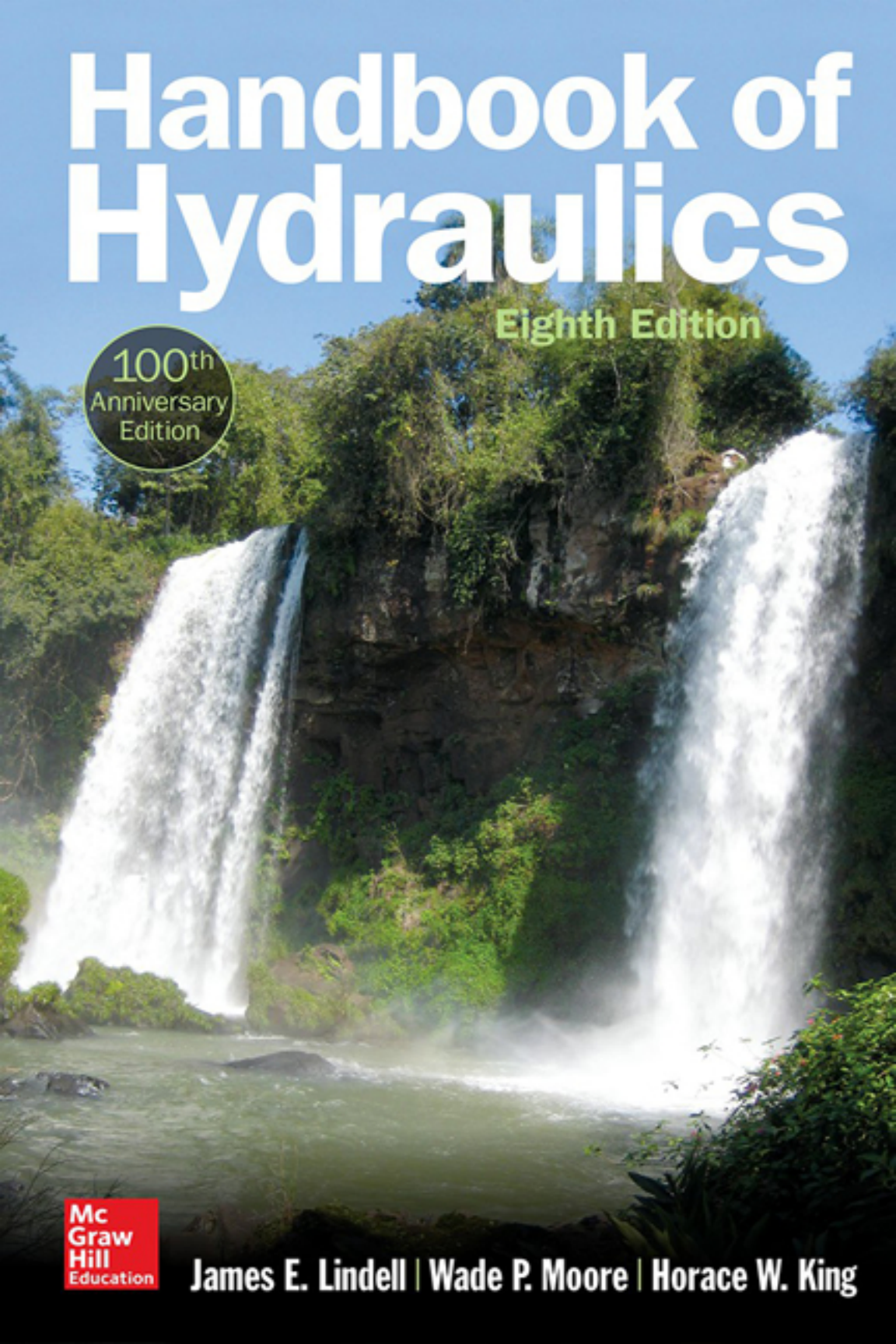
Handbook of Hydraulics

Eighth Edition

100th Anniversary Edition



James E. Lindell | Wade P. Moore | Horace W. King

Mc Graw Hill Education

Handbook of Hydraulics

About the Authors

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Handbook of Hydraulics

James E. Lindell
Wade P. Moore
Horace W. King

Eighth Edition

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Preface to the Eighth Edition

Horace Williams King, as Professor of Engineering Hydraulics at the University of Michigan, was the creator of this *Handbook of Hydraulics*, which became such a standard for hydraulic engineers that it became known as *King's Handbook*.

