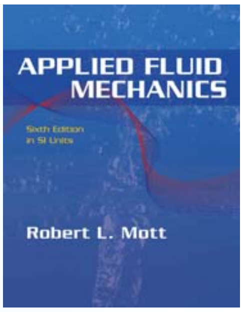
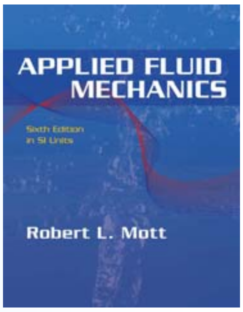
## Applied Fluid Mechanics




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

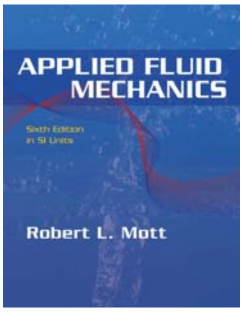


## Applied Fluid Mechanics




9. Velocity Profiles for Circular Sections and Flow in Noncircular Sections
10. Minor Losses
11. Series Pipeline Systems
12. Parallel Pipeline Systems
13. Pump Selection and Application
14. Open-Channel Flow
15. Flow Measurement
16. Forces Due to Fluids in Motion

## 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. Minor Losses

### 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:

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

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. Minor Losses

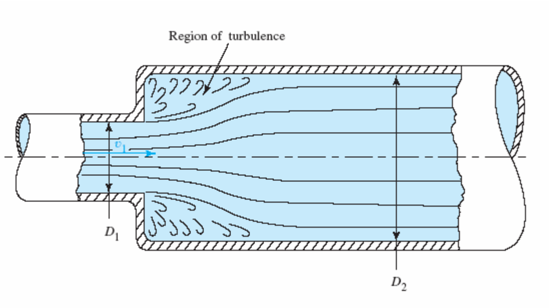
### 10.2 Resistant Coefficient

- 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. Minor Losses

### 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.






## 10. Minor Losses

### 10.3 Sudden Enlargement

- The minor loss is calculated from the equation

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

where $v_1$ is the average velocity of flow in the smaller pipe ahead of the enlargement.

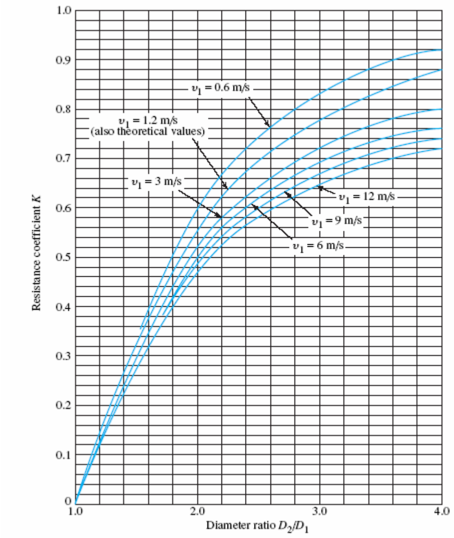
- By making some simplifying assumptions about the character of the flow stream as it expands through the sudden enlargement, it is possible to analytically predict the value of *K* from the following equation:

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

## 10. Minor Losses

### 10.3 Sudden Enlargement

- Fig 10.2 shows the resistance coefficient—sudden enlargement.






## 10. Minor Losses

### 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.

## 10. Minor Losses

### 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.



## 10. Minor Losses

### 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

$$D_1 = 25.3\ \text{mm} = 0.0253\ \text{m}$$
$$A_1 = 5.017 \times 10^{-4}\ \text{m}^2$$
$$D_2 = 73.8\ \text{mm} = 0.0738\ \text{m}$$
$$A_2 = 4.282 \times 10^{-3}\ \text{m}^2$$
$$v_1 = \frac{Q}{A_1} = \frac{100\ \text{L/min}}{5.017 \times 10^{-4}\ \text{m}^2} \times \frac{1\ \text{m}^3/\text{s}}{60\,000\ \text{L/min}} = 3.32\ \text{m/s}$$
$$\frac{v_1^2}{2g} = \frac{(3.32)^2}{(2)(9.81)}\text{m} = 0.56\ \text{m}$$

