

UNIVERSITI KUALA LUMPUR
Malaysia France Institute

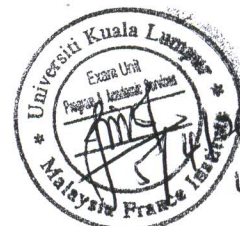
FINAL EXAMINATION
JANUARY 2010 SESSION

SUBJECT CODE : FCB 30801
SUBJECT TITLE : ABSORPTION SYSTEM
LEVEL : BACHELOR
DURATION : 2 hours
DATE / TIME : 7 May 2010
9.00 AM – 11.00 AM

INSTRUCTIONS TO CANDIDATES

1. ALL documents authorized (Open Book Examination)
2. Answer all questions in English.
3. Please write your answers on the answer booklet provided.
4. Answer should be written in blue or black ink except for sketching, graphic and illustration.

THERE ARE 3 PAGES OF QUESTIONS, EXCLUDING THIS PAGE.



4:00pm

INSTRUCTION: Answer ALL questions.

Please use the answer booklet provided.

Question 1

The operating temperatures of a single stage vapour absorption refrigeration system are: generator: 100°C ; condenser and absorber: 40°C ; evaporator: 2°C . The system has a refrigeration capacity of 120 kW and the heat input to the system is 180 kW . The solution pump work is negligible.

- a) Find the COP of the system and the total heat rejection rate from the system.
- b) An inventor claims that by improving the design of all the components of the system he could reduce the heat input to the system to 100 kW while keeping the refrigeration capacity and operating temperatures same as before. Examine the validity of the claim.

(20 marks)

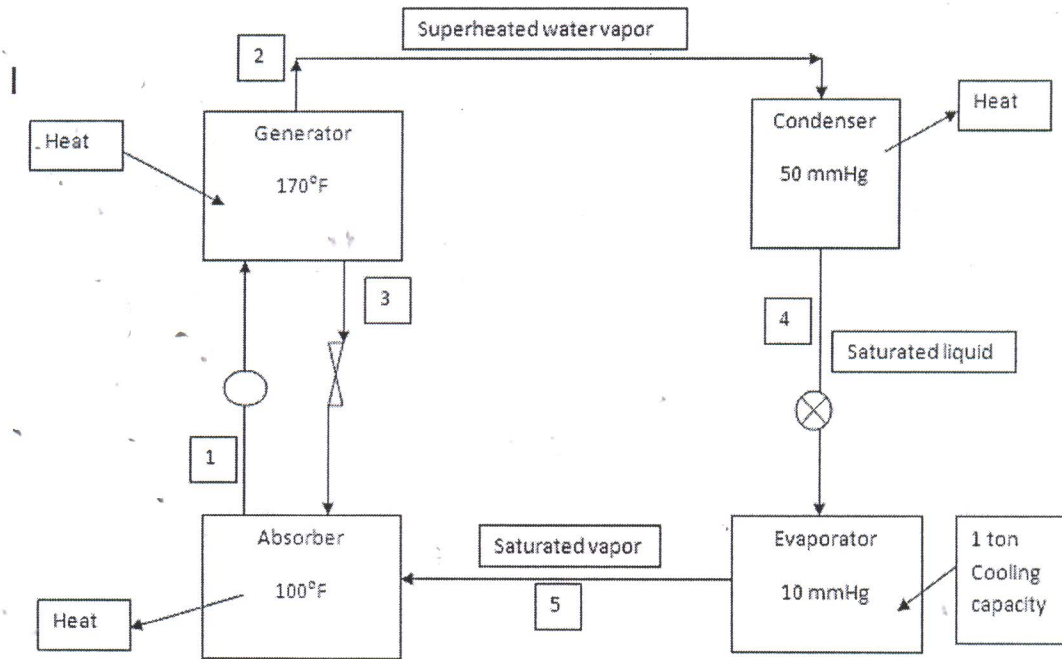
Question 3

For the LiBr-H₂O absorption system shown below, determine

- (a) heat required at generator per ton of cooling
- (b) COP
- (c) heat rejection ratio $(Q_a + Q_c) / Q_g$.

Show all your calculations.

(60 marks)



State	P (mmHg)	T (°F)	x	h (Btu/lbm)	m (lbm/min)
1					
2					
3					
4					
5					

END OF QUESTIONS

Specific Volume of Saturated Ammonia Solutions, m³/kg

Temp., °C	Concentration, Ammonia (Mass basis)										Temp., °C	
	0	10	20	30	40	50	60	70	80	90		100
-10	0.00100	0.00103	0.00106	0.00109	0.00114	0.00118	0.00122	0.00128	0.00135	0.00142	0.00151	-10
0	0.00100	0.00103	0.00107	0.00110	0.00114	0.00119	0.00124	0.00130	0.00137	0.00146	0.00156	0
10	0.00100	0.00104	0.00107	0.00111	0.00115	0.00120	0.00125	0.00132	0.00139	0.00149	0.00160	10
20	0.00100	0.00104	0.00108	0.00112	0.00116	0.00121	0.00127	0.00133	0.00142	0.00152	0.00164	20
30	0.00100	0.00105	0.00108	0.00113	0.00117	0.00123	0.00128	0.00135	0.00145	0.00156	0.00168	30
40	0.00101	0.00105	0.00109	0.00114	0.00119	0.00124	0.00130	0.00138	0.00148	0.00159	0.00173	40
50	0.00101	0.00106	0.00110	0.00115	0.00120	0.00125	0.00132	0.00140	0.00151	0.00163	0.00177	50
60	0.00102	0.00106	0.00111	0.00116	0.00121	0.00127	0.00134	0.00143	0.00154	0.00167	0.00183	60
70	0.00102	0.00107	0.00112	0.00117	0.00122	0.00129	0.00136	0.00146	0.00158	0.00172	0.00190	70
80	0.00103	0.00108	0.00113	0.00118	0.00124	0.00130	0.00139	0.00149	0.00162	0.00178	0.00198	80
90	0.00104	0.00109	0.00114	0.00119	0.00125	0.00132	0.00141	0.00153	0.00167	0.00184	0.00208	90
100	0.00104	0.00110	0.00115	0.00121	0.00127	0.00135	0.00145	0.00157	0.00172	0.00191	0.00219	100

