Appendix

Unit Conversion (from HEDH)

Physical quantity	Given in → / Gives ←	Multiplied by → / Divided by ←	Gives / Gives in	Approximate or useful relationship
Mass	lb_m	0.45359	kg	1 $lb_m \simeq .45$ kg
	kg	2.2046	lb_m	1 kg $\simeq 2.2$ lb_m
	metric ton	2204.6	lb_m	metric ton = 10^3 kg
	ton (2000 lb_m)	907.18	kg	
Force	lb_f	4.44822	N = kg m/sec^2	
	lb_f	0.45359	kgf	1 N ≈ 0.1 kg_f
	kg_f	2.2046	lbf	≈ 0.22 lb_f
	kg_f	9.80665	N	
	dyne	0.00001 (exact)	N	
Amount of substance	lb_m-mol	453.6	kmol	
	g-mol	1.000	mol	
	kg-mol	1.000	kmol	
	mol	1000	kmol	
Mass flow rate	lb_m/h	0.0001260	kg/sec	10^3 lb/h $\simeq .13$ kg/sec
	kg/sec	7936.51	lb_m/h	
	lb_m/sec	0.4536	kg/sec	
	lb_m/min	0.00756	kg/sec	

Volume flow rate	U.S.gal/min	$6.309 \cdot 10^{-5}$	m^3/sec	
	U.S. bbl/day	0.15899	m^3/day	
	U.S. bbl/day	$1.84 \cdot 10^{-6}$	m^3/sec	
	ft^3/sec	0.02822	m^3/sec	
	ft^3/min	0.000472	m^3/sec	
Mass velocity (mass flux)	$lb_m/h \cdot ft^2$	$1.356 \cdot 10^{-3}$	$kg/sec \cdot m^2$	
	$kg/sec \cdot m^2$	737.5	$lb_m/h \cdot ft^2$	
Energy (work) (heat)	Btu	1055.056	J = N·m = W·sec	1 Btu ≃ 1000 J
	Btu	0.2520	kcal	1 kcal ≃ 4 Btu
	Btu	778.28	$ft \cdot lb_f$ J	
	kcal	4186.8	J	1 kcal ≃ 4000 J
	$ft \cdot lb_f$	1.3558	J	
	W·h	3600	J	
Power	Btu/h	0.2931	W = J/sec	10^6 Btu/h ≃ 300 kW
	W	3.4118	Btu/h	
	kcal/h	1.163	W	
	$ft \cdot lb_f$/sec	1.3558	W	1000 kW ≃ $3.5 \cdot 10^6$
	hp (metric)	735.5	W	Btu/h
	Btu/h	0.2520	kcal/h	
	tons refrig.	3516.9	W	

Unit Conversion (continued)

Heat flux	Btu/h·ft^2	3.1546	W/m^2	1000 Btu/h·ft^2 ≃ 3.2 kW/m^2
	W/m^2	0.317	Btu/h·ft^2	
	kcal/cm^2·sec	41.868	W/m^2	
Heat transfer coefficient	Btu/h·ft^2·^{o}F	5.6784	W/m^2·K	1000 Btu/h·ft^2·^{o}F ≃ 5600 W/m^2·K
	W/m^2·K	0.1761	Btu/h·ft^2·^{o}F	
	kcal/cm^2·sec·^{o}C	41.868	W/m^2·K	
Heat transfer resistance	(Btu/h·ft^2·^{o}F)$^{-1}$	0.1761	(W/m^2·K)$^{-1}$	0.001 (Btu/h·ft^2·^{o}F)$^{-1}$ ≃ 0.00018 (W/m2·K)$^{-1}$
	(W/m^2·K)$^{-1}$	5.6784	(Btu/h·ft^2·^{o}F)$^{-1}$	
Pressure	lb$_f$/in^2 (psi)	6.8948	kN/m^2 = kPa	1 psi ≃ 7 kPa
	kPa	0.1450	psi	14.5 psi ≃ 100 kPa
	bar	100	kPa	1000 kPa = 1 MPa ≃ 150 psi
	lb$_f$/ft^2	0.0479	kPa	
	mm Hg (torr)	0.1333	kPa	
	in Hg	3.3866	kPa	
	mm H_2O	9.8067	Pa	
	in H_2O	249.09	Pa	1 in H_2O ≃ .25 kPa
	at (kg$_f$/cm^2)	98.0665	kPa	
	atm (normal)	101.325	kPa	atm = 760 mm Hg
Mass flux	lb$_m$/ft^2 sec	4.8824	kg/m^2·sec	
	lb$_m$/ft^2 sec	0.001356	kg/m^2·sec	

