PERRY'S CHEMICAL ENGINEERS' HANDBOOK

佩里化学工程师手册

SEVENTH EDITION

(第七版)

Robert H.Perry
Don W.Green

McGraw-Hill

科学出版社

佩里化学工程师手册

（第七版）

PERRY'S CHEMICAL ENGINEERS' HANDBOOK

SEVENTH EDITION

（影印版·上册）

Robert H. Perry
Don W. Green

科学出版社
McGraw-Hill Companies, Inc.

2001

ISBN：7-03-008789-5/TQ·36
图字：01-2000-2403

ISBN：0-07-115982-7

科学出版社 出版
北京东黄城根北街16号
邮政编码：100717
新蕾印刷厂 印刷
科学出版社发行 各地新华书店经销
*
2001年2月第 一 版 开本：850×1168 1/16
2001年2月第一次印刷 印张：165
印数：1—3 000 字数：5 820 000
定价：390.00元 （上、下册）
（如有印装质量问题，我社负责调换〈新欣〉）

ABOUT THE EDITORS

The late **Robert H. Perry** served as chairman of the Department of Chemical Engineering at the University of Oklahoma and program director for graduate research facilities at the National Science Research Foundation. He was a consultant to various United Nations and other international organizations. From 1973 until his death in 1978 Dr. Perry devoted his time to a study of the cross impact of technologies within the next half century. The subjects under his investigation on a global basis were energy, minerals and metals, transportation and communications, medicine, food production, and the environment.

Don W. Green is Chair and the Deane E. Ackers distinguished professor of chemical and petroleum engineering and codirector of the Tertiary Oil Recovery Project at the University of Kansas in Lawrence, Kansas, where he has taught since 1964. He received his doctorate in chemical engineering in 1963 from the University of Oklahoma, where he was Dr. Perry's first doctoral student. Dr. Green has won several teaching awards at the University of Kansas, and he is a fellow of the AIChE and a distinguished member of the Society of Petroleum Engineers. He is the author of numerous articles in technical journals.

James O. Maloney is Professor Emeritus of the Department of Chemical and Petroleum Engineering, University of Kansas. He holds a Ph.D. degree in chemical engineering from Pennsylvania State University. In 1941 he began his professional career at the DuPont de Nemours Company, before joining the University of Kansas in 1945, where he taught for 40 years. He served as department chairman for nineteen years. He is a fellow of the AIChE.

Dedicated to
Robert H. Perry

Contents

For the detailed contents of any section, consult the title page of that section. See also the alphabetical index in the back of the handbook.

Section 1

Conversion Factors and Mathematical Symbols*

James O. Maloney, Ph.D., P.E., *Emeritus Professor of Chemical Engineering, University of Kansas; Fellow, American Institute of Chemical Engineering; Fellow, American Association for the Advancement of Science; Member, American Chemical Society, American Society for Engineering Education*

* Much of the material was taken from Sec. 1. of the fifth edition. The contribution of Cecil H. Chilton in developing that material is acknowledged.

