

TABLE 6-4 Additional Frictional Loss for Turbulent Flow through Fittings and Valves*

Type of fitting or valve	Additional friction loss, equivalent no. of velocity heads, K
45° ell, standard ^{b,c,d}	0.35
45° ell, long radius ^b	0.2
90° ell, standard ^{b,c,d}	0.75
Long radius ^{b,c,d}	0.45
Square or round ^e	1.5
Tap ^f (round, elbow, or tee) ^{g,h}	1.75
Tees, standard, along run, branch blanked off ⁱ	0.4
Close or ell, entering run ^j	1.0
Close or ell, entering branch ^j	1.0
Branching flow ^k	1
Coasting ^l	0.04
Valves ^m	0.04
Gate valves ^{n,o} open	0.17
to open ^p	0.9
to open ^p	4.5
to open ^p	24.0
Diaphragm valve, ^q open	2.5
to open ^r	2.5
to open ^r	4.5
to open ^r	25.0
Globe valves ^s	
Round seat, open	6.0
to open ^r	9.5
Composition seat, open	6.0
to open ^r	9.5
Plug disk, open	9.0
to open ^r	13.0
to open ^r	26.0
to open ^r	112.0
Angle valves, ^t open	2.0
Yee (tee) valves, ^u open	3.0
Flow control ^v	
to 10°	0.05
to 15°	0.20
to 20°	1.50
to 40°	17.5
to 90°	206.0
Restrictor valves ^w	
to 10°	0.24
to 15°	0.52
to 20°	1.54
to 40°	10.5
to 90°	118.0
Check valves, ^{x,y} swing	
Disk	10.0
Ball	20.0
Foot valve ^z	15.0
Water meter, ^{aa} disk	7.0
Prism	15.0
Rotary (star-shaped disk)	10.0
Throttle-valved	6.0

*Lapple, *Chem. Eng.*, **56**(7), 96-104 (1949), general survey reference.
^bLoss of fluids through Valves, Fittings, and Pipes,[†] Tech. Pap. 439, Crane Co., 1939.
^cForrester, *Experiments upon the Flow of Water in Pipes and Pipe Fittings*, American Society of Mechanical Engineers, New York, 1911.
^dChenier, *J. Am. Soc. Heat Vent. Eng.*, **20**, 493 (1908).
^ePipe Friction Manual, 3d ed., Hydraulic Institute, New York, 1933.
^fInt. J. Heat Eng., **62**, 131-143 (1940).
^gChenier and Shultz, *Heat. Piping Air Cond.*, **4**(6), 443-447 (1912).
^hChenier and Thomson, *Hydraulics*, 3d ed., McGraw-Hill, New York, 1934, p. 223.
ⁱHooper, Balluff, Clarke, and Drew, *Chem. Eng. Prog.*, **44**, 691-696 (1946).
^jGilman, *Heat. Piping Air Cond.*, **22**(4), 141-147 (1910).
^kMcNown, *Proc. Am. Soc. Civ. Eng.*, **79**, Separate 259, 1-22 (1953); discussion, *ibid.*, **80**, Separate 359, 19-45 (1954). For the effect of branch spacing on friction losses in dividing flow, see Blacker, Neumann, and Quastler, *Proc. Am. Soc. Civ. Eng.*, *J. Hydraul. Div.*, **103**(1973), 205-229 (1977).
^lThis is pressure drop (including friction loss) between run and branch, based on velocity in the mainstem before branching. Actual value depends on the flow split, ranging from 0.5 to 1.0 of mainstem velocity run and from 0.7 to 1.5 of mainstem velocity branch.
^mLaminar Loss of Head in Flow of Fluids through Various Types of Fittings and Valves, *Trans. Inst. Mech. Engrs.* **140**, 1943.

pressures are both atmospheric and the fluid velocities are 0 and $V = 2$ m/s, respectively, and there is no shaft work, simplify to

$$\rho gZ = \frac{\rho V^2}{2} + L$$

Contributing to L are losses for the entrance to the pipe, the three sections of straight pipe, the butterfly valve, and the 90° bend. Note that no exit loss is used because the discharged jet is outside the control volume. Instead, the $V^2/2$ term accounts for the kinetic energy of the discharging stream. The Reynolds number in the pipe is

$$Re = \frac{\rho V D_p}{\mu} = \frac{998.25 \times 2 \times 0.025}{0.001} = 1.00 \times 10^5$$

