PROBLEMS 10.55, 10.56

10.57 Air (40°C, 1 atm) will be transported in a straight horizontal copper tube over a distance of 150 m at a rate of 0.1 m^3/s. If the pressure drop in the tube should not exceed 6 in H_2O, what is the minimum pipe diameter?

10.58 WILEY GO A fluid with $\nu = 10^{-6}$ m^2/s and $\rho = 800$ kg/m^3 fl through the 8-cm galvanized iron pipe. Estimate the flow rat for the conditions shown in the figure.



PROBLEM 10.58

10.59 Determine the diameter of commercial steel pipe required to convey 300 cfs of water at 60°F with a head loss 1 ft per 1000 ft of pipe. Assume pipes are available in the eve sizes when the diameters are expressed in inches (that is, 10 12 in., etc.).

10.60 A pipeline is to be designed to carry crude oil ($S = 0.9$ $\nu = 10^{-5}$ m^2/s) with a discharge of 0.10 m^3/s and a head loss kilometer of 50 m. What diameter of steel pipe is needed? Wh power output from a pump is required to maintain this flow? Available pipe diameters are 20, 22, and 24 cm.

Combined Head Loss in Systems (§10.8)

10.61 WILEY PLUS Use Table 10.5 (on p. 381 in §10.8) to select loss coefficients, K, for the following transitions and fittings.

a. A threaded pipe 90° elbow

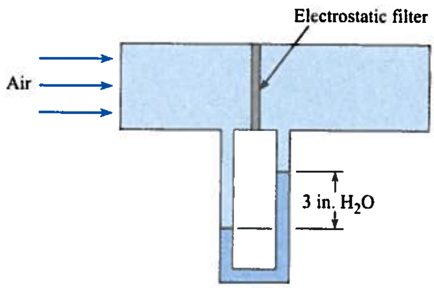
b. A 90° smooth bend with $r/d = 2$

c. A pipe entrance with r/d of 0.3

d. An abrupt contraction, with $\theta = 180°$, and $D_2/D_1 = ($

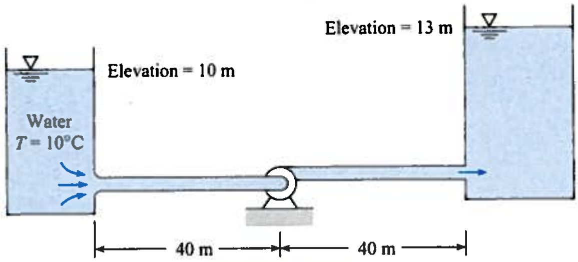
e. A gate valve, wide open

10.62 WILEY PLUS The sketch shows a test of an electrostatic air filte The pressure drop for the filter is 3 inches of water when the airspeed is 10 m/s. What is the minor loss coefficient for the filter? Assume air properties at 20°C.



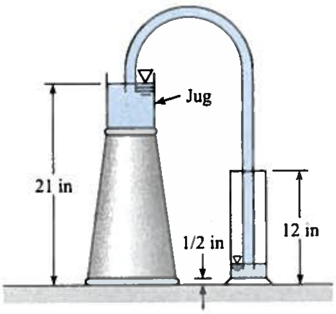
PROBLEM 10.62

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.



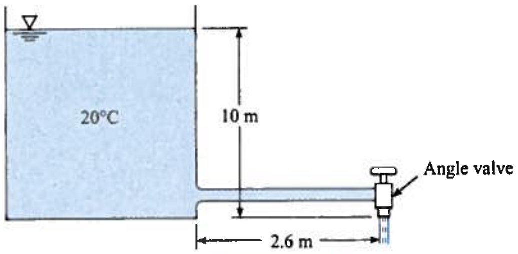
PROBLEM 10.63

10.64 Water will be siphoned through a 3/16-in.-diameter, 50-in.-long Tygon tube from a jug on an upside-down wastebasket into a graduated cylinder as shown. The initial level of the water in the jug is 21 in. above the tabletop. The graduated cylinder is a 500 mL cylinder, and the water surface in the cylinder is 12 in. above the tabletop when the cylinder is full. The bottom of the cylinder is 1/2 in. above the table. The inside diameter of the jug is 7 in. Calculate the time it will take to fill the cylinder from an initial depth of 2 in. of water in the cylinder.



