Applied Fluid Mechanics

Chapter 10

Minor Losses

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Many systems have numerous valves, elbows, and tees that have significant energy losses that must be considered by the designer.

Calculating Minor Losses

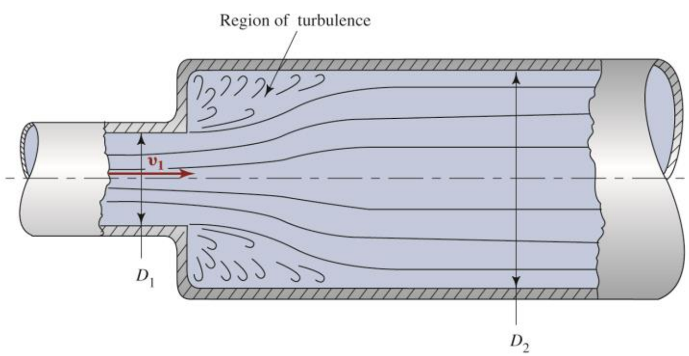
Energy losses are proportional to the *velocity head.*

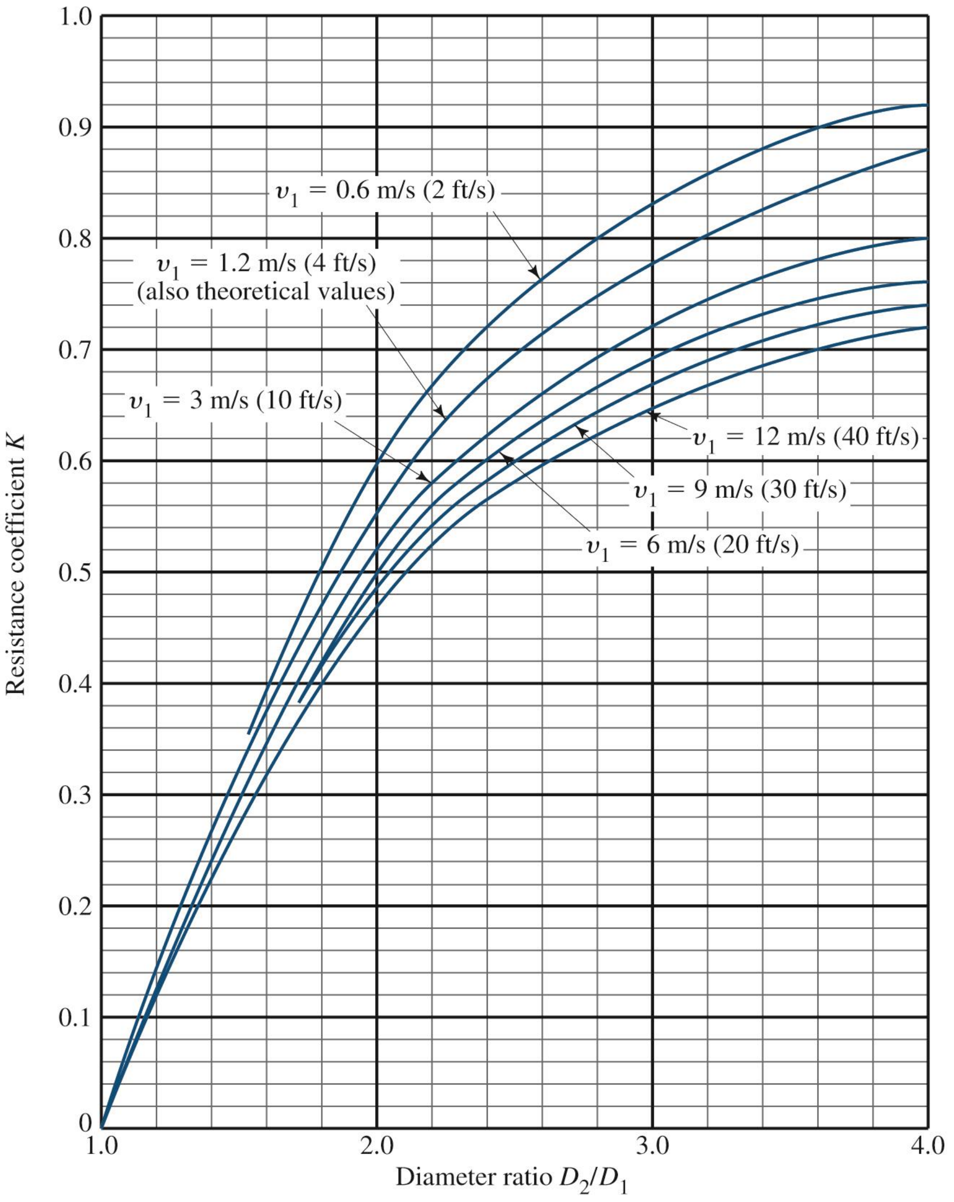
Minor Loss Using Resistance Coefficient

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

The sections that follow demonstrate ways to determine the Resistance Coefficient K

Sudden enlargement





Resistance coefficient—sudden enlargement in tabular form

	Velocity v_1						
D_2/D_1	0.6 m/s 2 ft/s	1.2 m/s 4 ft/s	3 m/s 10 ft/s	4.5 m/s 15 ft/s	6 m/s 20 ft/s	9 m/s 30 ft/s	12 m/s 40 ft/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

Example Problem 10.1

Example Problem 10.1

Determine the energy loss that will occur as 100 L/min of water flows through a sudden enlargement made from two sizes of copper hydraulic tubing. The small tube is 25 mm OD × 1.5 mm wall; the large tube is 80 mm OD × 2.8 mm wall. See Appendix G.2 for tube dimensions and areas.

Solution

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

$$D_1 = 22.0 \text{ mm} = 0.022 \text{ m}$$

$$A_1 = 3.801 \times 10^{-4} \text{ m}^2$$

$$D_2 = 74.4 \text{ mm} = 0.0744 \text{ m}$$

$$A_2 = 4.347 \times 10^{-3} \text{ m}^2$$

$$v_1 = \frac{Q}{A_1} = \frac{100 \text{ L/min}}{3.801 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60\,000 \text{ L/min}} = 4.385 \text{ m/s}$$

$$\frac{v_1^2}{2g} = \frac{(4.385)^2}{(2)(9.81)} \text{m} = 0.980 \text{ m}$$

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

$$D_2/D_1 - 74.4/22.0 - 3.382$$

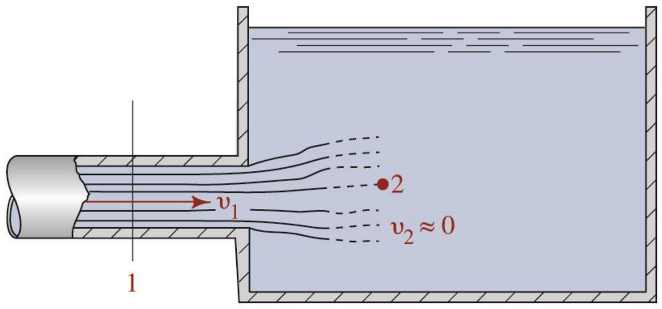
From Fig. 10.3, we read $K = 0.740$. Then we have