Work on this handbook has been continued over the years by Professor Ernest F. Brater and, most recently in the seventh edition, by James E. Lindell and C. Y. Wei, editors, and Wade P. Moore, a contributor.

Now, the eighth edition of the *Handbook of Hydraulics* takes further steps to keep abreast of developments in hydraulic engineering and advanced methods of problem-solving. Recognizing the increased capability of computers and other electronic devices, tables have been replaced, where appropriate, by methods to solve equations that can be easily accomplished using today's advanced technology. To make the handbook more useful to a wider audience, equations, examples, and coefficients are presented in both U.S. customary and metric units.

It is the objective of this handbook to present the fundamentals needed to solve common hydraulic problems and to provide tables, graphs, and computer techniques to facilitate their solution. Many numerical examples are included. The book has been organized to provide maximum assistance to engineers engaged in hydraulic engineering projects. In addition, it is suitable as a text, especially for courses that deal with nonuniform flow in open channels or coastal engineering. It is only by solving many numerical problems that the student or the young engineer will obtain a sound working knowledge of hydraulic engineering. The tools provided in this book will facilitate the solution of these problems.

The authors wish to acknowledge the vast contributions made by individual researchers, practicing engineers, and governmental organizations, whose published material provides the essential information for the solution of hydraulic problems. References to these many contributions are made throughout the text.

Special acknowledgment is made to Justin Bartels and James C. Lindell, who made valuable contributions to the preparation of figures and tables, and to Research Professor Steve Barfuss of Utah State University, who contributed Sec. 14.

James E. Lindell
Wade P. Moore

Preface to the First Edition

In applied hydraulics rational theory must give place to experimental knowledge. Though every particle of flowing water moves in accordance with definite fixed laws, such laws are intricate and imperfectly understood. In many instances the basic formulas used in hydraulic computations are derived from theoretical considerations, but they must invariably be corrected by experimental coefficients and frequently they become thereby so transformed as to bear but a slight resemblance to the original formulas.

Many thousands of experiments on flowing water have been performed during the last two centuries, the results of which form the basis of our present science of hydraulics. These experiments present many incongruities and as they do not cover the range of conditions required in practice, it is difficult to devise from them accurate working rules and formulas. The hydraulic engineer is therefore confronted with the task of making what appears to be the most reasonable applications of the available data to each problem that he encounters.

A great number of empirical formulas have been devised, which provide an indirect method of transferring experimental results to practical problems. In using such formulas, however, the engineer should not lose sight of the fact that results obtained by them will be subject to errors corresponding to the discrepancies in the experiments on which the formulas are based.

The active interest in experimental research during recent years has been productive of such a rapidly increasing number of hydraulic formulas that engineers generally are not in a position to make critical comparisons and select those that possess the greatest merit. The result has been a tendency to cling to the old and accepted formulas. The author believes that unless the newer formulas have apparent

advantages over the old, the latter are preferable inasmuch as their peculiarities are known and it is easier to select coefficients for them, but they should be discarded as soon as more accurate or simpler formulas become available.

In this book, the older and commonly accepted formulas are given preference except where a gain in accuracy or simplicity or both will result from the adoption of new formulas or methods. The author departs from standard American practice in advocating the use of the Manning formula in place of the Kutter formula. He has not done this, however, until he has been able to prove that the two formulas give practically identical results by using the same coefficient. New weir formulas are also submitted which are shown to be simpler and to conform to existing experimental data more consistently than other formulas. Exponential formulas are advocated for pipes but a simplified method of using them is given in detail.

This book is intended primarily to assist in the solution of hydraulic problems. In preparing the manuscript the author has continually kept in mind the twofold purpose, of securing an accuracy consistent with the best experiments and of simplifying calculations. This has necessitated an examination of a vast amount of data and has resulted in the preparation of a great many tables. A knowledge of the fundamental principles of hydraulics is presupposed and derivations have been omitted except where they have appeared necessary in explaining new methods. It is believed that the book will be useful to practising engineers and to students.

In the preparation of tables care has been taken to make them correct to the last figure and all computations and formulas have been independently checked. The author will be grateful to those who may call to his attention any errors or omissions.

