Appendix A.1

Conversion Factors Expressed as a Ratio

Denominator	*Numerators*		*Denominator*	*Numerators*	
I	II	III	I	II	III
Acre	0.4046873	Hectare	cPoise	0.001	Pa · s
Acre	43560.0	$(ft)^2$	$(cm)^3$	3.531* E – 5	$(ft)^3$
Atm (std)	101.325.0	Pascal	$(cm)^3$	0.061023	$(in)^3$
Atm (std)	14.696	lb_f/in^2	$(cm)^3$	2.642*E – 4	Gal
Atm (std)	29.921	in Hg	$(ft)^3$	7.48052	Gal
Atm (std)	76.0	cm Hg @ 0°C	$(ft)^3$	28.316	Liter
			Cup	2.36588* E – 4	$(m)^3$
Atm (std)	33.899	ft H_2O @ 32.2°F	Dyne	1.000* E – 5	Newton
			Dyne·cm	1.000* E – 7	Newton·m
BTU	1.0550* E + 10	Erg	Dyne	2.248* E – 6	lg_f
BTU	778.3	ft·lb_f			
BTU	3.9292* E – 4	Hp·h	Erg	9.486* E – 11	BTU
BTU	1054.8	Joule	Erg	2.389* E – 8	Cal
BTU	252	Cal	Erg	1.000* E – 7	Joule
BTU	2.928* E – 4	kW·h			
BTU/min	0.023575	Hp	Foot	0.3048	Meter
BTU/min	0.01757	kW	$(ft)^3$	2.83168* E – 2	$(m)^3$
BTU/min	17.5725	Watt	$(ft)^2$	9.29030* E – 2	$(m)^2$
BTU/s	1054.35	Watt	ft·lb_f	1.355818	Joule
BTU/h	0.29299	Watt			
$\frac{BTU}{h(ft^2)(°F)}$	5.678263	$W/m^2 \cdot K$	Gal (U.S.)	0.13368	$(ft)^3$
			Gal (U.S.)	3.78541	Liter
			Gal (U.S.)	3.78541*E–3	$(m)^3$
$\frac{BTU}{h(ft)(°F)}$	1.730735	$W/m \cdot K$	Gram	2.2046* E – 3	Pound

(Continued)

Denominator	*Numerators*		*Denominator*	*Numerators*	
I	II	III	I	II	III
BTU/lb	2326.0	J/kg			
			Hectare	2.471	Acre
$\frac{\text{BTU}}{\text{lb}(^\circ\text{F})}$	4186.8	J/kg· K	Hp	42.44	BTU/min
			Hp	33,000	ft · lb_f/min
Bushel	1.2445	ft^3	Hp	0.7457	kW
Bushel	0.035239	m^3	Hp(boiler)	33,480	BTU/h
Cal	4.1868	Joule	Inch	2.5400* E − 2	Meter
Cal	3.9684* E − 3	BTU	in Hg @	3.38638* E + 3	Pascal
Cal	4.1868* E + 7	Erg	0°C		
centimeter	0.3937	Inch	in Hg@	0.4912	lb_f/in^2
cm Hg@	1333.33	Pascal	0°C		
0°C					
cm H_2O@	98.0638	Pascal	Joule	9.48* E − 4	BTU
4°C			Joule	0.23889	Cal
cPoise	0.01	g/cm·s			
cPoise	3.60	kg/m·h			
cPoise	6.72* E − 4	lb/ft·s			
Joule	10.000* E + 7	Erg	Pound	453.5924	Gram
Joule	0.73756	ft·lb_f	Pound	0.45359	kg
Joule	2.77* E − 4	W·h	lb_f	4.44823	Newton
			$lb_f/in.^2$	0.068046	Atm (std)
kg	2.2046	Pound	$lb_f/in.^2$	68947	$dynes/cm^2$
km	3281	Foot	$lb_f/in.^2$	2.3066	ft H_2O@39.2°F
km	0.6214	Mile	$lb_f/in.^2$	2.035	in Hg@0°C
kW	3413	BTU/h	lb_f/ft^2	47.88026	Pascal
kW·h	3.6* E + 6	Joule	$lb_f/in.^2$	6894.757	Pascal
Liter	0.03532	$(ft)^3$	Qt (U.S.)	9.4635* E + 4	$(m)^3$
Liter	0.2642	Gal (U.S.)	Qt (U.S.)	946.358	$(cm)^3$
Liter	2.113	Pint	Qt (U.S.)	57.75	$(in.)^3$
			Qt (U.S.)	0.9463	liter
Meter	3.281	Foot	Qt (U.S.)	0.25	Gallon
Meter	39.37	Inch			
			Ton (metric)	1000	kg
Newton	1.000* E+5	Dyne	Ton (metric)	2204.6	Pound
			Ton (short)	2000	Pound
Oz (liq)	29.57373	$(cm)^3$	Ton (refri)	12,000	BTU/h
Oz (liq)	1.803	$(in)^3$	Torr (mmHg		
Oz (av)	28.3495	Gram	@0°C)	133.322	Pascal
Oz (av)	0.0625	Pound			
			Watt	3.413	BTU/h

(Continued)

Denominator	*Numerators*		*Denominator*	*Numerators*	
I	II	III	I	II	III
Pascal	1.4504* E − 4	$lb_f/in.^2$	Watt	44.27	$ft\cdot lb_f/min$
Pascal	1.0197*E − 5	kg_f/cm^2	Watt	1.341* E − 3	Hp
Pint	28.87	$(in.)^3$	Watt·h	3.413	BTU
Poise	0.1	Pa·s	Watt·h	860.01	Cal
lb_f	444823	Dyne	Watt·h	3600	Joule

To use: multiply quantities having units under Column 1 with the factors under Column II to obtain quantities having the units under Column III. Also use as a ratio in a dimensional equation Example: 10 acres = 10 × 0.4.046.873 hectares. The dimensional ratio is (0.4046873) hectare/acre. The symbol *E represents exponents of 10.9.486* $E - 11 = 9.486 \times 10^{-11}$.