$$h_L = K(v_1^2/2g) = (0.740)(0.980 \text{ m}) = 0.725 \text{ m}$$

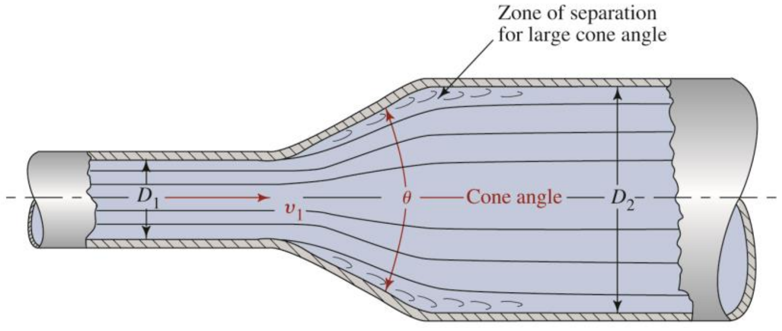
This result indicates that 0.725 N · m of energy is dissipated from each newton of water that flows through the sudden enlargement.

Other geometries are handled similarly

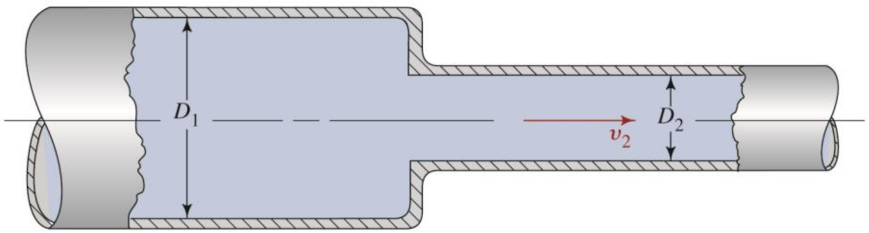
Pipe Exit



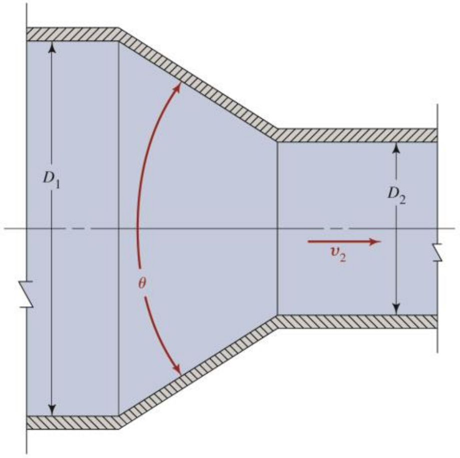
Gradual Enlargement



Sudden Contraction

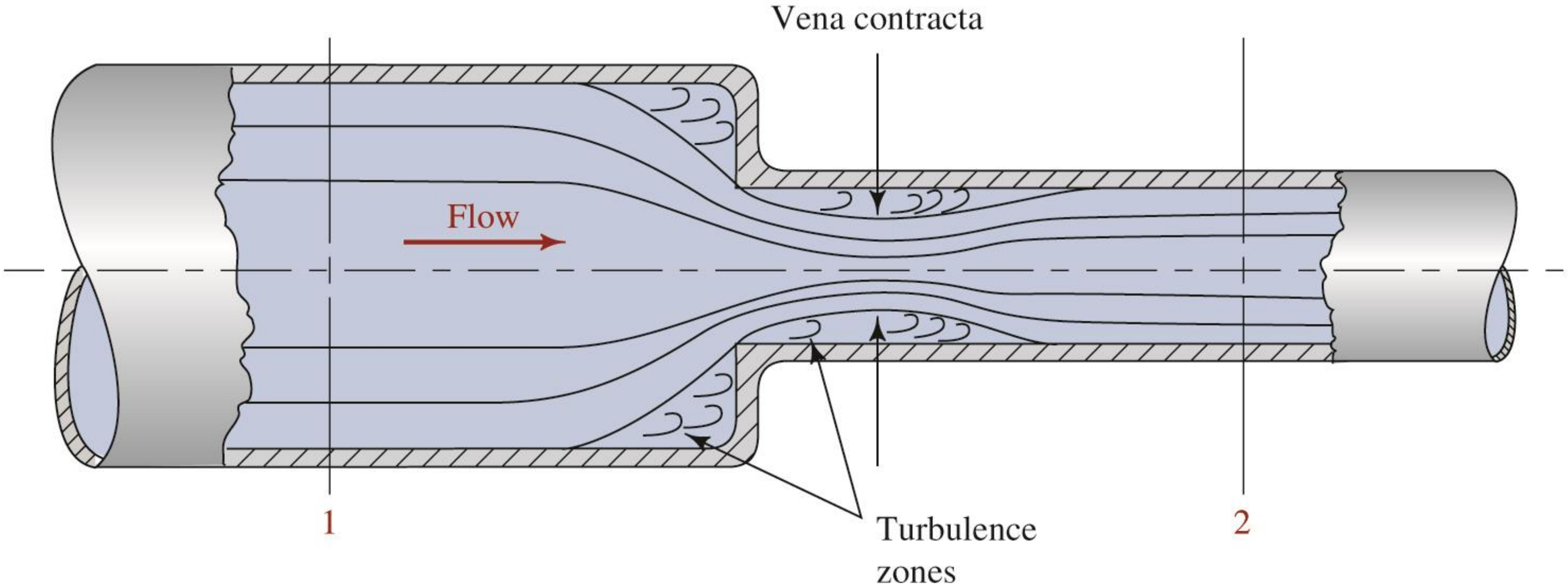


Gradual Contraction

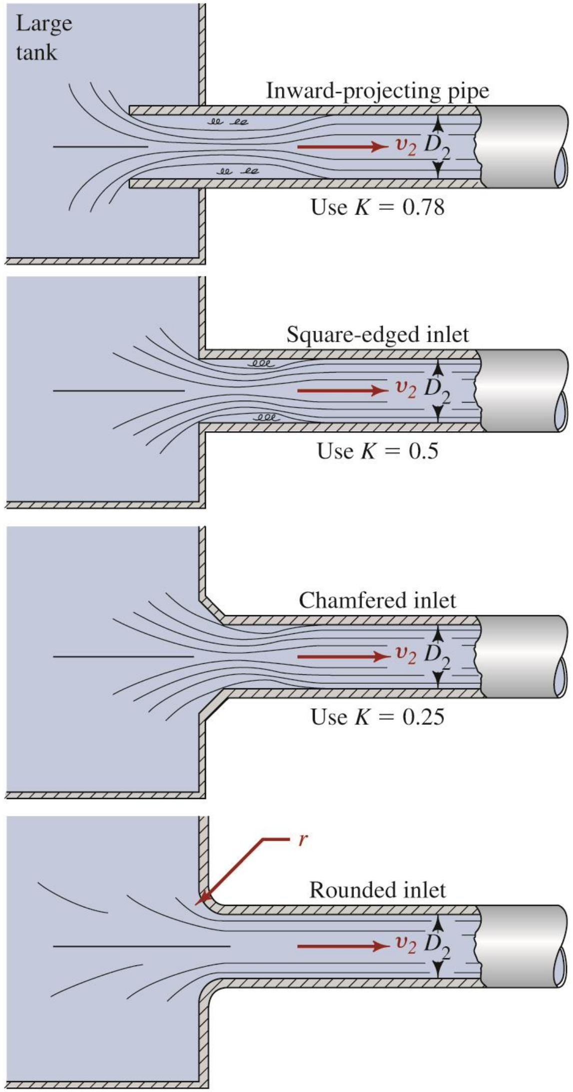


Vena contracta

The disruption of the flow results in losses. Higher losses result from more dramatic disruptions.



Pipe Entrance resistance coefficients



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)

Resistance Coefficient for Valves and Fittings

- Commercially available, standard valves and fittings have been tested and losses analyzed.