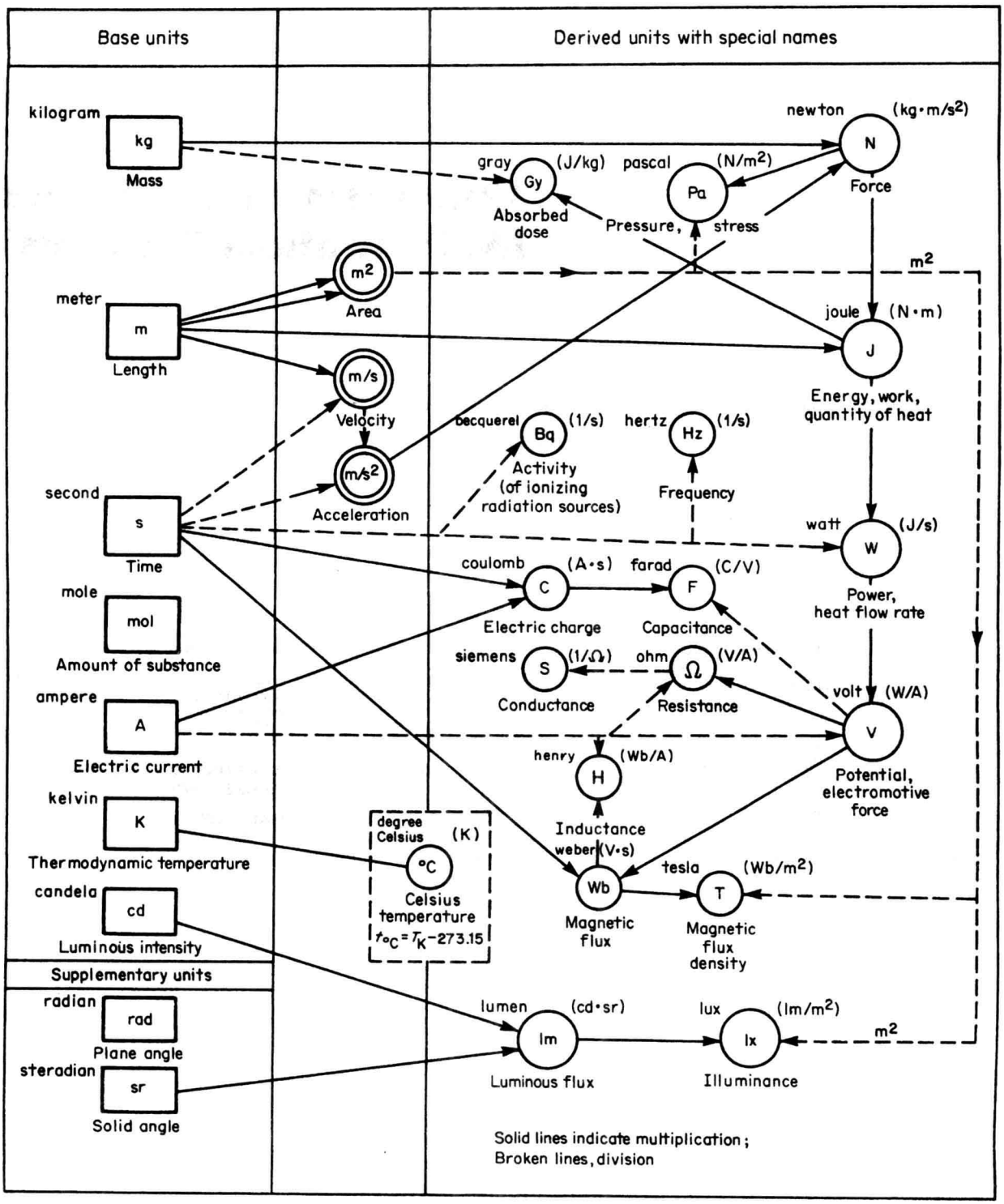

FIG. 1-1 Graphic relationships of SI units with names (*U.S. National Bureau of Standards, LC 1078, December 1976.*)

TABLE 1-1 SI Base and Supplementary Quantities and Units

Quantity or "dimension"	SI unit	SI unit symbol ("abbreviation"); Use roman (upright) type
Base quantity or "dimension"		
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole*	mol
luminous intensity	candela	cd
Supplementary quantity or "dimension"		
plane angle	radian	rad
solid angle	steradian	sr

*When the mole is used, the elementary entities must be specified; they may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

TABLE 1-2a Derived Units of SI that Have Special Names

Quantity	Unit	Symbol	Formula
frequency (of a periodic phenomenon)	hertz	Hz	1/s
force	newton	N	$(kg \cdot m)/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	$N \cdot m$
power, radiant flux	watt	W	J/s
quantity of electricity, electric charge	coulomb	C	$A \cdot s$
electric potential, potential difference, electromotive force	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
conductance	siemens	S	A/V
magnetic flux	weber	Wb	$V \cdot s$
magnetic-flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
luminous flux	lumen	lm	$cd \cdot sr$
illuminance	lux	lx	lm/m^2
activity (of radionuclides)	becquerel	Bq	1/s
absorbed dose	gray	Gy	J/kg

TABLE 1-2b Additional Common Derived Units of SI

Quantity	Unit	Symbol
acceleration	meter per second squared	m/s^2
angular acceleration	radian per second squared	rad/s^2
angular velocity	radian per second	rad/s
area	square meter	m^2
concentration (of amount of substance)	mole per cubic meter	mol/m^3
current density	ampere per square meter	A/m^2
density, mass	kilogram per cubic meter	kg/m^3
electric-charge density	coulomb per cubic meter	C/m^3
electric-field strength	volt per meter	V/m
electric-flux density	coulomb per square meter	C/m^2
energy density	joule per cubic meter	J/m^3
entropy	joule per kelvin	J/K
heat capacity	joule per kelvin	J/K
heat-flux density, irradiance	watt per square meter	W/m^2
luminance	candela per square meter	cd/m^2
magnetic-field strength	ampere per meter	A/m
molar energy	joule per mole	J/mol
molar entropy	joule per mole-kelvin	$J/(mol \cdot K)$
molar-heat capacity	joule per mole-kelvin	$J/(mol \cdot K)$
moment of force	newton-meter	$N \cdot m$
permeability	henry per meter	H/m
permittivity	farad per meter	F/m
radiance	watt per square-meter-steradian	$W/(m^2 \cdot sr)$
radiant intensity	watt per steradian	W/sr
specific-heat capacity	joule per kilogram-kelvin	$J/(kg \cdot K)$
specific energy	joule per kilogram	J/kg
specific entropy	joule per kilogram-kelvin	$J/(kg \cdot K)$
specific volume	cubic meter per kilogram	m^3/kg
surface tension	newton per meter	N/m
thermal conductivity	watt per meter-kelvin	$W/(m \cdot K)$
velocity	meter per second	m/s
viscosity, dynamic	pascal-second	$Pa \cdot s$
viscosity, kinematic	square meter per second	m^2/s
volume	cubic meter	m^3
wave number	1 per meter	1/m