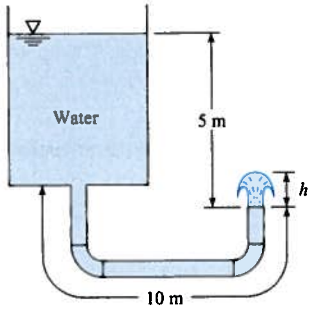
PROBLEM 10.64

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.



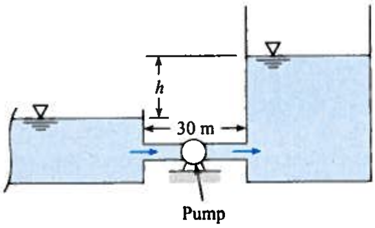
PROBLEM 10.65

10.66 WILEY PLUS A tank and piping system is 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. The velocity of the wat in the tank is negligible. Find (a) the exit velocity of the water and (b) the height (h) the water jet would rise on exiting the pipe. Th water temperature is 20°C.



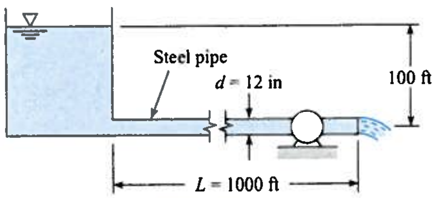
PROBLEM 10.66

10.67 A pump is used to fill a tank from a reservoir as shown. Th 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 lon will it take to fill the tank to a height, h, of 40 m?



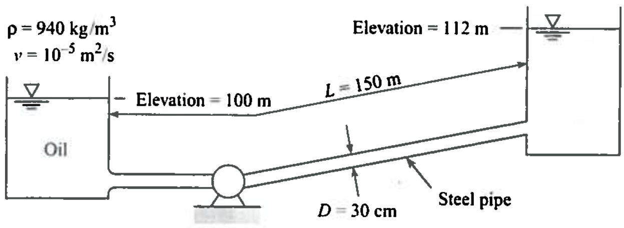
PROBLEM 10.67

10.68 WILEY GO A water turbine is connected to a reservoir as shown. The flow rate in this system is 5 cfs. What power can be delivered by the turbine if its efficiency is 80%? Assume a temperature of 70°F.



PROBLEM 10.68

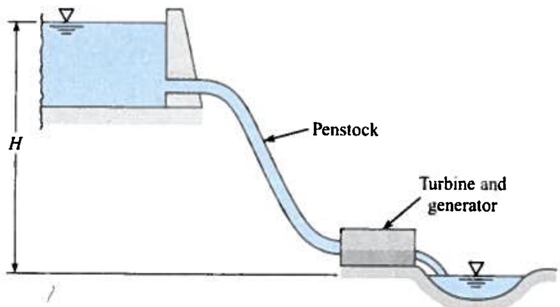
10.69 WILEY PLUS What power must the pump supply to the system to pump the oil from the lower reservoir to the upper reservoir at a rate of 0.20 m^3/s? Sketch the HGL and the EGL for the system.



PROBLEM 10.69

10.70 GO A cast-iron pipe 1.0 ft in diameter and 200 ft long joins two water (60°F) reservoirs. The upper reservoir has a water-surface elevation of 150 ft, and the lower on has a water-surface elevation of 40 ft. The pipe exits from the side of the upper reservoir at an elevation of 120 ft and enters the lower reservoir at an elevation of 30 ft. There are two wide-open gate valves in the pipe. (a) List all sources of h_L and the quantitative factors associated with each. (b) Draw the EGL and the HGL for the system, and (c) determine the discharge in the pipe.