Appendix A.2

Properties of Superheated Steam

Temp. °F	Absolute Pressure lb_f/in^2 (psi) 1 psi $T_s = 101.74°F$ v	h	5 psi $T_s = 162.24°F$ v	h	10 psi $T_s = 193.21°F$ v	h
200	392.5	1150.2	78.14	1148.6	38.84	1146.6
250	422.4	1172.9	84.21	1171.7	41.93	1170.2
300	452.3	1195.7	90.24	1194.8	44.98	1193.7
350	482.1	1218.7	96.25	1218.0	48.02	1217.1
400	511.9	1241.8	102.24	1241.3	51.03	1240.6
450	541.7	1265.1	108.23	1264.7	54.04	1264.1
500	571.5	1288.6	114.21	1288.2	57.04	1287.8
600	631.1	1336.1	126.15	1335.9	63.03	1335.5

Temp. °F	Absolute Pressure lb_f/in^2 (psi) 14.696 psi $T_s = 212.00°F$ v	h	15 psi $T_s = 213.03°F$ v	h	20 psi $T_s = 227.96°F$ v	h
250	28.42	1168.8	27.837	1168.7	20.788	1167.1
300	30.52	1192.6	29.889	1192.5	22.356	1191.4
350	32.60	1216.3	31.939	1216.2	23.900	1215.4
400	34.67	1239.9	33.963	1239.9	25.428	1239.2
450	36.72	1263.6	35.977	1263.6	26.946	1263.0
500	38.77	1287.4	37.985	1287.3	28.457	1286.9
600	42.86	1335.2	41.986	1335.2	31.466	1334.9

(Continued)

	Absolute Pressure lb_f/in^2 (psi)					
	25 psi $T_s = 240.07°F$		30 psi $T_s = 250.34°F$		35 psi $T_s = 259.29°F$	
Temp. °*F*	*v*	*h*	*v*	*h*	*v*	*h*
250	16.558	1165.6				
300	17.829	1190.2	14.810	1189.0	12.654	1187.8
350	19.076	1214.5	15.589	1213.6	12.562	1212.7
400	20.307	1238.5	16.892	1237.8	14.453	1237.1
450	21.527	1262.5	17.914	1261.9	15.334	1261.3
500	22.740	1286.4	18.929	1286.0	16.207	1285.5
600	25.153	1334.6	20.945	1334.2	17.939	1333.9

v = specific volume in ft^3/lb; h = enthalpy in BTU/lb.
T_s = saturation temperature at the designated pressure.

Source: Abridged from ASME. 1967. *Steam Tables. Properties of Saturated and Superheated Steam*—from 0.08865 to 15,500 lb per sq in. absolute pressure. American Society of Mechanical Engineers. NY. Used with permission.

Appendix A.3

Saturated Steam Tables: English Units

		Specific Volume (ft^3/lb)			Enthalpy (BTU/lb)		
Temp. $^\circ F$	*Abs. pressure* lb/in^2	*Sat. liquid* v_f	*Evap* v_{fx}	*Sat. vapor* v_x	*Sat. liquid* h_f	*Evap.* h_{fg}	*Sat. vapor* h_g
32	0.08859	0.016022	3304.7	3304.7	−0.0179	1075.5	1075.5
35	0.09998	0.016020	2950.5	2950.5	3.002	1073.8	1076.8
40	0.12163	0.016019	2445.8	2445.8	8.027	1071.0	1079.0
45	0.14753	0.016020	2039.3	2039.3	13.044	1068.2	1081.2
50	0.17796	0.016023	1704.8	1704.8	18.054	1065.3	1083.4
55	0.21404	0.016027	1384.2	1384.2	23.059	1062.5	1085.6
60	0.25611	0.016033	1207.6	1207.6	28.060	1059.7	1087.7
65	0.30562	0.016041	1022.8	1022.8	33.057	1056.9	1089.9
70	0.36292	0.016050	868.3	868.4	38.052	1054.0	1092.1
75	0.42985	0.016061	740.8	740.8	43.045	1051.3	1094.3
80	0.50683	0.016072	633.3	633.3	48.037	1048.4	1096.4
85	0.59610	0.016085	543.9	543.9	53.028	1045.6	1098.6
90	0.69813	0.016099	468.1	468.1	58.018	1042.7	1100.0
95	0.81567	0.016114	404.6	404.6	63.008	1039.9	1102.9
100	0.94924	0.016130	350.4	350.4	67.999	1037.1	1105.1
105	1.10218	0.016148	304.6	304.6	72.991	1034.3	1107.2
110	1.2750	0.016165	265.4	265.4	77.98	1031.4	1109.3
115	1.4716	0.016184	232.03	232.0	82.97	1028.5	1111.5
120	1.6927	0.016204	203.25	203.26	87.97	1025.6	1113.6
125	1.9435	0.016225	178.66	178.67	92.96	1022.8	1115.7
130	2.2230	0.016247	157.32	157.33	97.96	1019.8	1117.8
135	2.5382	0.016270	138.98	138.99	102.95	1016.9	1119.9
140	2.8892	0.016293	122.98	123.00	107.95	1014.0	1122.0
145	3.2825	0.016317	109.16	109.18	112.95	1011.1	1124.1
150	3.7184	0.016343	97.05	97.07	117.95	1008.2	1126.1

(Continued)