TABLE 1-3 SI Prefixes

Multiplication factor	Prefix	Symbol
$1\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{18}$	exa	E
$1\ 000\ 000\ 000\ 000\ 000 = 10^{15}$	peta	P
$1\ 000\ 000\ 000\ 000 = 10^{12}$	tera	T
$1\ 000\ 000\ 000 = 10^{9}$	giga	G
$1\ 000\ 000 = 10^{6}$	mega	M
$1\ 000 = 10^{3}$	kilo	k
$100 = 10^{2}$	hecto*	h
$10 = 10^{1}$	deka*	da
$0.1 = 10^{-1}$	deci*	d
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000\ 001 = 10^{-6}$	micro	μ
$0.000\ 000\ 001 = 10^{-9}$	nano	n
$0.000\ 000\ 000\ 001 = 10^{-12}$	pico	p
$0.000\ 000\ 000\ 000\ 001 = 10^{-15}$	femto	f
$0.000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$	atto	a

* Generally to be avoided.

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
		Space,† time		
Length	naut mi	km		1.852* E + 00
	mi	km		1.609 344* E + 00
	chain	m		2.011 68* E + 01
	link	m		2.011 68* E − 01
	fathom	m		1.828 8* E + 00
	yd	m		9.144* E − 01
	ft	m		3.048* E − 01
		cm		3.048* E + 01
	in	mm		2.54* E + 01
	in	cm		2.54 E + 00
	mil	μm		2.54* E + 01
Length/length	ft/mi	m/km		1.893 939 E − 01
Length/volume	ft/U.S. gal	m/m^3		8.051 964 E + 01
	ft/ft^3	m/m^3		1.076 391 E + 01
	ft/bbl	m/m^3		1.917 134 E + 00
Area	mi^2	km^2		2.589 988 E + 00
	section	ha		2.589 988 E + 02
	acre	ha		4.046 856 E − 01
	ha	m^2		1.000 000* E + 04
	yd^2	m^2		8.361 274 E − 01
	ft^2	m^2		9.290 304* E − 02
	in^2	mm^2		6.451 6* E + 02
		cm^2		6.451 6* E + 00
Area/volume	ft^2/in^3	m^2/cm^3		5.699 291 E − 03
	ft^2/ft^3	m^2/m^3		3.280 840 E + 00
Volume	cubem	km^3		4.168 182 E + 00
	acre·ft	m^3		1.233 482 E + 03
		ha·m		1.233 482 E − 01
	yd^3	m^3		7.645 549 E − 01
	bbl (42 U.S. gal)	m^3		1.589 873 E − 01
	ft^3	m^3		2.831 685 E − 02
		dm^3	L	2.831 685 E + 01
	U.K. gal	m^3		4.546 092 E − 03
		dm^3	L	4.546 092 E + 00
	U.S. gal	m^3		3.785 412 E − 03
		dm^3	L	3.785 412 E + 00
	U.K. qt	dm^3	L	1.136 523 E + 00
	U.S. qt	dm^3	L	9.463 529 E − 01
	U.S. pt	dm^3	L	4.731 765 E − 01
	U.K. fl oz	cm^3		2.841 307 E + 01
	U.S. fl oz	cm^3		2.957 353 E + 01
	in^3	cm^3		1.638 706 E + 01
Volume/length (linear displacement)	bbl/in	m^3/m		6.259 342 E + 00
	bbl/ft	m^3/m		5.216 119 E − 01
	ft^3/ft	m^3/m		9.290 304* E − 02
	U.S. gal/ft	m^3/m		1.241 933 E − 02
		L/m		1.241 933 E + 01
Plane angle	rad	rad		1
	deg (°)	rad		1.745 329 E − 02
	min (′)	rad		2.908 882 E − 04
	sec (″)	rad		4.848 137 E − 06
Solid angle	sr	sr		1
Time	year	a		1
	week	d		7.0* E + 00
	h	s		3.6* E + 03
		min		6.0* E + 01
	min	s		6.0* E + 01
		h		1.666 667 E − 02
	mμs	ns		1
		Mass, amount of substance		
Mass	U.K. ton	Mg	t	1.016 047 E + 00
	U.S. ton	Mg	t	9.071 847 E − 01
	U.K. cwt	kg		5.080 234 E + 01
	U.S. cwt	kg		4.535 924 E + 01
	lbm	kg		4.535 924 E − 01
	oz (troy)	g		3.110 348 E + 01