- Published data is used to determine the losses that result from standard valves and fittings such as:
  - globe valves
  - angle valves
  - gate valves
  - butterfly valves
  - check valves

Calculating loss for standard fittings and valves

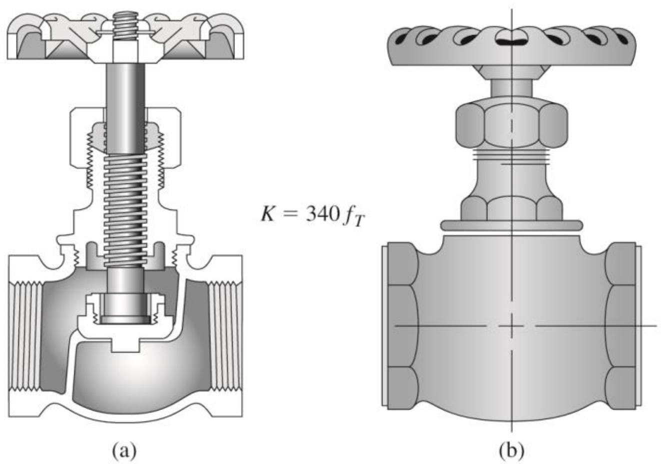
- Also an “Equivalent Length” format can be used to determine losses.
- The value of L_e is called the *equivalent length* and is the length of straight pipe of the same nominal diameter as the valve that would have the same resistance as the valve. The term D is the actual inside diameter of the pipe.

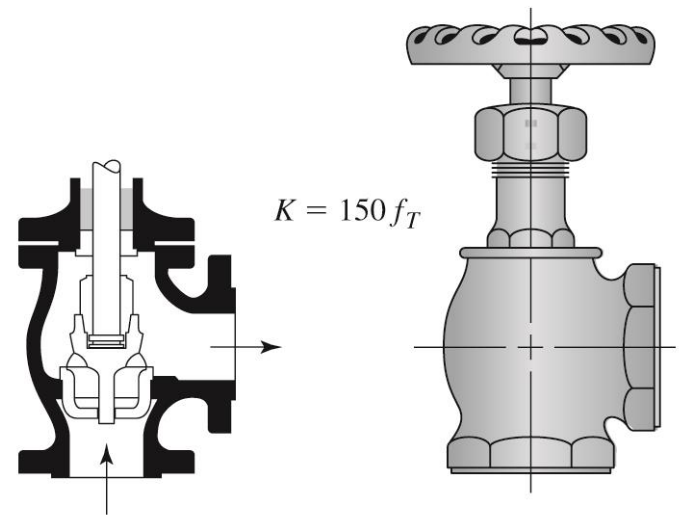
$$K = (L_e/D)f_T$$

- 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.

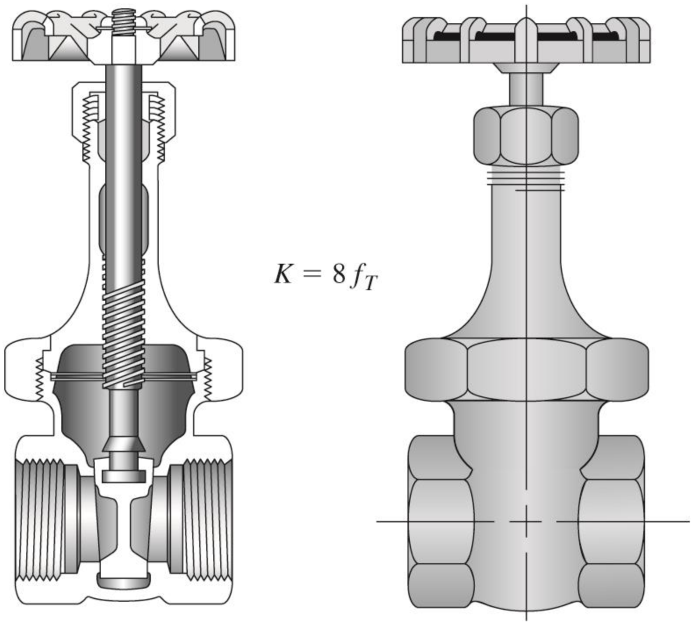
Globe valve

Angle valve



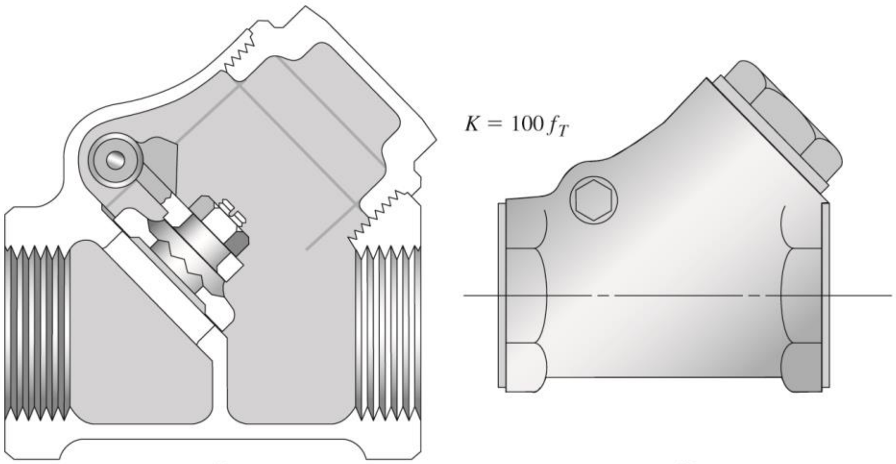


Gate valve



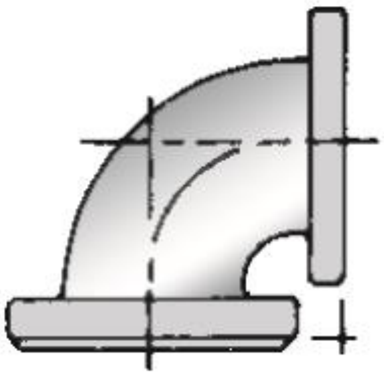
(a) (b)