		Specific Volume (ft^3/lb)			Enthalpy (BTU/lb)		
Temp. °*F*	*Abs. pressure* *lb/in*^{2}	*Sat. liquid* v_f	*Evap* v_{fx}	*Sat. vapor* v_x	*Sat. liquid* h_f	*Evap.* h_{fg}	*Sat. vapor* h_g
155	4.2047	0.016369	86.53	86.55	122.95	1005.2	1128.2
160	4.7414	0.016395	77.27	77.29	127.96	1002.2	1130.2
165	5.3374	0.016423	69.19	69.20	132.97	999.2	1132.2
170	5.9926	0.016451	62.04	62.06	137.97	996.2	1134.2
175	6.7173	0.016480	55.77	55.79	142.99	993.2	1136.2
180	7.5110	0.016510	50.21	50.22	148.00	990.2	1138.2
185	8.3855	0.016543	45.31	45.33	153.02	987.2	1140.2
190	9.340	0.016572	40.941	40.957	158.04	984.1	1142.1
195	10.386	0.016605	37.078	37.094	163.06	981.0	1144.1
200	11.526	0.016637	33.622	33.639	168.09	977.9	1146.0
205	12.776	0.016707	30.567	30.583	173.12	974.8	1147.8
210	14.132	0.016705	27.822	27.839	178.16	971.6	1149.8
212	14.696	0.016719	26.782	26.799	180.17	970.3	1150.5
220	17.186	0.016775	23.131	23.148	188.23	965.2	1153.4
225	18.921	0.016812	21.161	21.177	193.28	961.9	1155.2
230	20.791	0.016849	19.379	19.396	198.33	958.7	1157.1
235	22.804	0.016887	17.766	17.783	203.39	956.5	1158.9
240	24.968	0.016926	16.304	16.321	208.45	952.1	1160.6
245	27.319	0.016966	14.998	15.015	213.52	948.8	1162.4
250	29.840	0.017006	13.811	13.828	218.59	945.5	1164.1
255	32.539	0.017047	12.729	12.747	223.67	942.1	1165.8
260	35.427	0.017089	11.745	11.762	228.76	938.6	1167.4
265	38.546	0.017132	10.858	10.875	233.85	935.2	1169.0
270	41.875	0.017175	10.048	10.065	238.95	931.7	1170.7
275	45.423	0.017219	9.306	9.324	244.06	928.2	1172.2
280	49.200	0.017264	8.627	8.644	249.17	924.6	1173.8
285	53.259	0.017310	8.0118	8.0291	254.32	920.9	1175.3
290	57.752	0.017360	7.4468	7.4641	259.45	917.3	1176.8

Source: Abridged from: ASME 1967. *Steam Tables. Properties of Saturated and Superheated Steam.* American Society of Mechanical Engineers, NY. Used with permission.

Saturated Steam Tables: Metric Units

Temperature °C	Absolute pressure kPa	Enthalpy (MJ/kg) Saturated liquid h_f	(MJ/kg) Evaporation h_{fg}	Saturated vapor h_g
0	0.6108	-0.00004	2.5016	2.5016
2.5	0.7314	0.01049	2.4956	2.5061
5	0.8724	0.02100	2.4897	2.5108
7.5	1.0365	0.03151	2.4839	2.5153
10	1.2270	0.04204	2.4779	2.5200
12.5	1.4489	0.05253	2.4720	2.5245
15	1.7049	0.06292	2.4661	2.5291
17.5	2.0326	0.07453	2.4595	2.5342
20	2.3366	0.08386	2.4544	2.5381
22.5	2.7248	0.09780	2.4484	2.5428
25	3.1599	0.10477	2.4425	2.5473
27.5	3.6708	0.11522	2.4367	2.5518
30	4.2415	0.12566	2.4307	2.5563
32.5	4.8913	0.13611	2.4246	2.5609
35	5.6238	0.14656	2.4188	2.5653
37.5	6.4488	0.15701	2.4129	2.5699
40	7.3749	0.16745	2.4069	2.5744
42.5	8.4185	0.17789	2.4009	2.5788
45	9.5851	0.18834	2.3949	2.5832
47.5	10.8868	0.19880	2.3889	2.5877
50	12.3354	0.20925	2.3829	2.5921
52.5	13.9524	0.21971	2.3769	2.5966
55	15.7459	0.23017	2.3705	2.6000
57.5	17.7295	0.24062	2.3648	2.6054
60	19.9203	0.25109	2.3586	2.6098
62.5	22.3466	0.26155	2.3525	2.6140

(Continued)

		Enthalpy (MJ/kg)		
Temperature °C	Absolute pressure kPa	Saturated liquid h_f	(MJ/kg) Evaporation h_{fg}	Saturated vapor h_g
65	25.0159	0.27202	2.3464	2.6184
67.5	27.9479	0.28249	2.3402	2.6226
70	31.1622	0.29298	2.3339	2.6270
72.5	34.6961	0.30345	2.3276	2.6312
75	38.5575	0.31394	2.3214	2.6354
77.5	42.7706	0.32442	2.3151	2.6395
80	47.3601	0.33492	2.30879	2.64373
82.5	52.5777	0.34542	2.30251	2.64792
85	57.8159	0.34659	2.29611	2.65199
87.5	63.7196	0.36643	2.28971	2.65606
90	70.1059	0.37693	2.28320	2.66025
92.5	77.0489	0.38747	2.27669	2.66420
95	84.5676	0.39799	2.27023	2.66821
97.5	92.6379	0.40853	2.26349	2.67214
100	101.3250	0.41908	2.25692	2.67606
102.5	110.7410	0.42962	2.25035	2.67996
105	120.8548	0.44017	2.24354	2.68368
107.5	131.7114	0.45074	2.23674	2.68752
110	143.3489	0.46132	2.22994	2.69129
112.5	155.8051	0.47190	2.22313	2.69508
115	169.1284	0.48249	2.21615	2.69874
117.5	183.3574	0.49309	2.20929	2.70241
120	198.5414	0.50372	2.20225	2.70607
122.5	214.8337	0.51434	2.19519	2.70949
125	232.1809	0.52499	2.18807	2.71311
127.5	250.6391	0.53565	2.18083	2.71651
130	270.2538	0.54631	2.17365	2.71991
132.5	291.0837	0.55698	2.11632	2.72331
135	313.1771	0.56768	2.15899	2.72654

Source: Calculated from ASME 1967. *Steam Tables. Properties of Saturated and Superheated Steam*—from 0.08865 to 15.500 lb per sq in. absolute pressure. American Society of Mechanical Engineers, NY. Used with permission.