## 10. Minor Losses

### 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

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

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



## 10. Minor Losses

### 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:

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

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

## 10. Minor Losses

### 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

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



## 10. Minor Losses

### Example 10.2

Using $\gamma = 9.81\ \mathrm{kN/m^3}$ for water and $h_L = 0.40\mathrm{m}$ from Example Problem 10.1, we have

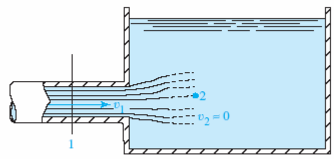
$$\begin{aligned} p_1 - p_2 &= \frac{9.81\ \mathrm{kN}}{\mathrm{m}^3}\left[0 + \frac{(0.39)^2 - (3.32)^2}{(2)(9.81)}\mathrm{m} + 0.40\ \mathrm{m}\right] \\ &= -1.51\ \mathrm{kN/m^2} = -1.51\ \mathrm{kPa} \end{aligned}$$

Therefore, $p_2$ is 1.51 kPa greater than $p_1$.

## 10. Minor Losses

### 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

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

- This is called the *exit loss*.



## 10. Minor Losses

### 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

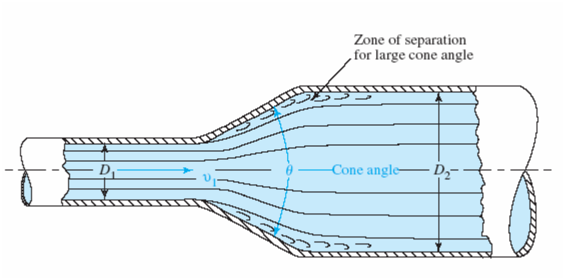
$$v_1 = 3.32\ \text{m/s}$$
$$v_1^2/2g = 0.56\ \text{m}$$

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

## 10. Minor Losses

### 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.

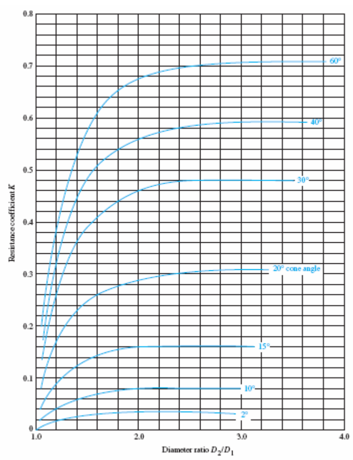





## 10. Minor Losses

### 10.5 Gradual Enlargement

- Fig 10.5 shows the resistance coefficient—gradual enlargement.



## 10. Minor Losses

### 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

| | Angle of Cone $\theta$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $D_2/D_1$ | 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. Minor Losses

### 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.

## 10. Minor Losses

### 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

$$v_1 = 3.32 \text{ m/s}$$
$$v_1^2/2g = 0.56 \text{ m}$$
$$D_2/D_1 = 73.8/25.3 = 2.92$$



## 10. Minor Losses

### 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. Minor Losses

### 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. Minor Losses

### 10.6 Sudden Contraction

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

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

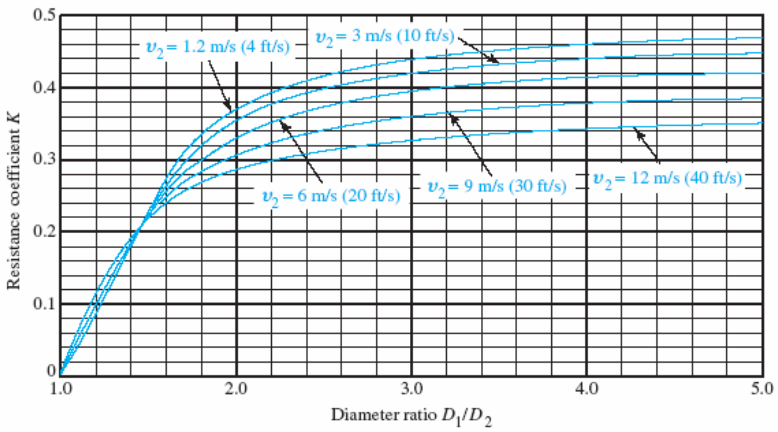
where $v^2$ is the velocity in the small pipe downstream from the contraction.

