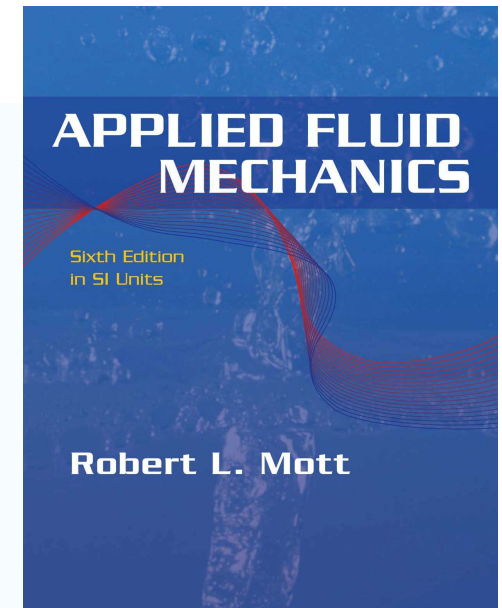# Applied Fluid Mechanics

1. The Nature of Fluid and the Study of Fluid Mechanics
2. Viscosity of Fluid
3. Pressure Measurement
4. Forces Due to Static Fluid
5. Buoyancy and Stability
6. Flow of Fluid and Bernoulli's Equation
7. General Energy Equation
8. Reynolds Number, Laminar Flow, Turbulent Flow and Energy Losses Due to Friction

Applied Fluid Mechanics

APPLIED FLUID MECHANICS

Sixth Edition in SI Units

Robert L. Mott
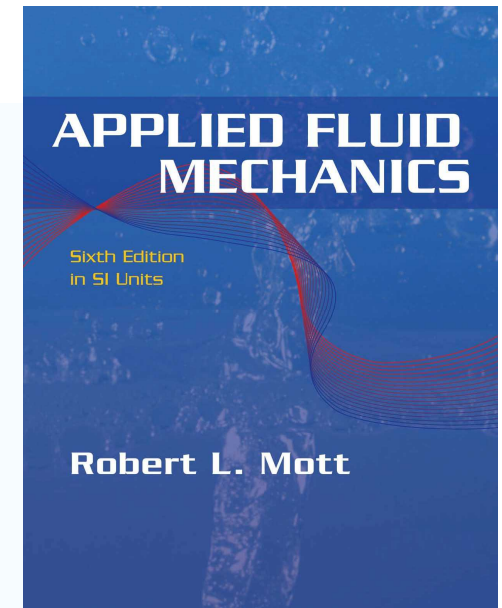
Applied Fluid Mechanics

17. Drag and Lift
18. Fans, Blowers, Compressors and the Flow of Gases
19. Flow of Air in Ducts

10. Minor Losses

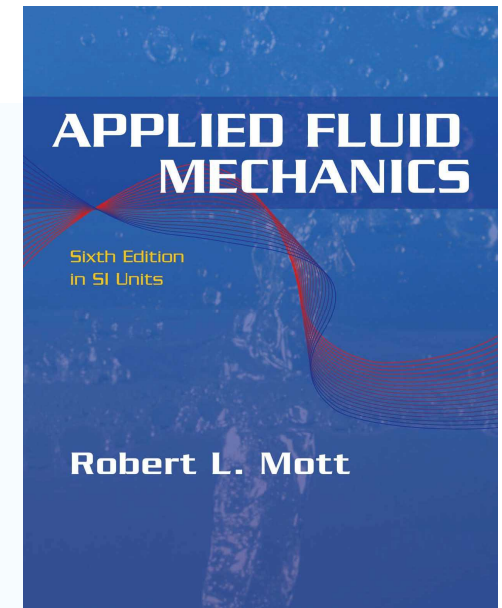### Chapter Objectives

- Recognize the sources of minor losses.

- Define *resistance coefficient*.

- Determine the energy loss for flow through the following types of minor losses:

a. Sudden enlargement of the flow path.

b. Exit loss when fluid leaves a pipe and enters a static reservoir.

c. Gradual enlargement of the flow path.

d. Sudden contraction of the flow path.

e. Gradual contraction of the flow path.

f. Entrance loss when fluid enters a pipe from a static reservoir.

10. Minor Losses

Chapter Objectives

- Define the term *vena contracta*.

- Define and use the *equivalent-length technique* for computing energy losses in valves, fittings, and pipe bends.

- Describe the energy losses that occur in a typical fluid power system.

- Demonstrate how the *flow coefficient C_V* is used to evaluate energy losses in some types of valves.

10. Minor Losses

Chapter Outline

1. Introductory Concepts
2. Resistance Coefficient
3. Sudden Enlargement
4. Exit Loss
5. Gradual Enlargement
6. Sudden Contraction
7. Gradual Contraction
8. Entrance Loss
9. Resistance Coefficients for Valves and Fittings
10. Application of Standard Valves

10. Minor Losses

Chapter Outline

11. Pipe Bends
12. Pressure Drop in Fluid Power Valves
13. Flow Coefficients for Valves Using C_V
14. Plastic Valves

10. Minor Losses

10.1 Introductory Concepts

- In Chapter 7, you developed the *general energy equation*, which extended Bernoulli's equation to account for energy losses and additions that typically occur in real flow systems.

10.2 Resistant Coefficient

- Energy losses are proportional to the velocity head of the fluid as it flows around an elbow, through an enlargement or contraction of the flow section, or through a valve.

- Experimental values for energy losses are usually reported in terms of a resistance coefficient K as follows:

$$h_L = K(v^2/2g) \qquad\qquad (10\text{–}1)$$

where h_L is the minor loss, K is the resistance coefficient, and is the average velocity of flow in the pipe in the vicinity where the minor loss occurs.

10.2 Resistant Coefficient

- The resistance coefficient is dimensionless because it represents a constant of proportionality between the energy loss and the velocity head.

- The magnitude of the resistance coefficient depends on the geometry of the device that causes the loss and sometimes on the velocity of flow.

10.3 Sudden Enlargement

- As a fluid flows from a smaller pipe into a larger pipe through a sudden enlargement, its velocity abruptly decreases, causing turbulence, which generates an energy loss.

- Fig 10.1 shows the sudden enlargement.

Region of turbulence

D_1

D_2
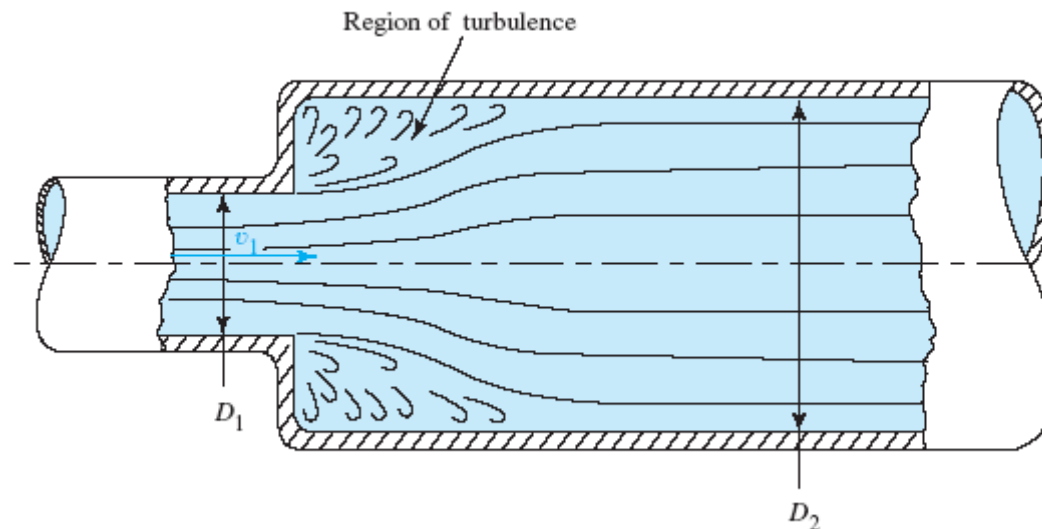
10.3 Sudden Enlargement

- The minor loss is calculated from the equation

$$h_L = K(v_1^2/2g) \qquad\qquad (10\text{–}2)$$

  where v_1 is the average velocity of flow in the smaller pipe ahead of the enlargement.
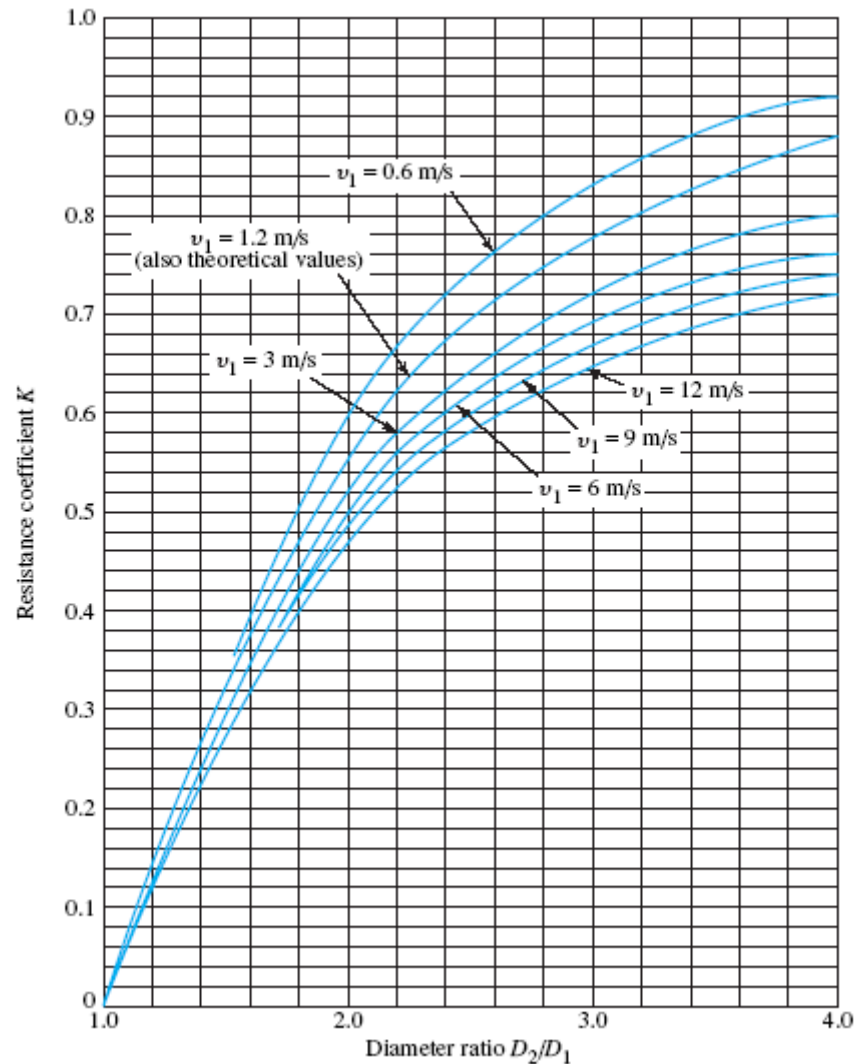
- By making some simplifying assumptions about the character of the flow stream as it expands through the sudden enlargement, it is possible to analytically predict the value of *K* from the following equation:

$$K = [1 - (A_1/A_2)]^2 = [1 - (D_1/D_2)^2]^2 \qquad (10\text{–}3)$$

10.3 Sudden Enlargement

- Fig 10.2 shows the resistance coefficient—sudden enlargement.