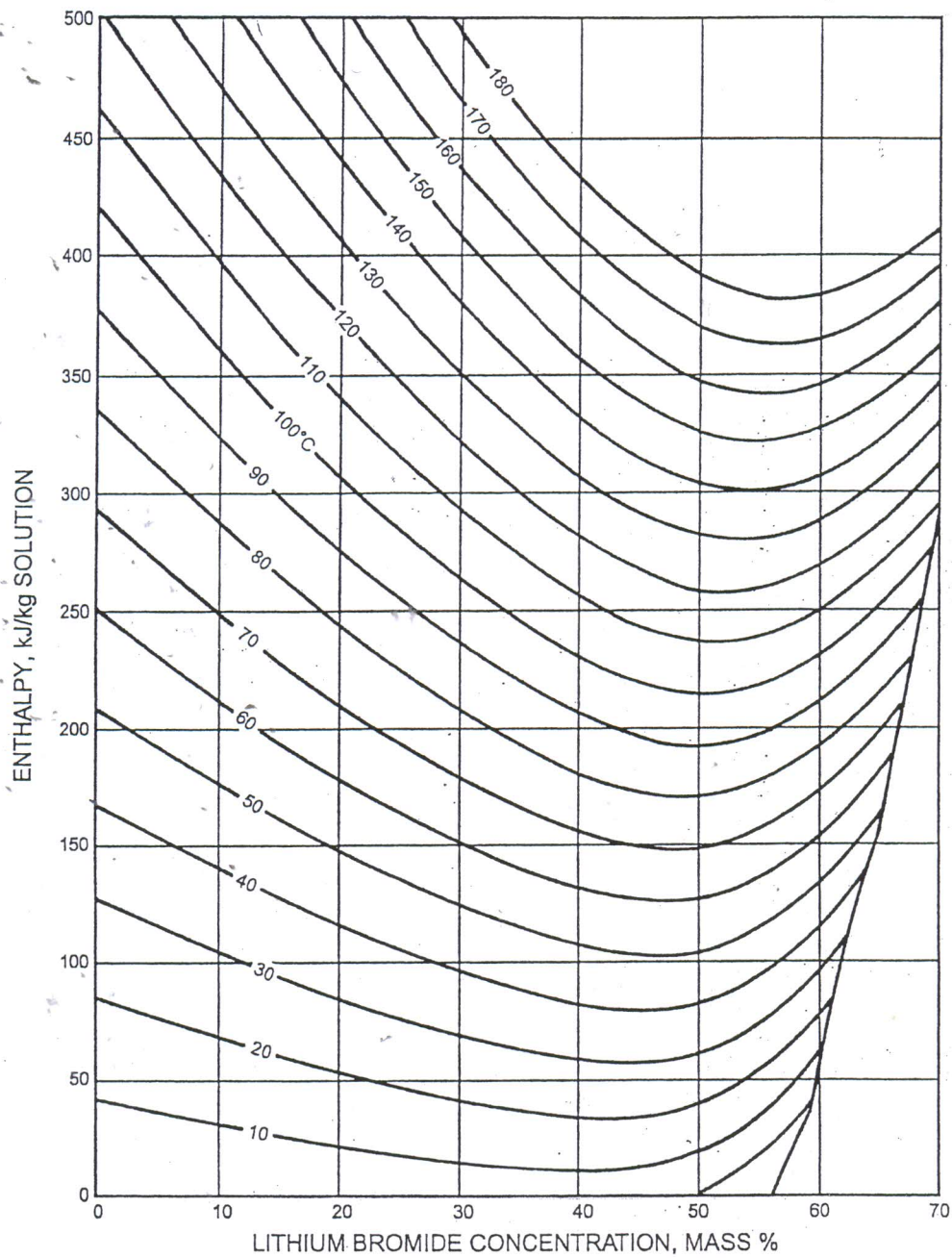
Prepared under Research Project No. 271-RP, sponsored by TC 8.3.
Data reference: B.H. Jennings, Ammonia water properties (paper presented at ASHRAE meeting, January 1965).

Refrigerant Temperature (t' = °C) and Enthalpy (h = kJ/kg) of Lithium Bromide Solutions

Temp., (t' = °C)		Percent LiBr										
		0	10	20	30	40	45	50	55	60	65	70
20	t'	20.0	19.1	17.7	15.0	9.8	5.8	-0.4	-7.7	-15.8	-23.4#	-29.3#
	h	84.0	67.4	52.6	40.4	33.5	33.5	38.9	53.2	78.0	111.0#	145.0#
30	t'	30.0	29.0	27.5	24.6	19.2	15.0	8.6	1.0	-7.3	-15.2#	-21.6#
	h	125.8	103.3	84.0	68.6	58.3	56.8	60.5	73.5	96.8	128.4#	161.7#
40	t'	40.0	38.9	37.3	34.3	28.5	24.1	17.5	9.8	1.3	-7.0#	-14.0#
	h	167.6	139.5	115.8	96.0	82.5	79.7	82.2	93.5	115.4	146.0#	178.3#
50	t'	50.0	48.8	47.2	44.0	37.9	33.3	26.5	18.5	9.9	1.3	-6.3#
	h	209.3	175.2	147.0	123.4	106.7	102.6	103.8	114.0	134.5	163.5	195.0#
60	t'	60.0	58.8	57.0	53.6	47.3	42.5	35.5	27.3	18.4	9.5	1.4#
	h	251.1	211.7	179.1	151.4	131.7	125.8	125.8	134.7	153.7	181.4	211.9#
70	t'	70.0	68.7	66.8	63.3	56.6	51.6	44.4	36.1	27.0	17.7	9.0#
	h	293.0	247.7	210.5	178.8	155.7	148.9	148.0	155.6	173.2	199.4	228.8#
80	t'	80.0	78.6	76.7	73.0	66.0	60.8	53.4	44.8	35.6	26.0	16.7#
	h	334.9	287.8	243.6	207.3	181.0	172.8	170.0	176.2	192.6	217.2	245.7#
90	t'	90.0	88.6	86.5	82.6	75.4	70.0	62.3	53.6	44.1	34.2	24.3#
	h	376.9	321.1	275.6	235.4	206.1	195.8	192.3	197.1	212.2	235.6	262.9#
100	t'	100.0	98.5	96.3	92.3	84.7	79.1	71.3	62.4	52.7	42.4	32.0
	h	419.0	357.6	307.9	263.8	231.0	219.9	214.6	218.2	231.5	253.5	279.7
110	t'	110.0	108.4	106.2	101.9	94.1	88.3	80.2	71.1	61.3	50.6	39.7
	h	461.3	394.3	340.1	292.4	255.9	243.3	236.8	239.1	251.0	271.4	296.3
120	t'	120.0*	118.3*	116.0*	111.6	103.4	97.5	89.2	79.9	69.8	58.9	47.3
	h	503.7*	431.0*	372.5*	320.9	281.0	267.0	259.0	260.0	270.2	289.5	313.4
130	t'	130.0*	128.3*	125.8*	121.3*	112.8	106.7	92.8	88.7	78.4	67.1	55.0
	h	546.5*	468.4*	404.5*	349.6*	306.2	290.7	281.0	280.4	289.1	306.9	330.2
140	t'	140.0*	138.2*	135.7*	130.9*	122.2*	115.8	107.1	97.4	87.0	75.3	62.7
	h	589.1*	505.6*	437.8*	377.9*	331.3*	314.2	303.2	301.1	308.1	324.7	346.9
150	t'	150.0*	148.1*	145.5*	140.6*	131.5*	125.0*	116.1*	106.2	95.5	83.5	70.3
	h	632.2*	542.7*	470.5*	406.8*	356.6*	337.8*	325.5*	321.6	327.3	342.7	363.6
160	t'	160.0*	158.1*	155.3*	150.3*	140.9*	134.2*	125.0*	115.0	104.1	91.8	78.9
	h	675.6*	580.8*	503.1*	435.4*	381.9*	361.2*	347.7*	342.2	346.1	360.3	380.1
170	t'	170.0*	168.0*	165.2*	159.9*	150.3*	143.3*	134.0*	123.7	112.7	100.0	85.7
	h	719.2*	618.9*	536.1*	464.3*	406.8*	384.9*	369.9*	362.9	365.4	378.3	396.0
180	t'	180.0*	177.9*	175.0*	169.6*	159.6*	152.5*	142.9*	132.5*	121.2*	108.2	93.3
	h	763.2*	657.1*	569.4*	493.4*	432.1*	408.8*	392.1*	383.4*	384.3*	395.8	411.3

*Extensions of data above 115°C are well above the original data and should be used with care.
#Supersaturated solution.