- 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.



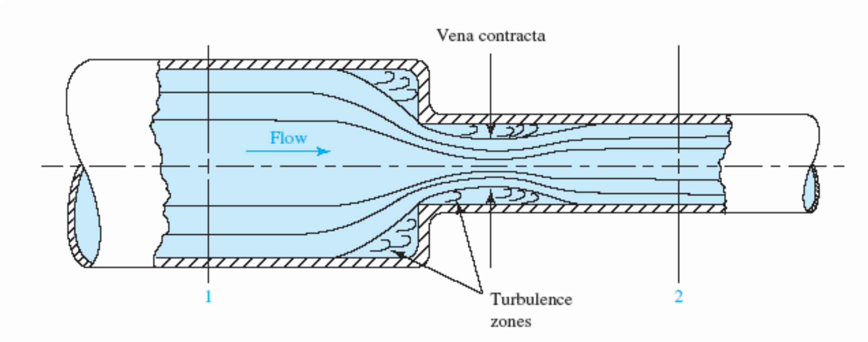
## 10. Minor Losses

### 10.6 Sudden Contraction



## 10. Minor Losses

### 10.6 Sudden Contraction






## 10. Minor Losses

### 10.6 Sudden Contraction

- Table 10.3 shows the resistance coefficient—sudden contraction

| | Velocity $v_2$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $D_1/D_2$ | 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 |
| $\infty$ | 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,

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

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

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



## 10. Minor Losses

### Example 10.5

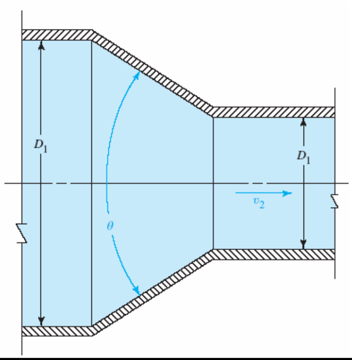
From Fig. 10.7 we can find K = 0.42. Then we have

