Appendix

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KEY EQUATIONS AND FORMULAE

pressure-height relation — $p = \gamma h = \rho g h$

resultant force on plane submerged surface A — $F_{resultant} = \gamma d_{cg} A$, where d_{cg} = distance from liquid surface to centroid of area A

location of center of pressure — $L_p = L_{cg} + \frac{I_{cg}}{L_{cg} A}$, with I_{cg}=inertia moment

volume **flowrate** (m^3/sec) — $Q = A v$ = (area * velocity)

mass flowrate (kg/sec) — $M(t) = \rho Q$ = (density * volume flowrate)

continuity — Q = constant = $A_1 v_1 = A_2 v_2$

Bernoulli's Equation (the "head" version) — $p_1/\gamma + z_1 + v_1^2/(2g) = p_2/\gamma + z_2 + v_2^2/(2g)$

General Energy Equation — $p_1/\gamma + z_1 + v_1^2/(2g) + H_{pump} = p_2/\gamma + z_2 + v_2^2/(2g) + H_{motor} + H_{loss}$

Reynolds # for **circular** flow — $N_R = \frac{v d \rho}{\mu} = \frac{v d}{\nu} = (4 Q)/(\pi d \nu)$

Reynolds # for non-circular flow — $N_R = \frac{v d_h \rho}{\mu} = \frac{v d_h}{\nu} = (4 Q)/(\pi d_h \nu)$

hydraulic diameter (non-circular cross-section) — $d_h = 4 \frac{A}{WP}$, with WP=wetted perimeter, and A = cross-sectional area

friction factor for laminar flow — $f = \frac{64}{N_R}$

friction factor **for turbulent flow** (Swamee's) — $f = 0.25(\log(0.27027 \frac{\varepsilon}{d} + 5.74 N_R^{-0.9}))^{-2}$

friction factor **for fittings** (Crane Company) — $f_t = 0.25(\log(0.27027 \frac{\varepsilon}{d}))^{-2}$

headloss due to **friction** (Darcy's equation) — $H_{loss} = f \frac{L v^2}{d 2 g}$

headloss due to **fittings** using equivalent length — $H_{loss} = f_t (\frac{L_e}{d}) \frac{v^2}{2g}$

headloss due to **fittings** using headloss coefficient — $H_{loss} = k \frac{v^2}{2g}$

pump: power delivered to fluid — $P_{fluid} = \gamma H_{added} Q$

power delivered to pump — $P_{pump} = P_{fluid}$ / (efficiency of pump)

turbine: power delivered by fluid — $P_{fluid} = \gamma H_{removed} Q$

power delivered by turbine — $P_{turbine} = P_{fluid}$ * (efficiency of turbine)

available **net positive suction head** — $NPSH_a = h_{sp} \pm h_s - h_{loss} - h_{vapor\ pressure}$

affinity laws for centrifugal pump: for flowrate: $Q_1/Q_2 = n_1/n_2$, for head: $H_1/H_2 = (n_1/n_2)^2$ and for power: $P_1 / P_2 = (n_1/ n_2)^3$

CONVERSIONS:

1 hr = 60 min = 3600 sec ; 1000 mm = 100 cm = 1 m = 10^{-3} km = 3.2808 feet = 39.37 in

1000 g = 1 kg , **and** 1000 N = 1 kN = 224.82 lb_{force} , **NOTE**:gall=gallon

1 liter = 1000 cm^3 = 10^{-3} m^3 = 4.546^{-1} **Imp.gall** = 3.785^{-1} **US gall**

159 liter = **1 US barrel** , 1000 lit/min = 219.974 Imp.gall/min = 264.2 US gall/min

1 Pa = 1.4503*10^{-4} **psi** **or** 1 psi = 6895 Pa

1 01.325 kPa = 14.67 psi = 760 **mm Hg** = 29.92 in Hg = 10.33 m of water

745.7 W = **1 horsepower** = 550 **ft lb**$_{force}$ **/sec**

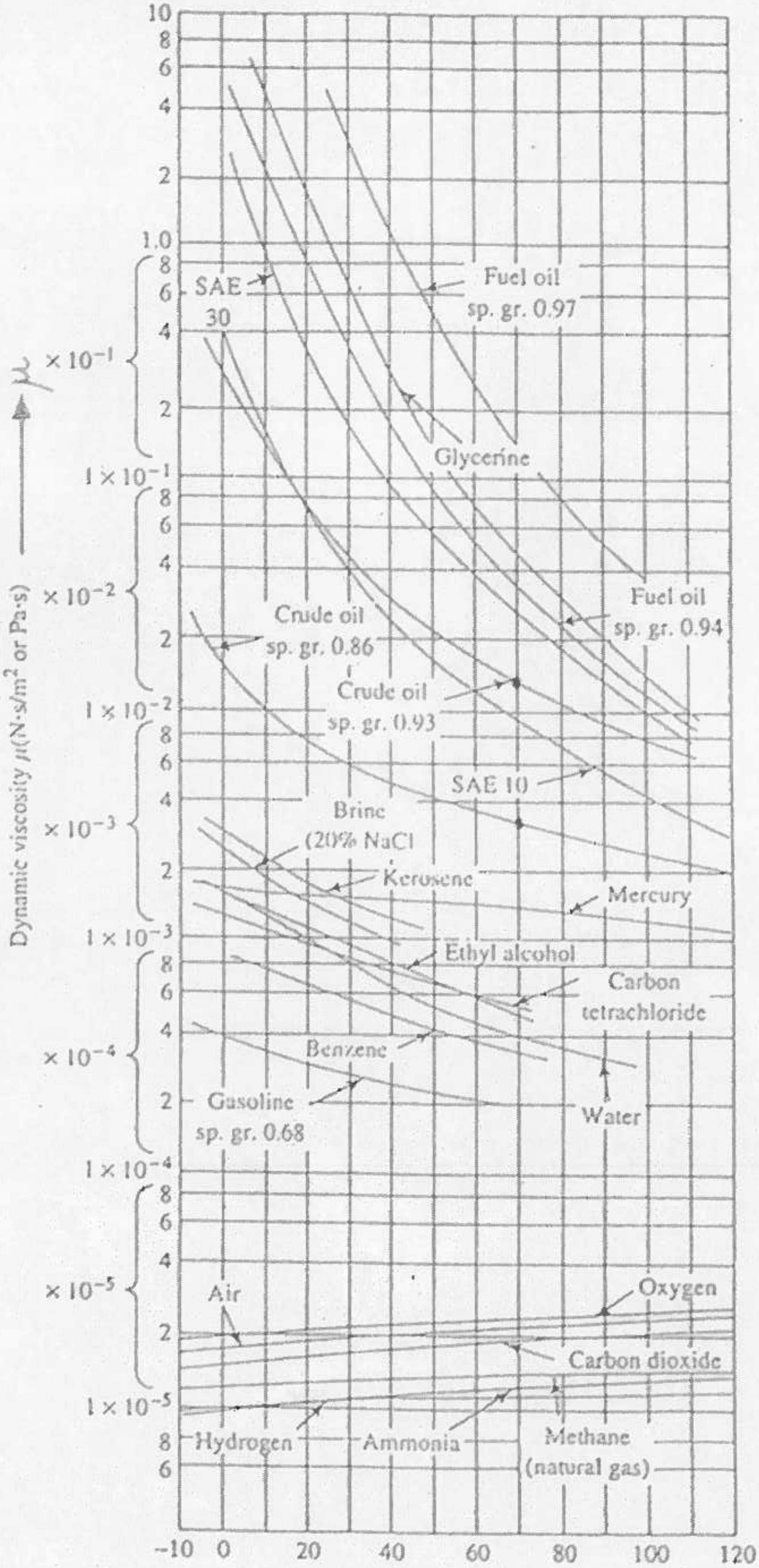
1 poise = 0.1 Pa s = 2.09*10^{-3} lb_{force} sec / ft^2 , **1 stoke** = 10^{-4} m^2 / sec = 1.076*10^{-3} ft^2/s