	oz (av)	g		2.834 952 E + 01
	gr	mg		6.479 891 E + 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Amount of substance	lbm·mol	kmol		4.535 924 E − 01
	std m^3(0°C, 1 atm)	kmol		4.461 58 E − 02
	std ft^3 (60°F, 1 atm)	kmol		1.195 30 E − 03
	Enthalpy, calorific value, heat, entropy, heat capacity			
Calorific value, enthalpy (mass basis)	Btu/lbm	MJ/kg		2.326 000 E − 03
		kJ/kg	J/g	2.326 000 E + 00
		kWh/kg		6.461 112 E − 04
	cal/g	kJ/kg	J/g	4.184* E + 00
	cal/lbm	J/kg		9.224 141 E + 00
Caloric value, enthalpy (mole basis)	kcal/(g·mol)	kJ/kmol		4.184* E + 03
	Btu/(lb·mol)	kJ/kmol		2.326 000 E + 00
Calorific value (volume basis—solids and liquids)	Btu/U.S. gal	MJ/m^3	kJ/dm^3	2.787 163 E − 01
		kJ/m^3		2.787 163 E + 02
		kWh/m^3		7.742 119 E − 02
	Btu/U.K. gal	MJ/m^3	kJ/dm^3	2.320 800 E − 01
		kJ/m^3		2.320 800 E + 02
	Btu/ft^3	kWh/m^3		6.446 667 E − 02
		MJ/m^3	kJ/dm^3	3.725 895 E − 02
		kJ/m^3		3.725 895 E + 01
		kWh/m^3		1.034 971 E − 02
	cal/mL	MJ/m^3		4.184* E + 00
	(ft·lbf)/U.S. gal	kJ/m^3		3.581 692 E − 01
Calorific value (volume basis—gases)	cal/mL	kJ/m^3	J/dm^3	4.184* E + 03
	$kcal/m^3$	kJ/m^3	J/dm^3	4.184* E + 00
	Btu/ft^3	kJ/m^3	J/dm^3	3.725 895 E + 01
		kWh/m^3		1.034 971 E − 02
Specific entropy	Btu/(lbm·°R)	kJ/(kg·K)	J/(g·K)	4.186 8* E + 00
	cal/(g·K)	kJ/(kg·K)	J/(g·K)	4.184* E + 00
	kcal/(kg·°C)	kJ/(kg·K)	J/(g·K)	4.184* E + 00
Specific-heat capacity (mass basis)	kWh/(kg·°C)	kJ/(kg·K)	J/(g·K)	3.6* E + 03
	Btu/(lbm·°F)	kJ/(kg·K)	J/(g·K)	4.186 8* E + 00
	kcal/(kg·°C)	kJ/(kg·K)	J/(g·K)	4.184* E + 00
Specific-heat capacity (mole basis)	Btu/(lb·mol·°F)	kJ/(kmol·K)		4.186 8* E + 00
	cal/(g·mol·°C)	kJ/(kmol·K)		4.184* E + 00
	Temperature, pressure, vacuum			
Temperature (absolute)	°R	K		5/9
	K	K		1
Temperature (traditional)	°F	°C		5/9(°F − 32)
Temperature (difference)	°F	K, °C		5/9
Pressure	atm (760 mmHg at 0°C or 14,696 psi)	MPa		1.013 250* E − 01
		kPa		1.013 250* E + 02
		bar		1.013 250* E + 00
	bar	MPa		1.0* E − 01
		kPa		1.0* E + 02
	mmHg (0°C) = torr	MPa		6.894 757 E − 03
		kPa		6.894 757 E + 00
		bar		6.894 757 E − 02
	μmHg (0°C)	kPa		3.376 85 E + 00
	μ bar	kPa		2.488 4 E − 01
	mmHg = torr (0°C)	kPa		1.333 224 E − 01
	cmH_2O (4°C)	kPa		9.806 38 E − 02
	lbf/ft^2 (psf)	kPa		4.788 026 E − 02
	mHg (0°C)	Pa		1.333 224 E − 01
	bar	Pa		1.0* E + 05
	dyn/cm^2	Pa		1.0* E − 01
Vacuum, draft	inHg (60°F)	kPa		3.376 85 E + 00
	inH_2O (39.2°F)	kPa		2.490 82 E − 01
	inH_2O (60°F)	kPa		2.488 4 E − 01
	mmHg (0°C) = torr	kPa		1.333 224 E − 01
	cmH_2O (4°C)	kPa		9.806 38 E − 02
Liquid head	ft	m		3.048* E − 01
	in	mm		2.54* E + 01
		cm		2.54* E + 00
Pressure drop/length	psi/ft	kPa/m		2.262 059 E + 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