APPENDIX A.5

Flow Properties of Food Fluids

Product	% Solids	Temperature °C	Flow constants n (dimensonless)	k dyne - dyne · s^n/cm^2
Applesauce	11	30	0.34	116
		82	0.34	90
Apple juice	50–65.5 Brix	30	0.65	–
	10.5–40 Brix	30	1.0	–
Apricot puree	16	30	0.30	68
		82	0.27	56
Apricot concentrate	26	4.5	0.26	860
		25	0.30	670
		60	0.32	400
Banana puree	—	24	0.458	65
Grape juice	64 Brix	30	0.9	—
	15–50 Brix	30	1.0	—
Orange juice concentrate	—-	15	0.584	11.9
		0	0.542	18.0
Orange juice concentrate	30 Brix	30	0.85	—
	60 Brix	30	0.55	15.5
	65 Brix	30	0.91	2.6
Pear puree	18.3	32	0.486	22.5
		82	0.484	14.5
	26	32	0.450	62
		82	0.455	36
	31	32	0.450	109
		82	0.459	56
	37	32	0.479	355
		82	0.481	160

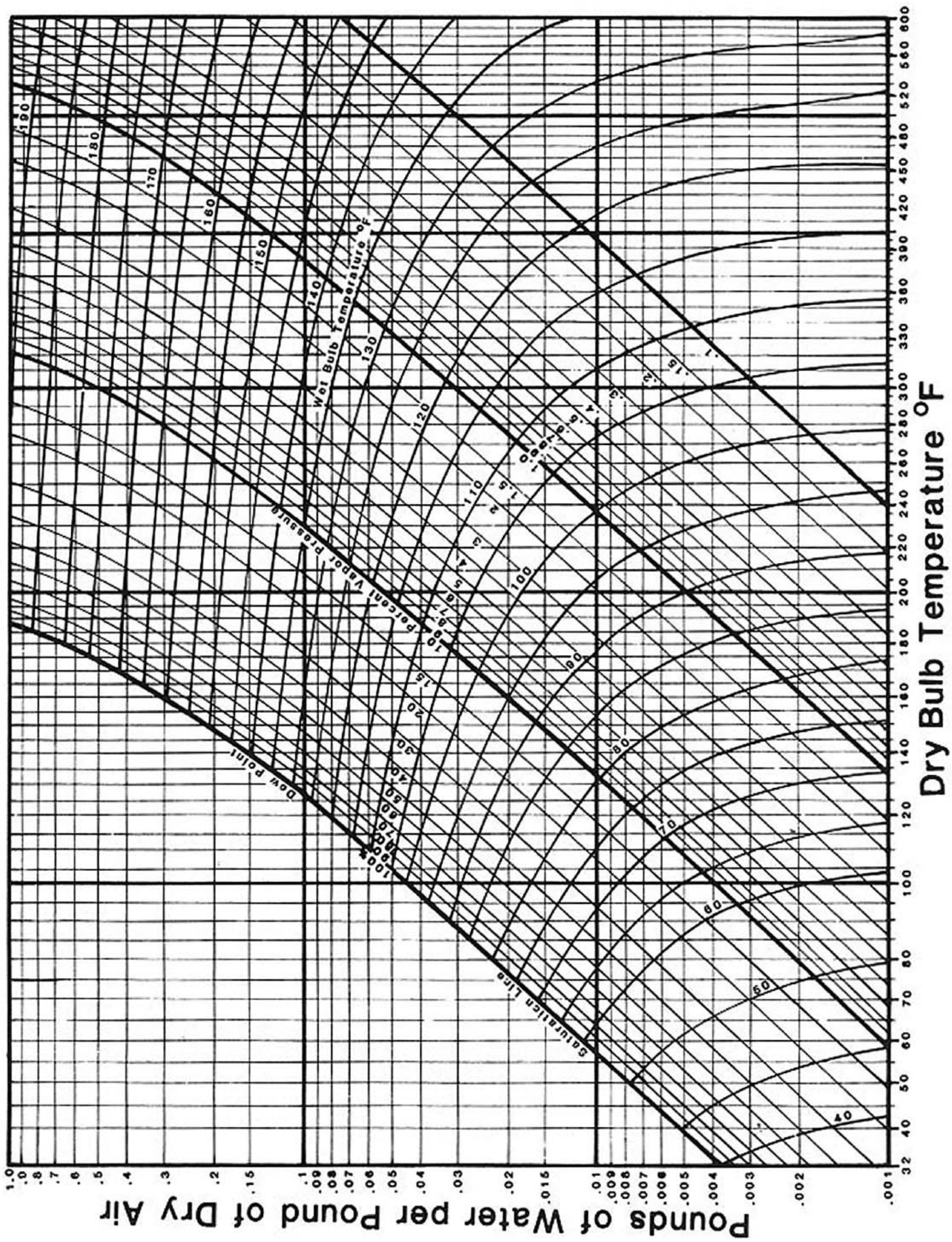
(Continued)

			Flow constants	
Product	*% Solids*	*Temperature °C*	*n (dimensonless)*	*k dyne - dyne · s^n/cm^2*
Peach puree	12	30	0.28	72
		82	0.27	58
Plum juice	14	30	0.34	22
		82	0.34	20
Tomato juice	12.8	32	0.43	20
		82	0.345	31.2
	25	32	0.405	129
		82	0.43	61
	30	32	0.40	187
		82	0.445	79
Tomato catsup (0.15 g tomato solids/g catsup)	36	30	0.441	81

Source: Holdsworth, S. D. Applicability of theological models to the interpretation of flow and processing behavior of fluid food products. J. Tex. Studies 2(4): 393–418, 1971.