Properties of Water

TABLE A.1 SI Units [101 kPa (abs)] Temperature (°C)	Specific Weight γ (kN/m^3)	Density ρ (kg/m^3)	Dynamic Viscosity μ ($Pa \cdot s$) or ($N \cdot s/m^2$)	Kinematic Viscosity ν (m^2/s)
0	9.81	1000	1.75×10^{-3}	1.75×10^{-6}
5	9.81	1000	1.52×10^{-3}	1.52×10^{-6}
10	9.81	1000	1.30×10^{-3}	1.30×10^{-6}
15	9.81	1000	1.15×10^{-3}	1.15×10^{-6}
20	9.79	998	1.02×10^{-3}	1.02×10^{-6}
25	9.78	997	8.91×10^{-4}	8.94×10^{-7}
30	9.77	996	8.00×10^{-4}	8.03×10^{-7}
35	9.75	994	7.18×10^{-4}	7.22×10^{-7}
40	9.73	992	6.51×10^{-4}	6.56×10^{-7}
45	9.71	990	5.94×10^{-4}	6.00×10^{-7}
50	9.69	988	5.41×10^{-4}	5.48×10^{-7}
55	9.67	986	4.98×10^{-4}	5.05×10^{-7}
60	9.65	984	4.60×10^{-4}	4.67×10^{-7}
65	9.62	981	4.31×10^{-4}	4.39×10^{-7}
70	9.59	978	4.02×10^{-4}	4.11×10^{-7}
75	9.56	975	3.73×10^{-4}	3.83×10^{-7}
80	9.53	971	3.50×10^{-4}	3.60×10^{-7}
85	9.50	968	3.30×10^{-4}	3.41×10^{-7}
90	9.47	965	3.11×10^{-4}	3.22×10^{-7}
95	9.44	962	2.92×10^{-4}	3.04×10^{-7}
100	9.40	958	2.82×10^{-4}	2.94×10^{-7}

Properties of Common Liquids

TABLE B.1 SI Units [101 kPa (abs) and 25°C]	Specific Gravity sg	Specific Weight γ (kN/m^3)	Density ρ (kg/m^3)	Dynamic Viscosity μ ($Pa \cdot s$) or ($N \cdot s/m^2$)
Acetone	0.787	7.72	787	3.16×10^{-4}
Alcohol, ethyl	0.787	7.72	787	1.00×10^{-3}
Alcohol, methyl	0.789	7.74	789	5.60×10^{-4}
Alcohol, propyl	0.802	7.87	802	1.92×10^{-3}
Ammonia	0.826	8.10	826	—
Benzene	0.876	8.59	876	6.03×10^{-4}
Carbon tetrachloride	1.590	15.60	1 590	9.10×10^{-4}
Castor oil	0.960	9.42	960	6.51×10^{-1}
Ethylene glycol	1.100	10.79	1 100	1.62×10^{-2}
Gasoline	0.68	6.67	680	2.87×10^{-4}
Glycerine	1.258	12.34	1 258	9.60×10^{-1}
Kerosene	0.823	8.07	823	1.64×10^{-3}
Linseed oil	0.930	9.12	930	3.31×10^{-2}
Mercury	13.54	132.8	13 540	1.53×10^{-3}
Propane	0.495	4.86	495	1.10×10^{-4}
Seawater	1.030	10.10	1 030	1.03×10^{-3}
Turpentine	0.870	8.53	870	1.37×10^{-3}
Fuel oil, medium	0.852	8.36	852	2.99×10^{-3}
Fuel oil, heavy	0.906	8.89	906	1.07×10^{-1}



Dynamic Viscosity vs. Temperature (°C)

Typical Properties of Petroleum Lubricating Oils

Type	Specific Gravity	Kinematic Viscosity, ν at 40°C (104°F) (m^2/s)	Kinematic Viscosity, ν at 40°C (104°F) (ft^2/s)	Kinematic Viscosity, ν at 100°C (212°F) (m^2/s)	Kinematic Viscosity, ν at 100°C (212°F) (ft^2/s)	Viscosity Index
Automotive hydraulic systems	0.887	3.99×10^{-5}	4.30×10^{-4}	7.29×10^{-6}	7.85×10^{-5}	141
Machine tool hydraulic systems						
Light	0.887	3.20×10^{-5}	3.44×10^{-4}	4.79×10^{-6}	5.16×10^{-5}	64
Medium	0.895	6.70×10^{-5}	7.21×10^{-4}	7.29×10^{-6}	7.85×10^{-5}	66
Heavy	0.901	1.96×10^{-4}	2.11×10^{-3}	1.40×10^{-5}	1.51×10^{-4}	70
Low temperature	0.844	1.40×10^{-5}	1.51×10^{-4}	5.20×10^{-6}	5.60×10^{-5}	226
Machine tool lubricating oils						
Light	0.881	2.20×10^{-5}	2.37×10^{-4}	3.90×10^{-6}	4.20×10^{-5}	80
Medium	0.915	6.60×10^{-5}	7.10×10^{-4}	7.00×10^{-6}	7.53×10^{-5}	83
Heavy	0.890	2.00×10^{-4}	2.15×10^{-3}	1.55×10^{-5}	1.67×10^{-4}	80

Given Unit ↓ / Desired Unit →	lb·s/ft²	Pa·s	Poise
lb·s/ft²	1	47.88	478.8
Pa·s*	2.089×10^{-2}	1	10
poise**	2.089×10^{-3}	0.1	1
centipoise	2.089×10^{-5}	0.001	0.01

* Standard SI units
Equivalent unit: N·s/m²

** dyne·s/cm²
Equivalent unit: g/cm·s

Units and conversion factors for dynamic viscosity, μ (Multiply number in table by viscosity in given unit to obtain viscosity in desired unit.)

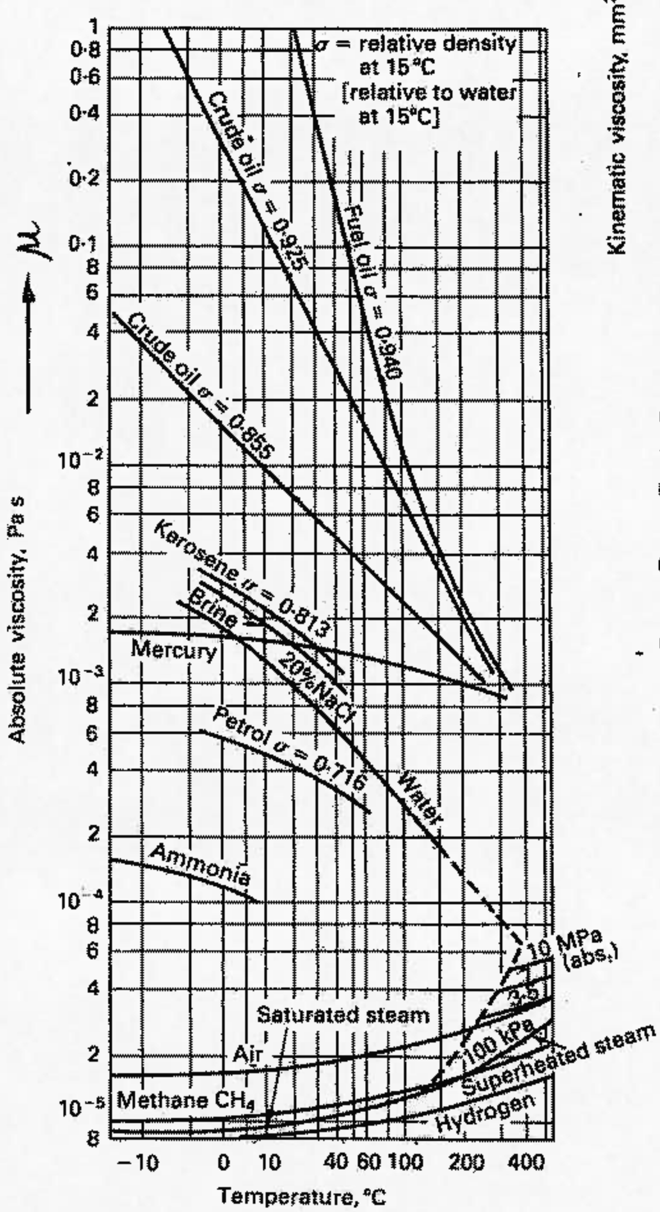
Given Unit ↓ / Desired Unit →	ft²/s	SSU	m²/s	Stoke
ft²/s	1	4.29×10^{5}	9.290×10^{-2}	929.0
SSU*	2.33×10^{-6}	1	2.17×10^{-7}	2.17×10^{-3}
m²/s†	10.764	4.61×10^{6}	1	10^{4}
stoke‡	1.076×10^{-3}	4.61×10^{2}	10^{-4}	1
centistoke	1.076×10^{-5}	4.61	10^{-6}	0.01