		Density, specific volume, concentration, dosage		
Density	lbm/ft^3	kg/m^3		1.601 846 E + 01
		g/m^3		1.601 846 E + 04
	lbm/U.S. gal	kg/m^3		1.198 264 E + 02
		g/cm^3		1.198 264 E − 01
	lbm/U.K. gal	kg/m^3		9.977 633 E + 01
	lbm/ft^3	kg/m^3		1.601 846 E + 01
		g/cm^3		1.601 846 E − 02
	g/cm^3	kg/m^3		1.0* E + 03
	lbm/ft^3	kg/m^3		1.601 846 E + 01
Specific volume	ft^3/lbm	m^3/kg		6.242 796 E − 02
		m^3/g		6.242 796 E − 05
	ft^3/lbm	dm^3/kg		6.242 796 E + 01
	U.K. gal/lbm	dm^3/kg	cm^3/g	1.002 242 E + 01
	U.S. gal/lbm	dm^3/kg	cm^3/g	8.345 404 E + 00
Specific volume (mole basis)	L/(g·mol)	m^3/kmol		1
	ft^3/(lb·mol)	m^3/kmol		6.242 796 E − 02
Specific volume	bbl/U.S. ton	m^3/t		1.752 535 E − 01
	bbl/U.K. ton	m^3/t		1.564 763 E − 01
Yield	bbl/U.S. ton	dm^3/t	L/t	1.752 535 E + 02
	bbl/U.K. ton	dm^3/t	L/t	1.564 763 E + 02
	U.S. gal/U.S. ton	dm^3/t	L/t	4.172 702 E + 00
	U.S. gal/U.K. ton	dm^3/t	L/t	3.725 627 E + 00
Concentration (mass/mass)	wt %	kg/kg		1.0* E − 02
		g/kg		1.0* E + 01
	wt ppm	mg/kg		1
Concentration (mass/volume)	lbm/bbl	kg/m^3	g/dm^3	2.853 010 E + 00
	g/U.S. gal	kg/m^3		2.641 720 E − 01
	g/U.K. gal	kg/m^3	g/L	2.199 692 E − 01
	lbm/1000 U.S. gal	g/m^3	mg/dm^3	1.198 264 E + 02
	lbm/1000 U.K. gal	g/m^3	mg/dm^3	9.977 633 E + 01
	gr/U.S. gal	g/m^3	mg/dm^3	1.711 806 E + 01
	gr/ft^3	mg/m^3		2.288 351 E + 03
	lbm/1000 bbl	g/m^3	mg/dm^3	2.853 010 E + 00
	mg/U.S. gal	g/m^3	mg/dm^3	2.641 720 E − 01
	gr/100 ft^3	mg/m^3		2.288 351 E + 01
Concentration (volume/volume)	ft^3/ft^3	m^3/m^3		1
	bbl/(acre·ft)	m^3/m^3		1.288 931 E − 04
	vol%	m^3/m^3		1.0* E − 02
	U.K. gal/ft^3	dm^3/m^3	L/m^3	1.605 437 E + 02
	U.S. gal/ft^3	dm^3/m^3	L/m^3	1.336 806 E + 02
	mL/U.S. gal	dm^3/m^3	L/m^3	2.641 720 E − 01
	mL/U.K. gal	dm^3/m^3	L/m^3	2.199 692 E − 01
	vol ppm	cm^3/m^3		1
		dm^3/m^3	L/m^3	1.0* E − 03
	U.K. gal/1000 bbl	cm^3/m^3		2.859 403 E + 01
	U.S. gal/1000 bbl	cm^3/m^3		2.380 952 E + 01
	U.K. pt/1000 bbl	cm^3/m^3		3.574 253 E + 00
Concentration (mole/volume)	(lb·mol)/U.S. gal	kmol/m^3		1.198 264 E + 02
	(lb·mol)/U.K. gal	kmol/m^3		9.977 644 E + 01
	(lb·mol)/ft^3	kmol/m^3		1.601 846 E + 01
	std ft^3 (60°F, 1 atm)/bbl	kmol/m^3		7.518 21 E − 03
Concentration (volume/mole)	U.S. gal/1000 std ft^3 (60°F/60°F)	dm^3/kmol	L/kmol	3.166 91 E + 00
	bbl/million std ft^3 (60°F/60°F)	dm^3/kmol	L/kmol	1.330 10 E − 01
		Facility throughput, capacity		
Throughput (mass basis)	U.K. ton/year	t/a		1.016 047 E + 00
	U.S. ton/year	t/a		9.071 847 E − 01
	U.K. ton/day	t/d		1.016 047 E + 00
		t/h		4.233 529 E − 02
	U.S. ton/day	t/d		9.071 847 E − 01
		t/h		3.779 936 E − 02
	U.K. ton/h	t/h		1.016 047 E + 00
	U.S. ton/h	t/h		9.071 847 E − 01