Only for liquid enthalpy



EQUATIONS CONCENTRATION RANGE 40 < X < 70% LiBr TEMPERATURE RANGE 15 < t < 165°C
 $h = \sum_0^4 A_n X^n + t \sum_0^4 B_n X^n + t^2 \sum_0^4 C_n X^n$ in kJ/kg, where t = °C and X = %LiBr

$A_0 = -2024.33$
 $A_1 = 163.309$
 $A_2 = -4.88161$
 $A_3 = 6.302948 \text{ E-2}$
 $A_4 = -2.913705 \text{ E-4}$

$B_0 = 18.2829$
 $B_1 = -1.1691757$
 $B_2 = 3.248041 \text{ E-2}$
 $B_3 = -4.034184 \text{ E-4}$
 $B_4 = 1.8520569 \text{ E-6}$

$C_0 = -3.7008214 \text{ E-2}$
 $C_1 = 2.8877666 \text{ E-3}$
 $C_2 = -8.1313015 \text{ E-5}$
 $C_3 = 9.9116628 \text{ E-7}$
 $C_4 = -4.4441207 \text{ E-9}$

Fig. 34 Enthalpy-Concentration Diagram for Water/Lithium Bromide Solutions.

Table 2-1 SI Thermodynamic Properties of Water

(Table 3, Chapter 6, 1997 Handbook—Fundamentals)