* Saybolt Seconds, Universal (conversions approximate for SSU > 100)
For SSU < 100: $\nu = (0.226\ SSU - 195/SSU)(10^{-6})\ m^2/s$

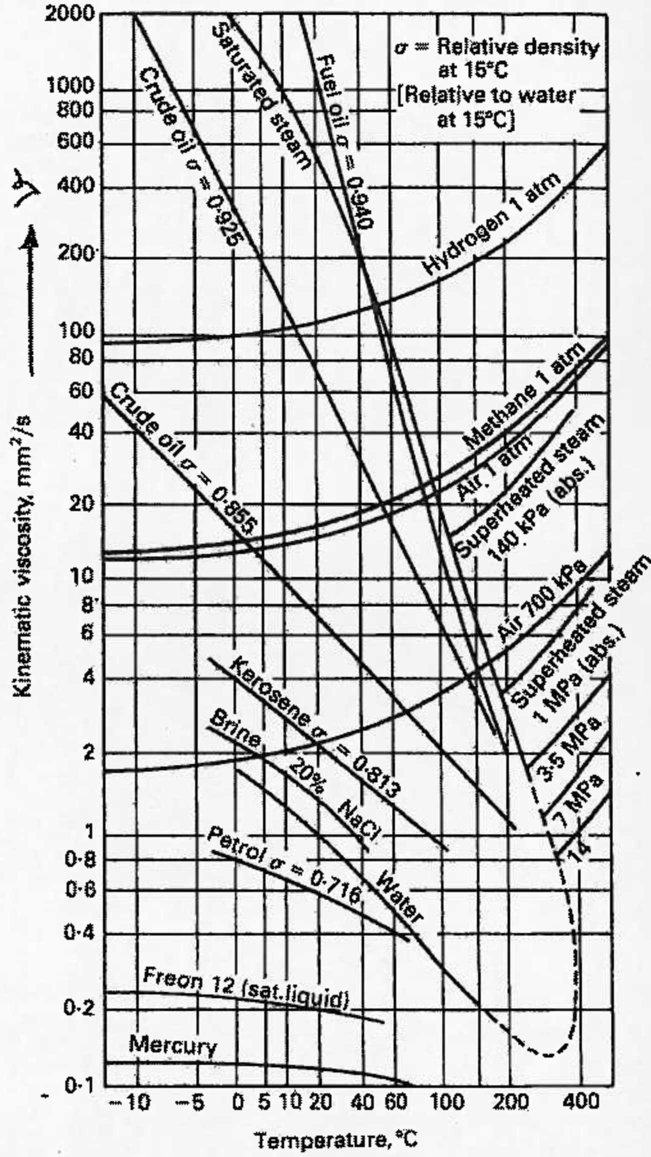
† Standard SI unit

‡ cm²/s

Units and conversion factors for kinematic viscosity, ν (Multiply number in table by viscosity in given unit to obtain viscosity in desired unit.)



Absolute viscosity of fluids.



Kinematic viscosity of fluids.

Dimensions of Steel Pipe

TABLE F.1 Schedule 40

Nominal Pipe Size (in)	Outside Diameter (in)	Outside Diameter (mm)	Wall Thickness (in)	Wall Thickness (mm)	Inside Diameter (in)	Inside Diameter (ft)	Inside Diameter (mm)	Flow Area (ft²)	Flow Area (m²)
1/8	0.405	10.3	0.068	1.73	0.269	0.0224	6.8	0.000 394	3.660×10^{-5}
1/4	0.540	13.7	0.088	2.24	0.364	0.0303	9.2	0.000 723	6.717×10^{-5}
3/8	0.675	17.1	0.091	2.31	0.493	0.0411	12.5	0.001 33	1.236×10^{-4}
1/2	0.840	21.3	0.109	2.77	0.622	0.0518	15.8	0.002 11	1.960×10^{-4}
3/4	1.050	26.7	0.113	2.87	0.824	0.0687	20.9	0.003 70	3.437×10^{-4}
1	1.315	33.4	0.133	3.38	1.049	0.0874	26.6	0.006 00	5.574×10^{-4}
1 1/4	1.660	42.2	0.140	3.56	1.380	0.1150	35.1	0.010 39	9.653×10^{-4}
1 1/2	1.900	48.3	0.145	3.68	1.610	0.1342	40.9	0.014 14	1.314×10^{-3}
2	2.375	60.3	0.154	3.91	2.067	0.1723	52.5	0.023 33	2.168×10^{-3}
2 1/2	2.875	73.0	0.203	5.16	2.469	0.2058	62.7	0.033 26	3.090×10^{-3}
3	3.500	88.9	0.216	5.49	3.068	0.2557	77.9	0.051 32	4.768×10^{-3}
3 1/2	4.000	101.6	0.226	5.74	3.548	0.2957	90.1	0.068 68	6.381×10^{-3}
4	4.500	114.3	0.237	6.02	4.026	0.3355	102.3	0.088 40	8.213×10^{-3}
5	5.563	141.3	0.258	6.55	5.047	0.4206	128.2	0.139 0	1.291×10^{-2}
6	6.625	168.3	0.280	7.11	6.065	0.5054	154.1	0.200 6	1.864×10^{-2}
8	8.625	219.1	0.322	8.18	7.981	0.6651	202.7	0.347 2	3.226×10^{-2}
10	10.750	273.1	0.365	9.27	10.020	0.8350	254.5	0.547 9	5.090×10^{-2}
12	12.750	323.9	0.406	10.31	11.938	0.9948	303.2	0.777 1	7.219×10^{-2}
14	14.000	355.6	0.437	11.10	13.126	1.094	333.4	0.939 6	8.729×10^{-2}
16	16.000	406.4	0.500	12.70	15.000	1.250	381.0	1.227	0.1140
18	18.000	457.2	0.562	14.27	16.876	1.406	428.7	1.553	0.1443
20	20.000	508.0	0.593	15.06	18.814	1.568	477.9	1.931	0.1794
24	24.000	609.6	0.687	17.45	22.626	1.886	574.7	2.792	0.2594

