

Equations Sheet:

$$g = 9.81 \text{ m/s}^2$$

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}} \quad T(\text{K}) = T(^{\circ}\text{C}) + 273$$

Ideal Gas Law: $p = \rho RT$

$$\gamma = \rho g \quad \text{SG} = \frac{\gamma_{\text{fluid}}}{\gamma_{\text{water}}} = \frac{\rho_{\text{fluid}}}{\rho_{\text{water}}} \quad \text{Re} = \frac{VD}{\nu} = \frac{4\dot{m}}{\pi D \mu}$$

Hydrostatics: $\frac{dp}{dz} = -\gamma$

$$P_{\text{avg}} = \gamma h_c, \quad F_R = P_{\text{avg}} A = \gamma h_c A, \quad y_{cp} = y_c + \frac{I_{xx,c}}{y_c A}$$

Bernoulli Equation: $\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2$

Energy Equation:

$$\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_{\text{pump},u} = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_{\text{turbine},e} + h_L$$

$$h_{\text{pump},u} = \frac{w_{\text{pump},u}}{g} = \frac{\dot{W}_{\text{pump},u}}{\dot{m}g} = \frac{\eta_{\text{pump}} \dot{W}_{\text{pump}}}{\dot{m}g} \quad \dot{W} = \gamma \dot{V} h$$

$$h_{\text{turbine},e} = \frac{w_{\text{turbine},e}}{g} = \frac{\dot{W}_{\text{turbine},e}}{\dot{m}g} = \frac{\dot{W}_{\text{turbine}}}{\eta_{\text{turbine}} \dot{m}g} \quad \dot{V} = V_{\text{avg}} A_c$$

$$h_L = \frac{e_{\text{mech loss, piping}}}{g} = \frac{\dot{E}_{\text{mech loss, piping}}}{\dot{m}g} \quad \dot{m} = \rho V_{\text{avg}} A_c$$

$$\eta_{\text{motor}} = \frac{\dot{W}_{\text{shaft, out}}}{\dot{W}_{\text{elect, in}}} \quad \eta_{\text{pump}} = \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{shaft, in}}} = \frac{\dot{W}_{\text{pump},u}}{\dot{W}_{\text{pump}}} \quad \eta_{\text{pump-motor}} = \eta_{\text{pump}} \eta_{\text{motor}} = \frac{\dot{W}_{\text{pump},u}}{\dot{W}_{\text{elect, in}}} = \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{elect, in}}}$$

$$\eta_{\text{generator}} = \frac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{shaft, in}}} \quad \eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft, out}}}{|\Delta \dot{E}_{\text{mech, fluid}}|} = \frac{\dot{W}_{\text{turbine}}}{\dot{W}_{\text{turbine},e}} \quad \eta_{\text{turbine-gen}} = \eta_{\text{turbine}} \eta_{\text{generator}} = \frac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{turbine},e}} = \frac{\dot{W}_{\text{elect, out}}}{|\Delta \dot{E}_{\text{mech, fluid}}|}$$

$$h_{L,\text{total}} = h_{L,\text{major}} + h_{L,\text{minor}} = \sum f_i \frac{L_i}{D_i} \frac{V_i^2}{2g} + \sum K_{L,j} \frac{V_j^2}{2g} \quad \Delta P_L = \rho g h_L \quad \dot{W}_{\text{pump},L} = \dot{V} \Delta P_L$$

Internal Flow $\text{Re} = \frac{V_m D}{\nu} = \frac{\rho V_m D}{\mu} \quad D_h = \frac{4A_c}{P} \quad \frac{L_{h,\text{laminar}}}{D} \cong 0.05 \text{Re} \quad \frac{L_{h,\text{turbulent}}}{D} \approx 10$

Laminar ($Re \leq 2300$): $f = \frac{64}{Re}$, Turbulent ($Re > 2300$): $\frac{1}{\sqrt{f}} \cong -1.8 \log \left[\left(\frac{6.9}{Re} \right) + \left(\frac{\epsilon/D}{3.7} \right)^{1.11} \right]$