A work of this kind is, in a large measure, a recompilation of the results of others, and a great many books and publications have necessarily been consulted. Reference to such use has been made at the proper place in the text. In the preparation of this volume, the author acknowledges assistance from the following:

Mr. Robert E. Horton reviewed the manuscript and proof and made many valuable criticisms and suggestions relative to the character of material and scope of the book. He gave the author free access to all of the records in his office and many of the data contained herein were obtained from this source. For being able to present the book in its present form the author is, in a large measure, indebted to Mr. Horton's helpful suggestions, and he takes this opportunity to express his grateful appreciation.

Professor Theodore R. Running rendered valuable assistance in mathematical computations, especially in checking the author's weir formula by the method of least squares and in suggesting the method employed in the construction of the Manning formula diagrams.

Mr. Chester O. Wisler assisted in checking formulas and tables and in reading proof, and gave many valuable suggestions which were made use of in preparing this book.

Mr. Harry R. Leach, Mr. Floyd A. Nagler, and Mr. Russell A. Dodge shared with the author the bulk of the labor of computing and checking tables, reading proof, and other details. It has only been through the hearty cooperation, loyalty, and active interest of these men that the completion of this volume at the present time has been made possible.

Messrs. M. J. Orbeck, J. B. Jewell, C. N. Ward, R. B. Sleight, and W. O'B. Henderson rendered valuable assistance in computing and checking.

Horace W. King
Ann Arbor, Michigan
January 1918

SECTION 1

Fluid Properties and Hydraulic Units

This section provides information on the fluid properties and quantities used to solve hydraulic engineering problems. Table 1.1 lists the quantities together with the commonly used symbols, dimensions, and basic units. The dimensions are expressed in terms of three fundamental quantities: mass *M*, length *L*, and time *T*. The basic units are given in both U.S. customary units (English units) and the metric system, also known as the International System (SI). Some numerical values of fluid properties are presented in Table 1.2. Table 1.3 is devoted to the conversion of units from the U.S. customary system to the metric system, and Table 1.4 lists the unit weights of materials used in hydraulic structures.

Fluid Properties

Before discussing fluid properties, it is necessary to define the unit of mass. To convert *weight W* to *mass M*, it is necessary to divide by the *gravitational acceleration g*,

$$M = \frac{W}{g} \tag{1.1}$$

The standard units of force and mass are slugs and pounds (U.S. customary) and newtons and kilograms (metric), respectively. In the U.S. customary system a force of 1 pound (lb) will accelerate 1 slug at a rate of 1 foot per second per second (ft/s^2). Likewise, in the metric system a force of 1 newton (N) will accelerate a mass of 1 kilogram (kg) at the rate of 1 meter per second per second (m/s^2). The standard gravitational acceleration is 32.2 ft/s^2 (9.81 m/s^2).

Table 1.1 Fluid Properties and Hydraulic Quantities

Quantity	Symbols	Dimensions	Basic units (English system)	Basic units (Metric system)
Length	l, d, D, h, H	L	Feet (ft)	Meters (m)
Area	a	L^2	Square feet (ft^2)	Square meters (m^2)
Volume	$\forall$	L^3	Cubic feet (ft^3)	Cubic meters (m^3)
Time	T, t	T	Seconds (s)	
Velocity	V, v, u	L/T	Feet per second (ft/s)	Meters per second (m/s)
Kinematic viscosity	v	L^2/T	Square feet per second (ft^2/s)	Square meters per second (m^2/s)
Discharge	Q	L^3/T	Cubic feet per second (ft^3/s)	Cubic meters per second (m^3/s)
Mass	M	M	Slug ($lb \cdot s^2/ft$)	Kilograms (kg)
Density	ρ	M/L^3	Slugs per cubic foot ($lb \cdot s^2/ft^4$)	Kilograms per cubic meter (kg/m^3)
Force, weight	F, W	ML/T^2	Pound (lb)	Newton (N)
Specific weight (unit weight)	γ	M/L^2T^2	Pounds per cubic foot (lb/ft^3)	Newtons per cubic meter (N/m^3)
Viscosity	μ	M/LT	Slugs per foot second ($lb \cdot s/ft^2$)	Newton-seconds per square meter ($N \cdot s/m^2$)
Surface tension	σ	M/T^2	Pounds per foot (lb/ft)	Newtons per meter (N/m)
Modulus of elasticity (bulk)	E	M/LT^2	Pounds per square foot (lb/ft^2)	Newtons per square meter (N/m^2)
Pressure intensity	p	M/LT^2	Pounds per square foot (lb/ft^2)	Newtons per square meter (N/m^2)
Shear stress	τ	M/LT^2	Pounds per square foot (lb/ft^2)	Newtons per square meter (N/m^2)
Momentum or impulse		ML/T	Slug-feet per second ($lb \cdot s$)	Kilogram-meters per second ($kg \cdot m/s$)
Energy or work		ML^2/T^2	Foot pound ($ft \cdot lb$)	Meter-newtons ($m \cdot N$)
Power		ML^2/T^3	Foot pound per second ($ft \cdot lb/s$)	Meter-newtons per second ($m \cdot N/s$)
Specific gravity	sp. gr.			
Vapor pressure	p_v	M/LT^2	Pound per square foot (lb/ft^2)	Newtons per square meter (N/m^2)