TABLE F.2 Schedule 80

Dimensions of Steel Pipe

Nominal Pipe Size (in)	Outside Diameter (in)	Outside Diameter (mm)	Wall Thickness (in)	Wall Thickness (mm)	Inside Diameter (in)	Inside Diameter (ft)	Inside Diameter (mm)	Flow Area (ft²)	Flow Area (m²)
1/8	0.405	10.3	0.095	2.41	0.215	0.017 92	5.5	0.000 253	2.350×10^{-5}
1/4	0.540	13.7	0.119	3.02	0.302	0.025 17	7.7	0.000 497	4.617×10^{-5}
3/8	0.675	17.1	0.126	3.20	0.423	0.035 25	10.7	0.000 976	9.067×10^{-5}
1/2	0.840	21.3	0.147	3.73	0.546	0.045 50	13.9	0.001 625	1.510×10^{-4}
3/4	1.050	26.7	0.154	3.91	0.742	0.061 83	18.8	0.003 00	2.787×10^{-4}
1	1.315	33.4	0.179	4.55	0.957	0.079 75	24.3	0.004 99	4.636×10^{-4}
1 1/4	1.660	42.2	0.191	4.85	1.278	0.106 5	32.5	0.008 91	8.278×10^{-4}
1 1/2	1.900	48.3	0.200	5.08	1.500	0.125 0	38.1	0.012 27	1.140×10^{-3}
2	2.375	60.3	0.218	5.54	1.939	0.161 6	49.3	0.020 51	1.905×10^{-3}
2 1/2	2.875	73.0	0.276	7.01	2.323	0.193 6	59.0	0.029 44	2.735×10^{-3}
3	3.500	88.9	0.300	7.62	2.900	0.241 7	73.7	0.045 90	4.264×10^{-3}
3 1/2	4.000	101.6	0.318	8.08	3.364	0.280 3	85.4	0.061 74	5.736×10^{-3}
4	4.500	114.3	0.337	8.56	3.826	0.318 8	97.2	0.079 86	7.419×10^{-3}
5	5.563	141.3	0.375	9.53	4.813	0.401 1	122.3	0.126 3	1.173×10^{-2}
6	6.625	168.3	0.432	10.97	5.761	0.480 1	146.3	0.181 0	1.682×10^{-2}
8	8.625	219.1	0.500	12.70	7.625	0.635 4	193.7	0.317 4	2.949×10^{-2}
10	10.750	273.1	0.593	15.06	9.564	0.797 0	242.9	0.498 6	4.632×10^{-2}
12	12.750	323.9	0.687	17.45	11.376	0.948 0	289.0	0.705 6	6.555×10^{-2}
14	14.000	355.6	0.750	19.05	12.500	1.042	317.5	0.852 1	7.916×10^{-2}
16	16.000	406.4	0.842	21.39	14.314	1.193	363.6	1.117	0.1038
18	18.000	457.2	0.937	23.80	16.126	1.344	409.6	1.418	0.1317
20	20.000	508.0	1.031	26.19	17.938	1.495	455.6	1.755	0.1630
24	24.000	609.6	1.218	30.94	21.564	1.797	547.7	2.535	0.2344

Dimensions of Steel Tubing

Outside Diameter (in)	Outside Diameter (mm)	Wall Thickness (in)	Wall Thickness (mm)	Inside Diameter (in)	Inside Diameter (ft)	Inside Diameter (mm)	Flow Area (ft^2)	Flow Area (m^2)
1/8	3.18	0.032	0.813	0.061	0.00508	1.549	2.029×10^{-5}	1.885×10^{-6}
		0.035	0.889	0.055	0.00458	1.397	1.650×10^{-5}	1.533×10^{-6}
3/16	4.76	0.032	0.813	0.124	0.01029	3.137	8.319×10^{-5}	7.728×10^{-6}
		0.035	0.889	0.117	0.00979	2.985	7.530×10^{-5}	6.996×10^{-6}
1/4	6.35	0.035	0.889	0.180	0.01500	4.572	1.767×10^{-4}	1.642×10^{-5}
		0.049	1.24	0.152	0.01267	3.861	1.260×10^{-4}	1.171×10^{-5}
5/16	7.94	0.035	0.889	0.243	0.02021	6.160	3.207×10^{-4}	2.980×10^{-5}
		0.049	1.24	0.215	0.01788	5.448	2.509×10^{-4}	2.331×10^{-5}
3/8	9.53	0.035	0.889	0.305	0.02542	7.747	5.074×10^{-4}	4.714×10^{-5}
		0.049	1.24	0.277	0.02308	7.036	4.185×10^{-4}	3.888×10^{-5}
1/2	12.70	0.049	1.24	0.402	0.03350	10.21	8.814×10^{-4}	8.189×10^{-5}
		0.065	1.65	0.370	0.03083	9.40	7.467×10^{-4}	6.937×10^{-5}
5/8	15.88	0.049	1.24	0.527	0.04392	13.39	1.515×10^{-3}	1.407×10^{-4}
		0.065	1.65	0.495	0.04125	12.57	1.336×10^{-3}	1.242×10^{-4}
3/4	19.05	0.049	1.24	0.652	0.05433	16.56	2.319×10^{-3}	2.154×10^{-4}
		0.065	1.65	0.620	0.05167	15.75	2.097×10^{-3}	1.948×10^{-4}
7/8	22.23	0.049	1.24	0.777	0.06475	19.74	3.293×10^{-3}	3.059×10^{-4}
		0.065	1.65	0.745	0.06208	18.92	3.027×10^{-3}	2.812×10^{-4}
1	25.40	0.065	1.65	0.870	0.07250	22.10	4.128×10^{-3}	3.835×10^{-4}
		0.083	2.11	0.834	0.06950	21.18	3.794×10^{-3}	3.524×10^{-4}
1 1/4	31.75	0.065	1.65	1.120	0.09333	28.45	6.842×10^{-3}	6.356×10^{-4}
		0.083	2.11	1.084	0.09033	27.53	6.409×10^{-3}	5.954×10^{-4}
1 1/2	38.10	0.065	1.65	1.370	0.1142	34.80	1.024×10^{-2}	9.510×10^{-4}
		0.083	2.11	1.334	0.1112	33.88	9.706×10^{-3}	9.017×10^{-4}
1 3/4	44.45	0.065	1.65	1.620	0.1350	41.15	1.431×10^{-2}	1.330×10^{-3}
		0.083	2.11	1.584	0.1320	40.23	1.368×10^{-2}	1.271×10^{-3}
2	50.80	0.065	1.65	1.870	0.1558	47.50	1.907×10^{-2}	1.772×10^{-3}
		0.083	2.11	1.834	0.1528	46.58	1.835×10^{-2}	1.704×10^{-3}

Dimensions of Type K Copper Tubing

Nominal Size (in)	Outside Diameter (in)	Outside Diameter (mm)	Wall Thickness (in)	Wall Thickness (mm)	Inside Diameter (in)	Inside Diameter (ft)	Inside Diameter (mm)	Flow Area (ft^2)	Flow Area (m^2)
1/8	0.250	6.35	0.035	0.889	0.180	0.0150	4.572	1.767×10^{-4}	1.642×10^{-5}
1/4	0.375	9.53	0.049	1.245	0.277	0.0231	7.036	4.185×10^{-4}	3.888×10^{-5}
3/8	0.500	12.70	0.049	1.245	0.402	0.0335	10.21	8.814×10^{-4}	8.189×10^{-5}
1/2	0.625	15.88	0.049	1.245	0.527	0.0439	13.39	1.515×10^{-3}	1.407×10^{-4}
5/8	0.750	19.05	0.049	1.245	0.652	0.0543	16.56	2.319×10^{-3}	2.154×10^{-4}
3/4	0.875	22.23	0.065	1.651	0.745	0.0621	18.92	3.027×10^{-3}	2.812×10^{-4}
1	1.125	28.58	0.065	1.651	0.995	0.0829	25.27	5.400×10^{-3}	5.017×10^{-4}
1 1/4	1.375	34.93	0.065	1.651	1.245	0.1037	31.62	8.454×10^{-3}	7.854×10^{-4}
1 1/2	1.625	41.28	0.072	1.829	1.481	0.1234	37.62	1.196×10^{-2}	1.111×10^{-3}
2	2.125	53.98	0.083	2.108	1.959	0.1632	49.76	2.093×10^{-2}	1.945×10^{-3}
2 1/2	2.625	66.68	0.095	2.413	2.435	0.2029	61.85	3.234×10^{-2}	3.004×10^{-3}
3	3.125	79.38	0.109	2.769	2.907	0.2423	73.84	4.609×10^{-2}	4.282×10^{-3}
3 1/2	3.625	92.08	0.120	3.048	3.385	0.2821	85.98	6.249×10^{-2}	5.806×10^{-3}
4	4.125	104.8	0.134	3.404	3.857	0.3214	97.97	8.114×10^{-2}	7.538×10^{-3}
5	5.125	130.2	0.160	4.064	4.805	0.4004	122.0	1.259×10^{-1}	1.170×10^{-2}
6	6.125	155.6	0.192	4.877	5.741	0.4784	145.8	1.798×10^{-1}	1.670×10^{-2}
8	8.125	206.4	0.271	6.883	7.583	0.6319	192.6	3.136×10^{-1}	2.914×10^{-2}
10	10.125	257.2	0.338	8.585	9.449	0.7874	240.0	4.870×10^{-1}	4.524×10^{-2}
12	12.125	308.0	0.405	10.287	11.315	0.9429	287.4	6.983×10^{-1}	6.487×10^{-2}