10.3 Sudden Enlargement

- Table 10.1 shows the resistance coefficient—sudden enlargement

D_2/D_1	Velocity v_1						
	0.6 m/s	1.2 m/s	3 m/s	4.5 m/s	6 m/s	9 m/s	12 m/s
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	0.11	0.10	0.09	0.09	0.09	0.09	0.08
1.4	0.26	0.25	0.23	0.22	0.22	0.21	0.20
1.6	0.40	0.38	0.35	0.34	0.33	0.32	0.32
1.8	0.51	0.48	0.45	0.43	0.42	0.41	0.40
2.0	0.60	0.56	0.52	0.51	0.50	0.48	0.47
2.5	0.74	0.70	0.65	0.63	0.62	0.60	0.58
3.0	0.83	0.78	0.73	0.70	0.69	0.67	0.65
4.0	0.92	0.87	0.80	0.78	0.76	0.74	0.72
5.0	0.96	0.91	0.84	0.82	0.80	0.77	0.75
10.0	1.00	0.96	0.89	0.86	0.84	0.82	0.80
∞	1.00	0.98	0.91	0.88	0.86	0.83	0.81

Source: King, H. W., and E. F. Brater. 1963. *Handbook of Hydraulics*, 5th ed. New York: McGraw-Hill, Table 6–7.

Example 10.1

Determine the energy loss that will occur as 100 L/min of water flows through a sudden enlargement from a 1-in copper tube (Type K) to a 3-in tube (Type K). See Appendix H for tube dimensions.

Example 10.1

Using the subscript 1 for the section just ahead of the enlargement and 2 for the section downstream from the enlargement, we get

$$D_1 = 25.3 \text{ mm} = 0.0253 \text{ m}$$

$$A_1 = 5.017 \times 10^{-4} \text{ m}^2$$

$$D_2 = 73.8 \text{ mm} = 0.0738 \text{ m}$$

$$A_2 = 4.282 \times 10^{-3} \text{ m}^2$$

$$v_1 = \frac{Q}{A_1} = \frac{100 \text{ L/min}}{5.017 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60\,000 \text{ L/min}} = 3.32 \text{ m/s}$$

$$\frac{v_1^2}{2g} = \frac{(3.32)^2}{(2)(9.81)} \text{ m} = 0.56 \text{ m}$$

Example 10.1

To find a value for *K*, the diameter ratio is needed. We find that

$$D_2/D_1 = 73.8/25.3 = 2.92$$

From Fig. 10.2, K = 10.2. Then we have

$$h_L = K(v_1^2/2g) = (0.72)(0.56 \text{ m}) = 0.40 \text{ m}$$

This result indicates that 0.40 Nm of energy is dissipated from each newton of water that flows through the sudden enlargement.

Example 10.2

Determine the difference between the pressure ahead of a sudden enlargement and the pressure downstream from the enlargement. Use the data from Example Problem 10.1.

First, we write the energy equation:

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$p_1 - p_2 = \gamma\left[(z_2 - z_1) + (v_2^2 - v_1^2)/2g + h_L\right]$$

Example 10.2

If the enlargement is horizontal, $z_2 - z_1 = 0$. Even if it were vertical, the distance between points 1 and 2 is typically so small that it is considered negligible. Now, calculating the velocity in the larger pipe, we get

$$v_2 = \frac{Q}{A_2} = \frac{100 \text{ L/min}}{4.282 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60\,000 \text{ L/min}} = 0.39 \text{ m/s}$$

Example 10.2

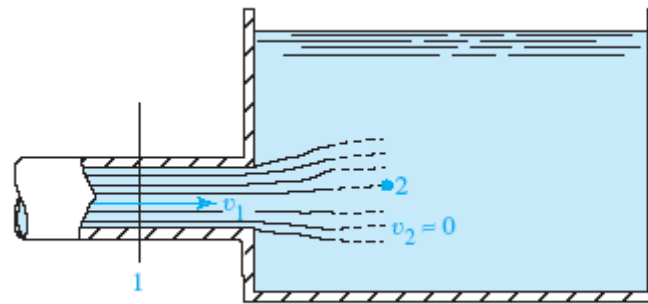Using = 9.81 kN/m³ for water and h_L = 0.40m from Example Problem 10.1, we have

$$p_1 - p_2 = \frac{9.81 \text{ kN}}{\text{m}^3}\left[0 + \frac{(0.39)^2 - (3.32)^2}{(2)(9.81)}\text{m} + 0.40 \text{ m}\right]$$

$$= -1.51 \text{ kN/m}^2 = -1.51 \text{ kPa}$$

Therefore, p_2 is 1.51 kPa greater than p_1.

10.4 Exit Loss

- As a fluid flows from a pipe into a large reservoir or tank, as shown in Fig. 10.3, its velocity is decreased to very nearly zero.

- Therefore, the energy loss for this condition is

$$h_L = 1.0(v_1^2/2g) \qquad\qquad (10\text{--}4)$$

- This is called the *exit loss*.

Example 10.3

Determine the energy loss that will occur as 100 L/min of water flows from a 1-in copper tube (Type K) into a large tank.

Using Eq. (10–4), we have

$$h_L = 1.0(v_1^2/2g)$$

From the calculations in Example Problem 10.1, we know that
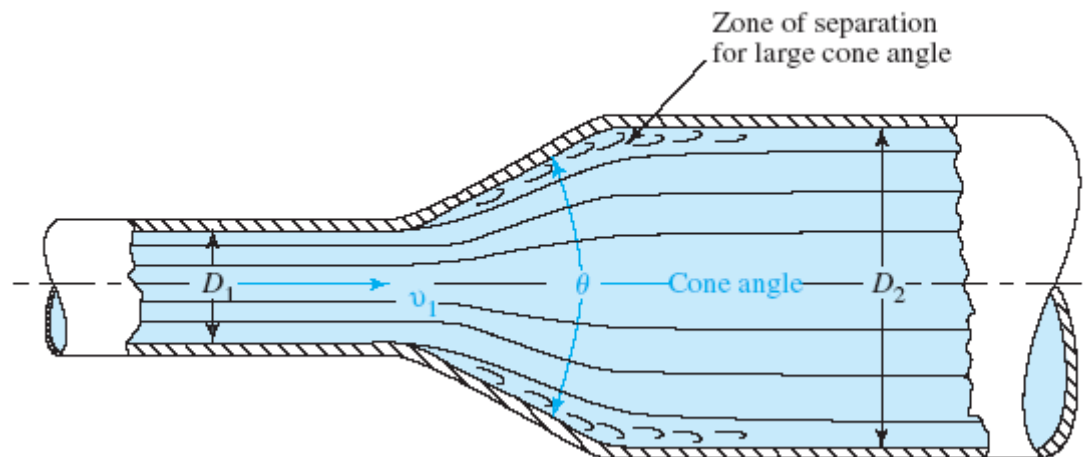
$$v_1 = 3.32 \text{ m/s}$$
$$v_1^2/2g = 0.56 \text{ m}$$

$$h_L = (1.0)(0.56 \text{ m}) = 0.56 \text{ m}$$
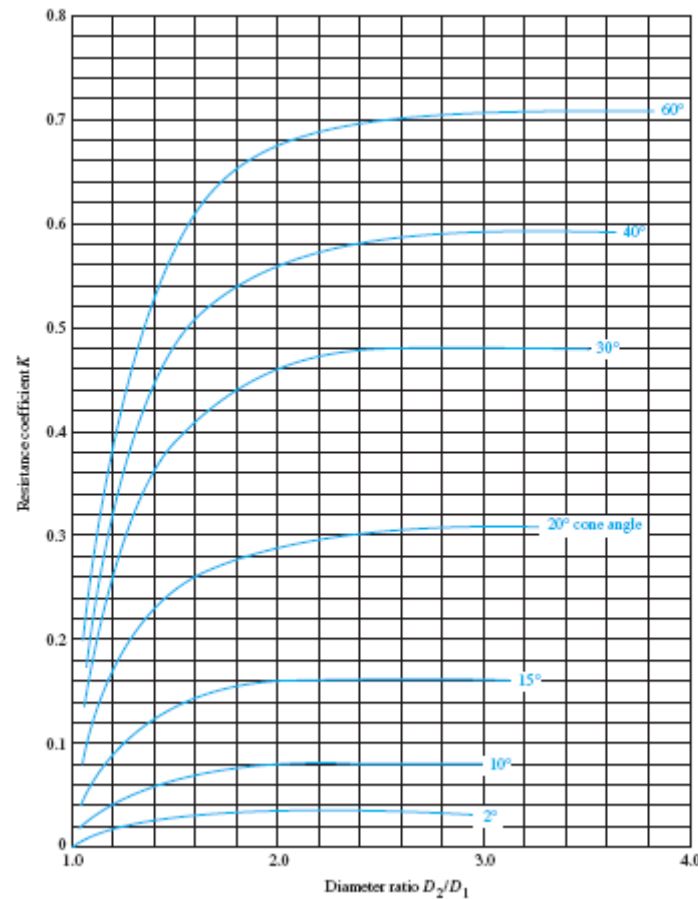
10.5 Gradual Enlargement

- If the transition from a smaller to a larger pipe can be made less abrupt than the square-edged sudden enlargement, the energy loss is reduced.

- This is normally done by placing a conical section between the two pipes as shown in Fig. 10.4.

10.5 Gradual Enlargement

- Fig 10.5 shows the resistance coefficient—gradual enlargement.

10.5 Gradual Enlargement

- The energy loss for a gradual enlargement is calculated from

$$h_L = K(v_1^2/2g) \qquad (10\text{-}5)$$

- Data for various values are given below

TABLE 10.2   Resistance coefficient—gradual enlargement

D_2/D_1	Angle of Cone θ											
	2°	6°	10°	15°	20°	25°	30°	35°	40°	45°	50°	60°
1.1	0.01	0.01	0.03	0.05	0.10	0.13	0.16	0.18	0.19	0.20	0.21	0.23
1.2	0.02	0.02	0.04	0.09	0.16	0.21	0.25	0.29	0.31	0.33	0.35	0.37
1.4	0.02	0.03	0.06	0.12	0.23	0.30	0.36	0.41	0.44	0.47	0.50	0.53
1.6	0.03	0.04	0.07	0.14	0.26	0.35	0.42	0.47	0.51	0.54	0.57	0.61
1.8	0.03	0.04	0.07	0.15	0.28	0.37	0.44	0.50	0.54	0.58	0.61	0.65
2.0	0.03	0.04	0.07	0.16	0.29	0.38	0.46	0.52	0.56	0.60	0.63	0.68
2.5	0.03	0.04	0.08	0.16	0.30	0.39	0.48	0.54	0.58	0.62	0.65	0.70
3.0	0.03	0.04	0.08	0.16	0.31	0.40	0.48	0.55	0.59	0.63	0.66	0.71
∞	0.03	0.05	0.08	0.16	0.31	0.40	0.49	0.56	0.60	0.64	0.67	0.72

Source: King, H. W., and E. F. Brater. 1963. *Handbook of Hydraulics*, 5th ed. New York: McGraw-Hill, Table 6–8.

10.5 Gradual Enlargement

- The energy loss calculated from Eq. (10–5) does not include the loss due to friction at the walls of the transition.

- For relatively steep cone angles, the length of the transition is short and therefore the wall friction loss is negligible.

Example 10.4

Determine the energy loss that will occur as 100 L/min of water flows from a 1-in copper tube (Type K) into a 3-in copper tube (Type K) through a gradual enlargement having an included cone angle of 30 degrees.