Temp. <i>t</i> , °C	Absolute Pressure kPa <i>p</i>	Specific Volume, m ³ /kg			Enthalpy, kJ/kg			Entropy, kJ/(kg·K)			Temp., °C
		Sat. Liquid <i>v_i/v_f</i>	Evap. <i>v_{ig}/v_{fg}</i>	Sat. Vapor <i>v_g</i>	Sat. Liquid <i>h_i/h_f</i>	Evap. <i>h_{ig}/h_{fg}</i>	Sat. Vapor <i>h_g</i>	Sat. Liquid <i>s_i/s_f</i>	Evap. <i>s_{ig}/s_{fg}</i>	Sat. Vapor <i>s_g</i>	
-60	0.00108	0.001082	90942.00	90942.00	-446.40	2836.27	2389.87	-1.6854	13.3065	11.6211	-60
-59	0.00124	0.001082	79858.69	79858.69	-444.74	2836.46	2391.72	-1.7667	13.2452	11.5677	-59
-58	0.00141	0.001082	70212.37	70212.37	-443.06	2836.64	2393.57	-1.6698	13.8145	11.5147	-58
-57	0.00161	0.001082	61805.35	61805.35	-441.38	2836.81	2395.43	-1.6620	13.1243	11.4623	-57
-56	0.00184	0.001082	54469.39	54469.39	-439.69	2836.97	2397.28	-1.6542	13.0646	11.4104	-56
-55	0.00209	0.001082	48061.05	48061.05	-438.00	2837.13	2399.12	-1.6464	13.0054	11.3590	-55
-54	0.00238	0.001082	42455.57	42455.57	-436.29	2837.27	2400.98	-1.6386	12.9468	11.3082	-54
-53	0.00271	0.001083	37546.09	37546.09	-434.59	2837.42	2402.83	-1.6308	12.8886	11.2578	-53
-52	0.00307	0.001083	33242.14	33242.14	-432.87	2837.55	2404.68	-1.6230	12.8309	11.2079	-52
-51	0.00348	0.001083	29464.67	29464.67	-431.14	2837.68	2406.53	-1.6153	12.7738	11.1585	-51
-50	0.00394	0.001083	26145.01	26145.01	-429.41	2837.80	2408.39	-1.6075	12.7170	11.1096	-50
-49	0.00445	0.001083	23223.69	23223.70	-427.67	2837.91	2410.24	-1.5997	12.6608	11.0611	-49
-48	0.00503	0.001083	20651.68	20651.69	-425.93	2838.02	2412.09	-1.5919	12.6051	11.0131	-48
-47	0.00568	0.001083	18383.50	18383.51	-424.27	2838.12	2413.94	-1.5842	12.5498	10.9656	-47
-46	0.00640	0.001083	16381.35	16381.36	-422.41	2838.21	2415.79	-1.5764	12.4949	10.9185	-46
-45	0.00721	0.001984	14612.35	14512.36	-420.65	2838.29	2417.65	-1.5686	12.4405	10.8719	-45
-44	0.00811	0.001084	13047.65	13047.66	-418.87	2838.37	2419.50	-1.5609	12.3866	10.8257	-44
-43	0.00911	0.001084	11661.85	11661.85	-417.09	2838.44	2421.35	-1.5531	12.3330	10.7799	-43
-42	0.01022	0.001084	10433.85	10433.85	-415.30	2838.50	2423.20	-1.5453	12.2799	10.7346	-42
-41	0.01147	0.001084	9344.25	9344.25	-413.50	2838.55	2425.05	-1.5376	12.2273	10.6897	-41
-40	0.01285	0.001084	8376.33	8376.33	-411.70	2838.60	2426.90	-1.5298	12.1750	10.6452	-40
-39	0.01438	0.001085	7515.86	7515.87	-409.88	2838.64	2428.76	-1.5221	12.1232	10.6011	-39
-38	0.01608	0.001085	6750.36	6750.36	-408.07	2838.67	1430.61	-1.5143	12.0718	10.5575	-38
-37	0.01796	0.001085	6068.16	6068.17	-406.24	2838.70	2432.46	-1.5066	12.0208	10.5142	-37
-36	0.02004	0.001085	5459.82	5459.82	-404.40	2838.71	2434.31	-1.4988	11.9702	10.4713	-36
-35	0.02235	0.001085	4917.09	4917.10	-402.56	2838.73	2436.16	-1.4911	11.9199	10.4289	-35
-34	0.02490	0.001085	4432.36	4432.37	-400.72	2838.75	2438.01	-1.4833	11.8701	10.3868	-34
-33	0.02771	0.001085	3998.71	3998.71	-398.86	2838.72	2439.86	-1.4756	11.8207	10.3451	-33
-32	0.03082	0.001086	3610.71	3610.71	-397.00	2838.71	2441.72	-1.4678	11.7716	10.3037	-32
-31	0.03424	0.001086	3263.20	3263.20	-395.12	2838.69	2443.57	-1.4601	11.7229	10.2628	-31
-30	0.03802	0.001086	2951.64	2951.64	-393.25	2838.66	2445.42	-1.4524	11.6746	10.2222	-30
-29	0.04217	0.001086	2672.03	2672.03	-391.36	2838.63	2447.27	-1.4446	11.6266	10.1820	-29
-28	0.04673	0.001086	2420.89	2420.89	-389.47	2838.59	2449.12	-1.4369	11.4790	10.1421	-28
-27	0.05174	0.001086	2195.23	2195.23	-387.57	2838.53	2450.97	-1.4291	11.5318	10.1026	-27
-26	0.05725	0.001087	1992.15	1992.15	-385.66	2838.48	2452.82	-1.4214	11.4849	10.0634	-26
-25	0.06329	0.001087	1809.35	1809.35	-383.74	2838.41	2454.67	-1.4137	11.4383	10.0246	-25
-24	0.06991	0.001087	1644.59	1644.59	-381.84	2838.34	2456.52	-1.4059	11.3921	9.9862	-24
-23	0.07716	0.001087	1495.98	1495.98	-379.89	2838.26	2458.37	-1.3982	11.3462	9.9480	-23
-22	0.08510	0.001087	1361.94	1361.94	-377.95	2838.17	2460.22	-1.3905	11.3007	9.9102	-22
-21	0.09378	0.001087	1240.77	1240.77	-376.01	2838.07	2462.06	-1.3828	11.2555	9.8728	-21
-20	0.10326	0.001087	1131.27	1131.27	-374.06	2837.97	2463.91	-1.3750	11.2106	9.8356	-20
-19	0.11362	0.001088	1032.18	1032.18	-372.10	2837.86	2465.76	-1.3673	11.1661	9.7988	-19
-18	0.12492	0.001088	942.46	942.47	-370.13	2837.74	2467.61	-1.3596	11.1218	9.7623	-18
-17	0.13725	0.001088	861.17	861.18	-368.15	2837.61	2469.46	-1.3518	11.0779	9.7261	-17
-16	0.15068	0.001088	787.48	787.49	-366.17	2837.47	2471.30	-1.3441	11.0343	9.6902	-16
-15	0.16530	0.001088	720.59	720.59	-364.18	2837.33	2473.15	-1.3364	10.9910	9.6546	-15
-14	0.18122	0.001088	659.86	659.86	-362.18	2837.18	2474.99	-1.3287	10.9480	9.6193	-14
-13	0.19852	0.001089	604.65	604.65	-360.18	2837.02	2476.84	-1.3210	10.9053	9.5844	-13
-12	0.21732	0.001089	554.45	554.45	-358.17	2836.85	2478.68	-1.3132	10.8629	9.5497	-12
-11	0.23774	0.001089	508.75	508.75	-356.15	2836.68	2480.53	-1.3055	10.8208	9.5153	-11
-10	0.25990	0.001089	467.14	467.14	-354.12	2836.49	2482.37	-1.2978	10.7790	9.4812	-10
-9	0.28393	0.001089	429.21	429.21	-352.08	2836.30	2484.22	-1.2901	10.7375	9.4474	-9
-8	0.30998	0.001090	394.64	394.64	-350.04	2836.10	2486.06	-1.2824	10.6962	9.4139	-8
-7	0.33819	0.001090	363.07	363.07	-347.99	2835.89	2487.90	-1.2746	10.6552	9.3806	-7
-6	0.36874	0.001090	334.25	334.25	-345.93	2835.68	2489.74	-1.2669	10.6145	9.3476	-6
-5	0.40176	0.001090	307.91	307.91	-343.87	2835.45	2491.58	-1.2592	10.4741	9.3149	-5
-4	0.43747	0.001090	283.83	283.83	-341.80	2835.22	2493.42	-1.2515	10.5340	9.2825	-4
-3	0.47606	0.001090	261.79	261.79	-339.72	2834.98	2495.26	-1.2438	10.4941	9.2503	-3
-2	0.51772	0.001091	241.60	241.60	-337.63	2834.72	2497.10	-1.2361	10.4544	9.2184	-2
-1	0.56267	0.001091	223.11	223.11	-335.53	2834.47	2498.93	-1.2284	10.4151	9.1867	-1
0	0.61115	0.001091	206.16	206.16	-333.43	2834.20	2500.77	-1.2206	10.3760	9.1553	0
0	0.6112	0.001000	206.141	206.143	-0.04	2500.81	2500.77	-0.0002	9.1555	9.1553	0
1	0.6571	0.001000	192.455	192.456	4.18	2498.43	2502.61	0.0153	9.1134	9.1286	1
2	0.7060	0.001000	179.769	179.770	8.39	2496.05	2504.45	0.0306	9.0716	9.1022	2
3	0.7580	0.001000	168.026	168.027	12.60	2493.68	2506.28	0.0459	9.0302	9.0761	3
4	0.8135	0.001000	157.137	157.138	16.81	2491.31	2508.12	0.0611	8.9890	9.0501	4
5	0.8725	0.001000	147.032	147.033	21.02	2488.94	2509.96	0.0763	8.9482	9.0244	5
6	0.9353	0.001000	137.653	137.654	25.22	2486.57	2511.79	0.0913	8.9077	8.9990	6
7	1.0020	0.001000	128.947	128.948	29.42	2484.20	2513.62	0.1064	8.8674	8.9738	7
8	1.0728	0.001000	120.850	120.851	33.62	2481.84	2515.46	0.1213	8.8273	8.9488	8
9	1.1481	0.001000	113.326	113.327	37.82	2479.47	2517.29	0.1362	8.7878	8.9245	9
10	1.2280	0.001000	106.328	106.329	42.01	2477.11	2519.12	0.1511	8.7484	8.8995	10
11	1.3127	0.001000	99.812	99.813	46.21	2474.74	2520.95	0.1659	8.7093	8.8752	11
12	1.4026	0.001001	93.743	93.744	50.40	2472.38	2522.78	0.1806	8.6705	8.8511	12

Table 2-1 SI Thermodynamic Properties of Water (Continued)

(Table 3, Chapter 6, 1997 Handbook—Fundamentals)