Check valve—swing type



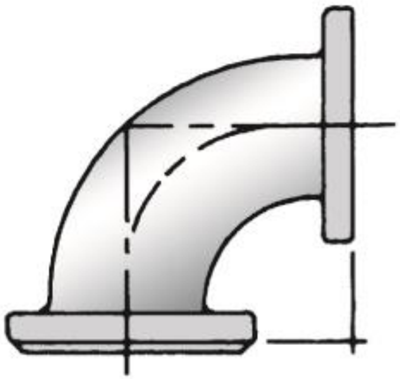
(a) (b)

Pipe elbows



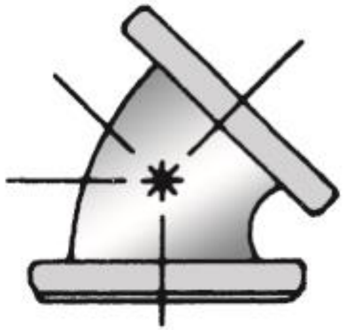
$K = 30f_T$

(a) 90° elbow



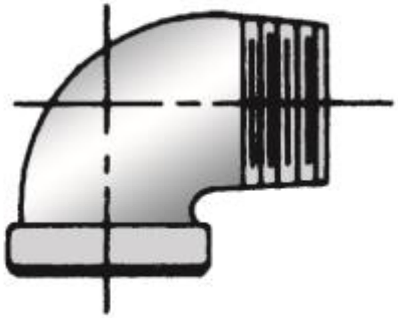
$K = 20f_T$

(b) 90° long radius elbow



$K = 16f_T$

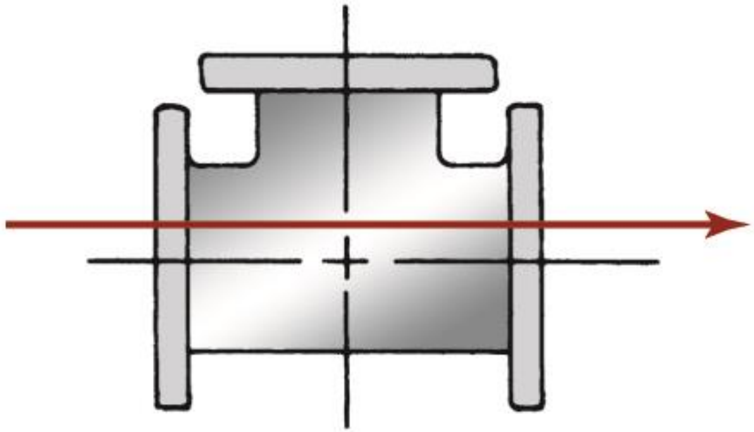
(c) 45° elbow



$K = 50f_T$

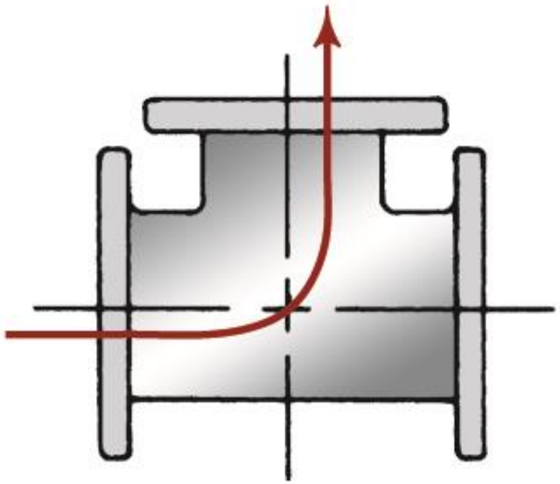
(d) 90° street elbow

Standard tees



$K = 20f_T$

(a) Flow through run



$K = 60f_T$

(b) Flow through branch

Resistance in valves and fittings expressed as equivalent length in pipe diameters, L_e/D

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, 2–8 in	45
—10–14 in	35
—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

Friction factor in zone of complete turbulence for new, clean, commercial Schedule 40 steel pipe

Nominal Pipe Size		Friction Factor, f_T	Nominal Pipe Size		Friction Factor, f_T
U.S. (in)	Metric (mm)		U.S. (in)	Metric (mm)	
½	DN 15	0.026	3, 3½	DN 80, DN 90	0.017
¾	DN 20	0.024	4	DN 100	0.016
1	DN 25	0.022	5, 6	DN 125, DN 150	0.015
1¼	DN 32	0.021	8	DN 200	0.014
1½	DN 40	0.020	10–14	DN 250 to DN 350	0.013
2	DN 50	0.019	16–22	DN 400 to DN 550	0.012
2½	DN 65	0.018	24–36	DN 600 to DN 900	0.011

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 Schedule 40 steel:*

Find f_T from Table 10.5.

2b. *For other pipe materials or schedules:*

Determine the pipe wall roughness ε from Table 8.2.

Compute D/ε.

Use the Moody diagram, Fig. 8.7, 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 Problem 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 L_e/D for a fully open globe valve is 340. From Table 10.5 we find $f_T = 0.015$ for a 6-in pipe. Then,