Using data from Appendix H and the results of some calculations in preceding example problems, we know that

$$v_1 = 3.32 \text{ m/s}$$

$$v_1^2/2g = 0.56 \text{ m}$$

$$D_2/D_1 = 73.8/25.3 = 2.92$$

Example 10.4

From Fig. 10.5, we find that K = 0.48. Then we have

$$h_L = K(v_1^2/2g) = (0.48)(0.56 \text{ m}) = 0.27 \text{ m}$$

Compared with the sudden enlargement described in Example Problem 10.1, the energy loss decreases by 33 percent when 30 degrees the gradual enlargement is used.

10.5.1 Diffuser

- Another term for an enlargement is a *diffuser*.

- The function of a diffuser is to convert kinetic energy (represented by velocity head) to pressure energy (represented by the pressure head) by decelerating the fluid as it flows from the smaller to the larger pipe.

- The theoretical maximum pressure after the expansion could be computed from Bernoulli's equation,

$$p_1/\gamma + z_1 + v_1^2/2g = p_2/\gamma + z_2 + v_2^2/2g$$

10. Minor Losses

10.5.1 Diffuser

- If the diffuser is in a horizontal plane, the elevation terms can be cancelled out.

- Then the pressure increase across the ideal diffuser is

$$\Delta p = p_2 - p_1 = \gamma(v_1^2 - v_2^2)/2g$$

- This is often called *pressure recovery*.

- In a *real diffuser*, energy losses do occur and the general energy equation must be used:

$$p_1/\gamma + z_1 + v_1^2/2g - h_L = p_2/\gamma + z_2 + v_2^2/2g$$

$$\Delta p = p_2 - p_1 = \gamma[(v_1^2 - v_2^2)/2g - h_L]$$

10.6 Sudden Contraction

- The energy loss due to a sudden contraction, such as that sketched in Fig. 10.6, is calculated from

$$h_L = K(v_2^2/2g) \qquad\qquad (10\text{--}6)$$

  where v^2 is the velocity in the small pipe downstream from the contraction.

- Fig 10.7 shows the resistance coefficient—sudden contraction.

- Figure 10.8 illustrates what happens as the flow stream converges. The lines in the figure represent the paths of various parts of the flow stream called *streamlines.*

10.6 Sudden Contraction

10.6 Sudden Contraction

Vena contracta

Flow

Turbulence
zones

1

2
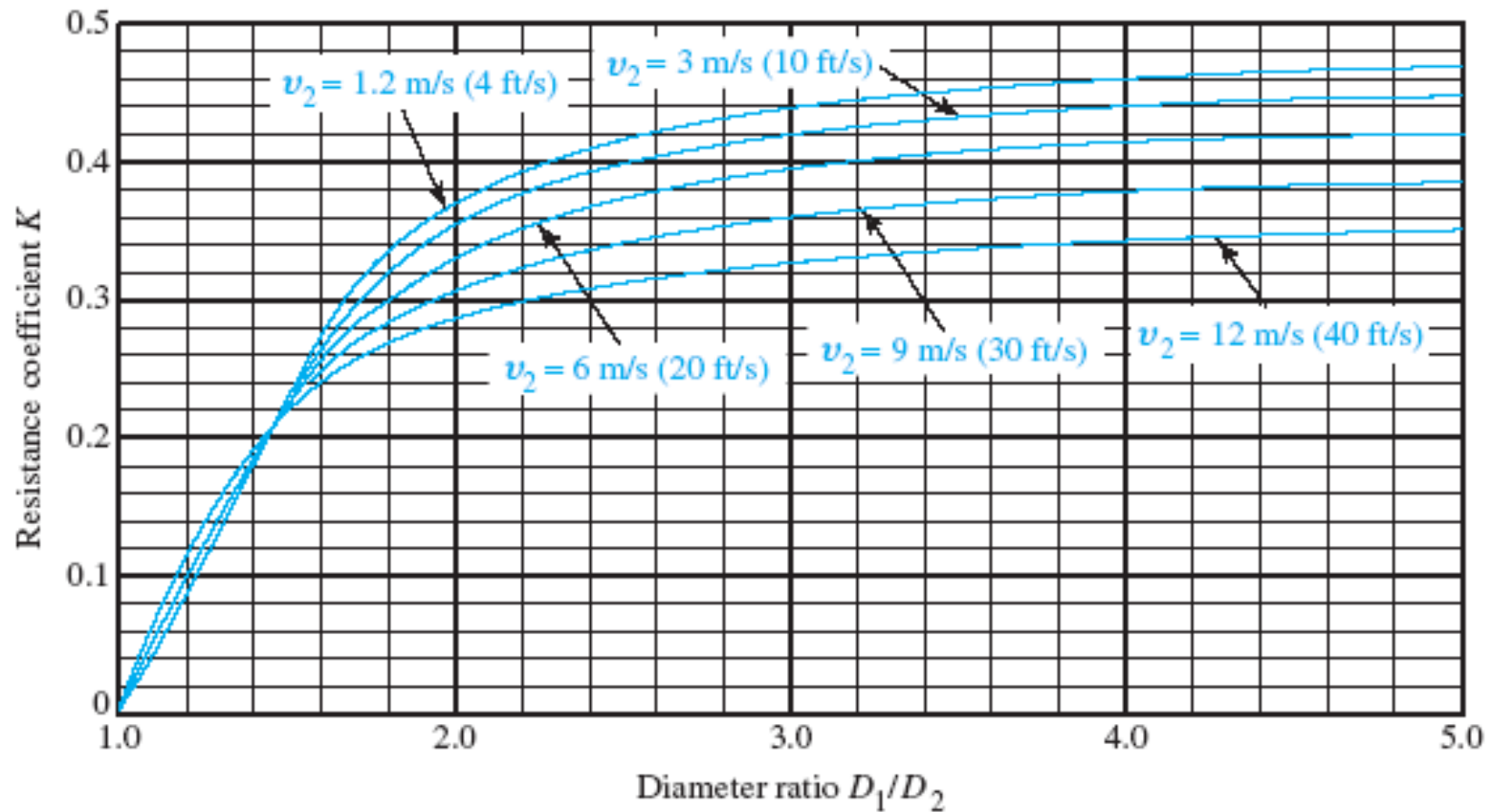
10.6 Sudden Contraction

- Table 10.3 shows the resistance coefficient—sudden contraction

D_1/D_2	Velocity v_2								
	0.6 m/s	1.2 m/s	1.8 m/s	2.4 m/s	3 m/s	4.5 m/s	6 m/s	9 m/s	12 m/s
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06
1.2	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.10	0.11
1.4	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.20
1.6	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24
1.8	0.34	0.34	0.34	0.33	0.33	0.32	0.31	0.29	0.27
2.0	0.38	0.37	0.37	0.36	0.36	0.34	0.33	0.31	0.29
2.2	0.40	0.40	0.39	0.39	0.38	0.37	0.35	0.33	0.30
2.5	0.42	0.42	0.41	0.40	0.40	0.38	0.37	0.34	0.31
3.0	0.44	0.44	0.43	0.42	0.42	0.40	0.39	0.36	0.33
4.0	0.47	0.46	0.45	0.45	0.44	0.42	0.41	0.37	0.34
5.0	0.48	0.47	0.47	0.46	0.45	0.44	0.42	0.38	0.35
10.0	0.49	0.48	0.48	0.47	0.46	0.45	0.43	0.40	0.36
∞	0.49	0.48	0.48	0.47	0.47	0.45	0.44	0.41	0.38

Source: King, H. W., and E. F. Brater, 1963. *Handbook of Hydraulics*, 5th ed. New York: McGraw-Hill, Table 6–9.

10. Minor Losses

Example 10.5

Determine the energy loss that will occur as 100 L/min of water flows from a 3-in copper tube (Type K) into a 1-in copper tube (Type K) through a sudden contraction.

From Eq. (10–6), we have

$$h_L = K(v_2^2/2g)$$

For the copper tube,

$$D_1/D_2 = 73.8/25.3 = 2.92$$

$$v_2 = \frac{Q}{A_2} = \frac{100 \, \text{L/min}}{5.017 \times 10^{-4} \, \text{m}^2} \times \frac{1 \, \text{m}^3/\text{s}}{60\,000 \, \text{L/min}} = 3.32 \, \text{m/s}$$

$$v_2^2/2g = 0.56 \, \text{m}$$

Example 10.5

From Fig. 10.7 we can find K = 0.42. Then we have

$$h_L = K(v_2^2/2g) = (0.42)(0.56 \text{ m}) = 0.24 \text{ m}$$

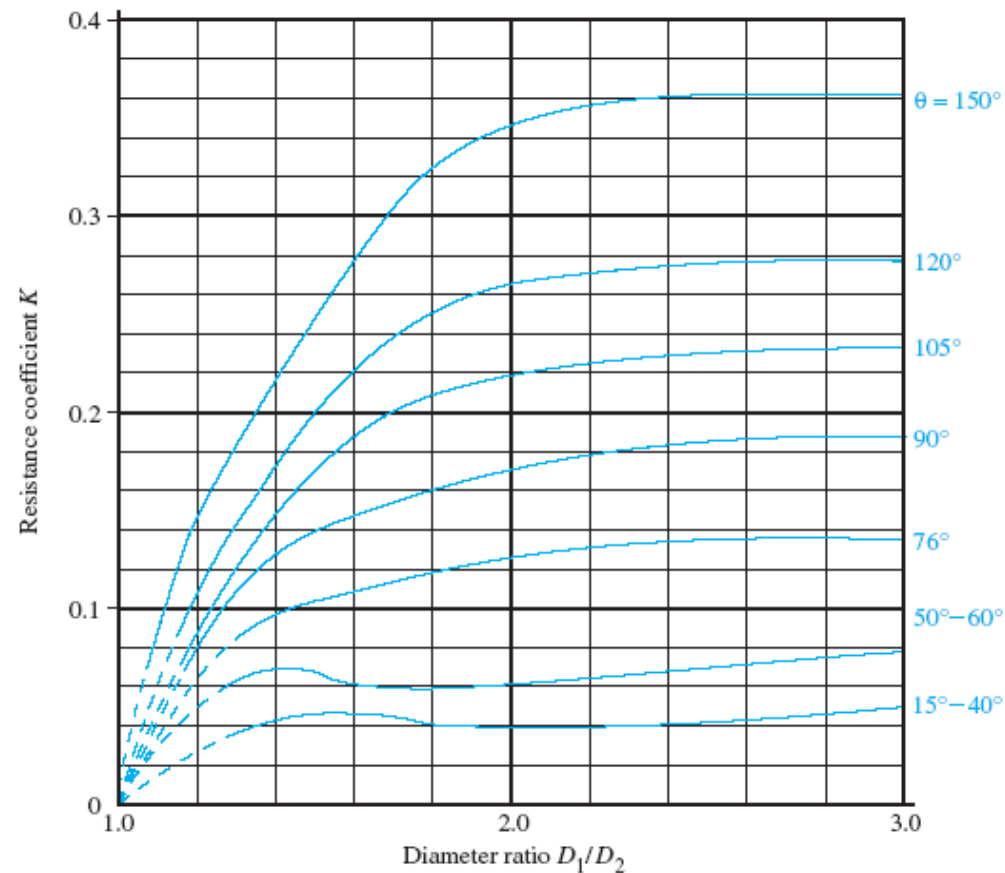## 10.7 Gradual Contraction

- The energy loss in a contraction can be decreased substantially by making the contraction more gradual.

