

Conservation of Mass

$$0 = \frac{\partial}{\partial t} \int_{CV} \rho dV + \int_{CS} \rho \vec{V} \cdot d\vec{A}$$

Conservation of Momentum

$$\vec{F}_S + \vec{F}_B = \frac{\partial}{\partial t} \int_{CV} \vec{V} \rho dV + \int_{CS} \vec{V} \rho \vec{V} \cdot d\vec{A}$$

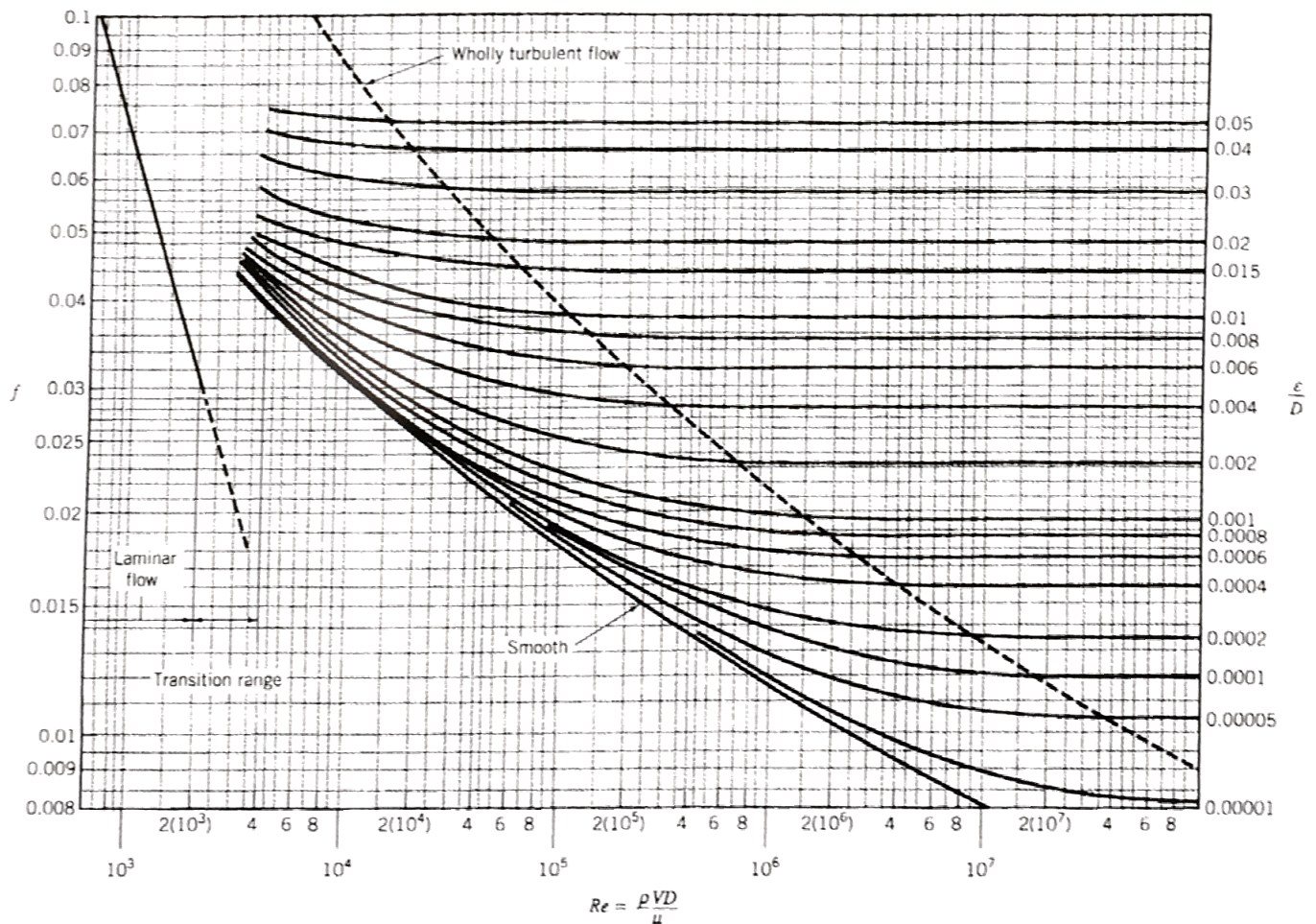
Conservation of Energy

$$\dot{Q}_{net\ in} + \dot{W}_{net\ in} = \frac{\partial}{\partial t} \int_{CV} e \rho dV + \int_{CS} e \rho \vec{V} \cdot d\vec{A}$$

Steady Flow Energy Equation

$$\left(\frac{p_1}{\rho g} + \alpha_1 \frac{\bar{V}_1^2}{2g} + z_1 \right) + \frac{\dot{W}'_{in}}{\dot{m}g} - \left(\frac{p_2}{\rho g} + \alpha_2 \frac{\bar{V}_2^2}{2g} + z_2 \right) - \frac{\dot{W}'_{out}}{\dot{m}g} = h_{L\ major} + \sum h_{L\ minor}$$

$$= f \frac{l}{D} \frac{\bar{V}^2}{2g} + \sum K_L \frac{\bar{V}^2}{2g}$$



■ Figure 8.20 Friction factor as a function of Reynolds number and relative roughness for round pipes—the Moody chart.