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

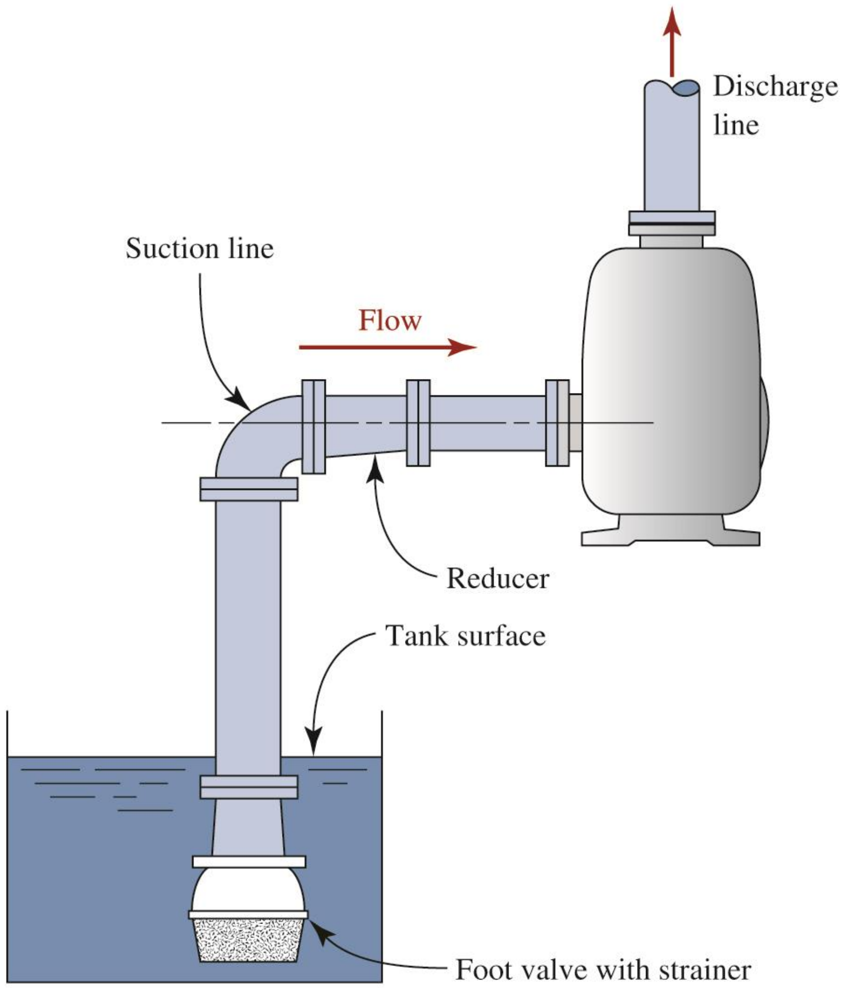
Using $D = 0.5054$ ft for the pipe, we find the equivalent length

$$L_e = KD/f_T = (5.10)(0.5054 \text{ ft})/(0.015) = 172 \text{ ft}$$

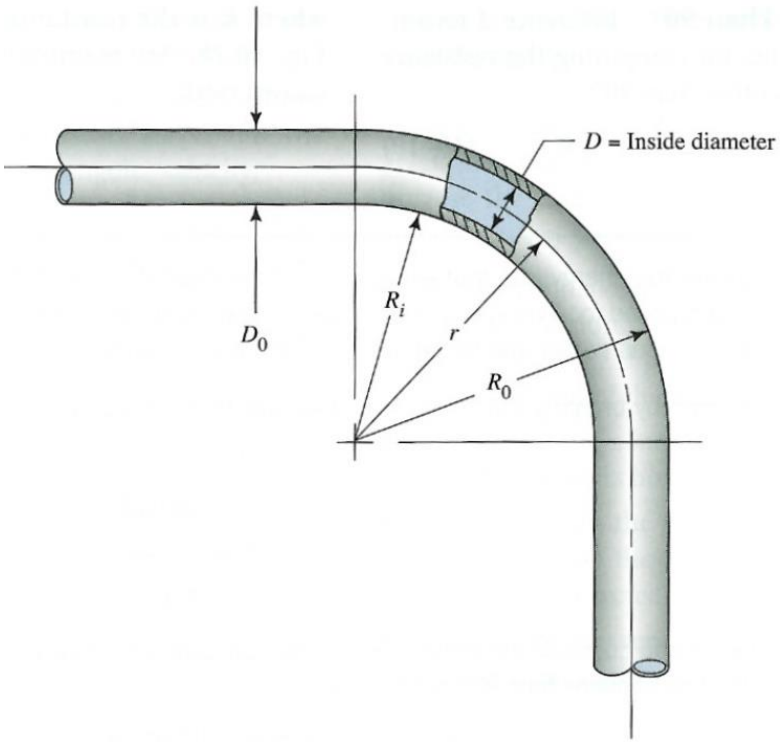
Or, if the flow is in the zone of complete turbulence,

$$L_e = (L_e/D)D = (340)(0.5054 \text{ ft}) = 172 \text{ ft}$$

Pumping system with a foot valve in the suction line



Pipe Bends



When we compute the r/D ratio, r is defined as the radius to the *centerline* of the pipe or tube, called the *mean radius* (see Fig. 10.29). That is, if R_o is the radius to the outside of the bend, R_i is the radius to the inside of the bend, and D_o is the *outside diameter* of the pipe or tube:

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

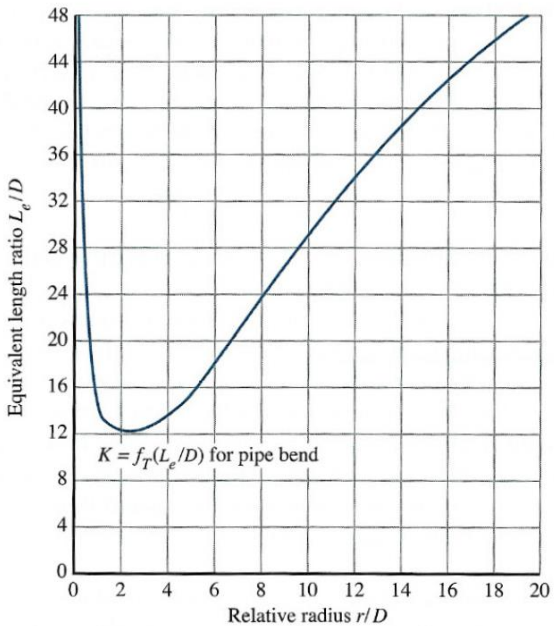


FIGURE 10.28 Resistance due to 90° pipe bends. (*Source:* Beij, K. H., Pressure Losses for Fluid Flow in 90 Degree Pipe Bends. 1938. *Journal of Research of the National Bureau of Standards* 21: 1–18) See Reference 1.

Pipe Bends

Example Problem 10.10

A distribution system for liquid propane is made from steel hydraulic tube, 32 mm OD × 2.0 mm wall. 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 due to each bend.

Solution

Darcy's equation should be used to compute the energy loss with the L_e/D ratio for the bends found from Fig. 10.28. First, let's determine r/D, recalling that D is the inside diameter of the tube and r is the radius to the centerline of the tube. From Appendix G.2 we find $D = 28.0\text{ mm} = 0.028\text{ m}$. The radius r must be computed from

$$r = R_i + D_o/2$$

where $D_o = 32.0\text{ mm}$, the outside diameter of the tube, as found from Appendix G.2. Completion of the calculation gives

$$r = 200\text{ mm} + (32.0\text{ mm})/2 = 216\text{ mm}$$

and

$$r/D = 216\text{ mm}/28.0\text{ mm} = 7.71$$

From Fig. 10.28 we find the equivalent-length ratio to be 23.