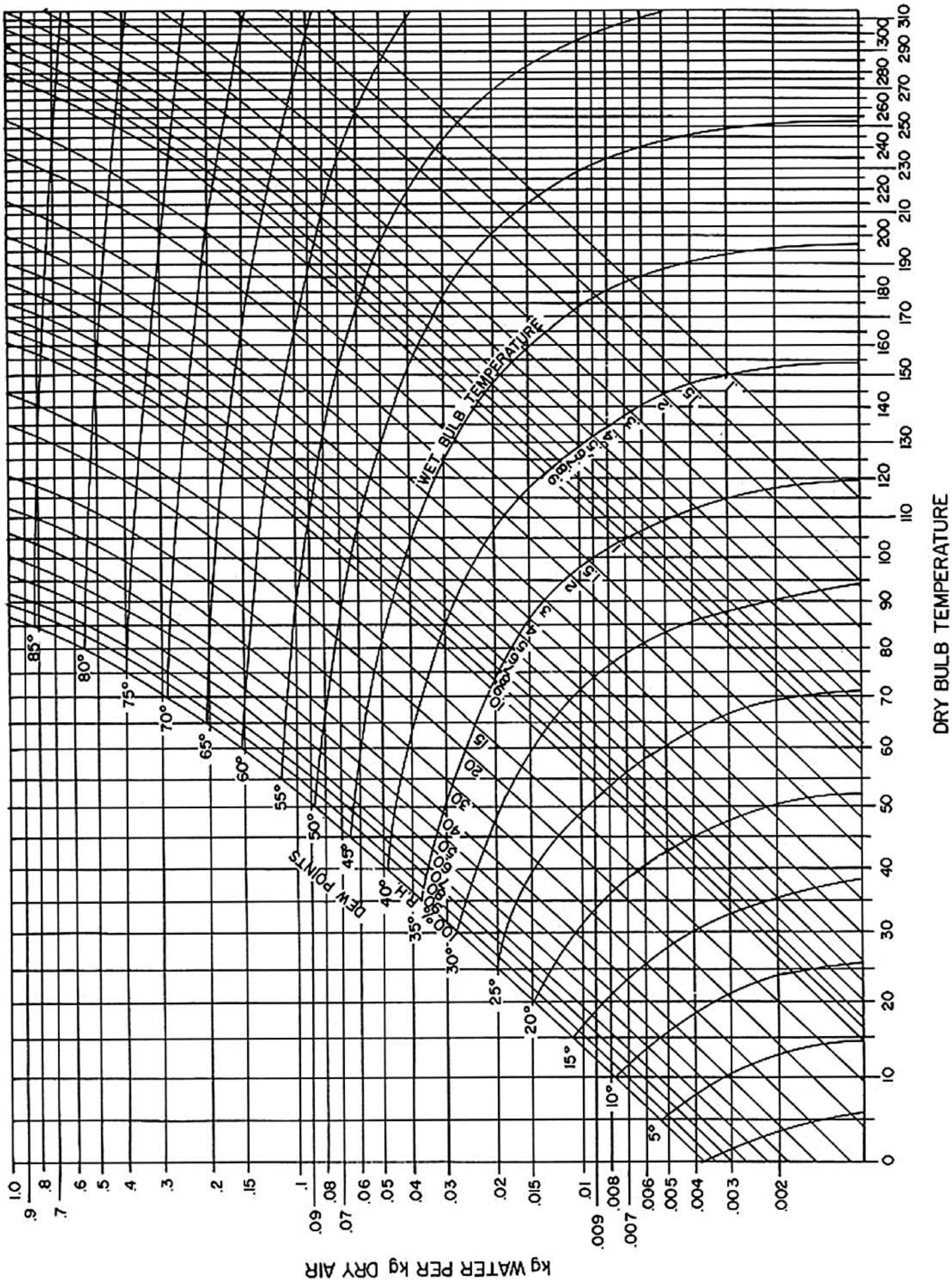
Appendix A.6

Psychrometric Chart: English Units


Dry Bulb Temperature °F
Pounds of Water per Pound of Dry Air
Wet Bulb Temperature °F
Percent Vapor Pressure
Dew Point
Saturation Line

Appendix A.7

Psychrometric Chart: Metric Units


DRY BULB TEMPERATURE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310
kg WATER PER kg DRY AIR
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .15 .1 .09 .08 .07 .06 .05 .04 .03 .02 .015 .01 .009 .008 .007 .006 .005 .004 .003 .002
WET BULB TEMPERATURE
DEW POINTS
R.H.
85° 80° 75° 70° 65° 60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10° 5°

APPENDIX A.8

Average Composition of Foods, In Per Cent (From USDA Handbook 8)

Product	Water	Protein	Fat	Carbohydrate	Fiber	Ash
Sausage						
Beef Bologna	55.3	12.2	28.5	0.8	0	3.2
B/P Bologna	54.3	11.7	28.3	2.8	0	3
Pork Bologna	60.6	15.3	19.9	0.73	0	3.5
Beef Franks	54.7	12	28.5	1.8	0	2.9
B/P Franks	53.9	11.3	29.2	2.6	0	3.2
Chick. Franks	57.5	12.9	19.5	6.8	0	3.3
Turkey Franks	63	14.3	17.7	1.5	0	3.5
Canned Chopped Ham,	60.8	16.1	18.8	0.3	0	4.1
Sliced Ham (Ex. Lean)	70.5	19.4	5	1	0	4.2
Sliced Ham (Reg.)	64.6	17.6	10.6	3.1	0	4.1
Salami, Beef (Cooked)	59.3	14.7	20.1	2.5	0	4.4
Salami, Pork, Dry	36.2	22.6	33.7	1.6	0	5.9
Salami, B/F, Dry	34.7	22.9	34.4	2.6	0	5.5
Smoked Link Sausage	52.2	13.4	30.3	1.4	0	2.7
Turkey Roll (light meat)	71.6	18.7	7.2	0.5	0	2
Beef						
Brisket (cooked)	44.8	23.5	31.6	0	0	0.85
Brisket (raw)	55.1	16.9	26.5	0	0	0.8
Lean, Prime, Raw	68.6	21.2	9.7	0	0	1
Lean, Prime, Cooked	58.1	29	13	0	0	1.2
Chuck, Raw	61.8	18.5	18.4	0	0	0.9
Chuck, Braised	52.5	29.7	17	0	0	1
Round , Raw	65.9	20.4	11.6	0	0	1
Round , Cooked	58.1	27.4	11.7	0	0	1.3
Top Sirloin, Ch. Raw	62.7	19	16.2	0	0	0.9
Top Sirloin, Ch. Cooked	55.6	27.6	16.7	0	0	1.2
Top Sirloin, Sel. Raw	64.2	19.3	13.8	0	0	1
Top Sirloin, Sel. Cooked	57.6	28	13.9	0	0	1.3