	lbm/h	kg/h		4.535 924 E − 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Throughput (volume basis)	bbl/day	t/a		5.803 036 E + 01
		m^3/d		1.589 873 E − 01
	ft^3/day	m^3/h		1.179 869 E − 03
	bbl/h	m^3/h		1.589 873 E − 01
	ft^3/h	m^3/h		2.831 685 E − 02
	U.K. gal/h	m^3/h		4.546 092 E − 03
		L/s		1.262 803 E − 03
	U.S. gal/h	m^3/h		3.785 412 E − 03
		L/s		1.051 503 E − 03
	U.K. gal/min	m^3/h		2.727 655 E − 01
		L/s		7.576 819 E − 02
	U.S. gal/min	m^3/h		2.271 247 E − 01
		L/s		6.309 020 E − 02
Throughput (mole basis)	(lbm·mol)/h	kmol/h		4.535 924 E − 01
		kmol/s		1.259 979 E − 04
	Flow rate			
Flow rate (mass basis)	U.K. ton/min	kg/s		1.693 412 E + 01
	U.S. ton/min	kg/s		1.511 974 E + 01
	U.K. ton/h	kg/s		2.822 353 E − 01
	U.S. ton/h	kg/s		2.519 958 E − 01
	U.K. ton/day	kg/s		1.175 980 E − 02
	U.S. ton/day	kg/s		1.049 982 E − 02
	million lbm/year	kg/s		5.249 912 E + 00
	U.K. ton/year	kg/s		3.221 864 E − 05
	U.S. ton/year	kg/s		2.876 664 E − 05
	lbm/s	kg/s		4.535 924 E − 01
	lbm/min	kg/s		7.559 873 E − 03
	lbm/h	kg/s		1.259 979 E − 04
Flow rate (volume basis)	bbl/day	m^3/d		1.589 873 E − 01
		L/s		1.840 131 E − 03
	ft^3/day	m^3/d		2.831 685 E − 02
		L/s		3.277 413 E − 04
	bbl/h	m^3/s		4.416 314 E − 05
		L/s		4.416 314 E − 02
	ft^3/h	m^3/s		7.865 791 E − 06
		L/s		7.865 791 E − 03
	U.K. gal/h	dm^3/s	L/s	1.262 803 E − 03
	U.S. gal/h	dm^3/s	L/s	1.051 503 E − 03
	U.K. gal/min	dm^3/s	L/s	7.576 820 E − 02
	U.S. gal/min	dm^3/s	L/s	6.309 020 E − 02
	ft^3/min	dm^3/s	L/s	4.719 474 E − 01
	ft^3/s	dm^3/s	L/s	2.831 685 E + 01
Flow rate (mole basis)	(lb·mol)/s	kmol/s		4.535 924 E − 01
	(lb·mol)/h	kmol/s		1.259 979 E − 04
	million scf/D	kmol/s		1.383 45 E − 02
Flow rate/length (mass basis)	lbm/(s·ft)	kg/(s·m)		1.488 164 E + 00
	lbm/(h·ft)	kg/(s·m)		4.133 789 E − 04
Flow rate/length (volume basis)	U.K. gal/(min·ft)	m^2/s	$m^3/(s·m)$	2.485 833 E − 04
	U.S. gal/(min·ft)	m^2/s	$m^3/(s·m)$	2.069 888 E − 04
	U.K. gal/(h·in)	m^2/s	$m^3/(s·m)$	4.971 667 E − 05
	U.S. gal/(h·in)	m^2/s	$m^3/(s·m)$	4.139 776 E − 05
	U.K. gal/(h·ft)	m^2/s	$m^3/(s·m)$	4.143 055 E − 06
	U.S. gal/(h·ft)	m^2/s	$m^3/(s·m)$	3.449 814 E − 06
Flow rate/area (mass basis)	lbm/(s·ft^2)	kg/(s·m^2)		4.882 428 E + 00
	lbm/(h·ft^2)	kg/(s·m^2)		1.356 230 E − 03
Flow rate/area (volume basis)	ft^3/(s·ft^2)	m/s	$m^3/(s·m^2)$	3.048* E − 01
	ft^3/(min·ft^2)	m/s	$m^3/(s·m^2)$	5.08* E − 03
	U.K. gal/(h·in^2)	m/s	$m^3/(s·m^2)$	1.957 349 E − 03
	U.S. gal/(h·in^2)	m/s	$m^3/(s·m^2)$	1.629 833 E − 03
	U.K. gal/(min·ft^2)	m/s	$m^3/(s·m^2)$	8.155 621 E − 04
	U.S. gal/(min·ft^2)	m/s	$m^3/(s·m^2)$	6.790 972 E − 04
	U.K. gal/(h·ft^2)	m/s	$m^3/(s·m^2)$	1.359 270 E − 05
	U.S. gal/(h·ft^2)	m/s	$m^3/(s·m^2)$	1.131 829 E − 05