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

$$v = \frac{Q}{A} = \frac{160\text{ L/min}}{6.158 \times 10^{-4}\text{ m}^2}\,\frac{1.0\text{ m}^3/\text{s}}{60\,000\text{ L/min}} = 4.33\text{ m/s}$$

The relative roughness is

$$D/\varepsilon = (0.028\text{ m})(1.5 \times 10^{-6}\text{ m}) = 18\,667$$

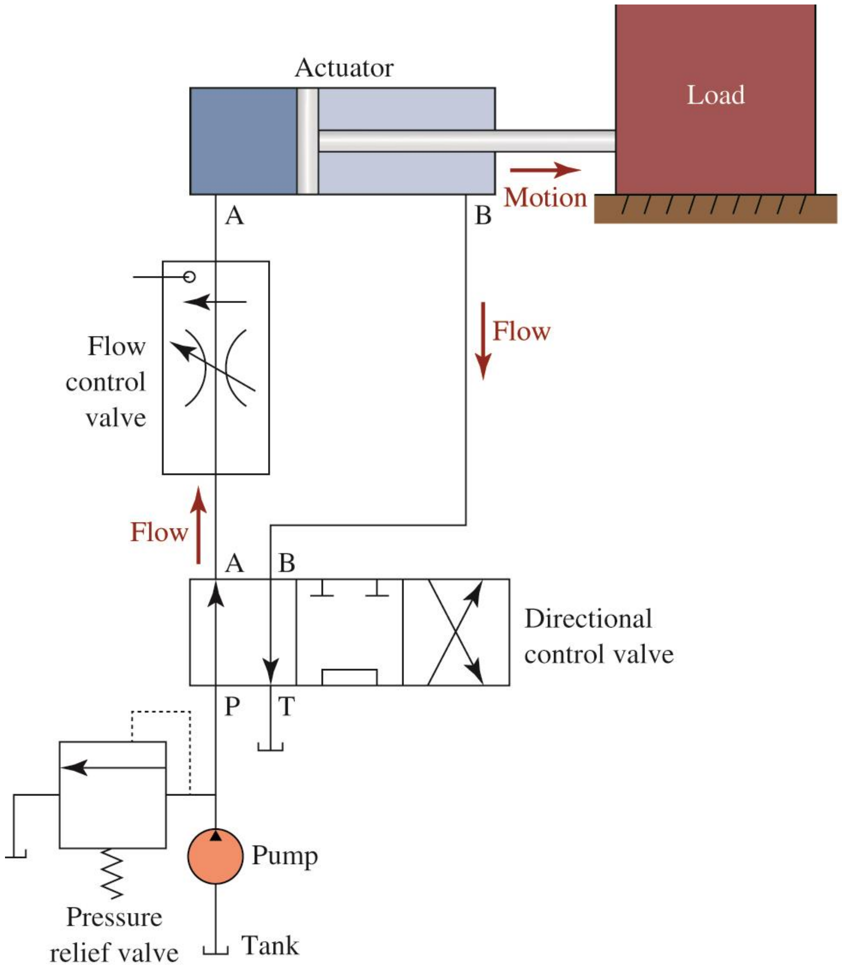
Then, we can find $f_T = 0.0108$ from the Moody diagram (Fig. 8.7) in the zone of complete turbulence. Then,

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

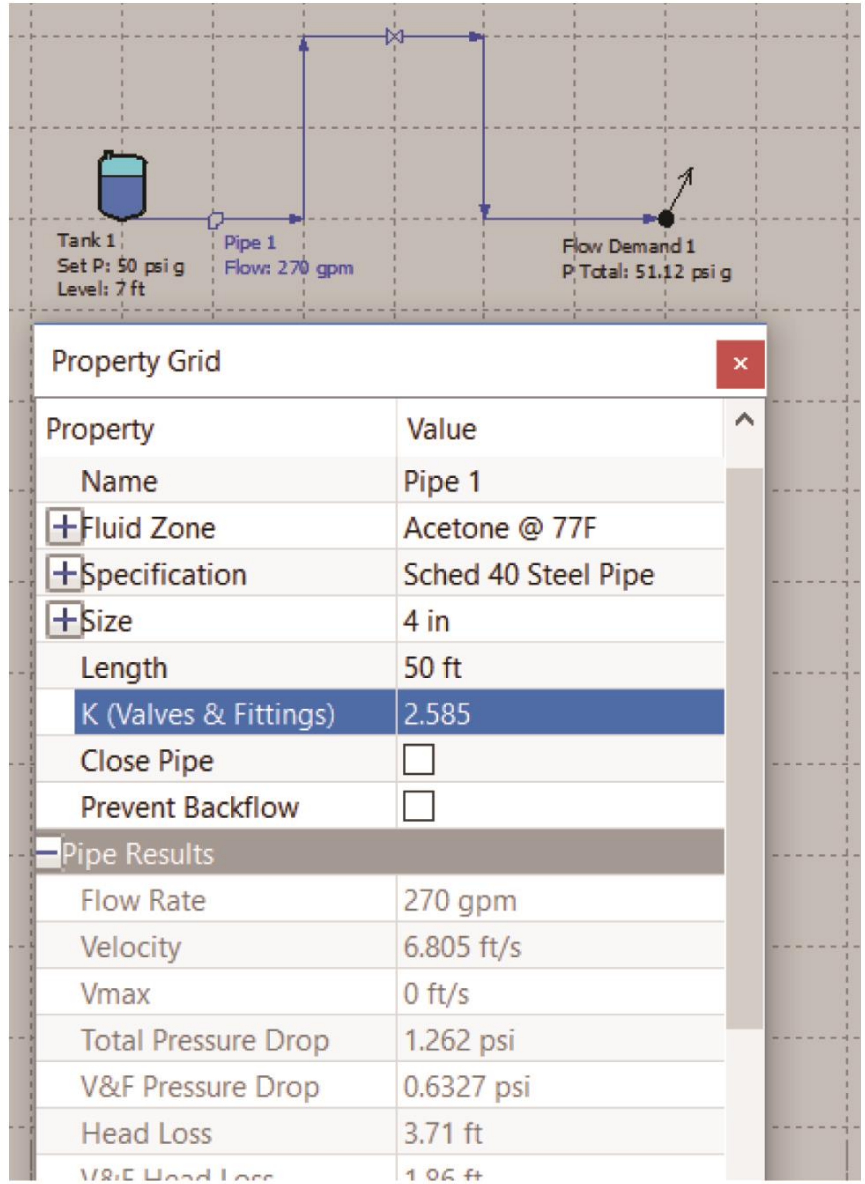
Now the energy loss can be computed:

$$h_L = K\frac{v^2}{2g} = 0.248\frac{(4.33)^2}{(2)(9.81)} = 0.237\text{ m} = 0.237\text{ N·m/N}$$

Valves and fittings in hydraulic fluid power systems result in losses that must be carefully considered using the methodology explained in this chapter.



PIPE-FLO Software can perform all of the tedious tasks. Engineering principles must be understood first and care must be taken in the use of software.