10.71 GO An engineer is making an estimate of hydroelectric power for a home owner. This owner has a small stream ($Q = 2$ cfs, $T = 40$ °F) that is located at an elevation $H = 34$ ft above the owner's residence. The owner is proposing to divert the stream and operate a water turbine connected to an electric generator to supply electrical power to the residence. The maximum acceptable head loss in the penstock (a penstock is a conduit that supplies a turbine) is 3 ft. The penstock has a length of 87 ft. If the penstock is going to be fabricated from commercial-grade, plastic pipe, find the minimum diameter that can be used. Neglect component head losses. Assume that pipes are available in even sizes—that is, 2 in., 4 in., 6 in., etc.

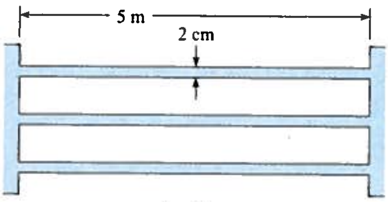


PROBLEM 10.71

10.72 The water-surface elevation in a reservoir is 150 ft. A straight pipe 100 ft long and 6 in. in diameter conveys water from the reservoir to an open drain. The pipe entrance (it is abrupt) is at elevation 100 ft, and the pipe outlet is at elevation 60 ft. At the outlet the water discharges freely into the air. The water temperature is 50°F. If the pipe is asphalted cast iron, what will be the discharge rate in the pipe? Consider all head losses. Also draw the HGL and the EGL for this system.

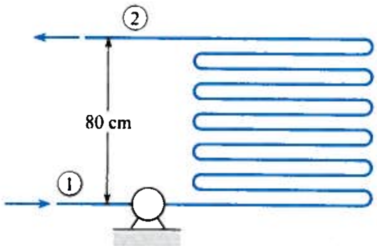
10.73 PLUS A heat exchanger is being designed as a compon of a geothermal power system in which heat is transferred fr the geothermal brine to a "clean" fluid in a closed-loop powe cycle. The heat exchanger, a shell-and-tube type, consists of 1 galvanized-iron tubes 2 cm in diameter and 5 m long, as sho The temperature of the fluid is 200°C, the density is 860 kg/m and the viscosity is 1.35×10^{-4} N · s/m². The total mass flow through the exchanger is 50 kg/s.

a. Calculate the power required to operate the heat exchanger, neglecting entrance and outlet losses.
b. After continued use, 2 mm of scale develops on the inside surfaces of the tubes. This scale has an equiva roughness of 0.5 mm. Calculate the power required under these conditions.



PROBLEM 10.73

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} m³/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 hea exchanger.



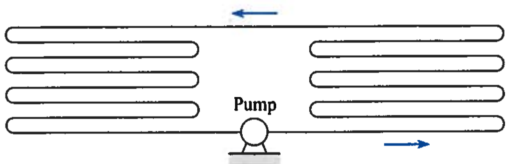
PROBLEM 10.74

10.75 PLUS A heat exchanger consists of a closed system with series of parallel tubes connected by 180° elbows as shown in t figure. There are a total of 14 return elbows. The pipe diameter 2 cm, and the total pipe length is 10 m. The head loss coefficie for each return elbow is 2.2. The tube is copper. Water with an average temperature of 40°C flows through the system with a mean velocity of 8 m/s. Find the power required to operate the pump if the pump is 85% efficient.

10.76 A heat exchanger consists of 15 m of copper tubing with an internal diameter of 15 mm. There are 14 return elbows in the system with a loss coefficient of 2.2 for each elbow. The pump in the system has a pump curve given by

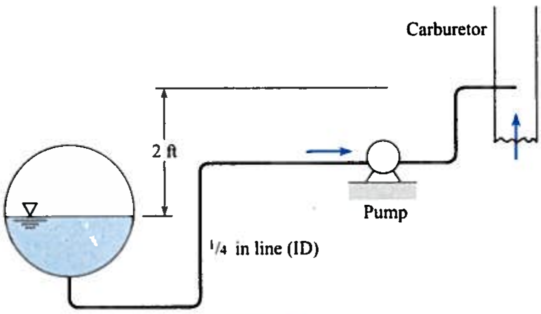
$$h_p = h_{p0}\left[1 - \left(\frac{Q}{Q_{max}}\right)^3\right]$$

where h_{p0} is head provided by the pump at zero discharge and Q_{max} is 10^{-3} m^3/s. Water at 40°C flows through the system. Find the system operating point for values of h_{p0} of 2 m, 10 m, and 20 m.