- Figure 10.9 shows such a gradual contraction, formed by a conical section between the two diameters with sharp breaks at the junctions.

10.7 Gradual Contraction

- Figure 10.10 shows the data (from Reference 8) for the resistance coefficient versus the diameter ratio for several values of the cone angle.
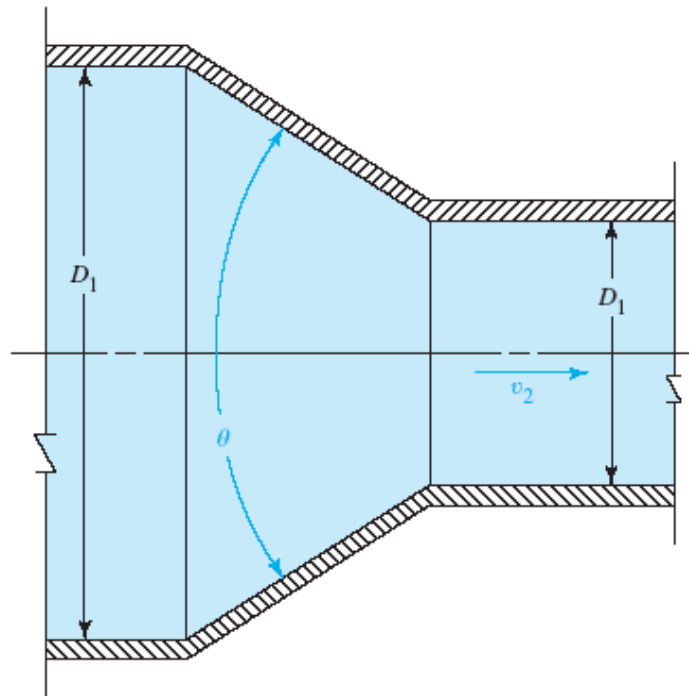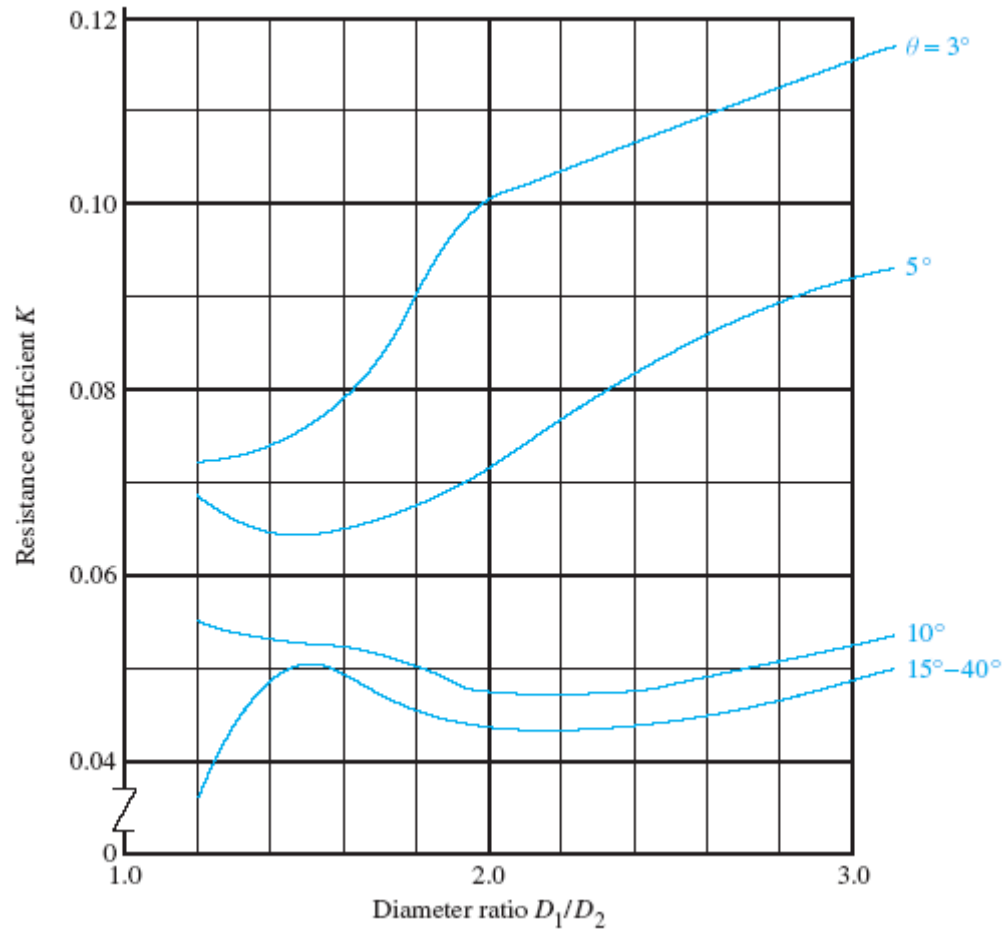
10. Minor Losses

10.7 Gradual Contraction

- As the cone angle of the contraction decreases below the resistance coefficient actually increases, as shown in Fig. 10.11.

- The reason is that the data include the effects of both the local turbulence caused by flow separation and pipe friction.

- For the smaller cone angles, the transition between the two diameters is very long, which increases the friction losses.

10.7 Gradual Contraction
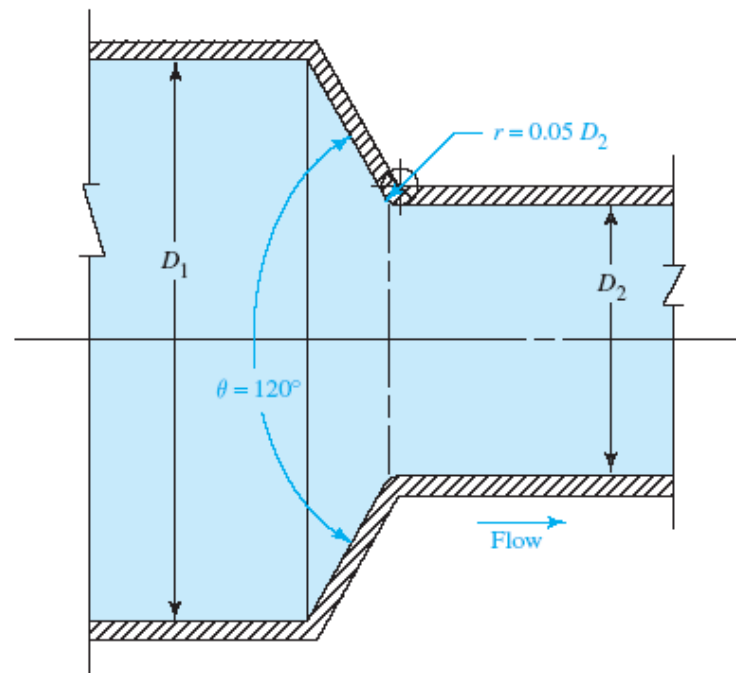
10.7 Gradual Contraction

- In Fig. 10.12, which shows a contraction with a 120° included angle and $D_1/D_2 = 2.0$, the value of K decreases from approximately 0.27 to 0.10 with a radius of only $0.05(D_2)$ where D_2 is the inside diameter of the smaller pipe.
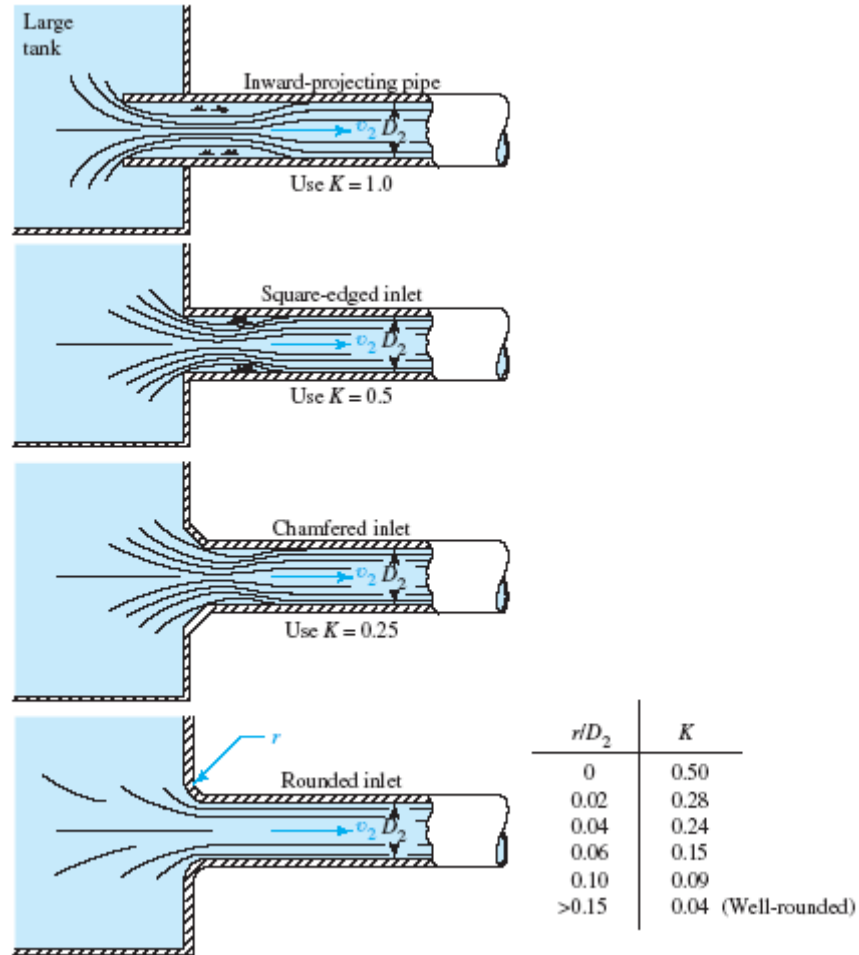
10.8 Entrance Loss

- A special case of a contraction occurs when a fluid flows from a relatively large reservoir or tank into a pipe.

- The fluid must accelerate from a negligible velocity to the flow velocity in the pipe.

- The ease with which the acceleration is accomplished determines the amount of energy loss, and therefore the value of the entrance resistance coefficient is dependent on the geometry of the entrance.

- Figure 10.13 shows four different configurations and the suggested value of *K* for each.

10.8 Entrance Loss

10.8 Entrance Loss

- In summary, after selecting a value for the resistance coefficient from Fig. 10.13, we can calculate the energy loss at an entrance from

$$h_L = K(v_2^2/2g) \qquad (10\text{--}7)$$

where v_2 is the velocity of flow in the pipe.

Example 10.6

Determine the energy loss that will occur as 100 L /min of water flows from a reservoir into a 1-in copper tube (Type K) (a) through an inward-projecting tube and (b) through a well rounded inlet.