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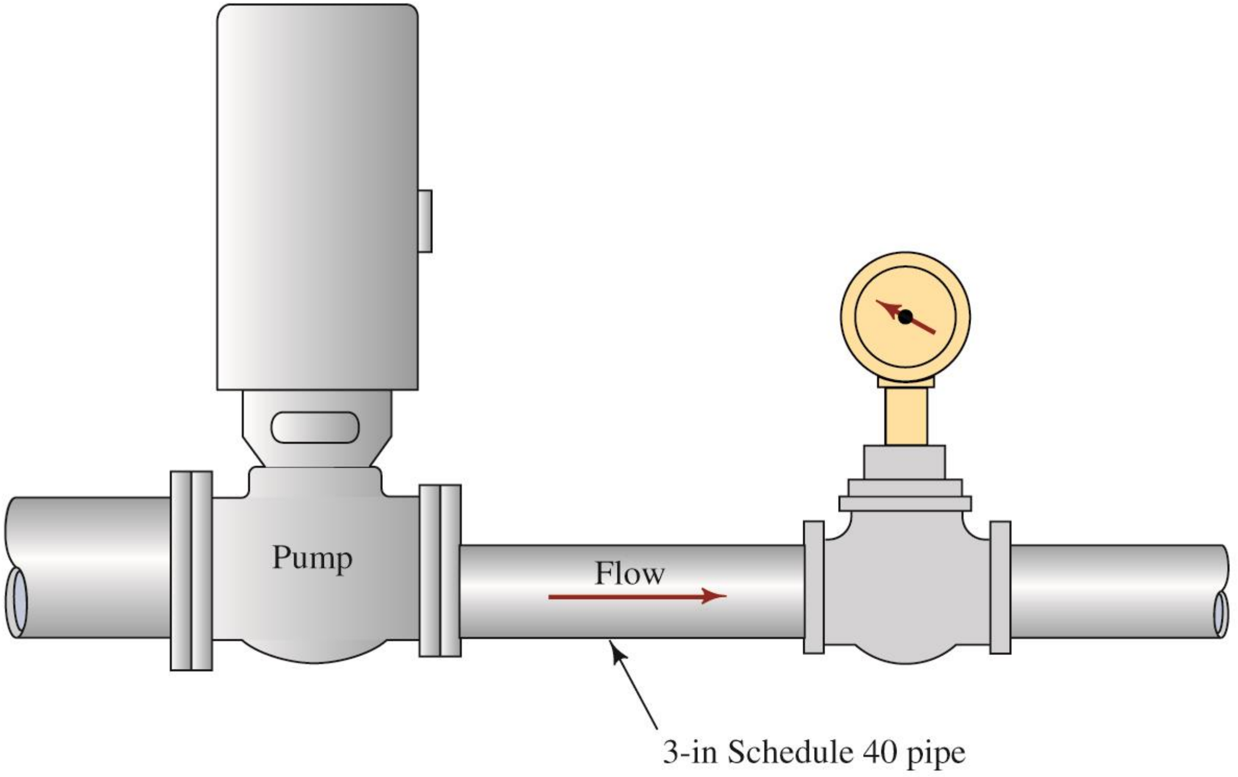
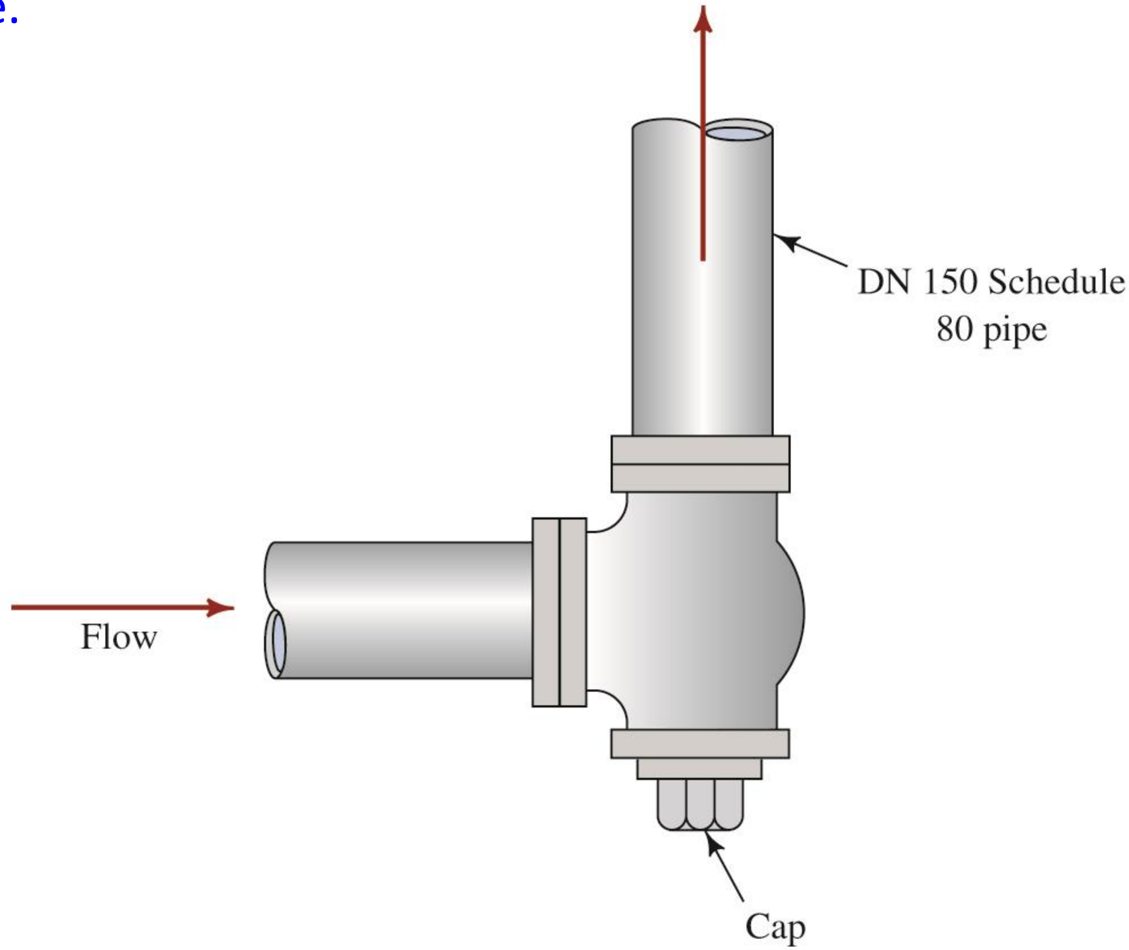
Pumping system for Problem 10.39

A piping system for a pump contains a tee, as shown in Fig. 10.34, to permit the pressure at the outlet of the pump to be measured. However, there is no flow into the line leading to the gage. Compute the energy loss as 0.40 ft^3/s of water at 50°F flows through the tee.