Table 1.2a Numerical Values of Some Fluid Properties,* U.S. Customary System

Fluid	Temperature T, °F	Specific gravity, sp. gr.	Specific weight w, lb/ft³	Absolute viscosity μ, slugs/ft·s	Kinematic viscosity υ, ft²/s	Vapor pressure p_v, lb/ft²	Surface tension σ, lb/ft
Water	32	0.9999	62.42	0.00003746	0.00001931	12.7	0.518
	39.2	1.0000	62.427	0.00003274	0.00001687	16.9	0.514
	50	0.9997	62.41	0.00002735	0.00001410	25.6	0.509
	60	0.9990	62.37	0.00002359	0.00001217	36.8	0.504
	70	0.9980	62.30	0.00002050	0.00001059	52.3	0.498
	80	0.9966	62.22	0.00001799	0.00000930	73	0.492
	100	0.9931	62.00	0.00001424	0.00000739	136	0.480
	200	0.9630	60.12	0.00000637	0.00000341	1650	0.412
Seawater	—	—	64.00	—			
Mercury	32		—	0.00000.355			
	68		—	0.00000328			
	80.6		—	—			
Castor oil	50	—	—	0.0505			
	59		—	0.0315			
	68	—	—	0.0206			
Dry air at standard atmospheric pressure	32	0.00129	—	$0.355(10^{-6})$			
	50	0.00125	—	$0.372(10^{-6})$			
	59	0.00122	—	$0.376(10^{-6})$			
	68	0.00121	—	$0.380(10^{-6})$			

*Values are based on *Handbook of Chemistry and Physics*, *International Critical Tables*, and *ASCE Manual for Hydraulic Laboratory Studies*. Many are averages of those obtained from various sources. Other sources of similar data are *Smithsonian Physical Tables* and *Standard Density and Volumetric Tables*, U.S. Bureau of Standards.

Table 1.2b Numerical Values of Some Fluid Properties,* Metric System

Fluid	Temperature T, °C	Specific gravity, sp. gr.	Specific weight w, N/m³	Absolute viscosity μ, N·s/m²	Kinematic viscosity υ, m²/s	Vapor pressure p_v, N/m²	Surface tension σ, N/m
Water	0	0.9999	9805	0.00179	1.795×10^{-6}	608	0.0756
	4	1.0000	9806	0.00157	1.568×10^{-6}	809	0.0750
	10	0.9997	9804	0.00131	1.310×10^{-6}	1226	0.0743
	15	0.9990	9798	0.00113	1.131×10^{-6}	1762	0.0735
	21	0.9980	9787	0.00098	0.984×10^{-6}	2504	0.0727
	27	0.9966	9774	0.00086	0.864×10^{-6}	3495	0.0718
	38	0.9931	9739	0.00068	0.687×10^{-6}	6512	0.0700
	93	0.9630	9444	0.00030	0.317×10^{-6}	79,002	0.0601
Seawater	—	—	10,054	—			
Mercury	0	13.60	—	0.00170			
	20	13.55	—	0.00157			
	27	13.53	—	—			
Castor oil	10	—	—	2.418			
	15	0.969	—	1.508			
	20	—	—	0.986			
Dry air at standard atmospheric pressure	0	0.00129	—	0.000017			
	10	0.00125	—	0.000018			
	15	0.00122	—	0.000018			
	20	0.00121	—	0.000018			

*Values are based on *Handbook of Chemistry and Physics*, *International Critical Tables*, and *ASCE Manual for Hydraulic Laboratory Studies*. Many are averages of those obtained from various sources. Other sources of similar data are *Smithsonian Physical Tables* and *Standard Density and Volumetric Tables*, U.S. Bureau of Standards.