Part (a): For the tube,

$$v_2 = Q/A_2 = 3.32 \text{ m/s} \qquad \text{(from Example Problem 10.1)}$$
$$v_2^2/2g = 0.56 \text{ m}$$

Example 10.6

For an inward-projecting entrance, K = 1.0. Then we have
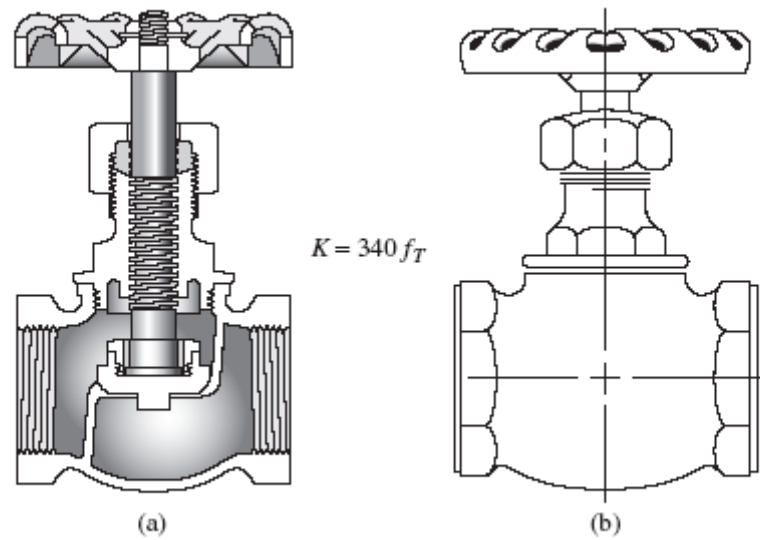
$$h_L = (1.0)(0.56 \text{ m}) = 0.56 \text{ m}$$

For well rounded entrance, K = 0.04. Then we have

$$h_L = (0.04)(0.56 \text{ m}) = 0.02 \text{ m}$$

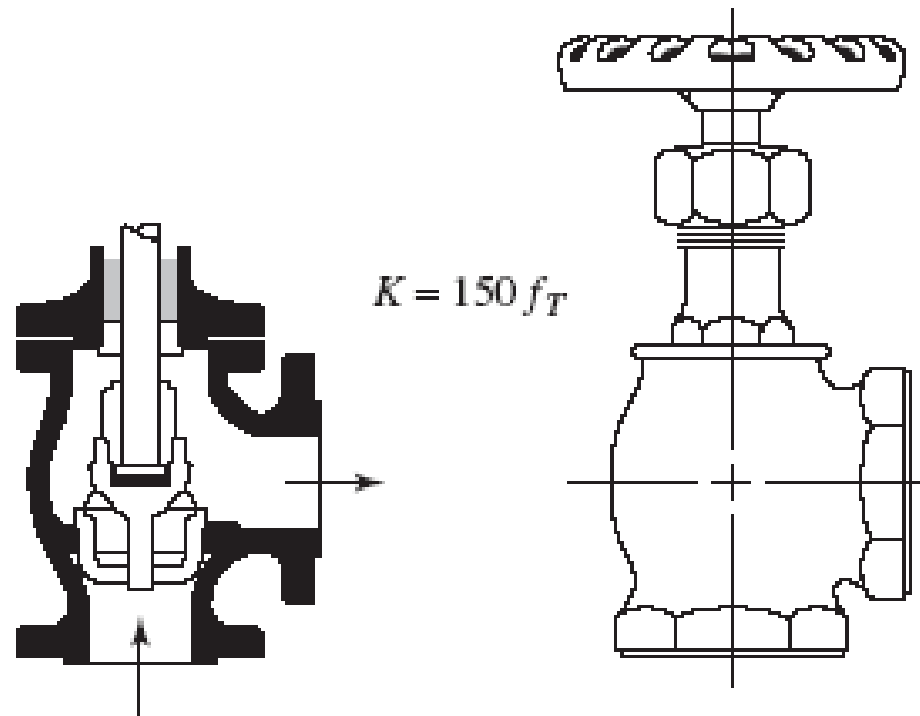## 10.9 Resistance Coefficients for Valves and Fittings

- Valves are used to control the amount of flow and may be globe valves, angle valves, gate valves, butterfly valves, any of several types of check valves, and many more.

- Fig 10.14 shows the globe value.

$$K = 340 f_T$$

(a)   (b)
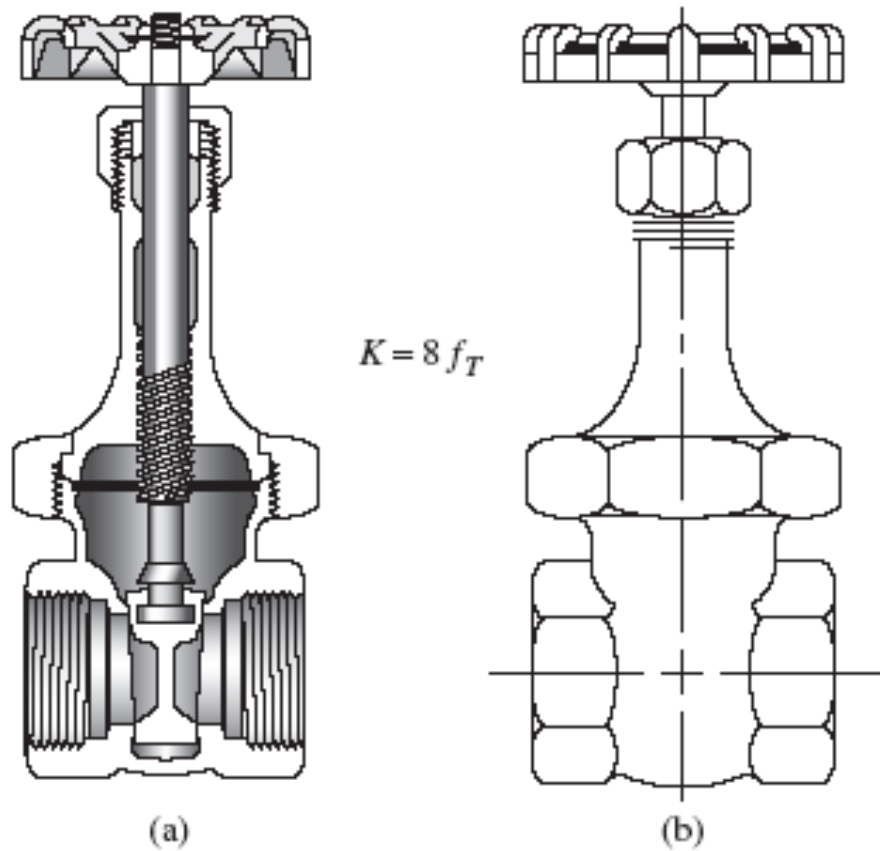
10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.15 shows the angle valve.

$$K = 150 f_T$$

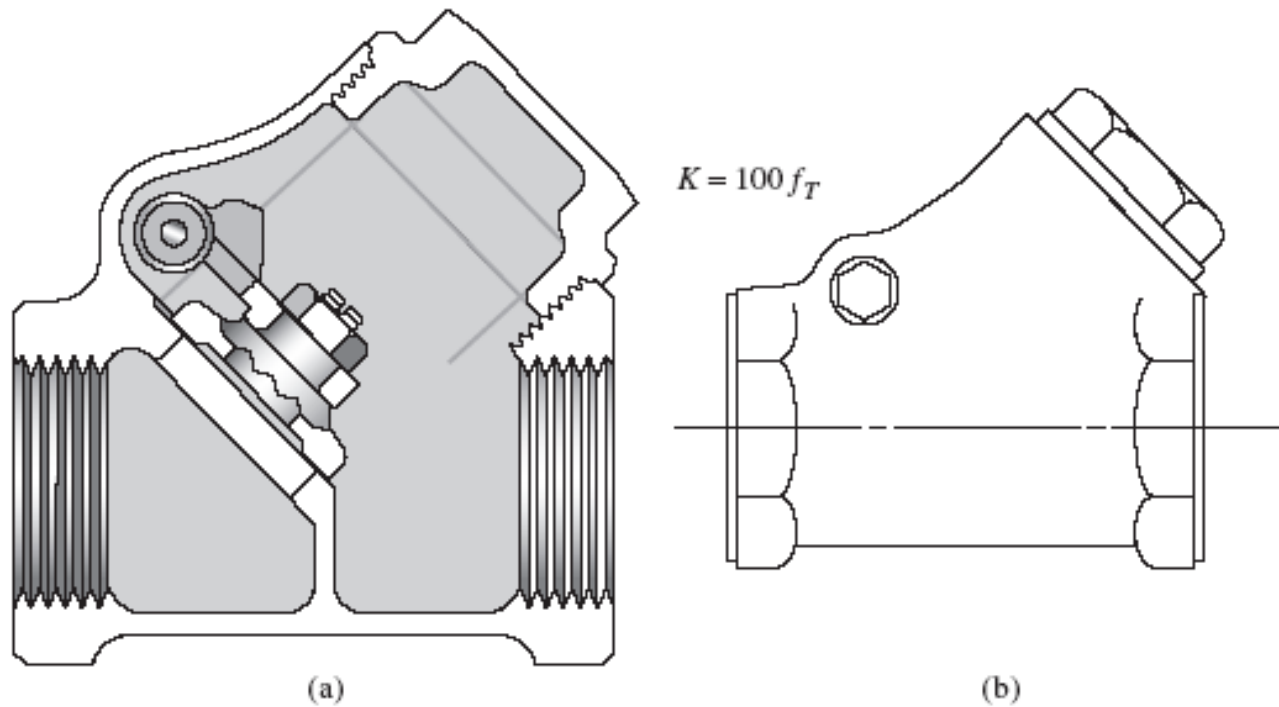## 10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.16 shows the gate valve.

$$K = 8 f_T$$

(a)   (b)

10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.17 shows the check valve.

$$K = 100\, f_T$$

(a)   (b)

10.9 Resistance Coefficients for Valves and Fittings
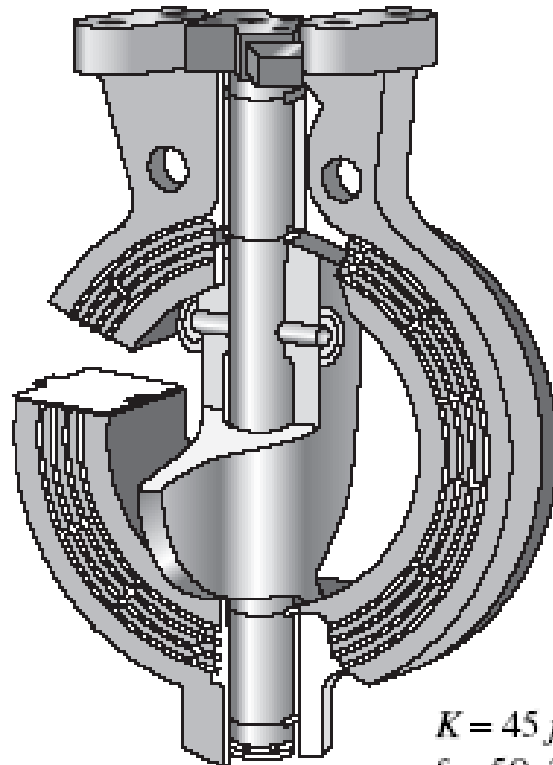
- Fig 10.18 shows the check valve – ball type.

$$K = 150 f_T$$

10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.19 shows the butterfly valve.

$$K = 45 f_T$$
for 50–200 mm sizes

10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.20 shows the foot valve with strainer—poppet disc type.

$$K = 420 f_T$$

10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.22 shows the pipe elbows.

(a) 90° elbow $K = 30f_T$

(b) 90° long radius elbow $K = 20f_T$

(c) 45° elbow $K = 16f_T$

(d) 90° street elbow $K = 50f_T$

(e) 45° street elbow $K = 26f_T$

(f) Return bend $K = 50f_T$

10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.23 shows the standard tees.