Dimensions of Ductile Iron Pipe

TABLE 1.1 Class 150 for 150 psi (1.03 MPa) pressure service

Nominal Pipe Size	Outside Diameter		Wall Thickness		Inside Diameter			Flow Area	
(in)	(in)	(mm)	(in)	(mm)	(in)	(ft)	(mm)	(ft^2)	(m^2)
3	3.96	100.6	0.320	8.13	3.32	0.277	84.3	0.0601	5.585×10^{-3}
4	4.80	121.9	0.350	8.89	4.10	0.342	104.1	0.0917	8.518×10^{-3}
6	6.90	175.3	0.380	9.65	6.14	0.512	156.0	0.2056	1.910×10^{-2}
8	9.05	229.9	0.410	10.41	8.23	0.686	209.0	0.3694	3.432×10^{-2}
10	11.10	281.9	0.440	11.18	10.22	0.852	259.6	0.5697	5.292×10^{-2}
12	13.20	335.3	0.480	12.19	12.24	1.020	310.9	0.8171	7.591×10^{-2}
14	15.65	397.5	0.510	12.95	14.63	1.219	371.6	1.167	0.1085
16	17.80	452.1	0.540	13.72	16.72	1.393	424.7	1.525	0.1417
18	19.92	506.0	0.580	14.73	18.76	1.563	476.5	1.920	0.1783
20	22.06	560.3	0.620	15.75	20.82	1.735	528.8	2.364	0.2196
24	26.32	668.5	0.730	18.54	24.86	2.072	631.4	3.371	0.3132

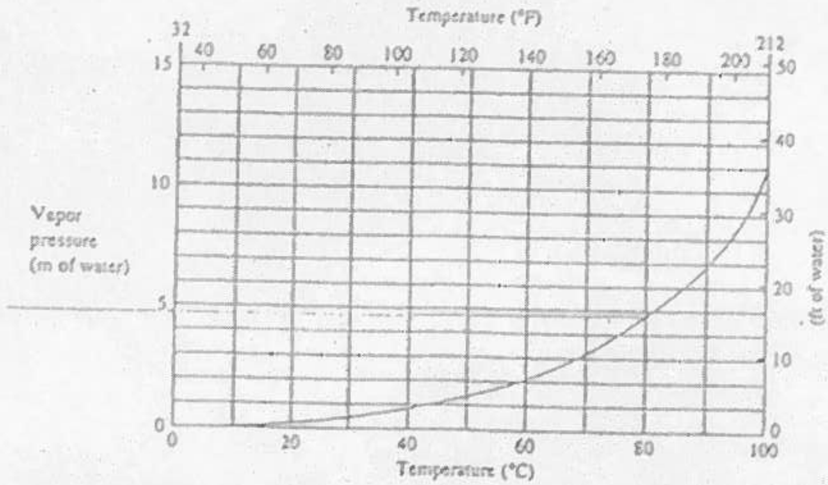


FIGURE 15.36 Vapor pressure of water.

Material	Roughness, ε (m)	Roughness, ε (ft)
Glass, plastic	Smooth	Smooth
Copper, brass, lead (tubing)	1.5×10^{-6}	5×10^{-6}
Cast iron—uncoated	2.4×10^{-4}	8×10^{-4}
Cast iron—asphalt coated	1.2×10^{-4}	4×10^{-4}
Commercial steel or welded steel	4.6×10^{-5}	1.5×10^{-4}
Wrought iron	4.6×10^{-5}	1.5×10^{-4}
Riveted steel	1.8×10^{-3}	6×10^{-3}
Concrete	1.2×10^{-4}	4×10^{-4}

Reynold's Number

$$N_R = \frac{v D \rho}{\mu} = \frac{v D}{\nu} = \frac{4 q}{\pi D \nu} = \frac{4 \gamma q}{\pi g \mu D}$$

Critical Reynold's Numbers

If $N_R < 2000$, the flow is laminar

If $N_R > 4000$, the flow is turbulent

Swamee, Jain (1976) Equation

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{e}\right)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2}$$

Total Head Loss

$$h_L = \frac{v^2}{2g}\left[f\,\frac{L}{D} + f_t \sum \frac{L_e}{D} + \sum K\right]$$

Hagen-Poiseuille

$$h_L = \frac{32\,\mu\,L\,v}{\gamma D^2} = \frac{64}{N_R}\,\frac{L}{D}\,\frac{v^2}{2g}$$

Darcy-Weisbach

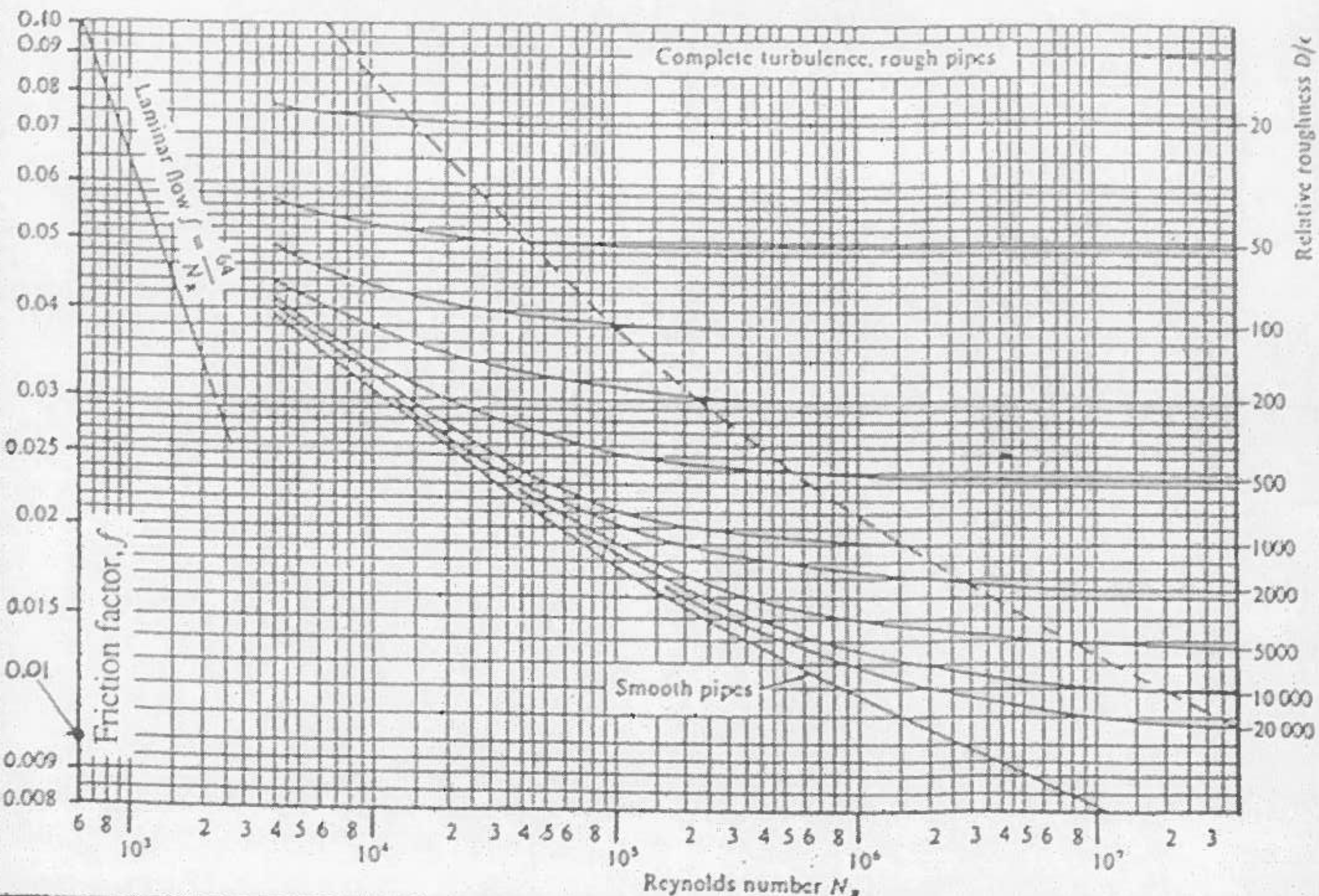
$$h_L = f\,\frac{L}{D}\,\frac{v^2}{2g}$$