TABLE 14-2

Equivalent roughness values for new commercial pipes*

Material	Roughness, ϵ	
	ft	mm
Glass, plastic	0 (smooth)	
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

$$\dot{Q}_{\text{cond}} = -kA \frac{dT}{dx} \quad \dot{Q}_{\text{convection}} = hA_s (T_s - T_\infty) \quad \dot{Q}_{\text{rad}} = \epsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4) \quad \Delta T = \dot{Q}R$$

$$R_{\text{wall}} = \frac{L}{kA} \quad R_{\text{conv}} = \frac{1}{hA} \quad R_{\text{rad}} = \frac{1}{h_{\text{rad}} A} \quad h_{\text{rad}} = \epsilon \sigma (T_s^2 + T_{\text{surr}}^2)(T_s + T_{\text{surr}})$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt} \quad b = \frac{hA_s}{\rho c_p V} = \frac{h}{\rho c_p L_c} \quad \text{time constant: } \tau = \left(\frac{1}{hA_s} \right) (\rho V c_p) = \frac{1}{b}$$

Cylinder: $V = \pi (D^2/4)L$, $A_s = \pi DL$, **Sphere:** $V = \pi D^3/6$, $A_s = \pi D^2$, $L_c = V/A_s$, $\text{Bi} = hL_c/k$

Stefan-Boltzmann constant; $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$

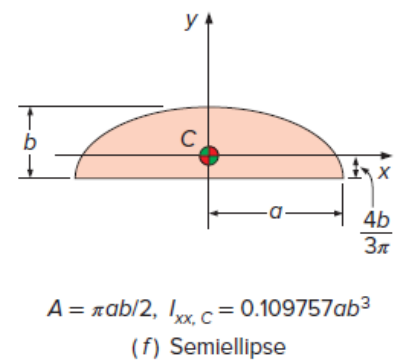
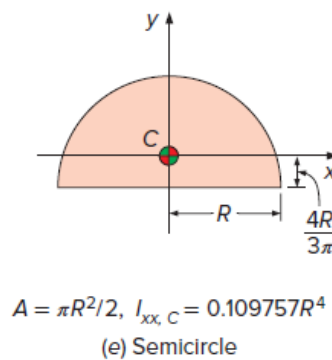
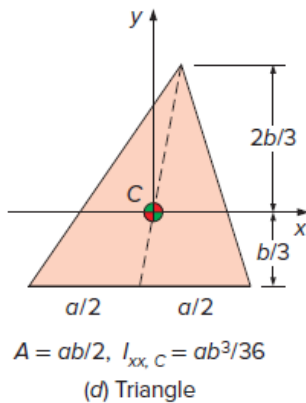
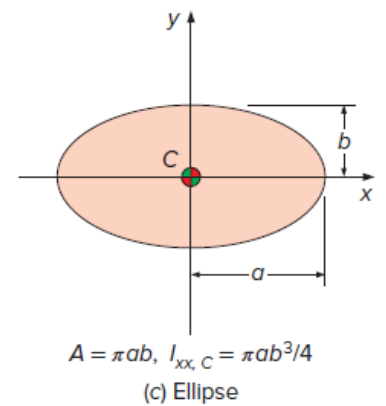
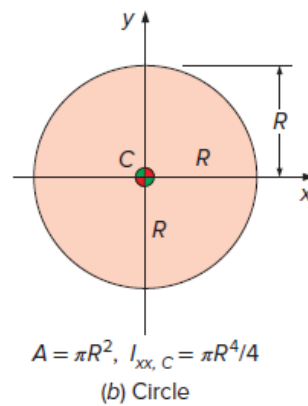
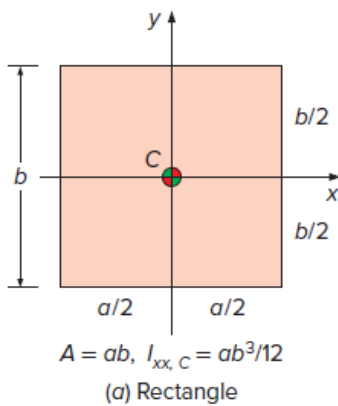