Physical and Transport Properties				
Thermal conductivity	Btu/ft·h·°F	1.7308	W/m·K	steel ≃ 50 W/m·K
	W/m·K	0.5778	Btu/ft·h·°F	water (20°C) 0.6 W/m·K≈
	kcal/m·h·°C	1.163	W/m·K	air (STP) ≃ 24 mW/m·K
Density	lb_m/ft^3	16.0185	kg/m^3	
	kg/m^3	0.06243	lb_m/ft^3	62.4 lb_m/ft^3 ≃ 1000
	lb_m/U.S. gal	119.7	kg/m^3	kg/m^3
Specific heat capacity	Btu/lb_m·°F	4186.8	J/kg·K	1 Btu/lb_m· °F ≃ 4.2
	kcal/kg·°C	4186.8	J/kg·K	kJ/kg·K
Enthalpy	Btu/lb_m	2326	J/kg	
	kcal/kg_m	4186.8	J/kg	
Dynamic (absolute) viscosity	centipoise (cP)	0.001	kg/m·sec	kg/m·sec = N·sec/m^2 = Pa·sec
	poise (P)	0.1	Pa·sec	
	cP	1.000	mPa·sec	
	cP	1000	μPa·sec	water (100°C), 0.31 cP
	lb_m/ft·h	0.0004134	Pa·sec	
	lb_m/ft·h	0.4134	cP	
	cP	2.4189	lb_m/ft·h	air (100°C), 0.021 cP
	lb_m/ft·sec	1.4482	Pa·sec	

Unit Conversion (continued)

Kinematic viscosity	stoke (St), $cm^2 \cdot sec$	0.0001	m^2/sec	
	centistoke (cSt)	10^{-6}	m^2/sec	
	ft^2/sec	0.092903	m^2/sec	
Diffusivity	ft^2/sec	0.92903	m^2/sec	
Thermal diffusivity	m^2/h	0.0002778	m^2/sec	
	ft^2/sec	0.92903	m^2/sec	
	ft^2/h	$25.81 \cdot 10^{-6}$	m^2/sec	
Surface tension	dyne/cm	0.001	N/m	
	dyne/cm	$6.852 \cdot 10^{-5}$	lb_f/ft	
	lb_f/ft	14.954	N/m	
Temperature relations:	$^oC = \frac{5}{9}[^oF - 32]$	$^oC = (^oF + 40)\frac{5}{9} - 40$	$\Delta T(^oC) = \frac{9}{5}\Delta T(^oF)$	$K = {}^oC + 273.15$
	$^oF = \frac{9}{5}(^oC) + 32$	$^oF = (^oC + 40)\frac{9}{5} - 40$	$\Delta T(^oF) = \frac{5}{9}\Delta T(^oC)$	$R = {}^oF + 459.67$
Miscellaneous:	Acceleration of gravity (standard):		$g = 9.80665\ m/sec^2$	
	Gas constant:		$R = 8314.3\ m \cdot N/K \cdot kmol$	
	Stefan–Boltzmann constant:		$5.6697 \cdot 10^{-8}\ W/m^2 \cdot K^4$	

Conversion Factors

The following tables of conversion factors are convenient. In order to convert the numerical value of a property expressed in one of the units in the left-hand column of the table to the numerical value of the same property expressed in one of the units in the tow row of the table, multiply the former value by the factor in the block common to both units.

In tables involving energy, *cal* denotes the thermochemical calorie; *IT cal* denotes the International Steam Table calorie. The thermochemical calorie (cal) equals 4.184 joule. The International Steam Table calorie (IT cal) equals 4.186 joule. the Btu is the International Steam Table Btu, it equals 1055.04 joule.