PROBLEMS 10.75, 10.76

10.77 WILEY PLUS Gasoline (T = 50°F) is pumped from the gas tank of an automobile to the carburetor through a 1/4-in. fuel line of drawn tubing 10 ft long. The line has five 90° smooth bends with an r/d of 6. The gasoline discharges through a 1/32-in. jet in the carburetor to a pressure of 14 psia. The pressure in the tank is 14.7 psia. The pump is 80% efficient. What power must be supplied to the pump if the automobile is consuming fuel at the rate of 0.12 gpm? Obtain gasoline properties from Figs. A.2 and A.3.

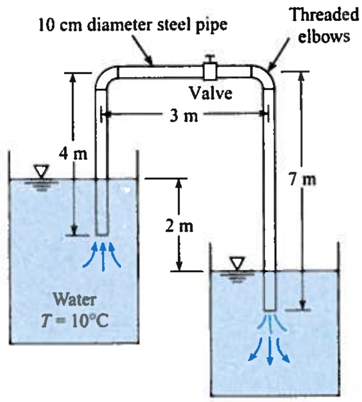


PROBLEM 10.77

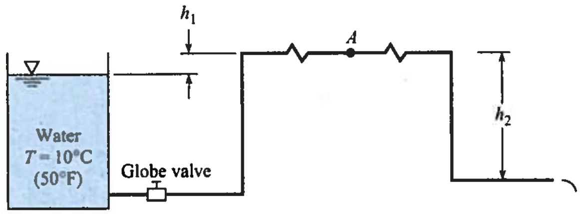
10.78 Find the loss coefficient K_v of the partially closed valve that is required to reduce the discharge to 50% of the flow with the valve wide open as shown.

10.79 The pressure at a water main is 350 kPa gage. What size of pipe is needed to carry water from the main at a rate of 0.025 m^3/s to a factory that is 160 m from the main? Assume that galvanized-steel pipe is to be used and that the pressure required at the factory is 70 kPa gage at a point 8 m above the main connection.

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?

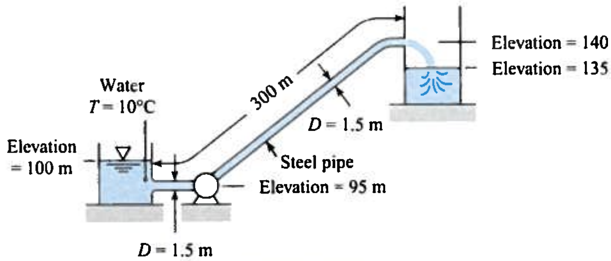


PROBLEM 10.78



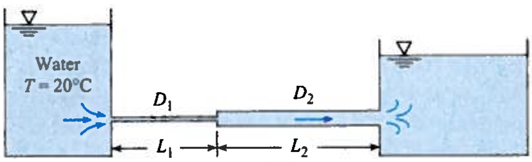
PROBLEM 10.80

10.81 WILEY PLUS Water is pumped at a rate of 25 m^3/s from the reservoir and out through the pipe, which has a diameter of 1.50 m. What power must be supplied to the water to effect this discharge?



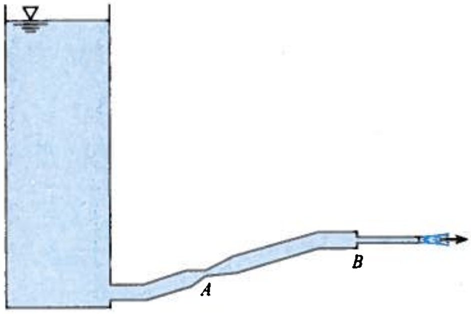
PROBLEM 10.81

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.