TABLE A-15

Properties of saturated water

Temp. $T, ^\circ\text{C}$	Saturation pressure $P_{\text{sat}}, \text{kPa}$	Density $\rho, \text{kg/m}^3$		Enthalpy of vaporization $h_{\text{fg}}, \text{kJ/kg}$	Specific heat $c_p, \text{J/kg}\cdot\text{K}$		Thermal conductivity $k, \text{W/m}\cdot\text{K}$		Dynamic viscosity $\mu, \text{kg/m}\cdot\text{s}$		Prandtl number Pr		Volume expansion coefficient $\beta, 1/\text{K}$
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	-0.068×10^{-3}
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015×10^{-3}
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195×10^{-3}
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247×10^{-3}
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294×10^{-3}
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377×10^{-3}
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415×10^{-3}
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451×10^{-3}
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548×10^{-3}
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578×10^{-3}
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670×10^{-3}
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702×10^{-3}
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716×10^{-3}
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}

TABLE 14-4 (CONCLUDED)

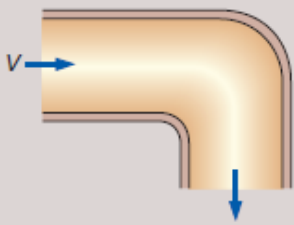
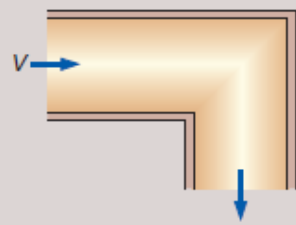
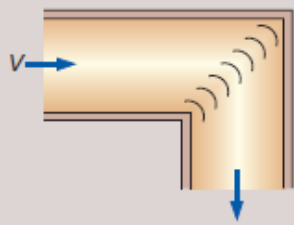
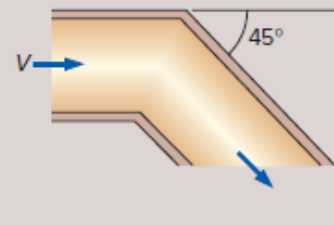
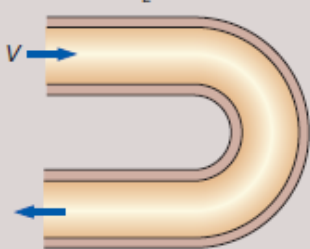
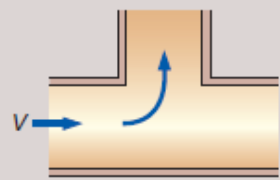
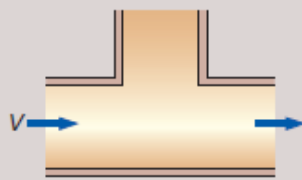
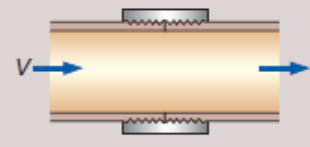
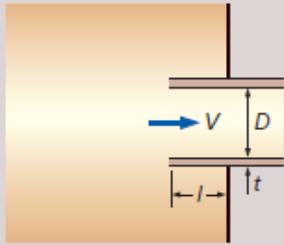
<p>Bends and Branches</p> <p>90° smooth bend: Flanged: $K_L = 0.3$ Threaded: $K_L = 0.9$</p> 	<p>90° miter bend (without vanes): $K_L = 1.1$</p> 	<p>90° miter bend (with vanes): $K_L = 0.2$</p> 	<p>45° threaded elbow: $K_L = 0.4$</p> 
<p>180° return bend: Flanged: $K_L = 0.2$ Threaded: $K_L = 1.5$</p> 	<p>Tee (branch flow): Flanged: $K_L = 1.0$ Threaded: $K_L = 2.0$</p> 	<p>Tee (line flow): Flanged: $K_L = 0.2$ Threaded: $K_L = 0.9$</p> 	<p>Threaded union: $K_L = 0.08$</p> 
<p>Valves</p> <p>Globe valve, fully open: $K_L = 10$ Angle valve, fully open: $K_L = 5$ Ball valve, fully open: $K_L = 0.05$ Swing check valve: $K_L = 2$</p> <p>Gate valve, fully open: $K_L = 0.2$ $\frac{1}{4}$ closed: $K_L = 0.3$ $\frac{1}{2}$ closed: $K_L = 2.1$ $\frac{3}{4}$ closed: $K_L = 17$</p>			