Conversion Factors for Mass

	lb_m	slugs	g	kg	ton
1 lb_m	1	0.03108	453.59	0.45359	0.0005
1 slug	32.174	1	$1.4594 \cdot 10^4$	14.594	0.016087
1 g	$2.2046 \cdot 10^{-3}$	$6.8521 \cdot 10^{-5}$	1	0.001	$1.1023 \cdot 10^{-6}$
1 kg	2.2046	$6.8521 \cdot 10^{-3}$	1000	1	$1.1023 \cdot 10^{-3}$
1 ton	2000	61.162	$0.0718 \cdot 10^5$	907.18	1

SOURCE: Modified and extended from "Selected Values of Properties of Hydrocarbons", National Bureau of Standards.

Conversion Factors for Density

	lb_m/ft^3	$slug/ft^3$	lb_m/in^3	lb_m/gal	g/cc
1 lb_m/ft^3	1	0.03108	$5.787 \cdot 10^{-4}$	0.13368	0.01602
1 $slug/ft^3$	32.174	1	0.1862	4.3010	0.51543
1 lb_m/in^3	1728	53.706	1	231	27.680
1 lb_m/gal	7.4805	0.2325	$4.329 \cdot 10^{-3}$	1	0.11983
1 g/cc	62.428	1.9403	0.03613	8.345	1

SOURCE: Modified and extended from "Selected Values of Properties of Hydrocarbons", National Bureau of Standards.

Conversion Factors

	lb_f/ft^2	lb_f/in^2	atm
1 lb_f/ft^2	1	0.006944	$4.726 \cdot 10^{-4}$
1 lb_f/in^2	144	1	0.06805
1 atm	2116.2	14.696	1
1 in Hg	70.726	0.49116	0.033421
1 in H_2O	5.197	0.036092	0.002456
1 mm Hg	2.7845	0.019337	$1.315 \cdot 10^{-3}$
1 mm H_2O	0.204816	$14.2333 \cdot 10^{-4}$	$9.67841 \cdot 10^{-5}$

Conversion Factors

	abs joule	cal	IT cal	Btu
1 abs joule	1	0.239005	0.238848	$9.47827 \cdot 10^{-4}$
1 cal	4.18401	1	0.999344	$3.96572 \cdot 10^{-3}$
1 IT cal	1.18676	1.000657	1	$3.96832 \cdot 10^{-3}$
1 Btu	1055.045	252.161	251.996	1
1 int. kW·h	$3.600612 \cdot 10^{6}$	$8.60565 \cdot 10^{5}$	8.60000·105	3412.76
1 hp·h	$2.684525 \cdot 10^{6}$	641.615	641.194	2544.46
1 ft·lb_f	1.355821	0.324028	0.323836	$1.285083 \cdot 10^{-3}$
1 liter·atm	101.3278	24.2179	24.2020	0.0960412

Conversion Factors

	abs joule/g	cal/g	IT cal/g	Btu/lb_m
1 abs joule/g	1	0.2390	0.2388	0.4299
1 cal/g	4.184	1	0.9993	1.7988
1 IT cal/g	4.186	1.0007	1	1.8
1 Btu/lb_m	2.326	0.5559	0.5556	1
1 ft·lb_f/lb_m	$2.989 \cdot 10^{-3}$	$7.144 \cdot 10^{-4}$	$7.139 \cdot 10^{-4}$	$1.285 \cdot 10^{-3}$
1 int. kW·h/g	$3.610 \cdot 10^{6}$	$8.60565 \cdot 10^{5}$	$8.60000 \cdot 10^{5}$	$1.548 \cdot 10^{6}$
1 hp·h/lb_m	5919	1414.5	1413.6	2545
1 ft^2/sec^2	$9.291 \cdot 10^{-5}$	$2.220 \cdot 10^{-5}$	$2.219 \cdot 10^{-5}$	$3.994 \cdot 10^{-5}$