Temp. t , °C	Absolute Pressure kPa \bar{a}	Specific Volume, m ³ /kg			Enthalpy, kJ/kg			Entropy, kJ/(kg·K)			Temp., °C
		Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g	
13	1.4978	0.001001	88.088	88.089	54.59	2470.02	2524.61	0.1953	8.6319	8.8272	13
14	1.5987	0.001001	82.815	82.816	58.78	2467.66	2526.44	0.2099	8.5936	8.8035	14
15	1.7055	0.001001	77.897	77.898	62.97	2465.30	2528.26	0.2244	8.5556	8.7801	15
16	1.8184	0.001001	73.307	73.308	67.16	2462.93	2530.09	0.2389	8.5178	8.7568	16
17	1.9380	0.001001	69.021	69.022	71.34	2460.57	2531.92	0.2534	8.4804	8.7338	17
18	2.0643	0.001002	65.017	65.018	75.53	2458.21	2533.74	0.2678	8.4431	8.7109	18
19	2.1978	0.001002	61.274	61.273	79.72	2455.85	2535.56	0.2821	8.4061	8.6883	19
20	2.3388	0.001002	57.774	57.773	83.90	2453.48	2537.38	0.2964	8.3694	8.6658	20
21	2.4877	0.001002	54.450	54.500	88.08	2451.12	2539.20	0.3107	8.3329	8.6436	21
22	2.6448	0.001002	51.433	51.434	92.27	2448.75	2541.02	0.3249	8.2967	8.6215	22
23	2.8104	0.001003	48.562	48.563	96.45	2446.39	2542.84	0.3390	8.2607	8.5996	23
24	2.9851	0.001003	45.872	45.873	100.63	2444.02	2544.65	0.3531	8.2249	8.5780	24
25	3.1692	0.001003	43.350	43.351	104.81	2441.66	2546.47	0.3672	8.1894	8.5565	25
26	3.3631	0.001003	40.985	40.986	108.99	2439.29	2548.28	0.3812	8.1541	8.5352	26
27	3.5673	0.001004	38.766	38.767	113.18	2436.92	2550.09	0.3951	8.1190	8.5141	27
28	3.7822	0.001004	36.682	36.683	117.36	2434.55	2551.90	0.4090	8.0842	8.4932	28
29	4.0083	0.001004	34.726	34.727	121.54	2432.17	2553.71	0.4229	8.0496	8.4724	29
30	4.2460	0.001004	32.889	32.889	125.72	2429.80	2555.52	0.4367	8.0152	8.4519	30
31	4.4959	0.001005	31.160	31.161	129.90	2427.43	2557.32	0.4505	7.9810	8.4315	31
32	4.7585	0.001005	29.535	29.536	134.08	2425.05	2559.13	0.4642	7.9471	8.4112	32
33	5.0343	0.001005	28.006	28.007	138.26	2422.67	2560.93	0.4779	7.9133	8.3912	33
34	5.3239	0.001006	26.567	26.568	142.44	2420.29	2562.73	0.4915	7.8790	8.3713	34
35	5.6278	0.001006	25.212	25.213	146.62	2417.91	2564.53	0.5051	7.8465	8.3516	35
36	5.9466	0.001006	23.935	23.936	150.80	2415.53	2566.33	0.5186	7.8134	8.3320	36
37	6.2810	0.001007	22.733	22.734	154.98	2413.14	2568.12	0.5321	7.7805	8.3127	37
38	6.6315	0.001007	21.599	21.600	159.16	2410.76	2569.91	0.5456	7.7479	8.2934	38
39	6.9987	0.001008	20.529	20.530	163.34	2408.37	2571.71	0.5590	7.7154	8.2744	39
40	7.3835	0.001008	19.520	19.521	167.52	2405.98	2573.50	0.5724	7.6831	8.2555	40
41	7.7863	0.001008	18.567	18.568	171.70	2403.58	2575.28	0.5857	7.6510	8.2367	41
42	8.2080	0.001009	17.667	17.668	175.88	2401.19	2577.07	0.5990	7.6191	8.2181	42
43	8.6492	0.001009	16.818	16.819	180.06	2398.79	2578.85	0.6122	7.5875	8.1997	43
44	9.1107	0.001010	16.014	16.015	184.24	2396.39	2580.63	0.6254	7.5560	8.1814	44
45	9.5932	0.001010	15.255	15.256	188.42	2393.99	2582.41	0.6386	7.5247	8.1632	45
46	10.0976	0.001010	14.537	14.538	192.60	2391.59	2584.19	0.6517	7.4936	8.1452	46
47	10.6246	0.001011	13.858	13.859	196.78	2389.18	2585.96	0.6648	7.4626	8.1274	47
48	11.1751	0.001011	13.214	13.215	200.97	2386.77	2587.74	0.6778	7.4319	8.1097	48
49	11.7500	0.001012	12.606	12.607	205.15	2384.36	2589.51	0.6908	7.4013	8.0921	49
50	12.3499	0.001012	12.029	12.029	209.33	2381.94	2591.27	0.7038	7.3709	8.0747	50
51	12.9759	0.001013	11.482	11.483	213.51	2379.53	2593.04	0.7167	7.3407	8.0574	51
52	13.6290	0.001013	10.964	10.965	217.70	2377.10	2594.80	0.7296	7.3107	8.0403	52
53	14.3100	0.001014	10.473	10.474	221.88	2374.68	2596.56	0.7424	7.2809	8.0233	53
54	15.0200	0.001014	10.001	10.008	226.06	2372.26	2598.32	0.7552	7.2512	8.0064	54
55	15.7597	0.001015	9.563	9.5663	230.25	2369.83	2600.07	0.7680	7.2217	7.9897	55
56	16.5304	0.001015	9.147	9.1468	234.43	2367.39	2601.82	0.7807	7.1924	7.9731	56
57	17.3331	0.001016	8.744	8.7489	238.61	2364.96	2603.57	0.7934	7.1632	7.9566	57
58	18.1690	0.001016	8.3690	8.3700	242.80	2362.52	2605.32	0.8061	7.1342	7.9403	58
59	19.0387	0.001017	8.0094	8.0114	246.99	2360.08	2607.06	0.8187	7.1054	7.9240	59
60	19.944	0.001017	7.6677	7.6697	251.17	2357.63	2608.80	0.8313	7.0767	7.9079	60
61	20.885	0.001018	7.3428	7.3438	255.36	2355.19	2610.54	0.8438	7.0482	7.8920	61
62	21.864	0.001018	7.0337	7.0347	259.54	2352.73	2612.28	0.8563	7.0198	7.8761	62
63	22.882	0.001019	6.7397	6.7407	263.73	2350.28	2614.01	0.8688	6.9916	7.8604	63
64	23.940	0.001019	6.4599	6.4609	267.92	2347.82	2615.74	0.8812	6.9636	7.8448	64
65	25.040	0.001020	6.1935	6.1946	272.11	2345.36	2617.46	0.8936	6.9357	7.8293	65
66	26.180	0.001020	5.9397	5.9409	276.30	2342.89	2619.19	0.9060	6.9080	7.8140	66
67	27.366	0.001021	5.6982	5.6992	280.49	2340.42	2620.90	0.9183	6.8804	7.7987	67
68	28.596	0.001022	5.4680	5.4690	284.68	2337.95	2622.62	0.9306	6.8530	7.7836	68
69	29.873	0.001022	5.2485	5.2495	288.87	2335.47	2624.33	0.9429	6.8257	7.7686	69
70	31.198	0.001023	5.0392	5.0402	293.06	2332.99	2626.04	0.9551	6.7986	7.7537	70
71	32.572	0.001023	4.8396	4.8407	297.25	2330.50	2627.75	0.9673	6.7716	7.7389	71
72	33.997	0.001024	4.6492	4.6502	301.44	2328.01	2629.45	0.9795	6.7448	7.7242	72
73	35.475	0.001025	4.4675	4.4685	305.63	2325.51	2631.15	0.9916	6.7181	7.7097	73
74	37.006	0.001025	4.2940	4.2951	309.83	2323.02	2632.84	1.0037	6.6915	7.6952	74
75	38.592	0.001026	4.1284	4.1294	314.02	2320.51	2634.53	1.0157	6.6651	7.6809	75
76	40.236	0.001026	3.9702	3.9712	318.22	2318.01	2636.22	1.0278	6.6389	7.6666	76
77	41.938	0.001027	3.8190	3.8201	322.41	2315.49	2637.90	1.0398	6.6127	7.6525	77
78	43.700	0.001028	3.6746	3.6756	326.61	2312.98	2639.58	1.0517	6.5867	7.6384	78
79	45.524	0.001028	3.5365	3.5375	330.81	2310.46	2641.26	1.0636	6.5609	7.6245	79
80	47.412	0.001029	3.4044	3.4055	335.00	2307.93	2642.93	1.0755	6.5351	7.6107	80