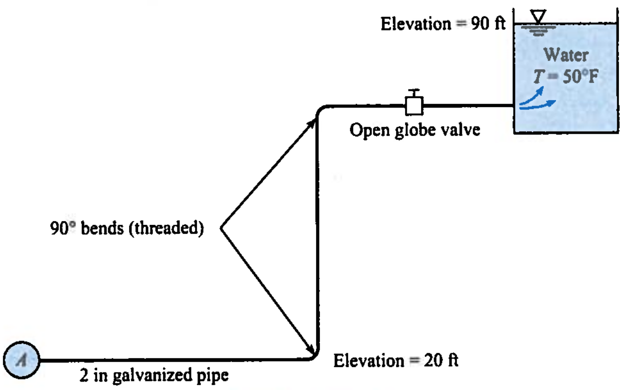
PROBLEM 10.82

10.83 Liquid discharges from a tank through the piping system shown. There is a venturi section at A and a sudden contraction at B. The liquid discharges to the atmosphere. Sketch the energy and hydraulic gradelines. Where might cavitation occur?



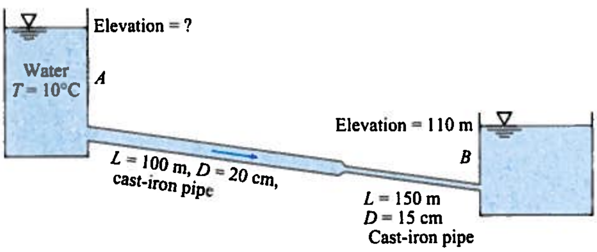
PROBLEM 10.83

10.84 The steel pipe shown carries water from the main pipe A to the reservoir and is 2 in. in diameter and 240 ft long. What must be the pressure in pipe A to provide a flow of 50 gpm?



PROBLEM 10.84

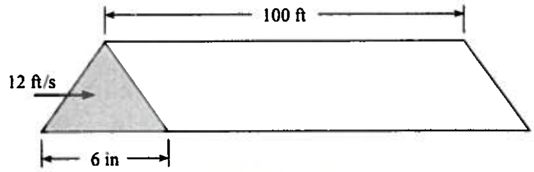
10.85 If the water surface elevation in reservoir B is 110 m, what must be the water surface elevation in reservoir A if a flow of 0.03 m³/s is to occur in the cast-iron pipe? Draw the HGL and the EGL, including relative slopes and changes in slope.



PROBLEM 10.85

Nonround Conduits (§10.9)

10.86 PLUS Air at 60°F and atmospheric pressure flows in a horizontal duct with a cross section corresponding to an equilateral triangle (all sides equal). The duct is 100 ft long, and the dimension of a side is 6 in. The duct is constructed of galvanized iron (k_s = 0.0005 ft). The mean velocity in the duct is 12 ft/s. What is the pressure drop over the 100 ft length?

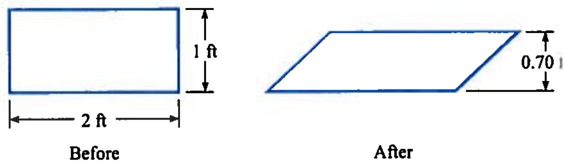


PROBLEM 10.86

10.87 PLUS A cold-air duct 100 cm by 15 cm in cross section is 100 m long and made of galvanized iron. This duct is to car air at a rate of 6 m³/s at a temperature of 15°C and atmospher pressure. What is the power loss in the duct?

10.88 PLUS Air (20°C) flows with a speed of 10 m/s through a horizontal rectangular air-conditioning duct. The duct is 20 m lo and has a cross section of 4 by 10 in. (102 by 254 mm). Calculate (a) the pressure drop in inches of water and (b) the power in wa needed to overcome head loss. Assume the roughness of the duc k_s = 0.004 mm. Neglect component head losses.