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

## 10. Minor Losses

### 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.

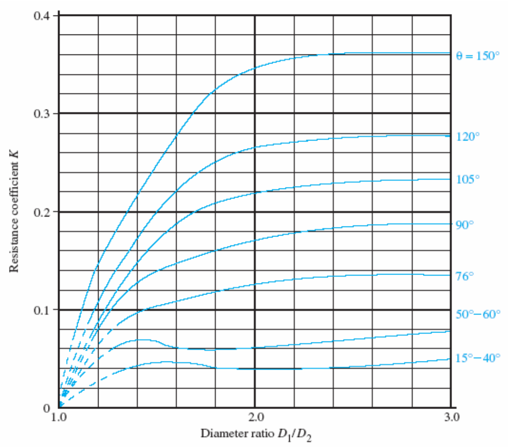





## 10. Minor Losses

### 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

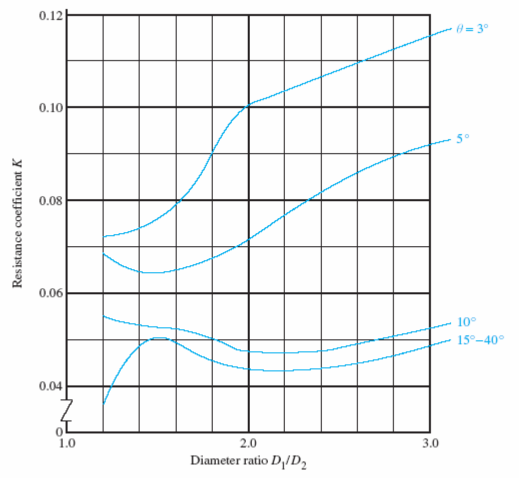
### 10.7 Gradual Contraction

- 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. Minor Losses

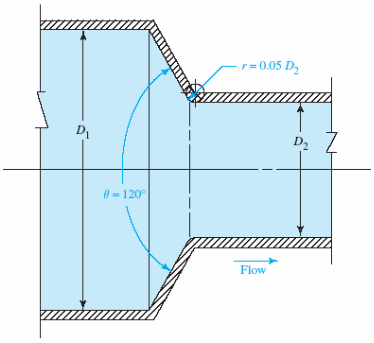
### 10.7 Gradual Contraction



## 10. Minor Losses

### 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.





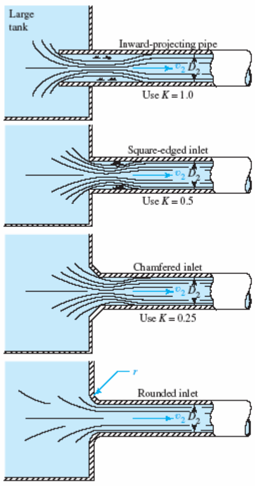

## 10. Minor Losses

### 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. Minor Losses

### 10.8 Entrance Loss




| $r/D_2$ | $K$ |
|---|---|
| 0 | 0.50 |
| 0.02 | 0.28 |
| 0.04 | 0.24 |
| 0.06 | 0.15 |
| 0.10 | 0.09 |
| >0.15 | 0.04 (Well-rounded) |



## 10. Minor Losses

### 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.

## 10. Minor Losses

### 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,

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



## 10. Minor Losses

### Example 10.6

For an inward-projecting entrance, K = 1.0. Then we have

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

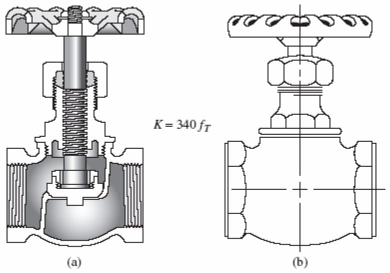
For well rounded entrance, K = 0.04. Then we have

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

## 10. Minor Losses

### 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.

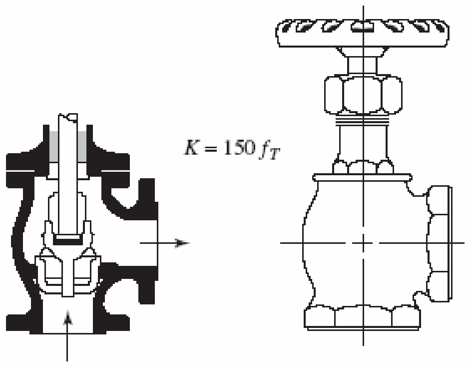





## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

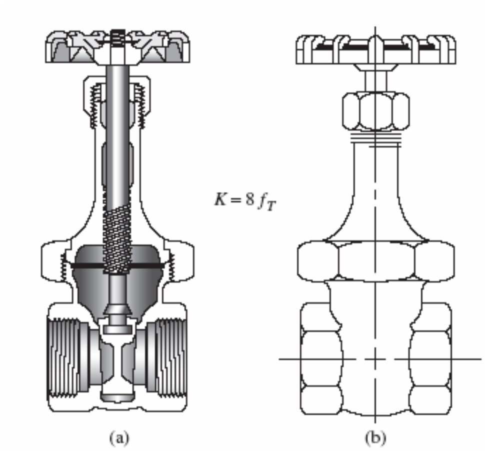
- Fig 10.15 shows the angle valve.



## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.16 shows the gate valve.