for Pressure

in Hg	in H_2O	mm Hg	bar
0.014139	0.19243	0.3591	$4.788 \cdot 10^{-4}$
2.036	27.71	51.715	0.06895
29.921	407.18	760	1.01325
1	13.608	25.40	0.03386
0.07348	1	1.8665	0.002488
0.03937	0.53577	1	$1.333 \cdot 10^{-3}$
$2.8959 \cdot 10^{-3}$	$3.93701 \cdot 10^{-2}$	$7.35559 \cdot 10^{-2}$	$9.81 \cdot 10^{-5}$

for Energy

int. kW·h	hp·h	ft·lb_f	liter·atm
$2.77731 \cdot 10^{-7}$	$3.72505 \cdot 10^{-7}$	0.737561	$9.86896 \cdot 10^{-3}$
$1.162028 \cdot 10^{-6}$	$1.558566 \cdot 10^{-6}$	3.08596	$4.12918 \cdot 10^{-2}$
$1.162791 \cdot 10^{-6}$	$1.559590 \cdot 10^{-6}$	3.08799	$4.13189 \cdot 10^{-2}$
$2.93018 \cdot 10^{-4}$	$3.93010 \cdot 10^{-4}$	778.16	10.41220
1	1.341247	$2.65669 \cdot 10^{6}$	35534.3
0.745575	1	$1.980000 \cdot 10^{6}$	26493.5
$3.76553 \cdot 10^{-7}$	$5.0501 \cdot 10^{-7}$	1	$1.338054 \cdot 10^{-2}$
$2.81418 \cdot 10^{-5}$	$3.77452 \cdot 10^{-5}$	74.7354	1

for Specific Energy

ft·lb_f/lb_m	int. kW·h/g	hp·h/lb_m	ft^2/sec^2
334.53	$2.777 \cdot 10^{-7}$	$1.690 \cdot 10^{-4}$	10763
1399.75	$1.162 \cdot 10^{-6}$	$7.069 \cdot 10^{-4}$	4.504·104
1400.69	$1.163 \cdot 10^{-6}$	$7.074 \cdot 10^{-4}$	4.506·104
778.16	$6.460 \cdot 10^{-7}$	$3.930 \cdot 10^{-4}$	25037
1	$8.302 \cdot 10^{-10}$	$5.051 \cdot 10^{-7}$	32.174
$1.2046 \cdot 10^{9}$	1	608.4	$3.876 \cdot 10^{10}$
$1.980 \cdot 10^{6}$	0.001644	1	$6.370 \cdot 10^{7}$
0.03108	$2.580 \cdot 10^{-11}$	$1.567 \cdot 10^{-8}$	1

Conversion Factors for Specific Energy per Degree

	abs joule/g·K	cal/g·K	IT cal/g·K	Btu/lb_m·°F	W·sec/kg·K
1 abs joule/g·K	1	0.2390	0.2388	0.2388	1000
1 cal/g·K	4.184	1	0.9993	0.9993	4184
1 IT cal/g·K	4.186	1.0007	1	1	4186
1 Btu/lb_m·°F	4.186	1.0007	1	1	4186
1 W·sec/kg·K	0.001	$2.390 \cdot 10^{-4}$	$2.388 \cdot 10^{-4}$	$2.388 \cdot 10^{-4}$	1

Conversion Factors for Thermal Conductivity

	cal/sec·cm·°C	Btu/h·ft·°F	Btu/h·ft^2·°F/in	W/cm·°C
1 cal/sec·cm·°C	1	241.9	2903	4.183
1 Btu/h·ft·°F	$4.13 \cdot 10^{-3}$	1	12	0.0173
1 Btu/h·ft^2·°F/in	$3.45 \cdot 10^{-4}$	0.833	1	$1.44 \cdot 10^{-3}$
1 W/cm·°C	0.239	57.8	694	1

Conversion Factors for Dynamic Viscosity

	poise g/cm·sec dyn·sec/cm^2	lb_m/ft·h pdl·h/ft^2	lb_m/ft·sec pdl·sec/ft^2
1 poise	1	242	0.0672
1 lb_m/ft·h	$4.13 \cdot 10^{-3}$	1	$2.78 \cdot 10^{-4}$
1 lb_m/ft·sec	14.87	3600	1