Table 1.3 Factors for Converting USCS Units to SI Units

Length:	
Feet (ft) × 0.3048*	= meters (m)
Inches (in.) × 0.0254*	= meters (m)
Miles (mi) × 1609.34	= meters (m)
Miles (mi) × 1.60934	= kilometers (km)
Nautical miles (nm) × 1852.0*	= meters (m)
Yards (yd) × 0.9144*	= meters (m)
Area:	
Feet^2 (ft^2) × 0.0929030	= meters^2 (m^2)
Acres × 4046.86	= meters^2 (m^2)
Miles^2 (mi^2) × 2.58999	= kilometers^2 (km^2)
Volume:	
Feet^3 (ft^3) × 0.02831685	= meters^3 (m^3)
Feet^3 (ft^3) × 28.31685	= liters†
Yards^3 (yd^3) × 0.764555	= meters^3 (m^3)
Acre-feet × 1233.48	= meters^3 (m^3)
Gallons (gal) × 0.00378541	= meters^3 (m^3)
Gallons (gal) × 3.78541	= liters†
Velocity:	
Feet per second (ft/s) × 0.3048*	= meters per second (m/s)
Miles per hour (mi/h) × 0.44704*	= meters per second (m/s)
Miles per hour (mi/h) × 1.60934	= kilometers per hour (km/h)
Knots × 0.514444	= meters per second (m/s)
Knots × 1.852*	= kilometers per hour (km/h)
Discharge:	
Feet^3 per second (ft^3/s) × 0.02831685	= meters^3 per second(m^3/s)
Millions of gallons per day (mgd) × 0.0438126	= meters^3 per second (m^3/s)
Acre-feet per day × 0.0142764	= meters^3 per second (m^3/s)
Gallons per minute (gal/min) × 0.0000630902	= meters^3 per second (m^3/s)
Force:	
Pounds (lb) × 0.453592	= kilograms force (kgf)
Pounds (lb) × 453.592	= grams (g)
Pounds (lb) × 4.44822	= newtons† (N)
Tons × 0.907185	= metric tons† (t)

(*Continued*)

Table 1.3 Factors for Converting USCS Units to SI Units (*Continued*)

Pressure:		
Pounds per foot^2 (lb/ft^2) × 47.8803	=	newtons per meter^2 (N/m^2)
Pounds per foot^2 (lb/ft^2) × 4.88243	=	kilograms force per meter^2 (kgf/m^2)
Pounds per inch^2 (lb/in.^{2}) × 6894.76	=	newtons per meter^2 (N/m^2)
Pounds per inch^2 (lb/in.^{2}) × 703.070	=	kilograms force per meter^2 (kgf/m^2
Millibars (mb) × 100.0*	=	newtons per meter^2 (N/m^2)
Unit weight:		
Pounds per foot^3 (lb/ft^3) × 157.0875	=	newtons per meter^3 (N/m^3)
Pounds per foot^3 (lb/ft^3) × 16.0185	=	kilograms force per meter^3 (kgf/m^3)
Pounds per foot^3 (lb/ft^3) × 0.0160185	=	grams per centimeter^3 (g/cm^3)
Mass and density:		
Slugs × 14.5939	=	kilograms (kg)
Slugs per foot^3 × 515.379	=	kilograms per meter^3 (kg/m^3)
Viscosity:		
Pound-seconds per foot^2 (lb·s/ft^2) or	=	newton-seconds per meter^2
slugs per foot-second × 47.8803	=	(N · s/m^2)†
Feet^2 per second (ft^2/s) × 0.0929031	=	meters^2 per second (m^2/s)

*Exact values.