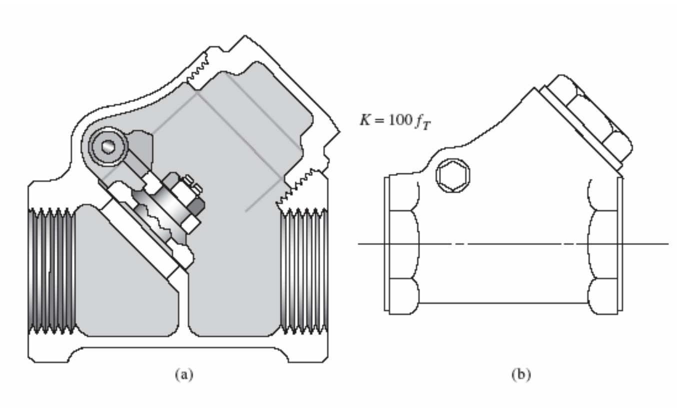





## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

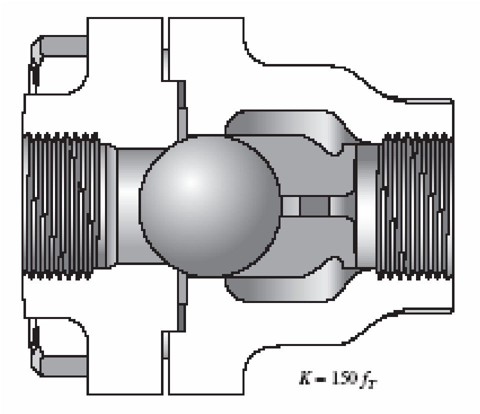
- Fig 10.17 shows the check valve.



## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.18 shows the check valve – ball type.

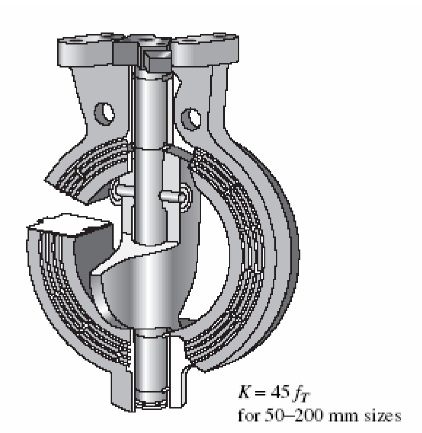





## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

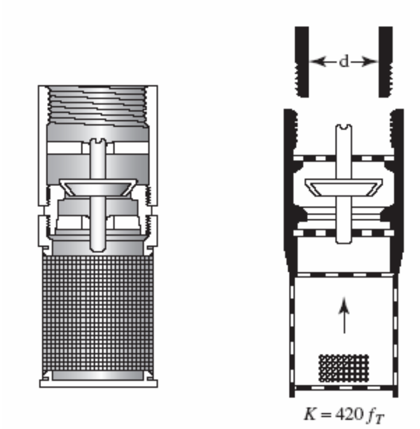
- Fig 10.19 shows the butterfly valve.



## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

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

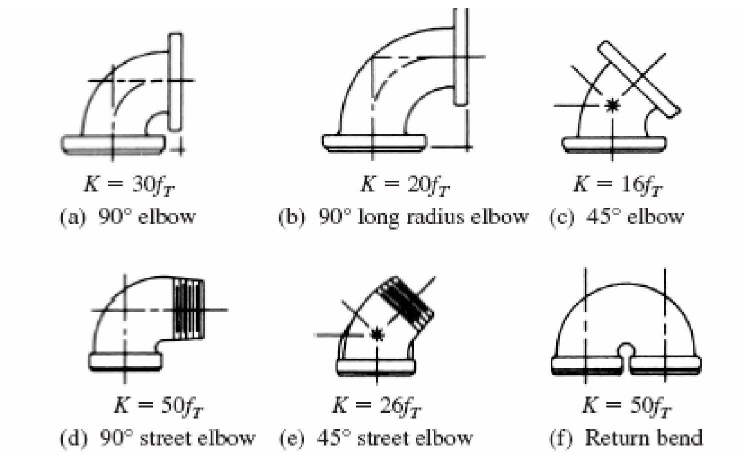





## 10. Minor Losses

### 10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.22 shows the pipe elbows.

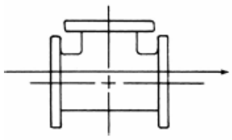



©2005 Pearson Education South Asia Pte Ltd

## 10. Minor Losses

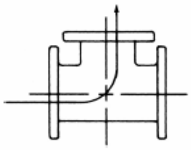
### 10.9 Resistance Coefficients for Valves and Fittings

- Fig 10.23 shows the standard tees.