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
		Energy, work, power		
Energy, work	therm	MJ		1.055 056 E + 02
		kJ		1.055 056 E + 05
		kWh		2.930 711 E + 01
	U.S. tonf·mi	MJ		1.431 744 E + 01
	hp·h	MJ		2.684 520 E + 00
		kJ		2.684 520 E + 03
		kWh		7.456 999 E − 01
	ch·h or CV·h	MJ		2.647 780 E + 00
		kJ		2.647 780 E + 03
		kWh		7.354 999 E − 01
	kWh	MJ		3.6* E + 00
		kJ		3.6* E + 03
	Chu	kJ		1.899 101 E + 00
		kWh		5.275 280 E − 04
	Btu	kJ		1.055 056 E + 00
		kWh		2.930 711 E − 04
	kcal	kJ		4.184* E + 00
	cal	kJ		4.184* E − 03
	ft·lbf	kJ		1.355 818 E − 03
	lbf·ft	kJ		1.355 818 E − 03
	J	kJ		1.0* E − 03
	$(lbf·ft^2)/s^2$	kJ		4.214 011 E − 05
	erg	J		1.0* E − 07
Impact energy	kgf·m	J		9.806 650* E + 00
	lbf·ft	J		1.355 818 E + 00
Surface energy	erg/cm^2	mJ/m^2		1.0* E + 00
Specific-impact energy	$(kgf·m)/cm^2$	J/cm^2		9.806 650* E − 02
	$(lbf·ft)/in^2$	J/cm^2		2.101 522 E − 03
Power	million Btu/h	MW		2.930 711 E − 01
	ton of refrigeration	kW		3.516 853 E + 00
	Btu/s	kW		1.055 056 E + 00
	kW	kW		1
	hydraulic horsepower—hhp	kW		7.460 43 E − 01
	hp (electric)	kW		7.46* E − 01
	hp [(550 ft·lbf)/s]	kW		7.456 999 E − 01
	ch or CV	kW		7.354 999 E − 01
	Btu/min	kW		1.758 427 E − 02
	(ft·lbf)/s	kW		1.355 818 E − 03
	kcal/h	W		1.162 222 E + 00
	Btu/h	W		2.930 711 E − 01
	(ft·lbf)/min	W		2.259 697 E − 02
Power/area	$Btu/(s·ft^2)$	kW/m^2		1.135 653 E + 01
	$cal/(h·cm^2)$	kW/m^2		1.162 222 E − 02
	$Btu/(h·ft^2)$	kW/m^2		3.154 591 E − 03
Heat-release rate, mixing power	hp/ft^3	kW/m^3		2.633 414 E + 01
	$cal/(h·cm^3)$	kW/m^3		1.162 222 E + 00
	$Btu/(s·ft^3)$	kW/m^3		3.725 895 E + 01
	$Btu/(h·ft^3)$	kW/m^3		1.034 971 E − 02
Cooling duty (machinery)	Btu/(bhp·h)	W/kW		3.930 148 E − 01
Specific fuel consumption (mass basis)	lbm/(hp·h)	mg/J	kg/MJ	1.689 659 E − 01
		kg/kWh		6.082 774 E − 01
Specific fuel consumption (volume basis)	m^3/kWh	dm^3/MJ	mm^3/J	2.777 778 E + 02
	U.S. gal/(hp·h)	dm^3/MJ	mm^3/J	1.410 089 E + 00
	U.K. pt/(hp·h)	dm^3/MJ	mm^3/J	2.116 806 E − 01
Fuel consumption	U.K. gal/mi	$dm^3/100$ km	L/100 km	2.824 807 E + 02
	U.S. gal/mi	$dm^3/100$ km	L/100 km	2.352 146 E + 02
	mi/U.S. gal	km/dm^3	km/L	4.251 437 E − 01
	mi/U.K. gal	km/dm^3	km/L	3.540 064 E − 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Velocity (linear), speed	knot	km/h		1.852* E + 00
	mi/h	km/h		1.609 344* E + 00
	ft/s	m/s		3.048* E − 01
		cm/s		3.048* E + 01
	ft/min	m/s		5.08* E − 03
	ft/h	mm/s		8.466 667 E − 02
	ft/day	mm/s		3.527 778 E − 03
		m/d		3.048* E − 01
	in/s	mm/s		2.54* E + 01
	in/min	mm/s		4.233 333 E − 01
Corrosion rate	in/year (ipy)	mm/a		2.54* E + 01
	mil/year	mm/a		2.54* E − 02
Rotational frequency	r/min	r/s		1.666 667 E − 02
		rad/s		1.047 198 E − 01
Acceleration (linear)	ft/s^2	m/s^2		3.048* E − 01
		cm/s^2		3.048* E + 01
Acceleration (rotational)	rpm/s	rad/s^2		1.047 198 E − 01
Momentum	(lbm·ft)/s	(kg·m)/s		1.382 550 E − 01
Force	U.K. tonf	kN		9.964 016 E + 00
	U.S. tonf	kN		8.896 443 E + 00
	kgf (kp)	N		9.806 650* E + 00
	lbf	N		4.448 222 E + 00
	dyn	mN		1.0 E − 02
Bending moment, torque	U.S. tonf·ft	kN·m		2.711 636 E + 00
	kgf·m	N·m		9.806 650* E + 00
	lbf·ft	N·m		1.355 818 E + 00
	lbf·in	N·m		1.129 848 E − 01
Bending moment/length	(lbf·ft)/in	(N·m)/m		5.337 866 E + 01
	(lbf·in)/in	(N·m)/m		4.448 222 E + 00
Moment of inertia	$lbm·ft^2$	$kg·m^2$		4.214 011 E − 02
Stress	U.S. $tonf/in^2$	MPa	N/mm^2	1.378 951 E + 01
	kgf/mm^2	MPa	N/mm^2	9.806 650* E + 00
	U.S. $tonf/ft^2$	MPa	N/mm^2	9.576 052 E − 02
	lbf/in^2 (psi)	MPa	N/mm^2	6.894 757 E − 03
	lbf/ft^2 (psf)	kPa		4.788 026 E − 02
	dyn/cm^2	Pa		1.0* E − 01
Mass/length	lbm/ft	kg/m		1.488 164 E + 00
Mass/area structural loading, bearing capacity (mass basis)	U.S. ton/ft^2	Mg/m^2		9.764 855 E + 00
	lbm/ft^2	kg/m^2		4.882 428 E + 00
	Miscellaneous transport properties			
Diffusivity	ft^2/s	m^2/s		9.290 304* E − 02
	m^2/s	mm^2/s		1.0* E + 06
	ft^2/h	m^2/s		2.580 64* E − 05
Thermal resistance	$(°C·m^2·h)/kcal$	$(K·m^2)/kW$		8.604 208 E + 02
	$(°F·ft^2·h)/Btu$	$(K·m^2)/kW$		1.761 102 E + 02
Heat flux	$Btu/(h·ft^2)$	kW/m^2		3.154 591 E − 03
Thermal conductivity	$(cal·cm)/(s·cm^2·°C)$	W/(m·K)		4.184* E + 02
	$(Btu·ft)/(h·ft^2·°F)$	W/(m·K)		1.730 735 E + 00
		$(kJ·m)/(h·m^2·K)$		6.230 646 E + 00
	$(kcal·m)/(h·m^2·°C)$	W/(m·K)		1.162 222 E + 00
	$(Btu·in)/(h·ft^2·°F)$	W/(m·K)		1.442 279 E − 01
	$(cal·cm)/(h·cm^2·°C)$	W/(m·K)		1.162 222 E − 01
Heat-transfer coefficient	$cal/(s·cm^2·°C)$	$kW/(m^2·K)$		4.184* E + 01
	$Btu/(s·ft^2·°F)$	$kW/(m^2·K)$		2.044 175 E + 01
	$cal/(h·cm^2·°C)$	$kW/(m^2·K)$		1.162 222 E − 02
	$Btu/(h·ft^2·°F)$	$kW/(m^2·K)$		5.678 263 E − 03
		$kJ/(h·m^2·K)$		2.044 175 E + 01
	$Btu/(h·ft^2·°R)$	$kW/(m^2·K)$		5.678 263 E − 03
	$kcal/(h·m^2·°C)$	$kW/(m^2·K)$		1.162 222 E − 03