†Liters × 1000.0 = centimeters^3

Liters × 0.001 = meters^3

Metric tons × 1000.0 = kilograms force

Kilograms force × 9.80665 = newtons

Newtons × 100,000.0 = dynes

Newton-seconds per meter^2 × 0.1 = poises

Specific weight, or *unit weight, w* is defined as the weight per unit of volume of a substance. The mass per unit of volume is called *density* ρ. It follows from the preceding discussion that the specific weight may be converted to density by dividing by the gravitational acceleration,

$$\rho = \frac{W}{g} \tag{1.2}$$

By solving either Eq. (1.1) or Eq. (1.2), it may be seen that g is the weight per unit of mass. In other words, 1 slug or kg of mass weighs 32.2 lb or 9.81 N. The value of g varies slightly with both latitude and altitude. The value 32.2 ft/s^2 or 9.81 m/s^2 is sufficiently accurate for hydraulic computations. The densities and specific weights of water and some other fluids are given in Table 1.2. The specific weights of various materials are given in Table 1.4.

Table 1.4 Average Specific Weights of Various Materials Used in Construction

Substance	lb/ft³	kN/m³
Clay, earth, and mud:		
Clay	122–162	19.2–25.5
Earth, dry and loose	72–80	11.2–12.6
Earth, dry and shaken	82–92	13.0–14.5
Earth, dry and moderately rammed	90–100	14.2–15.7
Earth, slightly moist, loose	70–76	11.0–12.0
Earth, more moist, loose	66–68	10.4–10.6
Earth, more moist, shaken	75–90	12.0–14.2
Earth, more moist, moderately rammed	90–100	14.2–15.7
Earth, as soft flowing mud	104–112	16.4–17.8
Earth, as soft mud well pressed into a box	110–120	17.3–19.0
Mud, dry, close	80–110	12.6–17.3
Mud, wet, moderately pressed	110–130	17.3–20.6
Mud, wet, fluid	104–120	16.4–19.0
Masonry and its materials:		
Brick, best, pressed	150	23.8
Brick, common, hard	125	19.9
Brick, soft, inferior	100	15.7
Brickwork, pressed brick, fine joints	140	22.1
Brickwork, medium quality	125	19.9
Brickwork, coarse, inferior soft bricks	100	15.7
Cement, pulverized, loose	72–105	11.4
Cement, pressed	115	18.3
Cement, set	168–187	26.4–29.4
Concrete, 1:3:6	140	22.1
Gravel, loose	82–125	13.0–19.9
Gravel, rammed	90–145	14.2–23.0
Masonry of granite or stone of like weight:		
Well dressed	165	25.9
Well-scabbled rubble, 20% mortar	154	24.4
Roughly scabbled rubble, 25–35% mortar	150	23.9
Well-scabbled dry rubble	138	21.8
Roughly scabbled dry rubble	125	19.9

(*Continued*)

Table 1.4 Average Specific Weights of Various Materials Used in Construction (*Continued*)

Substance	lb/ft³	kN/m³
Masonry and its materials (cont.):		
Masonry of sandstone or stone of like weight weighs about seven-eighths of the above		
Mortar, hardened	96–115	14.2–18.3
Sand, pure quartz, dry, loose	87–106	13.8–16.8
Sand, pure quartz, dry, slightly shaken	92–110	14.5–17.3
Sand, pure quartz, dry, rammed	100–120	15.7–19.0
Sand, natural, dry, loose	80–110	12.6–17.3
Sand, natural, dry, shaken	85–125	13.7–19.9
Sand, wet, voids full of water	118–128	18.7–20.2
Stone	135–195	21.6–30.6
Stone, quarried, loosely piled	80–110	12.6–17.3
Stone, broken, loose	77–112	12.2–17.8
Stone, broken, rammed	79–121	12.4–19.1
Metal and alloys:		
Brass (copper and zinc)	487–524	77–83
Bronze (copper and tin)	524–537	83–85
Copper, cast	537–548	85–87
Copper, rolled	548–562	87–89
Iron and steel, cast	438–483	70–77
Average	450	71
Iron and steel, wrought	475–494	75–78
Average	480	76
Spelter or zinc	425–450	68–71
Tin, cast	450–470	71–75
Steel	490	77
Tin	459	72
Zinc	438	69
Mercury (32°F, 0°C)	849	133
Woods (dry)*:		
White oak	46.4	7.3
White pine	25.6	4.0
Southern long-leaf pine	38.1	6.0
Douglas fir	32.1	5.1
Short-leaf yellow pine	38.4	6.0