Table 2-1 SI Thermodynamic Properties of Water (Continued)

(Table 3, Chapter 6, 1997 Handbook—Fundamentals)

Temp., <i>t</i> , °C	Absolute Pressure kPa <i>p</i>	Specific Volume, m ³ /kg			Enthalpy, kJ/kg			Entropy, kJ/(kg·K)			Temp., °C
		Sat. Liquid <i>v_f</i>	Evap. <i>v_{fg}</i>	Sat. Vapor <i>v_g</i>	Sat. Liquid <i>h_f</i>	Evap. <i>h_{fg}</i>	Sat. Vapor <i>h_g</i>	Sat. Liquid <i>s_f</i>	Evap. <i>s_{fg}</i>	Sat. Vapor <i>s_g</i>	
81	49.364	0.001030	3.2781	3.2792	339.20	2305.40	2644.60	1.0874	6.5095	7.5969	81
82	51.384	0.001030	3.1573	3.1583	343.40	2902.86	2646.26	1.0993	6.4841	7.5833	82
83	53.473	0.001031	3.0417	3.0427	347.60	2297.78	2647.92	1.1111	6.4587	7.5698	83
84	55.633	0.001032	2.9310	2.9320	351.80	2297.78	2649.58	1.1228	6.4335	7.5563	84
85	57.865	0.001032	2.8250	2.8260	356.01	2295.22	2651.23	1.1346	6.4084	7.5430	85
86	60.171	0.001033	2.7235	2.7245	350.21	2292.67	2652.88	1.1463	6.3834	7.5297	86
87	62.554	0.001034	2.6263	2.6273	364.41	2290.11	2654.52	1.1580	6.3586	7.5166	87
88	65.015	0.001035	2.5331	2.5341	368.62	2287.54	2656.16	1.1696	6.3339	7.5035	88
89	67.556	0.001035	2.4438	2.4448	372.82	2284.97	2657.79	1.1812	6.3093	7.4905	89
90	70.180	0.001036	2.3582	2.3592	377.03	2282.39	2659.42	1.1928	6.2848	7.4776	90
91	72.888	0.001037	2.2760	2.2771	381.24	2279.81	2661.04	1.2044	6.2605	7.4648	91
92	75.683	0.001037	2.1973	2.1983	385.45	2277.22	2662.66	1.2159	6.2362	7.4521	92
93	78.566	0.001038	2.1217	2.1228	389.66	2274.62	2664.28	1.2274	6.2121	7.4395	93
94	81.541	0.001039	2.0492	2.0502	393.87	2272.02	2665.89	1.2389	6.1881	7.4270	94
95	84.608	0.001040	1.9796	1.9806	398.08	2269.41	2667.49	1.2504	6.1642	7.4146	95
96	87.770	0.001040	1.9128	1.9138	402.29	2266.80	2669.09	1.2618	6.1404	7.4022	96
97	91.030	0.001041	1.8486	1.8496	406.51	2264.18	2670.69	1.2732	6.1168	7.3899	97
98	94.390	0.001042	1.7869	1.7880	410.72	2261.55	2672.28	1.2845	6.0932	7.3777	98
99	97.852	0.001044	1.7277	1.7287	414.94	2258.92	2673.86	1.2959	6.0697	7.3656	99
100	101.419	0.001044	1.6708	1.6718	419.16	2256.28	2675.44	1.3072	6.0464	7.3536	100
101	105.092	0.001044	1.6161	1.6171	423.38	2253.64	2677.02	1.3185	6.0232	7.3416	101
102	108.875	0.001045	1.5635	1.5645	427.60	2250.99	2678.58	1.3297	6.0000	7.3298	102
103	112.770	0.001046	1.5129	1.5139	431.82	2248.33	2680.15	1.3410	5.9770	7.3180	103
104	116.779	0.001047	1.4642	1.4652	436.04	2245.66	2681.71	1.3522	5.9541	7.3062	104
105	120.906	0.001047	1.4174	1.4184	440.27	2242.99	2683.26	1.3634	5.9313	7.2946	105
106	125.152	0.001048	1.3723	1.3734	444.49	2240.31	2684.80	1.3745	5.9086	7.2830	106
107	129.520	0.001049	1.3290	1.3300	448.72	2237.63	2686.35	1.3856	5.8860	7.2716	107
108	134.012	0.001050	1.2872	1.2883	452.95	2234.93	2687.88	1.3967	5.8635	7.2601	108
109	138.633	0.001051	1.2470	1.2481	457.18	2232.23	2689.41	1.4078	5.8410	7.2488	109
110	143.384	0.001052	1.2083	1.2093	461.41	2229.52	2690.93	1.4188	5.8187	7.2375	110
111	148.267	0.001052	1.1710	1.1720	465.64	2226.81	2692.45	1.4298	5.7965	7.2263	111
112	153.287	0.001053	1.1350	1.1361	469.88	2224.09	2693.96	1.4408	5.7744	7.2152	112
113	158.445	0.001054	1.1004	1.1015	474.11	2221.35	2695.47	1.4518	5.7524	7.2042	113
114	163.745	0.001055	1.0670	1.0681	478.35	2218.62	2696.97	1.4627	5.7304	7.1931	114
115	169.190	0.001056	1.0348	1.0359	482.59	2215.87	2698.46	1.4737	5.7086	7.1822	115
116	174.782	0.001057	1.0038	1.0048	486.83	2213.12	2699.95	1.4846	5.6868	7.1714	116
117	180.525	0.001058	0.9739	0.9749	491.07	2210.35	2701.43	1.4954	5.6652	7.1606	117
118	186.420	0.001059	0.9450	0.9460	495.32	2207.58	2702.90	1.5063	5.6436	7.1499	118
119	192.473	0.001059	0.9171	0.9182	499.56	2204.80	2704.37	1.5171	5.6221	7.1392	119
120	198.685	0.001060	0.8902	0.8913	503.81	2202.02	2705.83	1.5279	5.6007	7.1286	120
122	211.601	0.001062	0.8391	0.8402	512.31	2196.42	2706.73	1.5494	5.5582	7.1076	122
124	225.194	0.001064	0.7916	0.7927	520.82	2190.78	2711.60	1.5709	5.5160	7.0869	124
126	239.490	0.001066	0.7472	0.7483	529.33	2185.11	2714.44	1.5922	5.4742	7.0664	126
128	254.515	0.001068	0.7057	0.7068	537.86	2179.40	2717.26	1.6135	5.4326	7.0461	128
130	270.298	0.001070	0.6670	0.6681	546.39	2173.66	2720.05	1.6347	5.3914	7.0261	130
132	286.866	0.001072	0.6308	0.6318	554.93	2167.87	2722.80	1.6557	5.3505	7.0063	132
134	304.247	0.001074	0.5969	0.5979	563.48	2162.05	2725.53	1.6767	5.3099	6.9867	134
136	322.470	0.001076	0.5651	0.5662	572.04	2156.18	2728.22	1.6977	5.2697	6.9673	136
138	341.566	0.001078	0.5354	0.5364	580.60	2150.28	2730.88	1.7185	5.2296	6.9481	138
140	361.565	0.001080	0.5075	0.5085	589.18	2144.33	2733.51	1.7393	5.1899	6.9292	140
142	382.497	0.001082	0.4813	0.4824	597.76	2138.34	2736.11	1.7599	5.1505	6.9104	142
144	404.394	0.001084	0.4567	0.4578	606.36	2132.31	2738.67	1.7805	5.1113	6.8918	144
146	427.288	0.001086	0.4336	0.4347	614.97	2126.23	2741.19	1.8011	5.0724	6.8735	146
148	451.211	0.001088	0.4119	0.4130	623.58	2120.10	2743.68	1.8215	5.0338	6.8553	148
150	476.198	0.001091	0.3914	0.3925	632.21	2113.92	2746.13	1.8419	4.9954	6.8373	150
152	502.281	0.001093	0.3722	0.3733	640.85	2107.70	2748.55	1.8622	4.9573	6.8194	152
154	529.495	0.001095	0.3541	0.3552	649.50	2101.43	2750.93	1.8824	4.9194	6.8017	154
156	557.875	0.001097	0.3370	0.3381	658.16	2095.11	2753.27	1.9026	4.8817	6.7842	156
158	587.456	0.001100	0.3209	0.3220	666.83	2088.73	2755.57	1.9226	4.8443	6.7669	158
160	618.275	0.001102	0.3058	0.3069	675.52	2082.31	2757.82	1.9427	4.8070	6.7497	160
162	650.368	0.001104	0.2914	0.2925	684.22	2075.82	2760.04	1.9626	4.7701	6.7327	162
164	683.772	0.001107	0.2779	0.2790	692.93	2069.29	2762.22	1.9825	4.7333	6.7158	164
166	718.526	0.001109	0.2651	0.2662	701.65	2062.70	2764.35	2.0023	4.6967	6.6990	166
168	754.667	0.001112	0.2530	0.2541	710.39	2056.05	2766.44	2.0221	4.6603	6.6824	168
170	792.235	0.001114	0.2415	0.2427	719.14	2049.34	2768.48	2.0418	4.6242	6.6659	170
172	831.268	0.001117	0.2307	0.2318	727.91	2042.57	2770.48	2.0614	4.5882	6.6496	172
174	871.808	0.001119	0.2205	0.2216	736.69	2035.74	2772.43	2.0810	4.5524	6.6334	174
176	913.894	0.001122	0.2107	0.2119	745.48	2028.85	2774.33	2.1005	4.5168	6.6173	176
178	947.568	0.001125	0.2015	0.2026	754.29	2021.89	2776.19	2.1200	4.4813	6.6013	178
180	1002.871	0.001127	0.1928	0.1939	763.12	2014.87	2777.99	2.1394	4.4460	6.5854	180
182	1049.846	0.001130	0.1845	0.1856	771.96	2007.78	2779.74	2.1587	4.4109	6.5691	182
184	1098.535	0.001133	0.1766	0.1777	780.82	2000.63	2781.45	2.1780	4.3760	6.5540	184
186	1148.982	0.001136	0.1691	0.1703	789.69	1993.40	2783.10	2.1973	4.3412	6.5385	186
188	1201.230	0.001139	0.1620	0.1632	798.59	1986.11	2784.70	2.2165	4.3065	6.5230	188
190	1255.324	0.001141	0.1553	0.1564	807.50	1978.74	2786.24	2.2356	4.2720	6.5076	190
192	1311.309	0.001144	0.1488	0.1500	816.43	1971.30	2787.72	2.2547	4.2376	6.4924	192
194	1369.230	0.001147	0.1427	0.1439	825.37	1963.78	2789.15	2.2738	4.2034	6.4772	194
196	1429.133	0.001150	0.1369	0.1380	834.34	1956.19	2790.52	2.2928	4.1693	6.4621	196
198	1491.066	0.001153	0.1314	0.1325	843.32	1948.52	2791.83	2.3118	4.1353	6.4471	198
200	1555.074	0.001157	0.1261	0.1272	852.33	1940.76	2793.09	2.3307	4.1014	6.4321	200