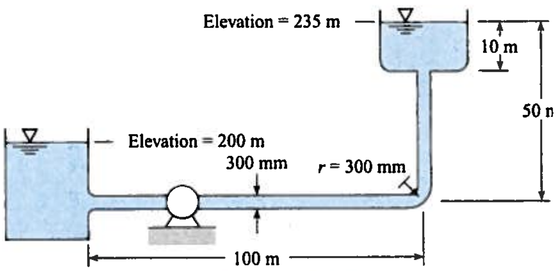
10.89 An air-conditioning system is designed to have a duct with a rectangular cross section 1 ft by 2 ft, as shown. During construction, a truck driver backed into the duct and made it trapezoidal section, as shown. The contractor, behind schedul installed it anyway. For the same pressure drop along the pipe what will be the ratio of the velocity in the trapezoidal duct to that in the rectangular duct? Assume the Darcy-Weisbach resistance coefficient is the same for both ducts.



PROBLEM 10.89

Modeling Pumps in Systems (§10.10)

10.90 What power must be supplied by the pump to the flow 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 m³/s?

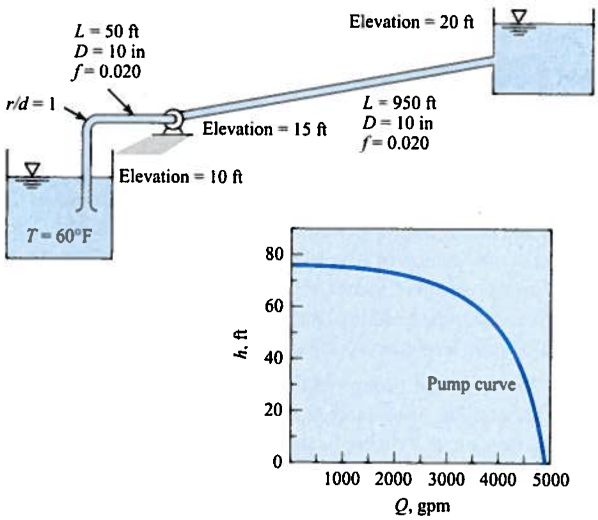


PROBLEM 10.90

10.91 If the pump for Fig. 10.20b is installed in the system of Prob. 10.90, what will be the rate of discharge of water from the lower tank to the upper one?

10.92 A pump that has the characteristic curve shown in the accompanying graph is to be installed as shown. What will be the discharge of water in the system?

10.93 If the liquid of Prob. 10.92 is a superliquid (zero head loss occurs with the flow of this liquid), then what will be the pumping rate, assuming that the pump curve is the same?

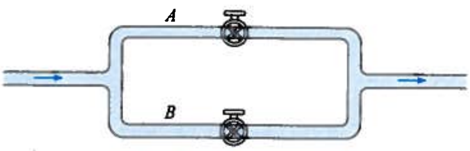


PROBLEMS 10.92, 10.93

Pipes in Parallel and in Networks (§10.10)

10.94 WILEY PLUS A pipe system consists of a gate valve, wide open ($K_v = 0.2$), in line A and a globe valve, wide open ($K_v = 10$), in line B. The cross-sectional area of pipe A is half of the cross-sectional area of pipe B. The head loss due to the junction, elbows, and pipe friction are negligible compared with the head loss through the valves. Find the ratio of the discharge in line B to that in line A.

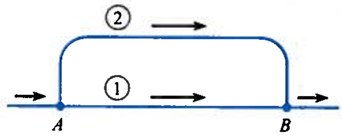
10.95 A flow is divided into two branches as shown. A gate valve, half open, is installed in line A, and a globe valve, fully open, is installed in line B. The head loss due to friction in each branch is negligible compared with the head loss across the valves. Find the ratio of the velocity in line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



PROBLEMS 10.94, 10.95

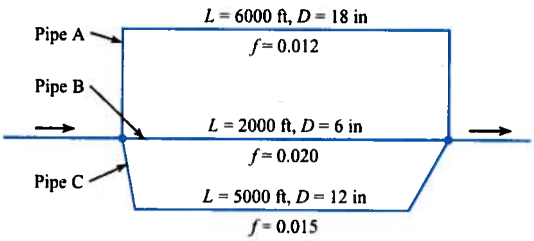
10.96 WILEY PLUS In the parallel system shown, pipe 1 is 1200 m long and is 50 cm in diameter. Pipe 2 is 1500 m long and 35 cm in diameter. Assume f is the same in both pipes. What is the division of the flow of water at 10°C if the flow rate will be 1.2 m^3/s?