Product	*Water*	*Protein*	*Fat*	*Carbohydrate*	*Fiber*	*Ash*
Gound, Ex-lean, Raw	63.2	18.7	17.1	0	0	0.9
Ground, Ex-lean, Cooked	58.6	24.5	16.1	0	0	0.8
Ground, Reg. Raw	48.9	28.8	21.5	0	0	1.2
Ground, Reg. Cooked	54.2	24.1	20.7	0	0	1
Pork						
Fresh Ham, Raw	64.7	18.7	15.7	0	0	0.9
Fresh Ham, Cooked	56.8	28.9	14.3	0	0	1.1
Loin, Raw	72.2	21.4	5.7	0	0	1.1
Loin, Cooked	61.4	28.6	9.1	0	0	1.4
Poultry						
Chicken Dark, Raw, no Skin	76	20.1	4.3	0	0	0.9
Chicken Dark, Cooked, no Skin	63.1	27.4	9.7	0	0	1
Chicken LT, Raw, no Skin	74.9	23.2	1.7	0	0	1
Chicken, LT, Cooked, no Skin	64.8	30.9	4.5	0	0	1
Turkey, Dark, Raw, no Skin	74.5	20.1	4.4	0	0	0
Turkey, Dark, Cooked, no Skin	63.1	28.6	7.2	0	0	1
Turkey, LT, Raw, no Skin	73.8	23.6	1.6	0	0	1
Turkey, LT, Cooked, no Skin	66.3	29.9	3.2	0	0	1.1
Dairy/Eggs						
Butter	15.9	0.9	81.1	0.1	0	2.1
Cheese, Cheddar	36.8	24.9	33.1	1.3	0	3.9
Cream, Half&Half	80.6	3	11.5	4.3	0	0.7
Cream, Whipping, Lt	63.5	2.2	30.9	3	0	0.5
Cream Whipping, Heavy	57.7	2.1	37	2.8	0	0.5
Egg, Whole	75.3	12.5	10	1.2	0	0.9
Egg, White	87.8	10.5	0	1	0	0.6
Egg, Yolk	48.8	16.8	30.9	1.8	0	1.8
Milk, Whole	88	3.3	3.4	4.7	0	0.7
Milk, Skim	90.8	3.4	0.2	4.9	0	0.8
Whey, acid	93.4	0.8	0.1	5.1	0	0.6
Whey, sweet	93.1	0.9	0.4	5.1	0	0.5
Fish/Shellfish						
Catfish Raw	75.4	15.6	7.6	0	0	1
Catfish Cooked	71.6	18.7	8	0	0	1.2
Cod, Raw	81.2	17.8	0.7	0	0	1.2
Cod, Cooked	75.9	22.8	0.9	0	0	1.5
Halibut, Raw	77.9	20.8	2.3	0	0	1.4
Halibut, Cooked	71.7	26.7	2.9	0	0	1.7
Mackerel, Raw	63.6	18.6	13.9	0	0	1.4
Mackerel, Cooked	53.3	23.9	17.8	0	0	1.5
Salmon, Farmed, Raw	68.9	19.9	10.9	0	0	1.1
Salmon, Farmed, Cooked	64.8	22.1	12.4	0	0	1.2
Shrimp, Raw	75.9	20.3	1.7	0.9	0	1.2
Shrimp, Steamed	77.3	20.9	1.1	0	0	1.6
Oyster, Raw	85.2	7.1	2.5	3.9	0	1.4

Product	Water	Protein	Fat	Carbohydrate	Fiber	Ash
Oyster, Steamed	70.3	14.1	4.9	7.8	0	2.8
Vegetables/Fruits						
Beans, Lima, Raw	70.2	6.8	0.9	20.2	1.9	1.9
Beans, Lima, Boiled	67.2	6.8	0.3	23.6	2.1	2.1
Beans, Snap, Raw	90.3	1.8	0.1	7.1	1.1	0.7
Beans, Snap, Boiled	89.2	1.9	0.3	7.9	1.4	0.7
Beets, Raw	87.6	1.6	0.2	0.6	0.8	1.1
Beets, Boiled	87.1	1.7	0.2	10	0.8	1.1
Carrots, Raw	87.8	1	0.2	10.1	1	0.9
Carrots, Boiled	87.4	1.1	0.2	10.5	1.5	0.9
Potatoes, Raw (Flesh)	79	2.1	0.1	18	0.4	0.9
Potatoes, Baked (Flesh)	75.4	2	0.1	21.6	0.4	1
Fruits/Juices						
Apples	83.9	0.2	0.4	15.3	0.8	0.3
Apple Juice, Bottled	87.9	0.1	0.1	11.7	0.2	0.2
Apricots	86.4	1.4	0.4	11.1	0.6	0.8
Avocados	72.6	2.1	17.3	6.9	2.1	1.1
Bananas	74.3	1	0.5	23.4	0.5	0.8
Cherries, Sour	86.1	1	0.3	12.2	0.2	0.4
Cherries, Sweet	80.8	1.2	1	16.6	0.4	0.5
Grapefruit, white	90.5	0.7	0.1	8.4	0.2	0.3
Grapefruit juice	90	0.5	0.1	9.2	0	0.2
Grape	81.3	0.6	0.4	17.2	0.8	0.6
Grape Juice	84.1	0.6	0.1	15	0	0.3
Peach	87.7	0.7	0.1	11.1	0.6	0.5
Pears	83.8	0.4	0.4	15.1	1.4	0.3
Pineapple	86.5	0.4	0.4	12.4	0.5	0.3
Strawberries	91.6	0.6	0.4	7	0.5	0.4