Conversion Factors for Kinematic Viscosity

	ft^2/h	strokes	m^2/h	m^2/sec
1 ft^2/h	1	0.25806	0.092903	$2.58 \cdot 10^{-5}$
1 stroke	3.885	1	0.36	0.0001
1 m^2/h	10.764	2.778	1	$2.778 \cdot 10^{-4}$
1 m^2/sec	38750	10^4	3600	1

Heat Flux, *q/A*

Multiply → number of To obtain ↓ by ↘	Btu/ft^2·h	W/cm^2	kcal/h·m^2	cal/sec·cm^2
Btu/ft^2·h	1	3170.75	0.36865	13277.26
W/cm^2	$3.154 \cdot 10^{-4}$	1	$1.163 \cdot 10^{-4}$	4.1868
kcal/h·m^2	2.7126	8,600	1	$2.778 \cdot 10^{-5}$
cal/sec·cm^2	$7.536 \cdot 10^{-5}$	0.2389	36000	1

Heat Transfer Coefficient, *h*

Multiply → number of To obtain ↓ by ↘	Btu/h·ft^2·^{o}F	W/cm^2·^{o}C	cal/sec·cm^2·^{o}C	kcal/h·m^2·^{o}C
Btu/h·ft^2·^{o}F	1	1761	7376	0.20489
W/cm^2·^{o}C	$5.6785 \cdot 10^{-4}$	1	4.186	$1.163 \cdot 10^{-4}$
cal/sec·cm^2·^{o}C	$1.356 \cdot 10^{-4}$	0.2391	1	$2.778 \cdot 10^{-5}$
kcal/h·m^2·^{o}C	4.8826	8600	36000	1

Thermal Conductivity, λ

Multiply → number of To obtain ↓ by ↘	Btu/h·ft·^{o}F	W/cm·^{o}C	cal/sec·cm·^{o}C	kcal/h·m·^{o}C	Btu·in/h·ft^2·^{o}F
Btu/h·ft·^{o}F	1	57.793	241.9	0.6722	0.08333
W/cm^2·^{o}C	0.01730	1	4.186	0.01171	$1.442 \cdot 10^{-3}$
cal/sec·cm·^{o}C	$4.134 \cdot 10^{-3}$	0.2389	1	$2.778 \cdot 10^{-3}$	$3.445 \cdot 10^{-4}$
kcal/h·m·^{o}C	1.488	86.01	360	1	0.1240
Btu·in/h·ft^2·^{o}F	12	693.5	2903	8.064	1

Viscosity, η

Multiply → number of To obtain ↓ by ↘	$lb_m/ft{\cdot}h$	$lb_f{\cdot}sec/ft^2$	Centipoise	$kg/m{\cdot}h$	$kg_f{\cdot}sec/m^2$
$lb_m/ft{\cdot}h$	1	116000	2.42	0.672	23733
$lb_f{\cdot}sec/ft^2$	$8.62{\cdot}10^{-6}$	1	$2.086{\cdot}10^{-5}$	$5.79{\cdot}10^{-6}$	0.2048
Centipoise	0.413	47880	1	0.278	9807
$kg/m{\cdot}h$	1.49	172000	3.60	1	35305
$kg_f{\cdot}sec/m^2$	$4.21{\cdot}10^{-5}$	4.882	$1.020{\cdot}10^{-4}$	$2.84{\cdot}10^{-5}$	1

100 centipoise = 1 Poise = 1 g/sec·cm = 1 syne·sec/cm^2

Kinematic Viscosity, ν

Multiply → number of To obtain ↓ by ↘	ft^2/h	Strokes	m^2/h	m^2/sec
ft^2/h	1	3875	10.764	38.751
Strokes	0.25806	1	2.778	10000
m^2/h	0.092903	0.3599	1	3600
m^2/sec	$2.581{\cdot}10^{-5}$	0.0001	$2.778{\cdot}10^{-4}$	1