$K = 20f_T$

(a) Flow through run

$K = 60f_T$

(b) Flow through branch

10.9 Resistance Coefficients for Valves and Fittings

- However, the method of determining the resistance coefficient *K* is different. The value of *K* is reported in the form

$$K = (L_e/D)f_T \qquad (10-8)$$

- The term f_T is the friction factor in the pipe to which the valve or fitting is connected, *taken to be in the zone of complete turbulence*.

10.9 Resistance Coefficients for Valves and Fittings

- Some system designers prefer to compute the equivalent length of pipe for a valve and combine that value with the actual length of pipe.

- Equation (10–8) can be solved for L_e

$$L_e = K\,D/f_T \qquad\qquad (10\text{–}9)$$

- Table 10.4 shows the resistance in valves and fittings expressed as equivalent length in pipe diameters, *Le>D.*

10. Minor Losses

10.9 Resistance Coefficients for Valves and Fittings

Type	Equivalent Length in Pipe Diameters L_e/D
Globe valve—fully open	340
Angle valve—fully open	150
Gate valve—fully open	8
—¾ open	35
—½ open	160
—¼ open	900
Check valve—swing type	100
Check valve—ball type	150
Butterfly valve—fully open, 50–200 mm (2–8 in.)	45
—250–350 mm (10–14 in.)	35
—400–600 mm (16–24 in.)	25
Foot valve—poppet disc type	420
Foot valve—hinged disc type	75
90° standard elbow	30
90° long radius elbow	20
90° street elbow	50
45° standard elbow	16
45° street elbow	26
Close return bend	50
Standard tee—with flow through run	20
—with flow through branch	60

Source: Crane Valves, Signal Hill, CA.

10.9 Resistance Coefficients for Valves and Fittings

- Table 10.5 shows the friction factor in zone of complete turbulence for new, clean, commercial steel pipe

Nominal Pipe Size (in)	Friction Factor f_T	Nominal Pipe Size (in)	Friction Factor f_T
½	0.027	3½, 4	0.017
¾	0.025	5	0.016
1	0.023	6	0.015
1¼	0.022	8–10	0.014
1½	0.021	12–16	0.013
2	0.019	18–24	0.012
2½, 3	0.018		

10.9 Resistance Coefficients for Valves and Fittings

Procedure for Computing the Energy Loss Caused by Valves and Fittings Using Eq. (10–8)

1.   Find L_e/D for the valve or fitting from Table 10.4.

2a. *If the pipe is new clean steel:*

     Find f_T from Table 10.5.

2b. *For other pipe materials:*

     Determine the pipe wall roughness ϵ from Table 8.2.

     Compute D/ϵ.

     Use the Moody diagram, Fig. 8.6, to determine f_T in the zone of complete turbulence.

3.   Compute $K = f_T (L_e/D)$.

4.   Compute $h_L = K (v_p^2/2g)$, where v_p is the velocity in the pipe.

Example 10.7

Determine the resistance coefficient K for a fully open globe valve placed in a 6-in Schedule 40 steel pipe.

From Table 10.4 we find that the equivalent-length ratio for a fully open globe valve is 340. From Table 10.5 we find $f_T = 0.016$ for a 6-in pipe. Then,

$$K = (L_e/D)f_T = (340)(0.015) = 5.10$$

Example 10.7

Using $D=0.154$ m for the pipe, we find the equivalent length

$$L_e = KD/f_T = (5.10)(0.154 \text{ m})/(0.015) = 52.36 \text{ m}$$

$$L_e = (L_e/D)D = (340)(0.154 \text{ m}) = 52.36 \text{ m}$$

Example 10.8

Calculate the pressure drop across a fully open globe valve placed in a 4-in Schedule 40 steel pipe carrying 0.0252 m³/s of oil (sg = 0.87)

A sketch of the installation is shown in Fig. 10.24. To determine the pressure drop, the energy equation should be written for the flow between points 1 and 2:

4-in Schedule 40 pipe

•1   •2

Globe
valve-fully open
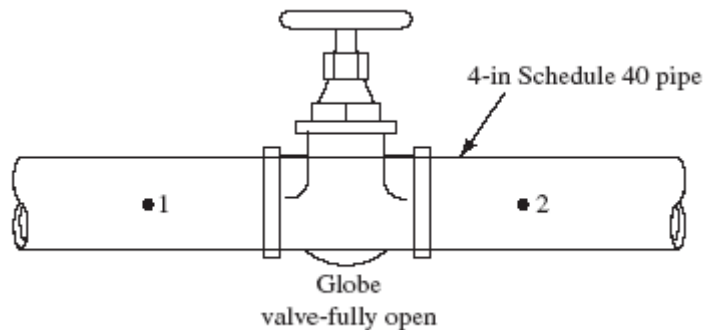
$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

Example 10.8

The energy loss h_L is the minor loss due to the valve only. The pressure drop is the difference between p_1 and p_2. Solving the energy equation for this difference gives

$$p_1 - p_2 = \gamma \left[(z_2 - z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

But $z_1 = z_2$ and $v_1 = v_2$. Then we have

$$p_1 - p_2 = \gamma h_L$$

$$h_L = K \times \frac{v^2}{2g} = f_T \times \frac{L_e}{D} \times \frac{v^2}{2g}$$

Example 10.8

For the pipe,

$$v = \frac{Q}{A} = \frac{0.0252 \text{ m}^3/\text{s}}{8.17 \times 10^{-3} \text{ m}^2} = 3.084 \text{ m/s}$$

From Table 10.5 we find $f_T = 0.017$ and for global valve, $L_e/D = 340$.

$$K = f_T \frac{L_e}{D} = (0.017)(340) = 5.78$$

$$h_L = K \times \frac{v^2}{2g} = (5.78) \frac{(3.084)^2}{(2)(9.81)} \text{ m} = 2.802 \text{ m}$$

Example 10.8

For the oil,

$$\gamma = (0.870)(1000)(9.81) \text{ N/m}^3 = 8534.7 \text{ N/m}^3.$$

$$p_1 - p_2 = \gamma h_L = \frac{8534.7 \text{ N}}{\text{m}^3} \times 2.802 \text{ m} = 23.9 \text{ kN/m}^2$$

$$= 23.9 \text{ kPa}$$

Therefore, the pressure in the oil drops by 23.9 kPa as it flows through the valve. Also, an energy loss of 2.802 m is dissipated as heat from each pound of oil that flows through the valve.

Example 10.9

Calculate the energy loss for the flow of 500 m³/h of water through a standard tee connected to a 6-in uncoated ductile iron pipe. The flow is through the branch.

Use the *Procedure for Computing the Energy Loss.*

1. From Table 10.4, $L_e/D = 60$.
2. For the ductile iron pipe, $\epsilon = 2.4 \times 10^{-4}$ m (Table 8.2) and $D = 0.156$ m (Apper

   The relative roughness is $D/\epsilon = (0.156\ \text{m})/(2.4 \times 10^{-4}\ \text{m}) = 650$.

   From the Moody diagram, $f_T = 0.022$ in the zone of complete turbulence.

3. The resistance coefficient is $K = f_T(L_e/D) = (0.022)(60) = 1.32$.
4. The velocity in the pipe is

$$v_p = \frac{Q}{A} = \frac{500\ \text{m}^3}{\text{h}} \frac{1\ \text{h}}{3600\ \text{s}} \frac{1}{1.910 \times 10^{-2}\ \text{m}^2} = 7.27\ \text{m/s}$$

Then the energy loss is

$$h_L = K(v_p^2/2g) = (1.32)(7.27\ \text{m/s})^2/[(2)(9.81\ \text{m/s}^2)] = 3.56\ \text{m}$$

10.10 Application of Standard Valves

- The resistance is heavily dependent on the path of the fluid as it travels into, through, and out from the valve.

- A valve with a more constricted path will cause more energy losses.

- Therefore, select the valve type with care if you desire the system you are designing to be efficient with relatively low energy losses.

10. Minor Losses

10.10.1 Globe Valve

- It is one of the most common valves and is relatively inexpensive.

- However, it is one of the poorest performing valves in terms of energy loss.

- Note that the resistance factor K is

$$K = f_T\,(L_e/D) = 340f_T$$

- If the globe valve were used in a commercial pipeline system where throttling is not needed, it would be very wasteful of energy.

10.10.2 Angle Valves

- The construction is very similar to that of the globe valve.

- However, the path is somewhat simpler because the fluid comes in through the lower port, moves around the valve seat, and turns to exit to the right.

- The resistance factor K is

$$K = f_T (L_e/D) = 150 f_T$$

10.10.3 Gate Valves

- When fully open, there is very little obstruction in the flow path to cause turbulence in the fluid flow stream.

- Therefore, this is one of the best types of valve for limiting the energy loss.

- The resistance factor K is

$$K = f_T (L_e/D) = 8f_T$$

10.10.4 Check Valves

- The function of a check valve is to allow flow in one direction while stopping flow in the opposite direction.

- A typical use is shown in Fig. 10.25, in which a sump pump is moving fluid from a sump below grade to the outside of a home or commercial building to maintain a dry basement area.

- When open, the swing check provides a modest restriction to the flow of fluid, resulting in the resistance factor of

$$K = f_T(L_e/D) = 100 f_T$$

10.10.4 Check Valves

Flow

Discharge pipe

Floor

Check valve

Sump pump

Float switch

Pit
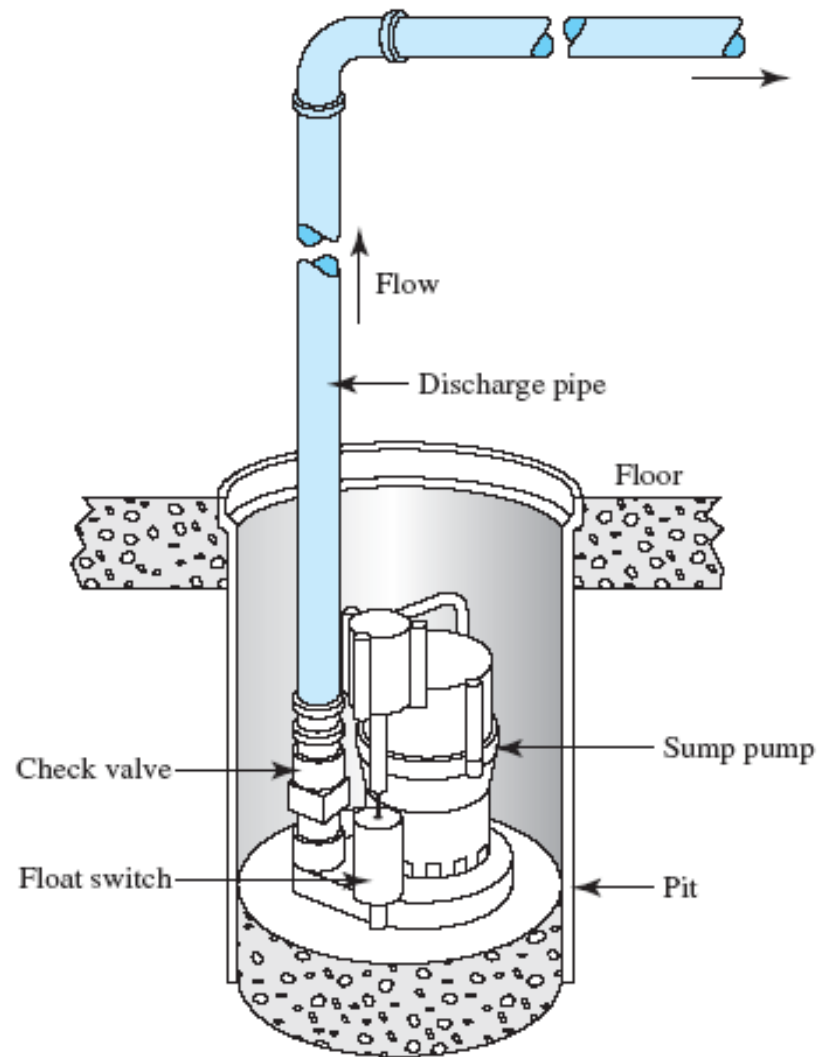
10.10.4 Check Valves

- The ball check causes more restriction because the fluid must flow completely around the ball.