(*Continued*)

Table 1.4 Average Specific Weights of Various Materials Used in Construction (*Continued*)

Substance	lb/ft³	kN/m³
Woods (dry)* (cont.):		
Norway pine	30.2	4.8
Spruce and eastern fir	25.0	4.0
Hemlock	26–32	4.1–5.1
Cypress	29.8	4.7
Cedar	23.1	3.7
Chestnut	41.0	6.5
California redwood	26.2	4.1
California spruce	25.0	4.0

*The weights of green or unseasoned timbers are 20–40% greater.

The *specific gravity* (sp. gr.) of a substance is obtained by dividing the weight of a certain volume of the substance by the weight of an equal volume of water at 39.2°F or 4.2°C. Values of the specific gravity of several fluids are given in Table 1.2.

The *viscosity* μ of a fluid is a measure of the relative ease or difficulty with which a particle of the fluid may be deformed. For example, heavy oil has a greater viscosity than water, and water is more viscous than air. The viscosity of a liquid decreases as the temperature increases, but the opposite is true of a gas. Assume that the space between the two horizontal plates, shown in Fig. 1.1, is filled with a fluid, that the upper plate is in motion with velocity V and that the lower plate is stationary. Those particles of fluid that are in contact with a boundary surface will have the same velocity as the boundary. It follows that the velocity of the fluid will vary from V at the top plate to zero at the bottom one and that the velocity of any layer of fluid will be different from that of the adjacent layers. As a result, all particles of fluid will be continuously deformed by the shear stresses between adjacent layers, as illustrated in Fig. 1.1 by successive positions of a

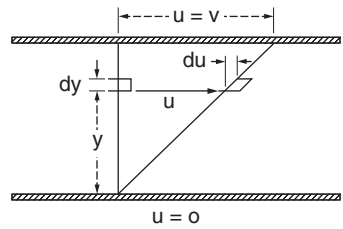


Figure 1.1 Velocity distribution in Newtonian fluids.

particle at a distance y from the lower plate. It has been shown by laboratory tests that for a particular fluid at a given temperature the ratio of the shear stress τ to the rate of deformation du/dy is constant. This constant is called coefficient of viscosity, dynamic viscosity, absolute viscosity, or simply viscosity. The preceding definition is expressed mathematically by the equation

$$\mu = \frac{\tau}{du/dy} \tag{1.3}$$

This relationship is called Newton's law of viscosity, and fluids which behave in this manner are called newtonian fluids. Most fluids dealt with by engineers are newtonian fluids. Some thick, highly viscous fluids are nonnewtonian, meaning that the shear stress is not directly proportional to du/dy for the entire range of shear stresses.

By inserting the units for the terms in the right side of Eq. (1.3), the units of viscosity are found to be pound-seconds per square foot or newton-seconds per square meter. The viscosities of a number of fluids are given in Table 1.2. The *kinematic viscosity* ν is obtained by dividing viscosity by density,

$$\nu = \frac{\mu}{\rho} \tag{1.4}$$

The unit of kinematic viscosity, obtained by inserting the units of μ and ρ into Eq. (1.4), is square feet per second or square meters per second.

The *surface tension* σ is the property of liquids that causes capillary action in small tubes. If the liquid *wets* the surface of the tube, the liquid surface will be concave upward, and the liquid will rise, as shown in Fig. 1.2*a*. If the liquid does not *wet* the tube, the surface will be concave downward, causing the liquid to be depressed, as shown in Fig. 1.2*b*. When pressures are measured by manometers, care must be exercised to avoid errors resulting from capillarity. A number of experimental values of capillary rise or fall for glass tubes of various sizes, as determined by Folsom,[1] are plotted in Fig. 1.3. The straight line shown on the graph indicates the rise that might be expected with very pure water in contact with air. Some values of surface tension of water are given in Table 1.2.