Minor Head Losses

$$h_L = K\,\frac{v^2}{2g} = f_t\,\frac{L_e}{D}\,\frac{v^2}{2g}$$

$$f_t = \left[\,2\log(3.7\,D/e)\right]^{-2}$$

Material	Roughness, ϵ (m)
Glass, plastic	Smooth
Copper, brass, lead (tubing)	1.5×10^{-6}
Cast iron—uncoated	2.4×10^{-4}
Cast iron—asphalt coated	1.2×10^{-4}
Commercial steel or welded steel	4.6×10^{-5}
Wrought iron	4.6×10^{-5}
Riveted steel	1.8×10^{-3}
Concrete	1.2×10^{-4}



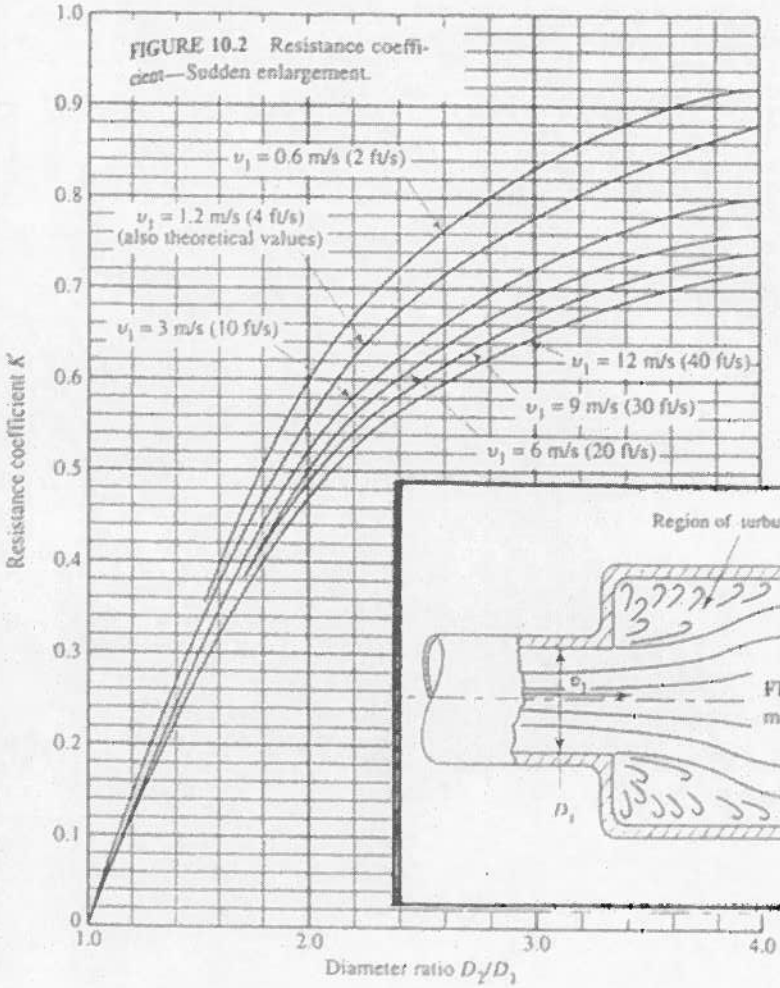


FIGURE 10.2 Resistance coefficient—Sudden enlargement.

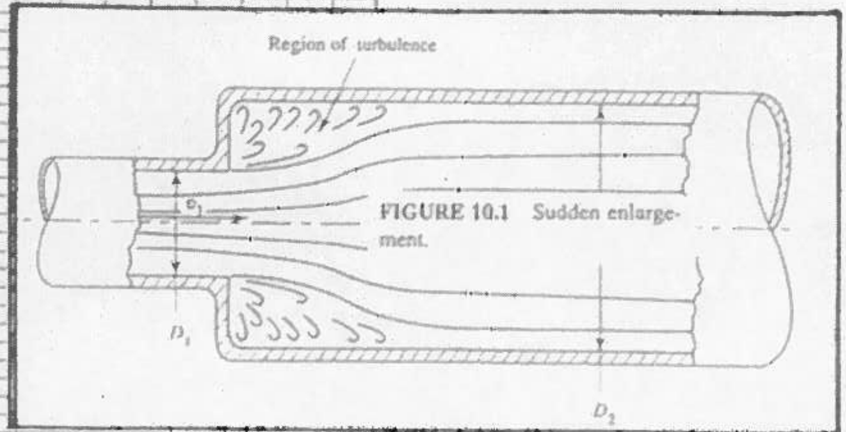


FIGURE 10.1 Sudden enlargement.

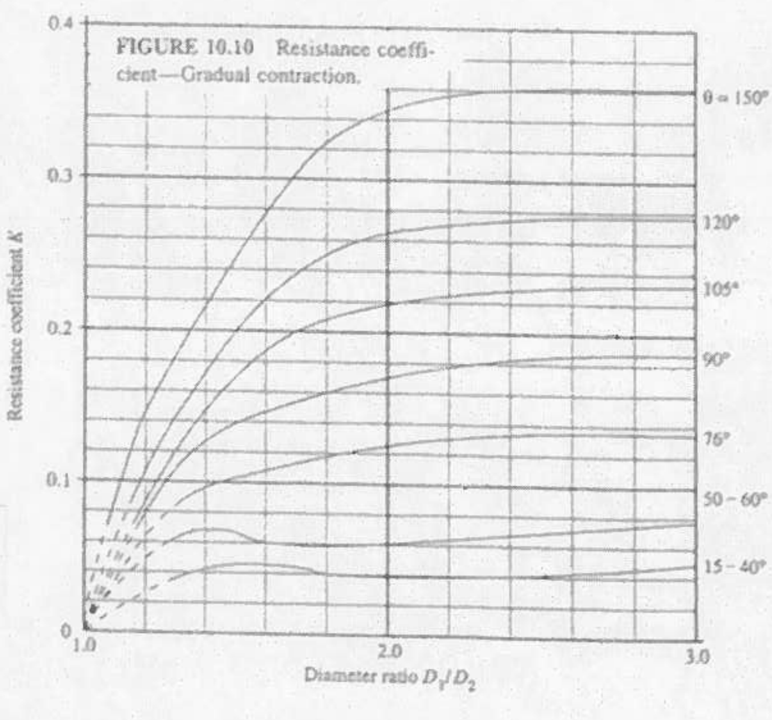


FIGURE 10.10 Resistance coefficient—Gradual contraction.