$K = 20f_T$

(a) Flow through run



$K = 60f_T$

(b) Flow through branch



## 10. Minor Losses

### 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

$$K = (L_e/D)f_T \qquad (10\text{–}8)$$

- 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. Minor Losses

### 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 $L_e$

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

- 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. Minor Losses

### 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. Minor Losses

### 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 $\epsilon$ from Table 8.2.
Compute $D/\epsilon$.
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.

## 10. Minor Losses

### 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,

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



## 10. Minor Losses

### Example 10.7

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

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

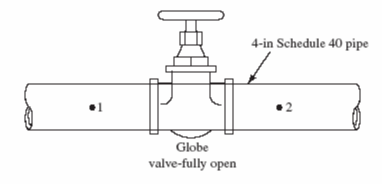
$$L_e = (L_e/D)D = (340)(0.154 \text{ m}) = 52.36 \text{ m}$$

## 10. Minor Losses

### 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 $m^3/s$ 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:




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



## 10. Minor Losses

### 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

$$p_1 - p_2 = \gamma h_L$$

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

## 10. Minor Losses

### 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.

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

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



## 10. Minor Losses

### 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.

## 10. Minor Losses

### Example 10.9

Calculate the energy loss for the flow of 500 m$^3$/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 (Appe

   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. Minor Losses

### 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. Minor Losses

### 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

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

## 10. Minor Losses

### 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. Minor Losses

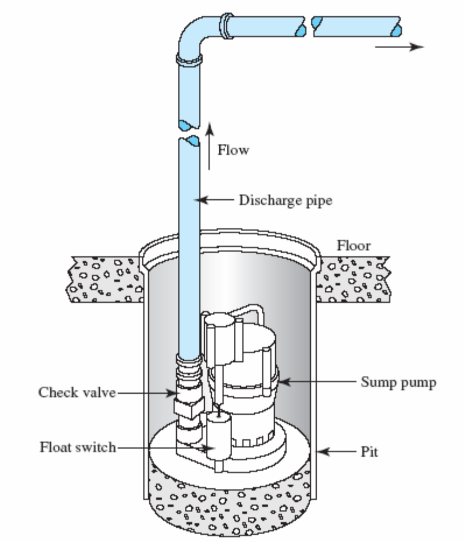
### 10.10.4 Check Valves

- 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

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

## 10. Minor Losses

### 10.10.4 Check Valves






## 10. Minor Losses

### 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

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

## 10. Minor Losses

### 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

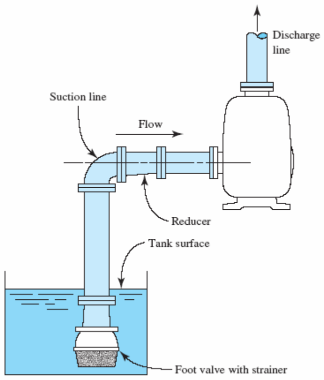
$$K = f_T(L_e/D) = 45 f_T$$



## 10. Minor Losses

### 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.



## 10. Minor Losses

### 10.10.6 Foot Valve with Strainers

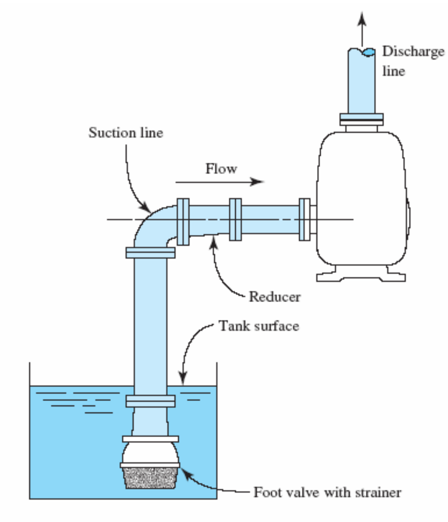
- Foot valves perform a similar function to that of check valves.
- They are used at the inlet of suction pipes that deliver fluid from a source tank or reservoir to a pump as illustrated in Fig. 10.26.
- The resistances for the two kinds of foot valves shown are