Cleanout for Problem 10.40

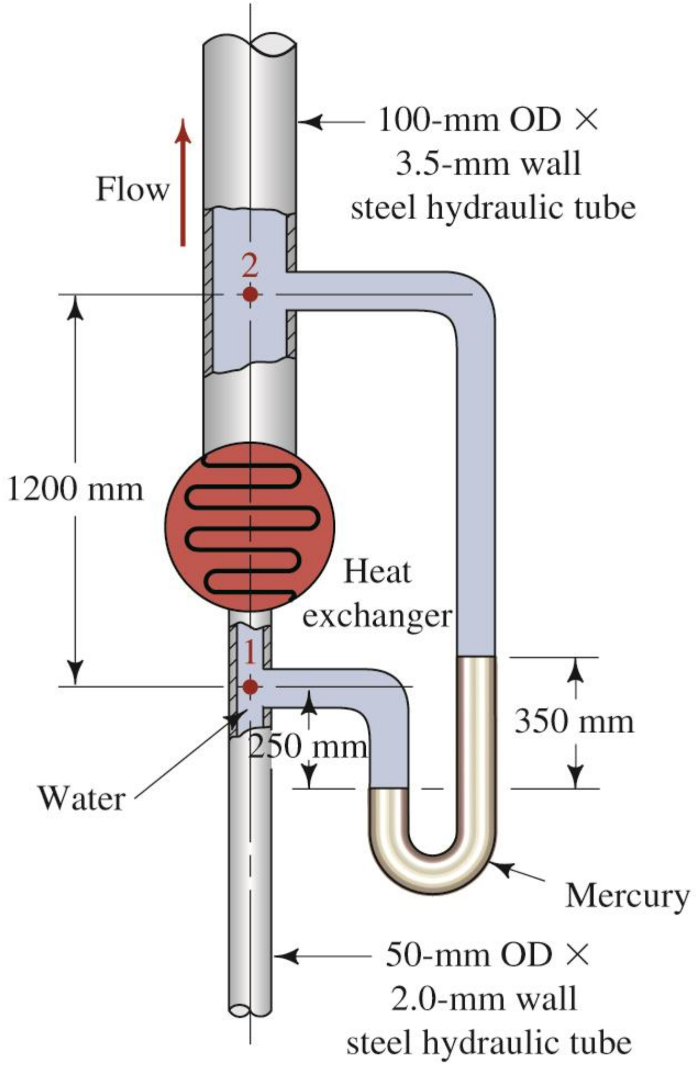
A piping system for supplying heavy fuel oil at 25°C is arranged as shown in Fig. 10.35. The bottom leg of the tee is normally capped, but the cap can be removed to clean the pipe. Compute the energy loss as 0.08 m^3/s flows through the tee.



Energy loss measurement - Problem 10.46

Figure 10.38 shows a test setup for determining the energy loss due to a heat exchanger. Water at 50°C is flowing vertically upward at 6.0×10^{-3} m^3/s.

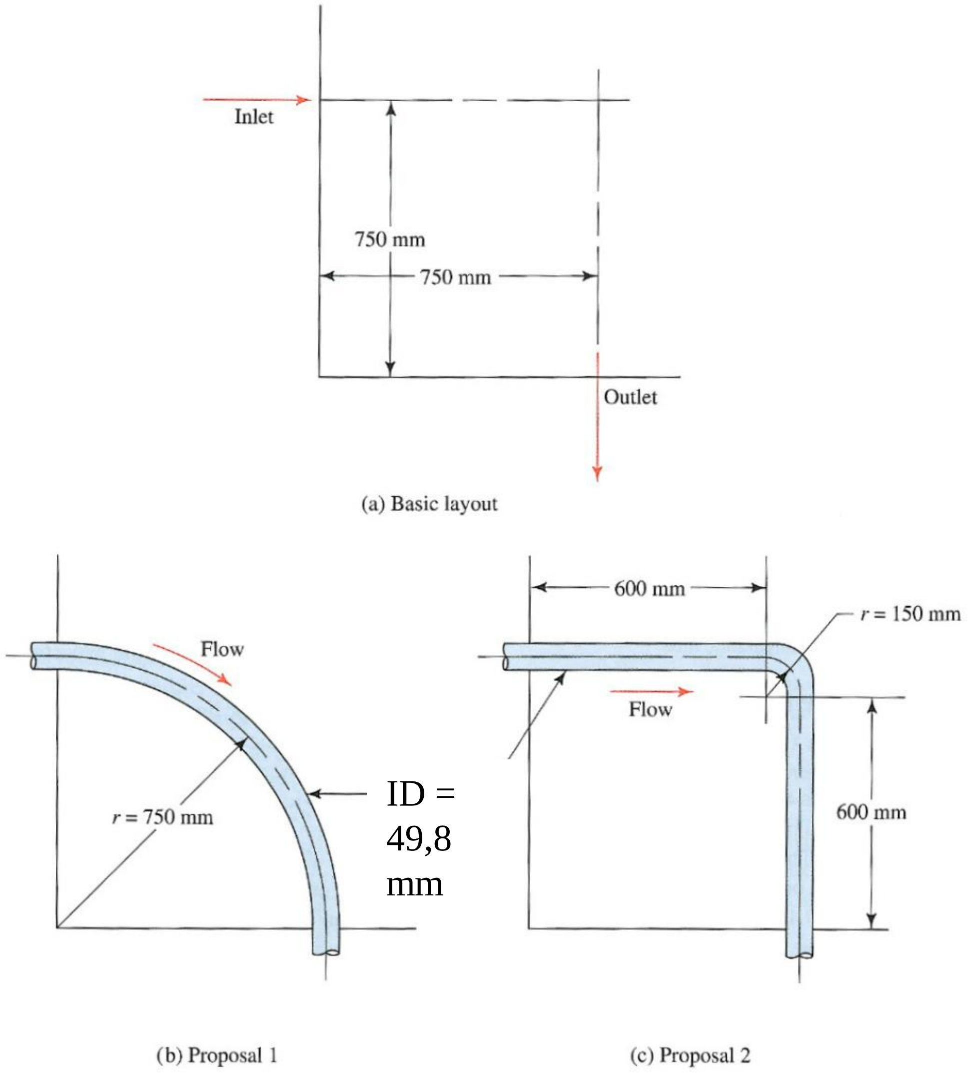
Calculate the energy loss between points 1 and 2. Determine the resistance coefficient for the heat exchanger based on the velocity in the inlet tube.



Energy loss due to pipe bends

The inlet and the outlet shown in the Fig. are to be connected with an ID of 49.8 mm copper tube to carry 750 L/min of propyl alcohol at 25°C.

Evaluate the two schemes shown in parts (b) and (c) of the figure with regard to the energy loss. Include the losses due to both the bend and the friction in the straight tube.



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