TABLE 6-4 Additional Frictional Loss for Turbulent Flow through Fittings and Valves[a]

Type of fitting or valve	Additional friction loss, equivalent no. of velocity heads, *K*
45° ell, standard[b,c,d,e,f]	0.35
45° ell, long radius[c]	0.2
90° ell, standard[b,c,e,f,g,h]	0.75
Long radius[b,c,d,e]	0.45
Square or miter[h]	1.3
180° bend, close return[b,c,e]	1.5
Tee, standard, along run, branch blanked off[e]	0.4
Used as ell, entering run[g,i]	1.0
Used as ell, entering branch[c,g,i]	1.0
Branching flow[i,j,k]	1[l]
Coupling[c,e]	0.04
Union[e]	0.04
Gate valve,[b,e,m] open	0.17
¾ open[n]	0.9
½ open[n]	4.5
¼ open[n]	24.0
Diaphragm valve,[o] open	2.3
¾ open[n]	2.6
½ open[n]	4.3
¼ open[n]	21.0
Globe valve,[e,m]	
Bevel seat, open	6.0
½ open[n]	9.5
Composition seat, open	6.0
½ open[n]	8.5
Plug disk, open	9.0
¾ open[n]	13.0
½ open[n]	36.0
¼ open[n]	112.0
Angle valve,[b,e] open	2.0
Y or blowoff valve,[b,m] open	3.0
Plug cock[p]	
$\theta = 5°$	0.05
$\theta = 10°$	0.29
$\theta = 20°$	1.56
$\theta = 40°$	17.3
$\theta = 60°$	206.0
Butterfly valve[p]	
$\theta = 5°$	0.24
$\theta = 10°$	0.52
$\theta = 20°$	1.54
$\theta = 40°$	10.8
$\theta = 60°$	118.0
Check valve,[b,e,m] swing	2.0[q]
Disk	10.0[q]
Ball	70.0[q]
Foot valve[e]	15.0
Water meter,[h] disk	7.0[r]
Piston	15.0[r]
Rotary (star-shaped disk)	10.0[r]
Turbine-wheel	6.0[r]

[a] Lapple, *Chem. Eng.,* **56**(5), 96–104 (1949), general survey reference.
[b] "Flow of Fluids through Valves, Fittings, and Pipe," Tech. Pap. 410, Crane Co., 1969.
[c] Freeman, *Experiments upon the Flow of Water in Pipes and Pipe Fittings,* American Society of Mechanical Engineers, New York, 1941.
[d] Giesecke, *J. Am. Soc. Heat. Vent. Eng.,* **32,** 461 (1926).
[e] *Pipe Friction Manual,* 3d ed., Hydraulic Institute, New York, 1961.
[f] Ito, *J. Basic Eng.,* **82,** 131–143 (1960).
[g] Giesecke and Badgett, *Heat. Piping Air Cond.,* **4**(6), 443–447 (1932).
[h] Schoder and Dawson, *Hydraulics,* 2d ed., McGraw-Hill, New York, 1934, p. 213.
[i] Hoopes, Isakoff, Clarke, and Drew, *Chem. Eng. Prog.,* **44,** 691–696 (1948).
[j] Gilman, *Heat. Piping Air Cond.,* **27**(4), 141–147 (1955).
[k] McNown, *Proc. Am. Soc. Civ. Eng.,* **79,** Separate 258, 1–22 (1953); discussion, ibid., **80,** Separate 396, 19–45 (1954). For the effect of branch spacing on junction losses in dividing flow, see Hecker, Nystrom, and Qureshi, *Proc. Am. Soc. Civ. Eng., J. Hydraul. Div.,* **103**(HY3), 265–279 (1977).
[l] This is pressure drop (including friction loss) between run and branch, based on velocity in the mainstream before branching. Actual value depends on the flow split, ranging from 0.5 to 1.3 if mainstream enters run and from 0.7 to 1.5 if mainstream enters branch.
[m] Lansford, *Loss of Head in Flow of Fluids through Various Types of 1½-in. Valves,* Univ. Eng. Exp. Sta. Bull. Ser. 340, 1943.

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

$$gZ = \frac{V^2}{2} + l_v$$

Contributing to l_v 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

$$\text{Re} = \frac{DV\rho}{\mu} = \frac{0.0525 \times 2 \times 1000}{0.001} = 1.05 \times 10^5$$

From Fig. 6-9 or Eq. (6-38), at $\epsilon/D = 0.046 \times 10^{-3}/0.0525 = 0.00088$, the friction factor is about 0.0054. The straight pipe losses are then

$$l_{v(\text{sp})} = \left(\frac{4fL}{D}\right)\frac{V^2}{2}$$
$$= \left(\frac{4 \times 0.0054 \times (1 + 1 + 1)}{0.0525}\right)\frac{V^2}{2}$$
$$= 1.23\,\frac{V^2}{2}$$

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 radius ($r/D = 1$), the table gives $K = 0.75$. The method of Eq. (6-94), using Fig. 6-14, gives

$$K = K^* C_{\text{Re}} C_o C_f$$
$$= 0.24 \times 1.24 \times 1.0 \times \left(\frac{0.0054}{0.0044}\right)$$
$$= 0.37$$

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

The total losses are then

$$l_v = (1.23 + 0.5 + 0.52 + 0.37)\,\frac{V^2}{2} = 2.62\,\frac{V^2}{2}$$

and the liquid level Z is

$$Z = \frac{1}{g}\left(\frac{V^2}{2} + 2.62\,\frac{V^2}{2}\right) = 3.62\,\frac{V^2}{2g}$$
$$= \frac{3.62 \times 2^2}{2 \times 9.81} = 0.73 \text{ m}$$

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

$$\text{Re}_{\text{crit}} = 2{,}100\left(1 + 12\sqrt{\frac{D}{D_c}}\right) \tag{6-100}$$

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

$$\text{De} = \frac{\text{Re}}{(D_c/D)^{1/2}} \tag{6-101}$$

In laminar flow, the friction factor for curved pipe f_c may be expressed in terms of the straight pipe friction factor $f = 16/\text{Re}$ as (Hart, *Chem. Eng. Sci.,* **43,** 775–783 [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	0.9	1.0	7.5	16
Gate valve	1.2	1.7	9.9	24
Globe valve, composition disk	11	12	20	30
Plug	12	14	19	27
Angle valve	8	8.5	11	19
Check valve, swing	4	4.5	17	55

SOURCE: From curves by Kittredge and Rowley, *Trans. Am. Soc. Mech. Eng.,* **79,** 1759–1766 (1957).