- However, the ball check is typically smaller and simpler than the swing check.

- Its resistance is

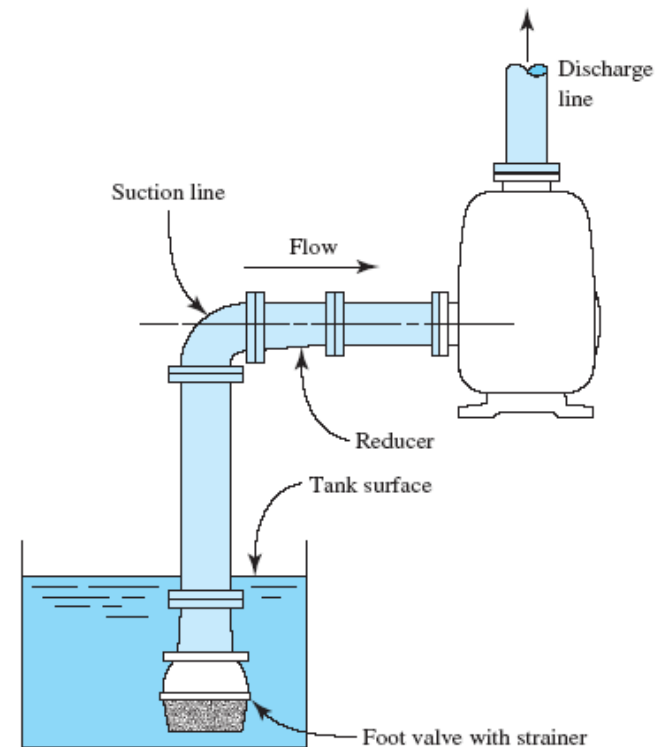$$K = f_T(L_e/D) = 150 f_T$$

10.10.5 Butterfly Valves

- Closing the valve requires only one-quarter turn of the handle, and this is often accomplished by a motorized operator for remote operation.

- The fully open butterfly valve has a resistance of

$$K = f_T (L_e/D) = 45 f_T$$

10.10.6 Foot Valve with Strainers

- Foot valves perform a similar function to that of check valves.

- They are used at the inlet of suction pipes that deliver fluid from a source tank or reservoir to a pump as illustrated in Fig. 10.26.

Discharge line

Suction line

Flow

Reducer

Tank surface

Foot valve with strainer

10.10.6 Foot Valve with Strainers

- Foot valves perform a similar function to that of check valves.

- They are used at the inlet of suction pipes that deliver fluid from a source tank or reservoir to a pump as illustrated in Fig. 10.26.

- The resistances for the two kinds of foot valves shown are

$$K = f_T (L_e/D) = 420 f_T \qquad \text{Poppet disc type}$$
$$K = f_T (L_e/D) = 75 f_T \qquad \text{Hinged disc type}$$

10. Minor Losses

10.10.6 Foot Valve with Strainers

Suction line

Flow

Discharge line

Reducer

Tank surface

Foot valve with strainer
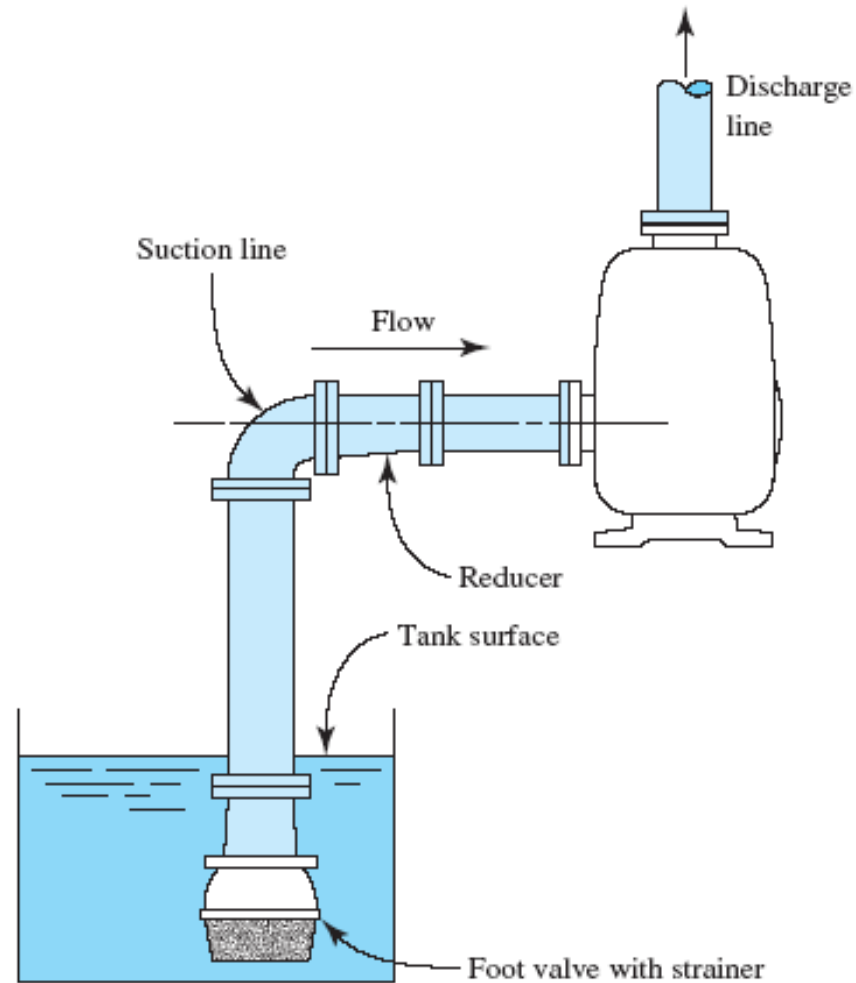
10.11 Pipe Bends

- Figure 10.27 shows that the minimum resistance for a 90° bend occurs when the ratio r/D is approximately three.
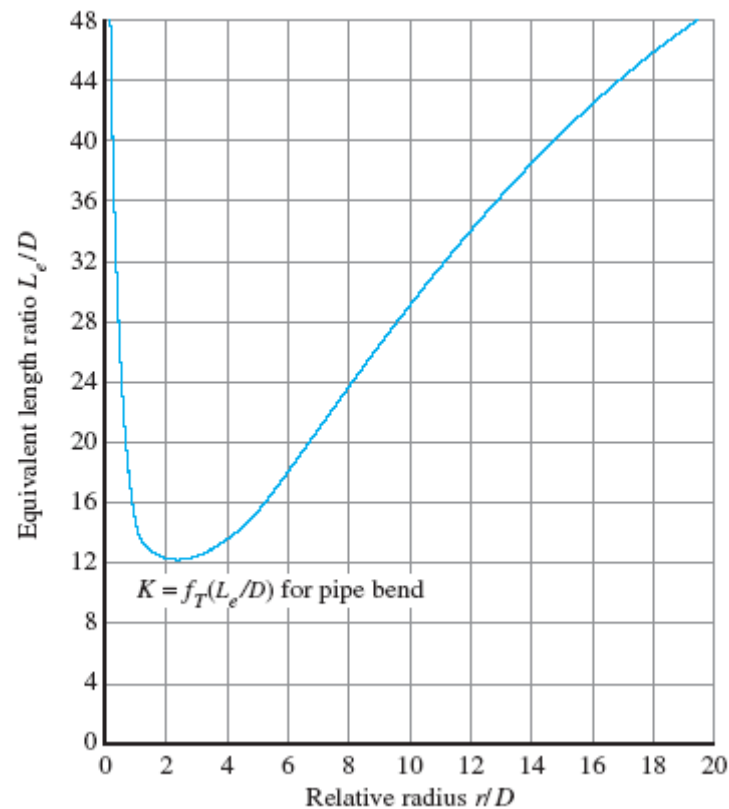
10.11 Pipe Bends

- Fig 10.28 shows a 90° bend.

10.11 Pipe Bends

- If R_o is the radius to the outside of the bend, R_i is the radius to the inside of the bend and is the *outside diameter* of the pipe or tube:

$$r = R_i + D_o/2$$
$$r = R_o - D_o/2$$
$$r = (R_o + R_i)/2$$

Example 10.10

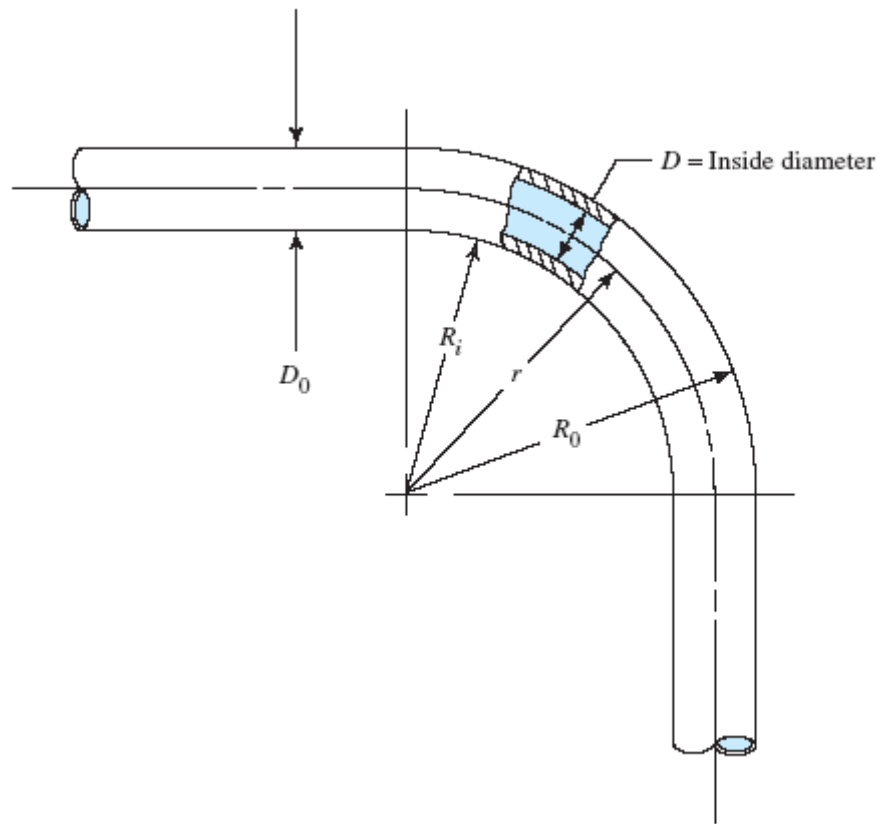A distribution system for liquid propane is made from 1.25in drawn steel tubing with a wall thickness of 0.083 in. Several 90° bends are required to fit the tubes to the other equipment in the system. The specifications call for the radius to the inside of each bend to be 200 mm. When the system carries 160 L /min of propane at 25°C, compute the energy loss to each bend.