TABLE 14-4

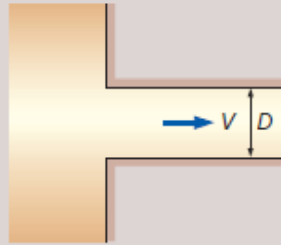
Loss coefficients K_L of various pipe components for turbulent flow (for use in the relation $h_L = K_L V^2 / (2g)$, where V is the average velocity in the pipe that contains the component)*

Pipe Inlet

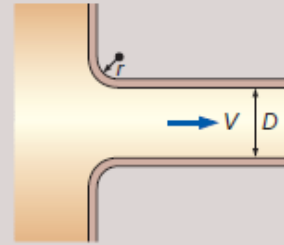
Reentrant: $K_L = 0.80$
($t \ll D$ and $l \approx 0.1D$)



Sharp-edged: $K_L = 0.50$

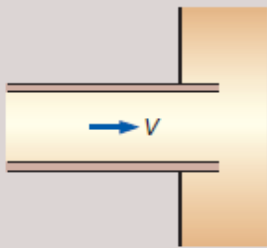


Well-rounded ($r/D > 0.2$): $K_L = 0.03$
Slightly rounded ($r/D = 0.1$): $K_L = 0.12$
(see Fig. 14-32)

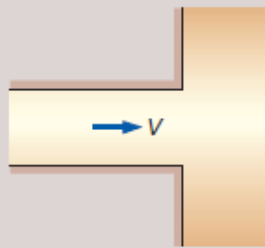


Pipe Exit

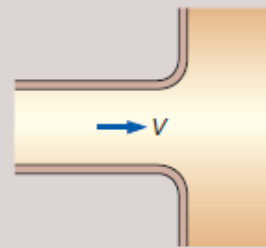
Reentrant: $K_L = \alpha$



Sharp-edged: $K_L = \alpha$



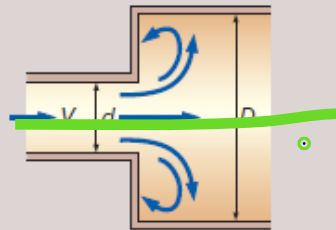
Rounded: $K_L = \alpha$



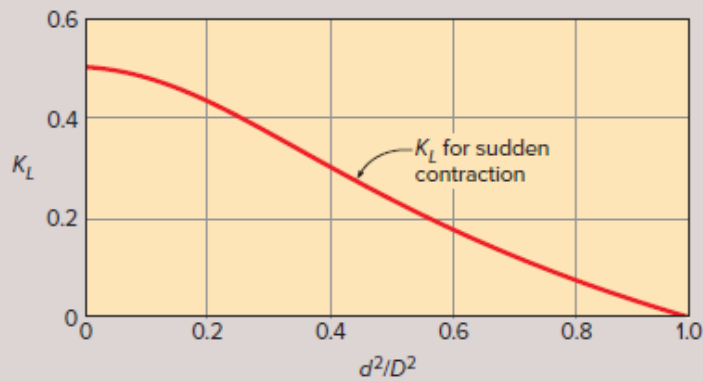
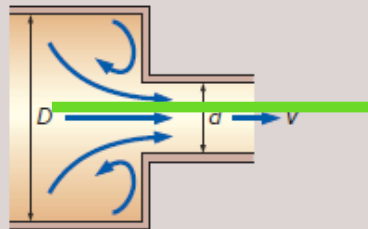
Note: The kinetic energy correction factor is $\alpha = 2$ for fully developed laminar flow, and $\alpha \approx 1.05$ for fully developed turbulent flow.