From Fig. 6-9 or Eq. (6-26), at $e/D = 0.046 \times 10^{-3}/0.025 = 0.00184$, the friction factor is about 0.0024. The straight pipe losses are then

$$L_{sp} = \left(\frac{4fL}{D} \right) \frac{V^2}{2} \\ = \left(\frac{4 \times 0.0024 \times (1 + 1 + 1)}{0.025} \right) \frac{V^2}{2} \\ = 1.21 \frac{V^2}{2}$$

The losses from Table 6-4 in terms of velocity heads K are $K = 0.5$ for the sudden contraction and $K = 0.52$ for the butterfly valve. For the 90° standard elbow ($r/D = 1$), the table gives $K = 0.75$. The method of Eq. (6-94), using Fig. 6-14, gives

$$K = K_1 C_1 + K_2 C_2 \\ = 0.24 + 1.24 \times 1.0 \times \left(\frac{0.0024}{0.0024} \right) \\ = 0.37$$

This value is more accurate than the value in Table 6-4. The value $f_{minor} = 0.0044$ is obtainable either from Eq. (6-37) or Fig. 6-9.

The total losses are then

$$L = (1.21 + 0.5 + 0.52 + 0.37) \frac{V^2}{2} = 2.60 \frac{V^2}{2}$$

and the liquid level Z_2 is

$$Z = \frac{1}{2} \left(\frac{V^2}{2} + 2.60 \frac{V^2}{2} \right) = 1.62 \frac{V^2}{2g} \\ = \frac{1.62 \times 2^2}{2 \times 9.81} = 0.73 \text{ m}$$

Curved Pipes and Coils. For flow through curved pipe or coil, a secondary circulation perpendicular to the main flow called the **Dean effect** occurs. This circulation increases the friction relative to straight pipe flow and stabilizes laminar flow, delaying the transition Reynolds number to about

$$Re_{crit} = 2,100 \left(1 + 12 \sqrt{\frac{D_c}{D}} \right) \quad (6-100)$$

where D_c is the coil diameter. Equation (6-100) is valid for $10 < D_c/D < 250$. The **Dean number** is defined as

$$Dn = \frac{Re}{(D_c/D)^{3/2}} \quad (6-101)$$

In laminar flow, the friction factor for curved pipe f_c may be expressed in terms of the straight pipe friction factor $f = 16/Re$ as (Haert, *Chem. Eng. Sci.*, **43**, 775-782 (1988))

TABLE 6-5 Additional Frictional Loss for Laminar Flow through Fittings and Valves

Type of fitting or valve	Additional frictional loss expressed as K			
	$Re = 1,000$	500	100	50
90° ell, short radius	0.0	1.0	2.5	9.0
Gate valve	1.2	1.7	6.9	24
Globe valve, composition disk	1.1	1.2	20	39
Plug	1.2	1.4	19	27
Angle valve	0	6.5	11	19
Check valve, swing	0	0.5	17	35

Source: D. From curves by Kenney and Rowley, *Trans. Am. Soc. Mech. Eng.*, **70**, 1706-1708 (1947).

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Table of Contents Chemical Engineering Handbook

1. Understanding the eBook Chemical Engineering Handbook
 - The Rise of Digital Reading Chemical Engineering Handbook
 - Advantages of eBooks Over Traditional Books
2. Identifying Chemical Engineering Handbook
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Chemical Engineering Handbook
 - User-Friendly Interface
4. Exploring eBook Recommendations from Chemical Engineering Handbook

- Personalized Recommendations
 - Chemical Engineering Handbook User Reviews and Ratings
 - Chemical Engineering Handbook and Bestseller Lists
5. Accessing Chemical Engineering Handbook Free and Paid eBooks
 - Chemical Engineering Handbook Public Domain eBooks
 - Chemical Engineering Handbook eBook Subscription Services
 - Chemical Engineering Handbook Budget-Friendly Options
 6. Navigating Chemical Engineering Handbook eBook Formats
 - ePub, PDF, MOBI, and More
 - Chemical Engineering Handbook Compatibility with Devices
 - Chemical Engineering Handbook Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Chemical Engineering Handbook
 - Highlighting and Note-Taking Chemical Engineering Handbook
 - Interactive Elements Chemical Engineering Handbook
 8. Staying Engaged with Chemical Engineering Handbook
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Chemical Engineering Handbook
 9. Balancing eBooks and Physical Books Chemical Engineering Handbook
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Chemical Engineering Handbook
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Chemical Engineering Handbook
 - Setting Reading Goals Chemical Engineering Handbook
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Chemical Engineering Handbook

- Fact-Checking eBook Content of Chemical Engineering Handbook
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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