Appendix A.9

Thermal Conductivity of Construction and Insulating Materials

	$\frac{BTU}{h(ft)(^\circ F)}$	$\frac{W}{m(K)}$
Building materials		
Asbestos cement boards	0.43	0.74
Building brick	0.40	0.69
Building plaster	0.25	0.43
Concrete	0.54	0.93
Concrete blocks		
Two oval core, 8 in. thick	0.60	1.04
Two rectangular core, 8 in. thick	0.64	1.11
Corkboard	0.025	0.043
Felt (wool)	0.03	0.052
Glass	0.3–0.61	0.52–1.06
Gypsum or plasterboard	0.33	0.57
Wood (laminated board)	0.045	0.078
Wood (across grain, dry)		
Maple	0.11	0.19
Oak	0.12	0.21
Pine	0.087	0.15
Wood (plywood)	0.067	0.12
Rubber (hard)	0.087	0.15
Insulating materials		
Air		
32°F (0°C)	0.014	0.024
212°F (100°C)	0.0183	0.032
392°F (200°C)	0.0226	0.039

(Continued)

	$\frac{BTU}{h(ft)(^\circ F)}$	$\frac{W}{m(K)}$
Fiberglass (9 lb/ft density)	0.02	0.035
Polystyrene		
2.4 lb/ft density	0.019	0.032
2.9 lb/ft density	0.015	0.026
1.6 lb/ft density	0.023	0.040
Polyurethane (5–8.5 lb/ft density)	0.019	0.033
Hog hair with asphalt binder		
(8.5 lb/ft density)	0.028	0.048
Mineral wool with binder	0.025	0.043
Metals		
Aluminum		
32°F (0°C)	117	202
212°F (100°C)	119	205
572°F (300°C)	133	230
Cast iron		
32°F (0°C)	32	55
212°F (100°C)	30	52
572°F (300°C)	26	45
Copper		
32°F (0°C)	294	509
212°F (100°C)	218	377
572°F(300°C)	212	367
Steel (carbon)		
212°F (100°C)	26	45
572°F (300°C)	25	43
Steel, stainless type 304 or 302	10	17
Steel, stainless type 316	9	15

APPENDIX A.10

Thermal Conductivity of Foods

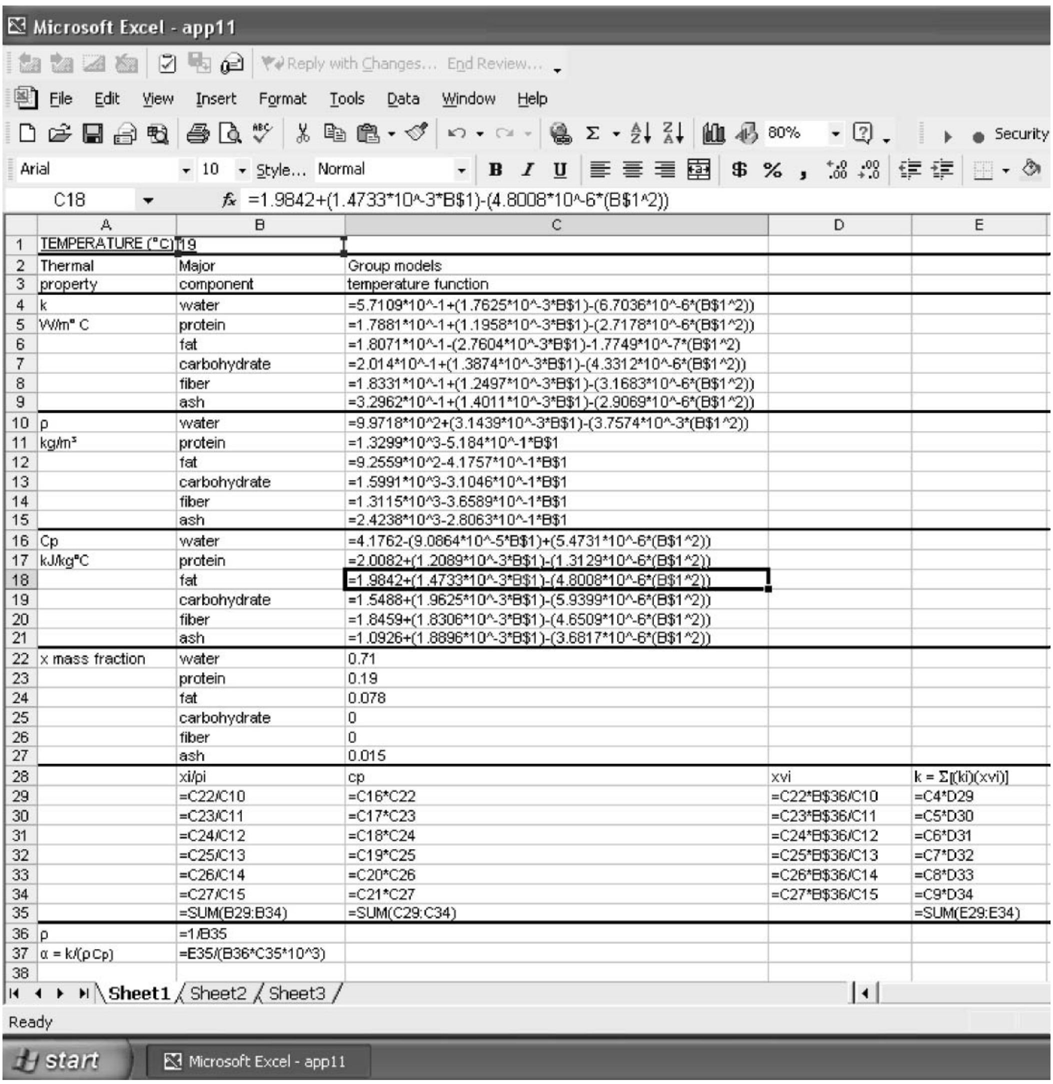
Food	*Temp.* $^\circ C$	*Thermal conductivity* $W/(m \cdot K)$
Apple juice	80	0.6317
Applesauce	29	0.5846
Avocado	—	0.4292
Banana	—	0.4811
Beef	5	0.5106
	10	0.5227
Beets	28	0.6006
Broccoli	−6.6	0.3808
Butter	—	0.1972
Butterfat	−10.6 to 10	0.1679
Cantaloupe	—	0.5711
Carrots		
Fresh	—	0.6058
Puree	—	1.263
Corn		
Yellow	—	0.1405
Dent	—	0.577
Egg white	—	0.338
Egg yolk	2.8	0.5435
Fish	−10	1.497
Cod	3.9	0.5019
Salmon	−2.5	1.2980
Gooseberries	—	0.2769
Dry	—	0.3288
Wet	—	0.0277
Frozen		
Lemon	—	1.817
Limes		
Peeled	—	0.4900
Margarine	—	0.2340
Milk		
3% fat	—	0.5296
2.5% fat	20	0.05054
Oatmeal, dry	—	0.6404
Olive oil	5.6	0.1887
	100	0.1627
Onions	8.6	0.5746
Oranges		
peeled	28	0.5800
Orange juice	−18	2.3880
Peaches	28	0.5815
Peanut oil	3.9	0.1679
Pear	8.7	0.5954
Pear juice	20	0.4760
	80	0.5365
Peas	2.8–	
Blackeye	16.7	0.3115
Pineapple	—	0.5486
Plums	—	0.5504
Pork	6	0.4881
	59.3	0.5400
Potato, raw	—	0.554
Poultry, broiler	—	0.4119