10.97 Pipes 1 and 2 are the same kind (cast-iron pipe), but pi 2 is three times as long as pipe 1. They are the same diameter (1 ft). If the discharge of water in pipe 2 is 1 cfs, then what wil be the discharge in pipe 1? Assume the same value of f in both pipes.



PROBLEMS 10.93, 10.97

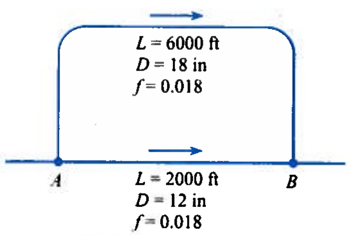
10.98 Water flows from left to right in this parallel pipe systerr The pipe having the greatest velocity is (a) pipe A, (b) pipe B, o (c) pipe C.



PROBLEM 10.98

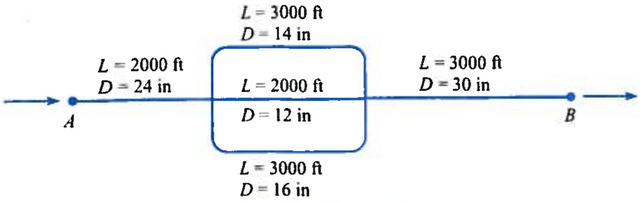
10.99 Two pipes are connected in parallel. One pipe is twice th diameter of the other and four times as long. Assume that f in t larger pipe is 0.010 and f in the smaller one is 0.012. Determine the ratio of the discharges in the two pipes.

10.100 WILEY PLUS With a total flow of 14 cfs, determine the division of flow and the head loss from A to B.



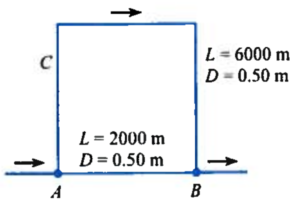
PROBLEM 10.100

10.101 WILEY PLUS The pipes shown in the system are all concrete. With a flow of 25 cfs of water, find the head loss and the division of flow in the pipes from A to B. Assume $f = 0.030$ for all pipes.



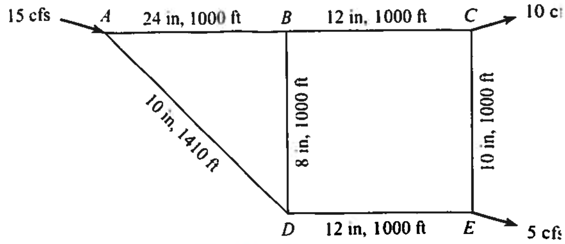
PROBLEM 10.101

10.102 A parallel pipe system is set up as shown. Flow occurs from *A* to *B*. To augment the flow, a pump having the characteristics shown in Fig. 10.20b is installed at point *C*. For a total discharge of 0.60 m^3/s, what will be the division of flow between the pipes and what will be the head loss between *A* and *B*? Assume commercial steel pipe.



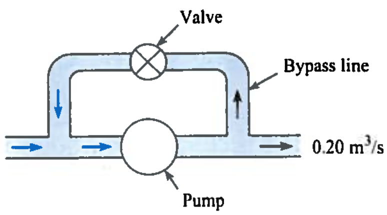
PROBLEM 10.102

10.103 For the given source and loads shown, how will the flow be distributed in the simple network, and what will be the pressures at the load points if the pressure at the source is 60 psi? Assume horizontal pipes and $f = 0.012$ for all pipes.



PROBLEM 10.103

10.104 Frequently in the design of pump systems, a bypass li will be installed in parallel to the pump so that some of the fl can recirculate as shown. The bypass valve then controls the f rate in the system. Assume that the head-versus-discharge cu for the pump is given by $h_p = 100 - 100Q$, where h_p is in met and Q is in m^3/s. The bypass line is 10 cm in diameter. Assum the only head loss is that due to the valve, which has a head-lo coefficient of 0.2. The discharge leaving the system is 0.2 m^3/s Find the discharge through the pump and bypass line.



PROBLEM 10.104