The *modulus of elasticity* E of liquids is defined as the change in pressure intensity divided by the corresponding change in volume per unit volume,

$$E = \frac{\Delta p}{\Delta \forall / \forall} \tag{1.5}$$

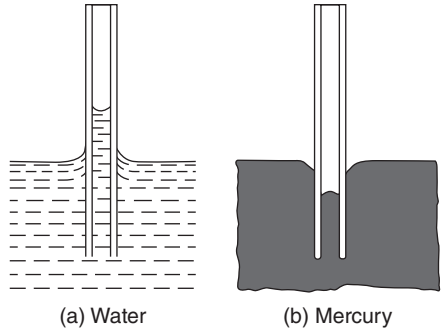


Figure 1.2 Capillary tubes.

The value of E for water is approximately 300,000 lb/in^2 or 2×10^9 N/m^2, varying slightly with temperature. This value is sufficiently high to permit the assumption in the solution of most hydraulic problems that liquids are incompressible.

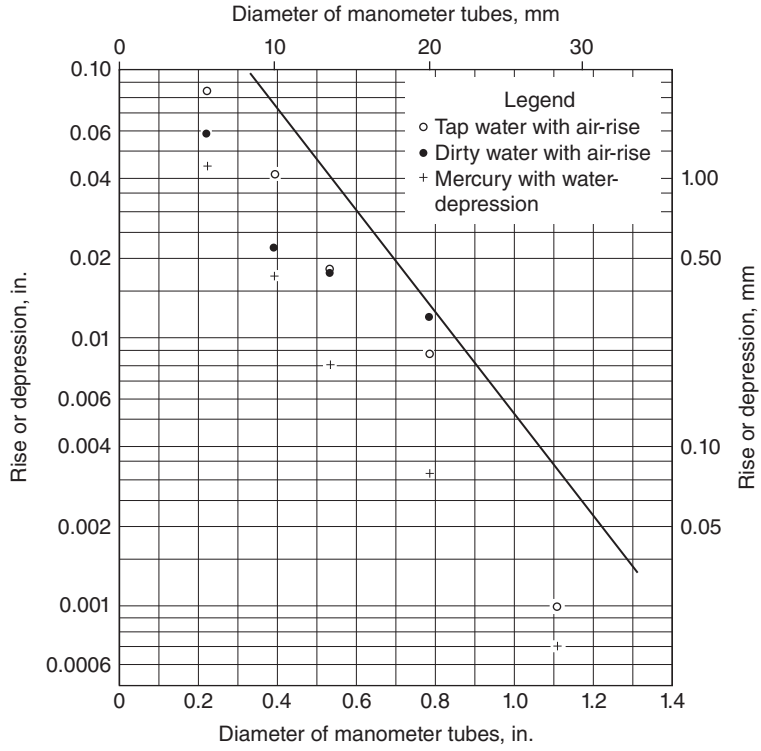


Figure 1.3 Capillary rise and fall in glass tubes.

Table 1.5 SI Prefixes

Prefix	Abbreviation	Meaning
Mega-	M	1,000,000
Kilo-	k	1,000
Hecto-	h	100
Deka-	da	10
Deci-	d	0.1
Centi-	c	0.01
Milli-	m	0.001
Micro-	μ	0.000001

The gaseous form of water is called *water vapor*, and the partial pressure due to the water vapor is called *vapor pressure*. Within a moderate range of temperatures and pressures and for conditions not too close to the point of condensation, water vapor obeys the gas laws reasonably well. For a given temperature, any given space can hold only a certain amount of water vapor in the presence of a solid or liquid surface. The pressure exerted by water vapor under saturation conditions is called *vapor pressure* p_v. Values of the vapor pressure of water for various temperatures are given in Table 1.2.

Hydraulic Units

The purpose of this subsection is to define the units used in hydraulic engineering. Most of the world currently uses the metric system in the form called International System (SI). The SI might also be called meter-newton-second system. The commonly used units of the U.S. customary system are given in Table 1.3 along with the factors for converting to the SI units and the abbreviations for both systems. The most used quantity in hydraulic engineering is the discharge, given in units of cubic meters per second. The prefixes commonly used in SI modify basic units by powers of 10. For example, milli means one thousandth and kilo means one thousand. The most used prefixes are shown in Table 1.5 together with their abbreviations and meanings.

Reference

1. R. G. Folsom, "Manometer Errors Due to Capillarity," *Instruments*, pp. 36–37, Feb. 1936.