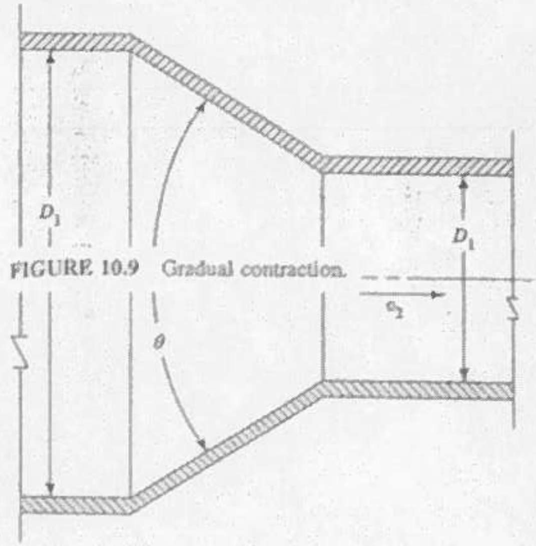


FIGURE 10.9 Gradual contraction.

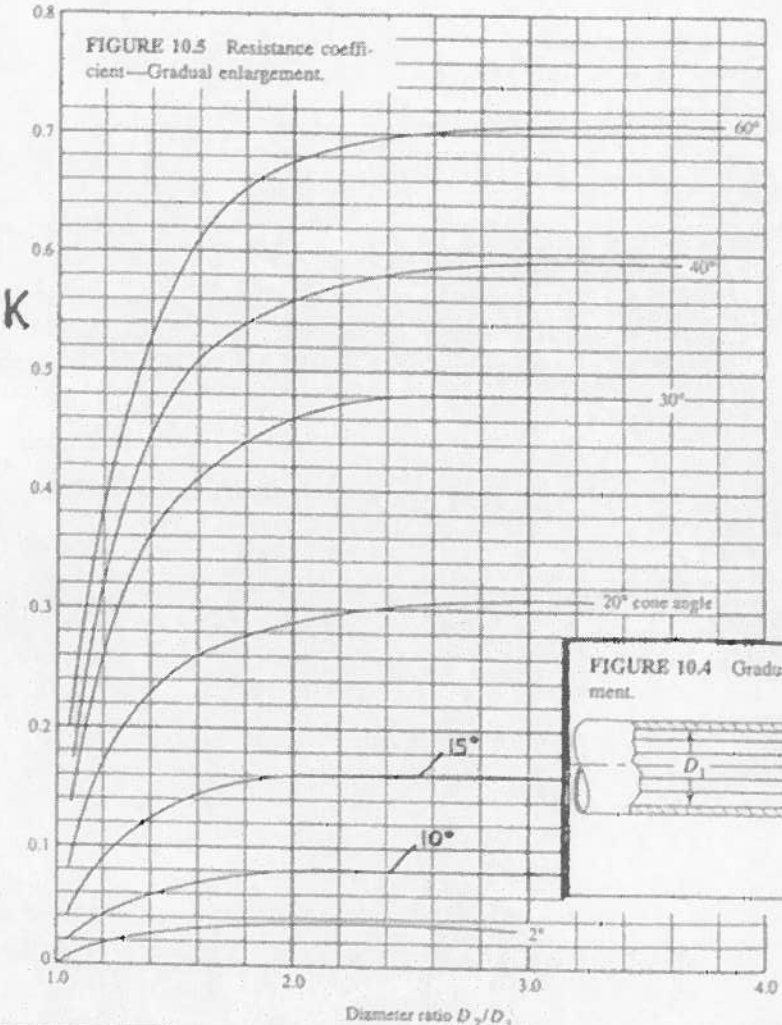


FIGURE 10.5 Resistance coefficient—Gradual enlargement.

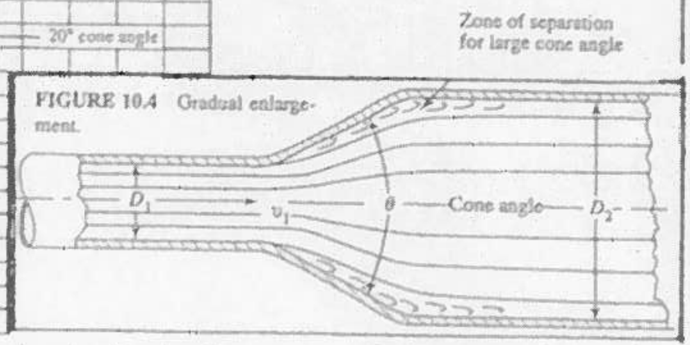


FIGURE 10.4 Gradual enlargement.

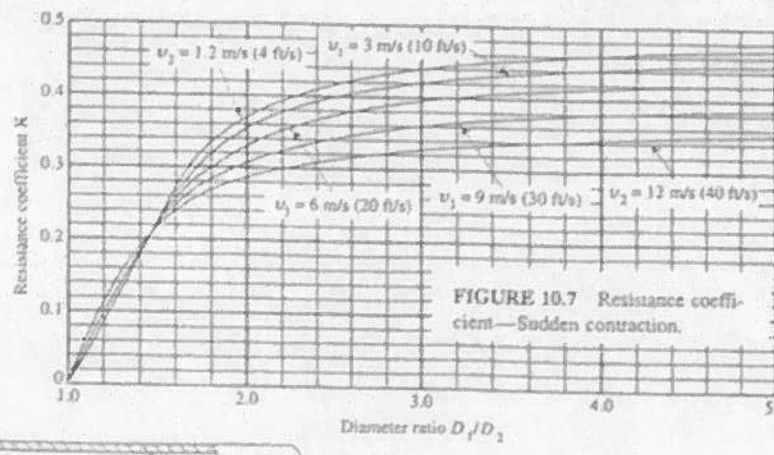


FIGURE 10.7 Resistance coefficient—Sudden contraction.

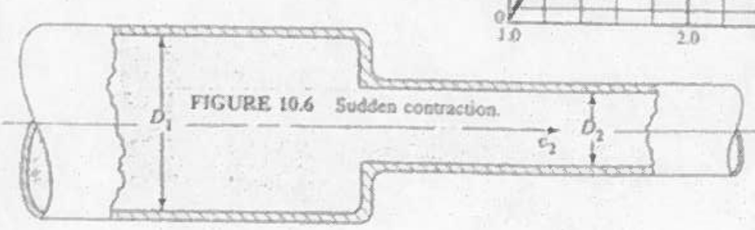


FIGURE 10.6 Sudden contraction.

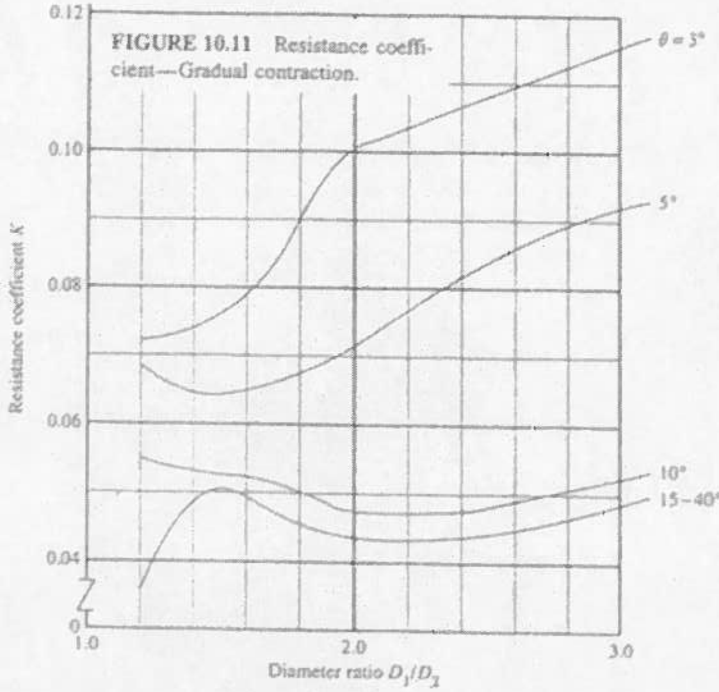


FIGURE 10.11 Resistance coefficient—Gradual contraction.