TABLE A.1 Conversion Factors

Area	
1 mm ² = 1.0 × 10 ⁻⁶ m ²	1 ft ² = 144 in. ²
1 cm ² = 1.0 × 10 ⁻⁴ m ² = 0.1550 in. ²	1 in. ² = 6.4516 cm ² = 6.4516 × 10 ⁻⁴ m ²
1 m ² = 10.7639 ft ²	1 ft ² = 0.092 903 m ²
Conductivity	
1 W/m-K = 1 J/s-m-K = 0.577 789 Btu/h-ft-R	1 Btu/h-ft-R = 1.730 735 W/m-K
Density	
1 kg/m ³ = 0.06242797 lbm/ft ³	1 lbm/ft ³ = 16.018 46 kg/m ³
1 g/cm ³ = 1000 kg/m ³	
1 g/cm ³ = 1 kg/L	
Energy	
1 J = 1 N-m = 1 kg-m ² /s ²	
1 J = 0.737 562 lbf-ft	1 lbf-ft = 1.355 818 J
1 cal (Int.) = 4.1868 J	= 1.28507 × 10 ⁻³ Btu
	1 Btu (Int.) = 1.055 056 kJ
1 erg = 1.0 × 10 ⁻⁷ J	= 778.1693 lbf-ft
1 eV = 1.602 177 33 × 10 ⁻¹⁹ J	
Force	
1 N = 0.224809 lbf	1 lbf = 4.448 222 N
1 kp = 9.80665 N (1 kgf)	
Gravitation	
g = 9.80665 m/s ²	g = 32.17405 ft/s ²
Heat capacity, specific entropy	
1 kJ/kg-K = 0.238 846 Btu/lbm-R	1 Btu/lbm-R = 4.1868 kJ/kg-K
Heat flux (per unit area)	
1 W/m ² = 0.316 998 Btu/h-ft ²	1 Btu/h-ft ² = 3.15459 W/m ²
Heat transfer coefficient	
1 W/m ² -K = 0.176 11 Btu/h-ft ² -R	1 Btu/h-ft ² -R = 5.67826 W/m ² -K
Length	
1 mm = 0.001 m = 0.1 cm	1 ft = 12 in.
1 cm = 0.01 m = 10 mm = 0.3970 in.	1 in. = 2.54 cm = 0.0254 m
1 m = 3.28084 ft = 39.370 in.	1 ft = 0.3048 m
1 km = 0.621 371 mi	1 mi = 1.609344 km
1 mi = 1609.3 m (US statute)	1 yd = 0.9144 m