Table 8.2

Loss Coefficients for Pipe Components ($h_L = K_L \frac{V^2}{2g}$) (Data from Refs. 5, 10, 27)

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	
	0.08
e. Valves	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210



90° elbow



45° elbow



180° return bend



Tee



Tee



Union

Table 8.1

Equivalent Roughness for New Pipes [Adapted from Moody (Ref. 7) and Colebrook (Ref. 8)]

Pipe	Equivalent Roughness, ϵ	
	Feet	Millimeters
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Wood stave	0.0006–0.003	0.18–0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

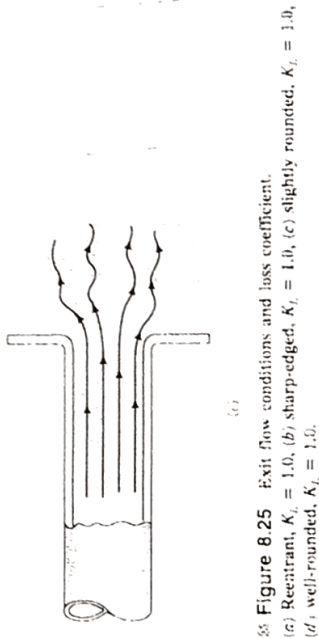
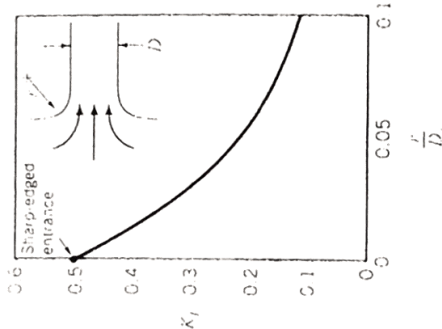


Figure 8.25 Exit flow conditions and loss coefficient. (a) Reentrant, $K_L = 1.0$. (b) sharp-edged, $K_L = 1.0$. (c) slightly rounded, $K_L = 1.0$. (d) well-rounded, $K_L = 1.0$.

Figure 8.24 Entrance loss coefficient as a function of rounding of the inlet edge (Data from Ref. 9).



*See Fig. 8.32 for typical valve geometry.

Table B.2

Physical Properties of Water (SI Units)*

Temperature (°C)	Density, ρ (kg/m ³)	Specific Weight ^b , γ (kN/m ³)	Dynamic Viscosity, μ (N·s/m ²)	Kinematic Viscosity, ν (m ² /s)	Surface Tension ^c , σ (N/m)	Vapor Pressure, p_v [N/m ² (abs)]	Speed of Sound ^d , c (m/s)
0	999.9	9.806	1.787 E - 3	1.787 E - 6	7.56 E - 2	6.105 E + 2	1403
5	1000.0	9.807	1.519 E - 3	1.519 E - 6	7.49 E - 2	8.722 E + 2	1427
10	999.7	9.804	1.307 E - 3	1.307 E - 6	7.42 E - 2	1.228 E + 3	1447
20	998.2	9.789	1.002 E - 3	1.004 E - 6	7.28 E - 2	2.338 E + 3	1481
30	995.7	9.765	7.975 E - 4	8.009 E - 7	7.12 E - 2	4.243 E + 3	1507
40	992.2	9.731	6.529 E - 4	6.580 E - 7	6.96 E - 2	7.376 E + 3	1526
50	988.1	9.690	5.468 E - 4	5.534 E - 7	6.79 E - 2	1.233 E + 4	1541
60	983.2	9.642	4.665 E - 4	4.745 E - 7	6.62 E - 2	1.992 E + 4	1552
70	977.8	9.589	4.042 E - 4	4.134 E - 7	6.44 E - 2	3.116 E + 4	1555
80	971.8	9.530	3.547 E - 4	3.650 E - 7	6.26 E - 2	4.734 E + 4	1555
90	965.3	9.467	3.147 E - 4	3.260 E - 7	6.08 E - 2	7.010 E + 4	1550
100	958.4	9.399	2.818 E - 4	2.940 E - 7	5.89 E - 2	1.013 E + 5	1543

*Based on data from Handbook of Chemistry and Physics, 69th Ed., CRC Press, 1988.

^bDensity and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 9.807 \text{ m/s}^2$.

^cIn contact with air.

^dBased on data from R. D. Blevins, Applied Fluid Dynamics Handbook, Van Nostrand Reinhold Co., Inc., New York, 1984.