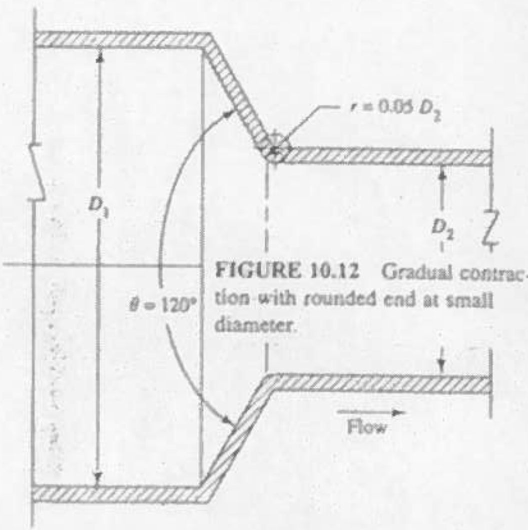


FIGURE 10.12 Gradual contraction with rounded end at small diameter.

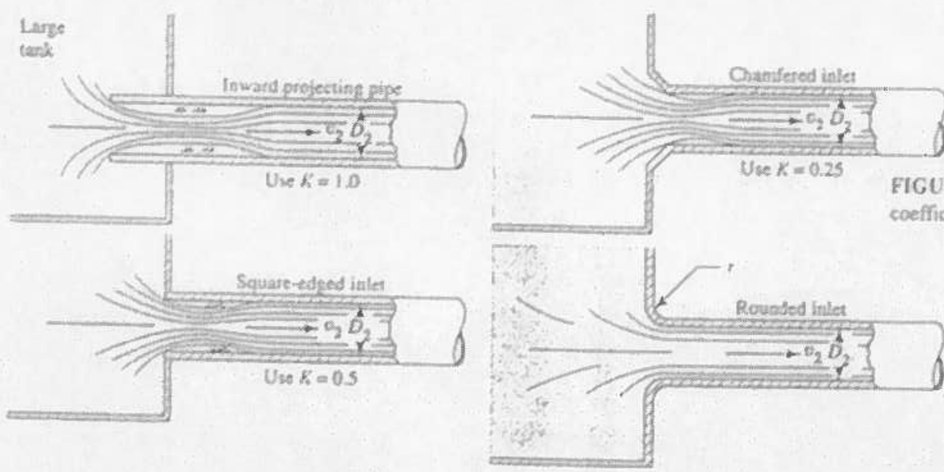


FIGURE 10.13 Entrance resistance coefficients.

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)

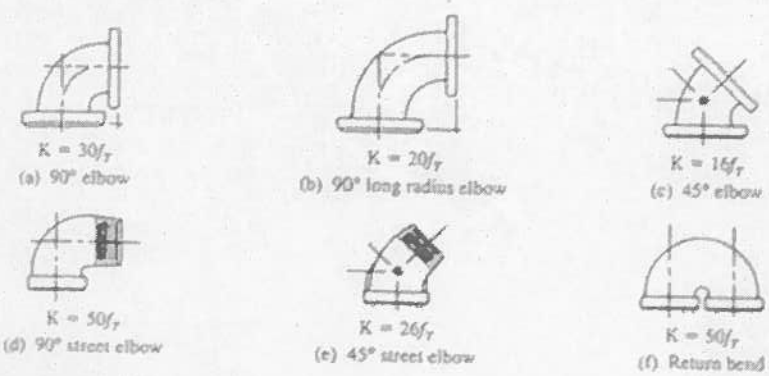


FIGURE 10.22 Pipe elbows.
(Source: Crane Valves, Joliet, IL)

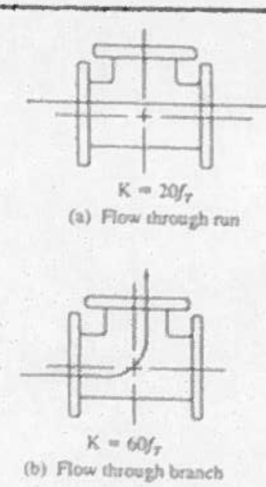


FIGURE 10.23 Standard tees.
(Source: Crane Valves, Joliet, IL)

TABLE 10.4 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
—3/4 open	35
—1/2 open	160
—1/4 open	900
Check valve—swing type	100
Check valve—ball type	150
Butterfly valve—fully open	45
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

Source: Crane Valves, Joliet, IL

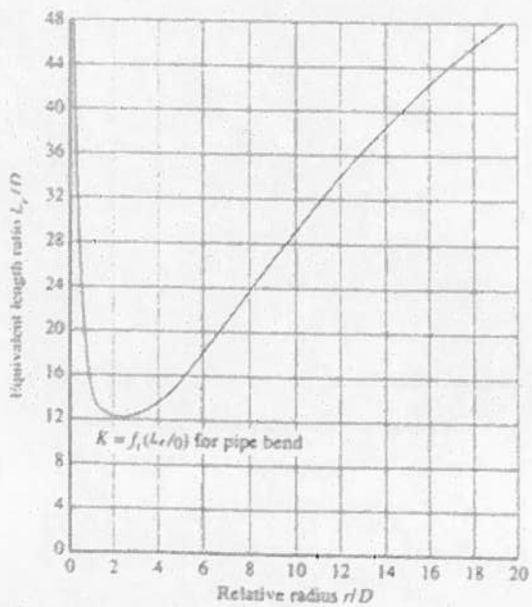


FIGURE 10.27 Resistance due to 90° pipe bends. (Source: Beij, K. H. Pressure Losses for Fluid Flow in 90 Degree Pipe Bends. *Journal of Research of the National Bureau of Standards* 21 [July 1938]: 1–18.)

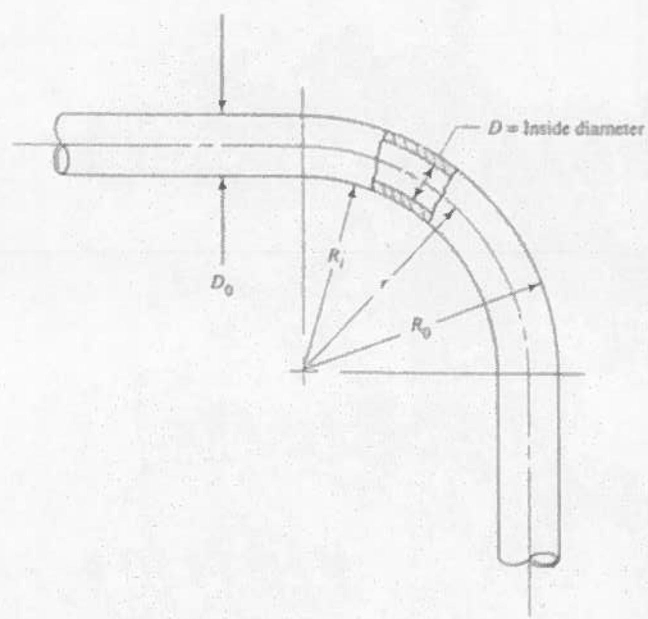


FIGURE 10.28 90° pipe bend.