Sudden Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Sudden expansion: $K_L = \alpha \left(1 - \frac{d^2}{D^2}\right)^2$

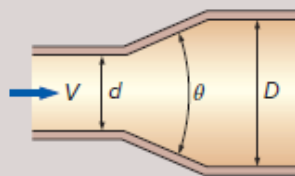


Sudden contraction: See chart.

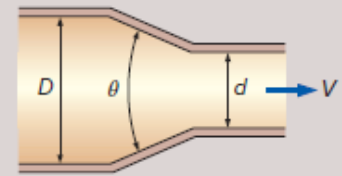


Gradual Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Expansion (for $\theta = 20^\circ$):
 $K_L = 0.30$ for $d/D = 0.2$
 $K_L = 0.25$ for $d/D = 0.4$
 $K_L = 0.15$ for $d/D = 0.6$
 $K_L = 0.10$ for $d/D = 0.8$



Contraction:
 $K_L = 0.02$ for $\theta = 30^\circ$
 $K_L = 0.04$ for $\theta = 45^\circ$
 $K_L = 0.07$ for $\theta = 60^\circ$



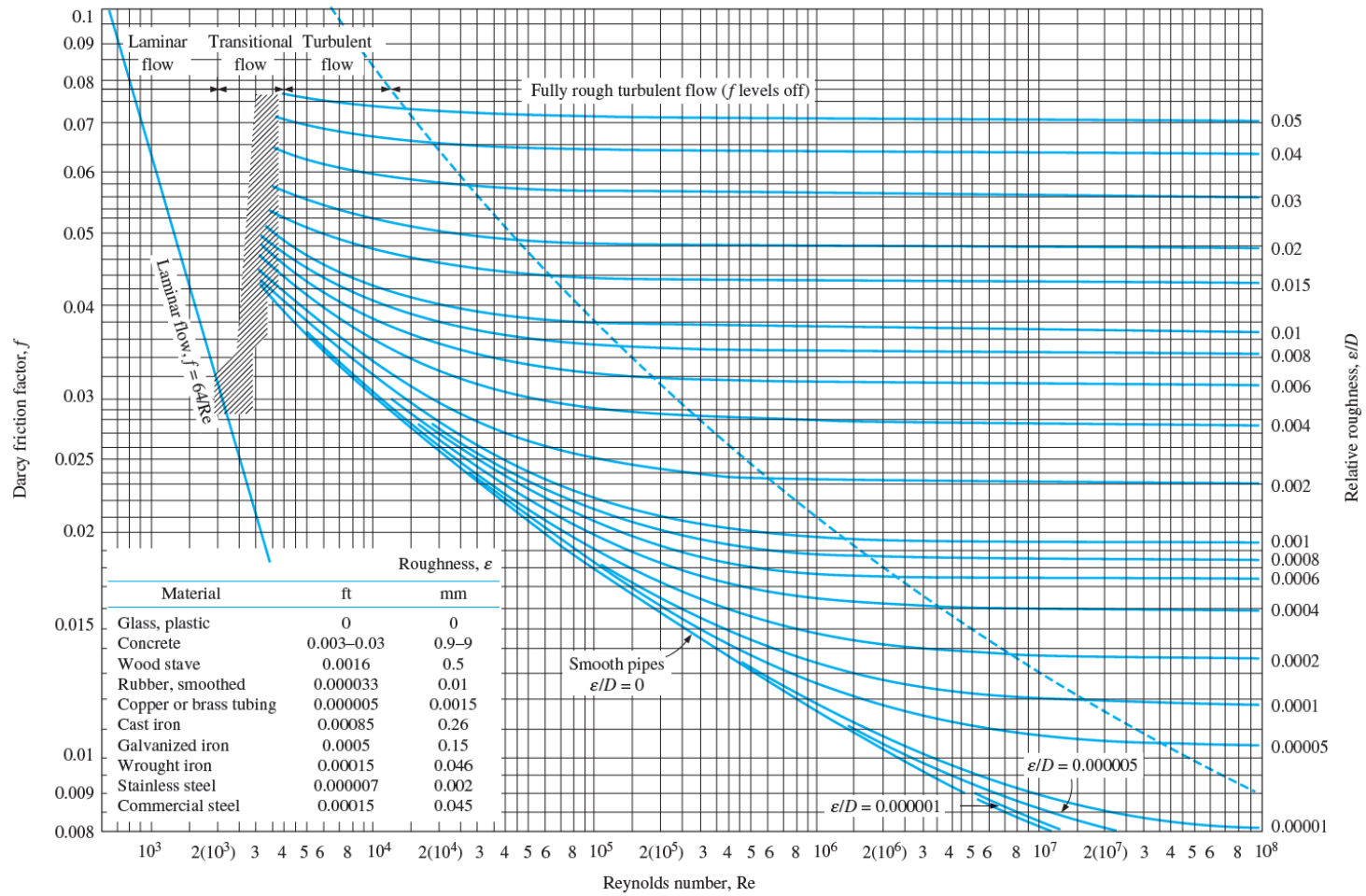


FIGURE A-27

The Moody chart for the friction factor for fully developed flow in circular pipes for use in the head loss relation $\Delta P_L = f \frac{L}{D} \frac{\rho V^2}{2}$. Friction factors in the turbulent flow are evaluated from the Colebrook equation $\frac{1}{\sqrt{f}} = -2 \log_{10} \left(\frac{\sum/D}{3.7} + \frac{2.51}{Re \sqrt{f}} \right)$.