TABLE A.1 (Continued) *Conversion Factors***Mass**

1 kg	= 2.204 623 lbm	1 lbm	= 0.453 592 kg
1 tonne	= 1000 kg	1 slug	= 14.5939 kg
1 grain	= 6.47989×10^{-5} kg	1 ton	= 2000 lbm

Moment (torque)

1 N-m	= 0.737 562 lbf-ft	1 lbf-ft	= 1.355 818 N-m
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Momentum (mV)

1 kg-m/s	= 7.232 94 lbm-ft/s	1 lbm-ft/s	= 0.138 256 kg-m/s
	= 0.224809 lbf-s		

Power

1 W	= 1 J/s = 1 N-m/s	1 lbf-ft/s	= 1.355 818 W
	= 0.737 562 lbf-ft/s		= 4.626 24 Btu/h
1 kW	= 3412.14 Btu/h	1 Btu/s	= 1.055 056 kW
1 hp (metric)	= 0.735 499 kW	1 hp (UK)	= 0.7457 kW
			= 550 lbf-ft/s
			= 2544.43 Btu/h
1 ton of refrigeration	= 3.516 85 kW	1 ton of refrigeration	= 12 000 Btu/h

Pressure

1 Pa	= 1 N/m ² = 1 kg/m-s ²	1 lbf/in. ²	= 6.894 757 kPa
1 bar	= 1.0×10^5 Pa = 100 kPa		
1 atm	= 101.325 kPa	1 atm	= 14.695 94 lbf/in. ²
	= 1.01325 bar		= 29.921 in. Hg [32 F]
	= 760 mm Hg [0°C]		= 33.899 5 ft H ₂ O [4°C]
	= 10.332 56 m H ₂ O [4°C]		
1 torr	= 1 mm Hg [0°C]	1 in. Hg [0°C]	= 0.49115 lbf/in. ²
1 mm Hg [0°C]	= 0.133 322 kPa	1 in. H ₂ O [4°C]	= 0.036126 lbf/in. ²
1 m H ₂ O [4°C]	= 9.806 38 kPa		

Specific energy

1 kJ/kg	= 0.42992 Btu/lbm	1 Btu/lbm	= 2.326 kJ/kg
	= 334.55 lbf-ft/lbm	1 lbf-ft/lbm	= 2.98907×10^{-3} kJ/kg
			= 1.28507×10^{-3} Btu/lbm

TABLE A.1 (Continued) *Conversion Factors*

Specific kinetic energy (V^2)

$1 \text{ m}^2/\text{s}^2 = 0.001 \text{ kJ/kg}$
 $1 \text{ kJ/kg} = 1000 \text{ m}^2/\text{s}^2$

$1 \text{ ft}^2/\text{s}^2 = 3.9941 \times 10^{-5} \text{ Btu/lbm}$
 $1 \text{ Btu/lbm} = 25037 \text{ ft}^2/\text{s}^2$

Specific potential energy (Zg)

$1 \text{ m-g}_{\text{std}} = 9.80665 \times 10^{-3} \text{ kJ/kg}$
 $= 4.21607 \times 10^{-3} \text{ Btu/lbm}$

$1 \text{ ft-g}_{\text{std}} = 1.0 \text{ lbf-ft/lbm}$
 $= 0.001285 \text{ Btu/lbm}$
 $= 0.002989 \text{ kJ/kg}$

Specific volume

$1 \text{ cm}^3/\text{g} = 0.001 \text{ m}^3/\text{kg}$
 $1 \text{ cm}^3/\text{g} = 1 \text{ L/kg}$
 $1 \text{ m}^3/\text{kg} = 16.01846 \text{ ft}^3/\text{lbm}$

$1 \text{ ft}^3/\text{lbm} = 0.062428 \text{ m}^3/\text{kg}$

Temperature

$1 \text{ K} = 1 \text{ }^\circ\text{C} = 1.8 \text{ R} = 1.8 \text{ F}$
 $\text{TC} = \text{TK} - 273.15$
 $= (\text{TF} - 32)/1.8$
 $\text{TK} = \text{TR}/1.8$

$1 \text{ R} = (5/9) \text{ K}$
 $\text{TF} = \text{TR} - 459.67$
 $= 1.8 \text{ TC} + 32$
 $\text{TR} = 1.8 \text{ TK}$

Universal Gas Constant

$R = N_0 k = 8.31451 \text{ kJ/kmol-K}$
 $= 1.98589 \text{ kcal/kmol-K}$
 $= 82.0578 \text{ atm-L/kmol-K}$

$R = 1.98589 \text{ Btu/lbmol-R}$
 $= 1545.36 \text{ lbf-ft/lbmol-R}$
 $= 0.73024 \text{ atm-ft}^3/\text{lbmol-R}$
 $= 10.7317 \text{ (lbf/in.}^2\text{)-ft}^3/\text{lbmol-R}$

Velocity

$1 \text{ m/s} = 3.6 \text{ km/h}$
 $= 3.28084 \text{ ft/s}$
 $= 2.23694 \text{ mi/h}$
 $1 \text{ km/h} = 0.27778 \text{ m/s}$
 $= 0.91134 \text{ ft/s}$
 $= 0.62137 \text{ mi/h}$

$1 \text{ ft/s} = 0.681818 \text{ mi/h}$
 $= 0.3048 \text{ m/s}$
 $= 1.09728 \text{ km/h}$
 $1 \text{ mi/h} = 1.46667 \text{ ft/s}$
 $= 0.44704 \text{ m/s}$
 $= 1.609344 \text{ km/h}$

Volume

$1 \text{ m}^3 = 35.3147 \text{ ft}^3$
 $1 \text{ L} = 1 \text{ dm}^3 = 0.001 \text{ m}^3$
 $1 \text{ Gal (US)} = 3.785412 \text{ L}$
 $= 3.785412 \times 10^{-3} \text{ m}^3$

$1 \text{ ft}^3 = 2.831685 \times 10^{-2} \text{ m}^3$
 $1 \text{ in.}^3 = 1.6387 \times 10^{-5} \text{ m}^3$
 $1 \text{ Gal (UK)} = 4.546090 \text{ L}$
 $1 \text{ Gal (US)} = 231.00 \text{ in.}^3$