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



## 10. Minor Losses

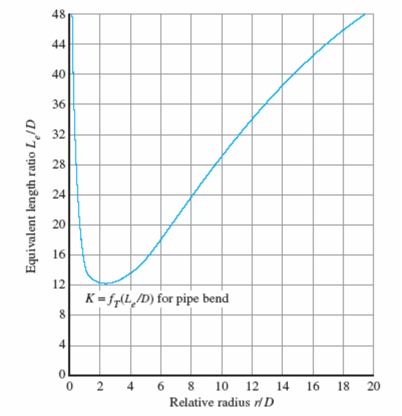
### 10.10.6 Foot Valve with Strainers



## 10. Minor Losses

### 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.

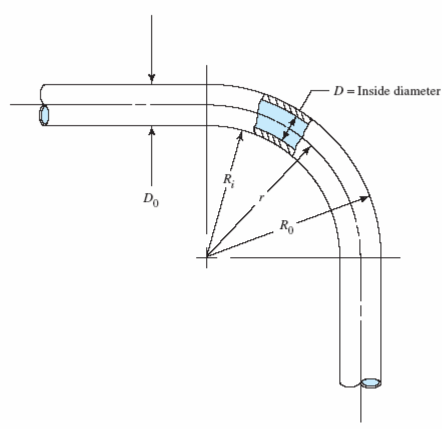





## 10. Minor Losses

### 10.11 Pipe Bends

- Fig 10.28 shows a 90° bend.



## 10. Minor Losses

### 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:

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



## 10. Minor Losses

### 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.

## 10. Minor Losses

### 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

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

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



## 10. Minor Losses

### 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

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

## 10. Minor Losses

### 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:

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



## 10. Minor Losses

### 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°

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

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

## 10. Minor Losses

### 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.

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



## 10. Minor Losses

### 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,

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

The total bend resistance is

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

## 10. Minor Losses

### Example 10.11

Then the energy loss is found from

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



## 10. Minor Losses

### 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. Minor Losses

### 10.12 Pressure Drop in Fluid Power Valves

- Common elements for a liquid hydraulic system include:

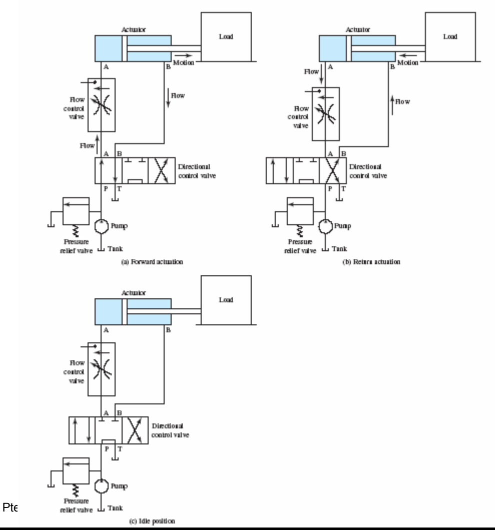
1. A pump to provide fluid to a system at an adequate pressure and at the appropriate volume flow rate to accomplish the desired task.
2. A tank or reservoir of hydraulic fluid from which the pump draws fluid and to which the fluid is returned after accomplishing the task. Most fluid power systems are closed circuits in which the fluid is continuously circulated.



## 10. Minor Losses

### 10.12 Pressure Drop in Fluid Power Valves

- Fig 10.29 shows some examples of fluid power system.



## 10. Minor Losses

### 10.13 Flow Coefficient for Valves Using $C_v$

- The basic liquid flow equation is

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

- Alternatively, flow equation is SI units is

$$\text{Flow in L/min} = 1.442C_V\sqrt{\frac{\Delta P}{\text{sg}}} \qquad (10\text{–}11)$$

where $\Delta p$ 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.

## 10. Minor Losses

### 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,

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



## 10. Minor Losses

### 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,

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

## 10. Minor Losses

### 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. Minor Losses

### 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. Minor Losses

### 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. Minor Losses

### 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. Minor Losses

### 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. Minor Losses

## 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<br>*Ball valve* | $C_V$ | Type and Size<br>*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 |