$$h_L = 1.07 \frac{\dot{V}^2 L}{gD^5} \left\{ \ln \left[\frac{\varepsilon}{3.7D} + 4.62 \left(\frac{\nu D}{\dot{V}} \right)^{0.9} \right] \right\}^{-2} \quad \begin{array}{l} 10^{-6} < \varepsilon/D < 10^{-2} \\ 3000 < \text{Re} < 3 \times 10^8 \end{array}$$

$$\dot{V} = -0.965 \left(\frac{gD^5 h_L}{L} \right)^{0.5} \ln \left[\frac{\varepsilon}{3.7D} + \left(\frac{3.17 \nu^2 L}{gD^3 h_L} \right)^{0.5} \right] \quad \text{Re} > 2000$$

$$D = 0.66 \left[\varepsilon^{1.25} \left(\frac{L \dot{V}^2}{gh_L} \right)^{4.75} + \nu \dot{V}^{9.4} \left(\frac{L}{gh_L} \right)^{5.2} \right]^{0.04} \quad \begin{array}{l} 10^{-6} < \varepsilon/D < 10^{-2} \\ 5000 < \text{Re} < 3 \times 10^8 \end{array}$$

Emissivities of some materials
at 300 K

Material	Emissivity
Aluminum foil	0.07
Anodized aluminum	0.82
Polished copper	0.03
Polished gold	0.03
Polished silver	0.02
Polished stainless steel	0.17
Black paint	0.98
White paint	0.90
White paper	0.92–0.97
Asphalt pavement	0.85–0.93
Red brick	0.93–0.96
Human skin	0.95
Wood	0.82–0.92
Soil	0.93–0.96
Water	0.96
Vegetation	0.92–0.96