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units *(Continued)*

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Volumetric heat-transfer coefficient	Btu/(s·ft³·°F)	kW/(m³·K)		6.706 611 E + 01
	Btu/(h·ft³·°F)	kW/(m³·K)		1.862 947 E − 02
Surface tension	dyn/cm	mN/m		1
Viscosity (dynamic)	(lbf·s)/in²	Pa·s	(N·s)/m²	6.894 757 E + 03
	(lbf·s)/ft²	Pa·s	(N·s)/m²	4.788 026 E + 01
	(kgf·s)/m²	Pa·s	(N·s)/m²	9.806 650* E + 00
	lbm/(ft·s)	Pa·s	(N·s)/m²	1.488 164 E + 00
	(dyn·s)/cm²	Pa·s	(N·s)/m²	1.0* E − 01
	cP	Pa·s	(N·s)/m²	1.0* E − 03
	lbm/(ft·h)	Pa·s	(N·s)/m²	4.133 789 E − 04
Viscosity (kinematic)	ft²/s	m²/s		9.290 304* E − 02
	in²/s	mm²/s		6.451 6* E + 02
	m²/h	mm²/s		2.777 778 E + 02
	ft²/h	m²/s		2.580 64* E − 05
	cSt	mm²/s		1
Permeability	darcy	μm²		9.869 233 E − 01
	millidarcy	μm²		9.869 233 E − 04
Thermal flux	Btu/(h·ft²)	W/m²		3.152 E + 00
	Btu/(s·ft²)	W/m²		1.135 E + 04
	cal/(s·cm²)	W/m²		4.184 E + 04
Mass-transfer coefficient	(lb·mol)/[h·ft²(lb·mol/ft³)]	m/s		8.467 E − 05
	(g·mol)/[s·m²(g·mol/L)]	m/s		1.0 E + 01
	Electricity, magnetism			
Admittance	S	S		1
Capacitance	μF	μF		1
Charge density	C/mm³	C/mm³		1
Conductance	S	S		1
	Ʊ (mho)	S		1
Conductivity	S/m	S/m		1
	Ʊ/m	S/m		1
	mƱ/m	mS/m		1
Current density	A/mm²	A/mm²		1
Displacement	C/cm²	C/cm²		1
Electric charge	C	C		1
Electric current	A	A		1
Electric-dipole moment	C·m	C·m		1
Electric-field strength	V/m	V/m		1
Electric flux	C	C		1
Electric polarization	C/cm²	C/cm²		1
Electric potential	V	V		1
	mV	mV		1
Electromagnetic moment	A·m²	A·m²		1
Electromotive force	V	V		1
Flux of displacement	C	C		1
Frequency	cycles/s	Hz		1
Impedance	Ω	Ω		1
Linear-current density	A/mm	A/mm		1
Magnetic-dipole moment	Wb·m	Wb·m		1
Magnetic-field strength	A/mm	A/mm		1
	Oe	A/m		7.957 747 E + 01
	gamma	A/m		7.957 747 E − 04
Magnetic flux	mWb	mWb		1