Example 10.10

The radius r must be computed from

$$r = R_i + D_o/2$$

where D_o = 31.75mm, the outside diameter of the tube as found from Appendix G.
Completion of the calculation gives

$$r = 200 \text{ mm} + (31.75 \text{ mm})/2 = 215.9 \text{ mm}$$

$$r/D = 215.9 \text{ mm}/27.5 \text{ mm} = 7.85$$

Example 10.10

We now must compute the velocity to complete the evaluation of the energy loss from Darcy's equation:

$$v = \frac{Q}{A} = \frac{160 \, \text{L/min}}{5.954 \times 10^{-4} \, \text{m}^2} \frac{1.0 \, \text{m}^3/\text{s}}{60\,000 \, \text{L/min}} = 4.48 \, \text{m/s}$$

The relative roughness is

$$D/\epsilon = (0.0275 \, \text{m})/(1.5 \times 10^{-6} \, \text{m}) = 18\,333$$

Example 10.10

Then, we can find f$_T$ = 0.0108 from the Moody diagram (Fig. 8.6) in the zone of complete turbulence. Then

$$K = f_T\left(\frac{L_e}{D}\right) = 0.0108(23) = 0.248$$

Now the energy loss can be computed:

$$h_L = K\frac{v^2}{2g} = 0.248\frac{(4.48)^2}{(2)(9.81)} = 0.254 \text{ m} = 0.254 \text{ N·m/N}$$

10.11.1 Bend at Angles Other Than 90°

- Reference 2 recommends the following formula for computing the resistance factor K for bends at angles other than 90°

$$K_B = (n - 1)[0.25\pi f_T (r/D) + 0.5 K] + K \qquad (10\text{--}10)$$

where K is the resistance for one 90° bend found from Fig. 10.27.

Example 10.11

Evaluate the energy loss that would occur if the drawn steel tubing described in Example Problem 10.10 is coiled for 4.5 revolutions to make a heat exchanger. The inside radius of the bend is the same 200 mm used earlier and the other conditions are the same.

Let's start by bringing some data from Example Problem 10.10.

$$r/D = 7.85$$
$$f_T = 0.0108$$
$$K = 0.248$$
$$v = 4.48 \text{ m/s}$$

Example 10.11

Now we can compute the value of K_B for the complete coil using Eq. (10–10). Note that each revolution in the coil contains four 90° bends. Then,

$$n = 4.5 \text{ revolutions } (4.0 \text{ 90° bends/rev}) = 18$$

The total bend resistance is

$$K_B = (n - 1)[0.25\pi f_T (r/D) + 0.5 K] + K$$
$$K_B = (18 - 1)[0.25\pi(0.0108)(7.85) + 0.5(0.248)] + 0.248$$
$$K_B = 3.49$$

Example 10.11

Then the energy loss is found from

$$h_L = K_B(v^2/2g) = 3.49(4.48)^2/[2(9.81)] = 3.57 \, \text{N·m/N}$$

10.12 Pressure Drop in Fluid Power Valves

- The field of fluid power encompasses both the flow of liquid hydraulic fluids and air flow systems called *pneumatic systems*.

- Liquid hydraulic fluids are generally some form of petroleum oil, although many types of blended and synthetic materials can be used.

10.12 Pressure Drop in Fluid Power Valves

- Common elements for a liquid hydraulic system include:

1. A pump to provide fluid to a system at an adequate pressure and at the appropriate volume flow rate to accomplish the desired task.

2. A tank or reservoir of hydraulic fluid from which the pump draws fluid and to which the fluid is returned after accomplishing the task. Most fluid power systems are closed circuits in which the fluid is continuously circulated.

10.12 Pressure Drop in Fluid Power Valves

- Fig 10.29 shows some examples of fluid power system.

(a) Forward actuation

(b) Return actuation

(c) Idle position

10.13 Flow Coefficient for Valves Using C_v

- The basic liquid flow equation is

$$\text{Flow in gal/min} = C_V \sqrt{\Delta p / sg} \qquad (10\text{--}10)$$

- Alternatively, flow equation is SI units is

$$\text{Flow in L/min} = 1.442 C_V \sqrt{\frac{\Delta P}{sg}} \qquad (10\text{--}11)$$
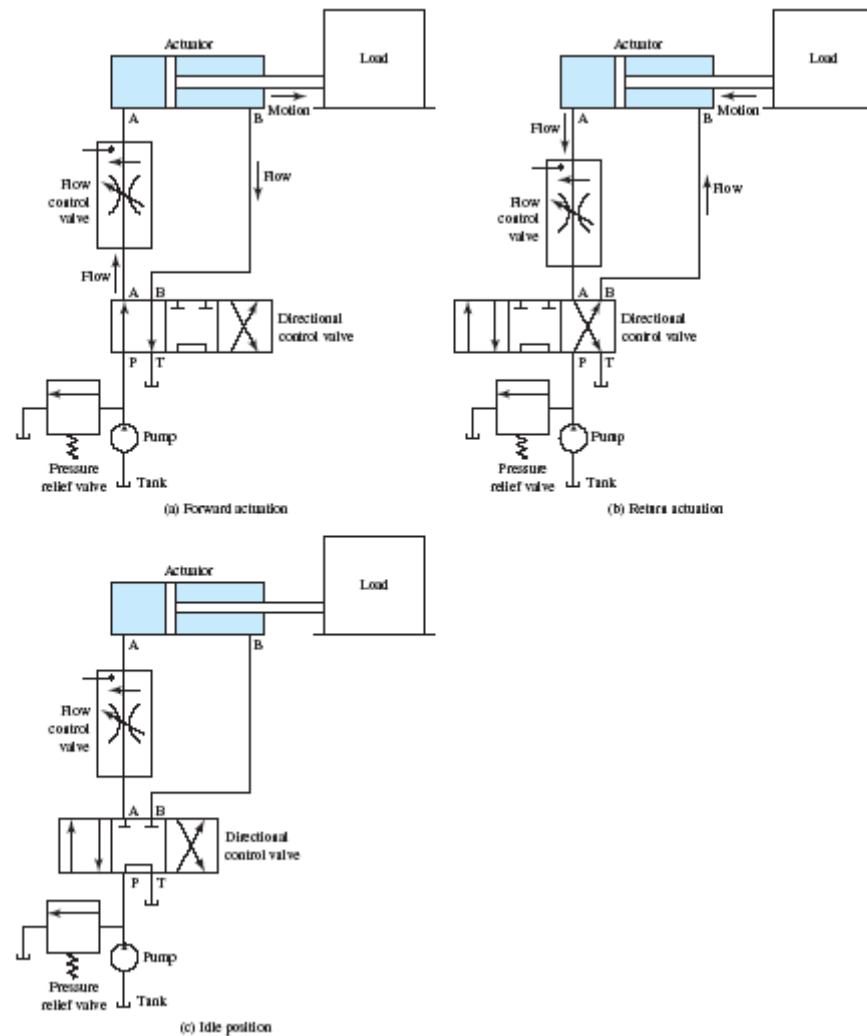
where $?p$ is in kPa.

10. Minor Losses

10.13 Flow Coefficient for Valves Using C_v

- Users of such valves for controlling the flow of air or other gases must account for the compressibility of the gas and the effect of the overall pressure difference across the valve.

- When the ratio of the upstream to the downstream pressure in a gas reaches the *critical pressure ratio*, no further increase of flow occurs as the downstream pressure is lowered.

- At the critical pressure ratio, the velocity of flow through the nozzle or valve is equal to the speed of sound in the gas at the local conditions.

Example 10.12

A particular design for a 0.5-in needle valve has a C_V rating of 1.5. Compute the pressure drop when 33 L/min of water at 15°C flows through the valve.

We solve for the following,

$$\Delta p = sg\left(\frac{Q}{1.442C_V}\right)^2 = 1.0\left(\frac{18.9}{1.5 \times 1.442}\right)^2 = 76.4 \text{ kPa}$$

Example 10.12

A particular design for a 4-in plastic butterfly valve has a C_V rating of 550. Compute the pressure drop when 3308 L/min of turpentine at 25°C flows through the valve.

The turpentine has a specific gravity of 0.87 (Appendix B). Then,

$$\Delta p = \text{sg} \left(\frac{Q}{1.442 C_V} \right)^2 = (0.87) \left(\frac{3308}{550 \times 1.442} \right)^2 = 15.14 \text{ kPa}$$

10.14 Plastic Valves

- Plastic valves are applied in numerous industries where excellent corrosion resistance and contamination control are required.

- Temperature and pressure limits are typically lower for plastic valves than for metal valves.

10. Minor Losses

10.14.1 Ball Valves

- Used most often for on/off operation, ball valves require only one-quarter turn to actuate them from full closed to full open.

- The rotating spherical ball is typically bored with a hole of the same diameter as the pipe or tube to which it is connected to provide low energy loss and pressure drop.

- They can be directly connected to the pipe or tube with adhesive or connected by flanges, unions, or screwed ends.

10.14.2 Butterfly Valves

- The butterfly disc provides easy opening and closure with one-quarter turn of the handle.

- Actuation can be manual, electric, or pneumatic. All parts that contact the flowing fluid are made from non-corroding materials.

- The shaft for the disc is typically made from stainless steel and is isolated from fluid contact.

10.14.3 Diaphragm Valves

- The valve is suitable for both on/off and modulated flow operation.

- The diaphragm isolates the brass hand-wheel shaft and other parts from the flowing fluid.

- Materials for wetted parts are selected for corrosion resistance to the particular fluid and temperatures to be encountered.

- The ends may be directly connected to the pipe or tube with adhesive or connected by flanges, unions, or screwed ends.

10.14.4 Swing Check Valves

- This valve opens easily in the proper direction of flow but closes rapidly to prevent backflow.

- All wetted parts are made from corrosion-resistant plastic, including the pin on which the disc pivots.

- External fasteners are typically made from stainless steel.

- The bonnet can be easily removed to clean the valve or to replace seals.

10.14.5 Sediment Strainers

- Strainers remove particulate impurities from the fluid stream to protect product quality or sensitive equipment.

- All fluid is directed to flow through perforated or screen-style filters as it passes through the body of the strainer.

10.14.6 Some Data for CV for Plastic Valves

- Table 10.6 gives representative sample data for plastic valves that can be used for problems in this book.

Type and Size Ball valve		C_V	Type and Size Butterfly valve		C_V
20 mm	(½ in)	12	50 mm	(1½ in)	90
25 mm	(¾ in)	25	63 mm	(2 in)	115
32 mm	(1 in)	37	90 mm	(3 in)	330
50 mm	(1½ in)	120	110 mm	(4 in)	550
63 mm	(2 in)	170	160 mm	(6 in)	1150
90 mm	(3 in)	450	225 mm	(8 in)	2280
110 mm	(4 in)	640	280 mm	(10 in)	4230
160 mm	(6 in)	1400	315 mm	(12 in)	5600
Diaphragm valve			**Swing check valve**		
20 mm	(½ in)	5	—		
25 mm	(¾ in)	9	25 mm	(¾ in)	25
32 mm	(1 in)	15	32 mm	(1 in)	40
50 mm	(1½ in)		50 mm	(1½ in)	80
63 mm	(2 in)	65	63 mm	(2 in)	11
90 mm	(3 in)	160	90 mm	(3 in)	330
110 mm	(4 in)	275	110 mm	(4 in)	500
160 mm	(6 in)	700	160 mm	(6 in)	1240
—			225 mm	(8 in)	2300