(Continued)

Food	*Temp. °C*	*Thermal conductivity W/(m · K)*	*Food*	*Temp. °C*	*Thermal conductivity W/(m · K)*
Grapefruit	—	1.3500	Sesame oil	—	0.1755
Mashed			Strawberries	13.3	0.6750
Honey		0.5019		−12.2	1.0970
80% water	2	0.5019	Tomato	—	0.5279
80% water	69	0.6230	Turkey	2.8	0.5019
14.8% water	69	2.4230		−10	1.461
Ice	−25	0.4500	Turnips	—	0.5625
Lamb	5.5	0.4777			
	61.1				

Source: Excerpted from *Food Technol*. 34(11): 76–94, 1980.

Spreadsheet Program for Calculating Thermophysical Properties of Foods from Their Composition



Microsoft Excel - app11

C18 fx =1.9842+(1.4733*10^-3*B$1)-(4.8008*10^-6*(B$1^2))

	A	B	C	D	E
1	TEMPERATURE (°C)	19			
2	Thermal	Major	Group models		
3	property	component	temperature function		
4	k	water	=5.7109*10^-1+(1.7625*10^-3*B$1)-(6.7036*10^-6*(B$1^2))		
5	W/m° C	protein	=1.7881*10^-1+(1.1958*10^-3*B$1)-(2.7178*10^-6*(B$1^2))		
6		fat	=1.8071*10^-1-(2.7604*10^-3*B$1)-1.7749*10^-7*(B$1^2)		
7		carbohydrate	=2.014*10^-1+(1.3874*10^-3*B$1)-(4.3312*10^-6*(B$1^2))		
8		fiber	=1.8331*10^-1+(1.2497*10^-3*B$1)-(3.1683*10^-6*(B$1^2))		
9		ash	=3.2962*10^-1+(1.4011*10^-3*B$1)-(2.9069*10^-6*(B$1^2))		
10	ρ	water	=9.9718*10^2+(3.1439*10^-3*B$1)-(3.7574*10^-3*(B$1^2))		
11	kg/m³	protein	=1.3299*10^3-5.184*10^-1*B$1		
12		fat	=9.2559*10^2-4.1757*10^-1*B$1		
13		carbohydrate	=1.5991*10^3-3.1046*10^-1*B$1		
14		fiber	=1.3115*10^3-3.6589*10^-1*B$1		
15		ash	=2.4238*10^3-2.8063*10^-1*B$1		
16	Cp	water	=4.1762-(9.0864*10^-5*B$1)+(5.4731*10^-6*(B$1^2))		
17	kJ/kg°C	protein	=2.0082+(1.2089*10^-3*B$1)-(1.3129*10^-6*(B$1^2))		
18		fat	=1.9842+(1.4733*10^-3*B$1)-(4.8008*10^-6*(B$1^2))		
19		carbohydrate	=1.5488+(1.9625*10^-3*B$1)-(5.9399*10^-6*(B$1^2))		
20		fiber	=1.8459+(1.8306*10^-3*B$1)-(4.6509*10^-6*(B$1^2))		
21		ash	=1.0926+(1.8896*10^-3*B$1)-(3.6817*10^-6*(B$1^2))		
22	x mass fraction	water	0.71		
23		protein	0.19		
24		fat	0.078		
25		carbohydrate	0		
26		fiber	0		
27		ash	0.015		
28		xi/ρi	cp	xvi	k = Σ[(ki)(xvi)]
29		=C22/C10	=C16*C22	=C22*B$36/C10	=C4*D29
30		=C23/C11	=C17*C23	=C23*B$36/C11	=C5*D30
31		=C24/C12	=C18*C24	=C24*B$36/C12	=C6*D31
32		=C25/C13	=C19*C25	=C25*B$36/C13	=C7*D32
33		=C26/C14	=C20*C26	=C26*B$36/C14	=C8*D33
34		=C27/C15	=C21*C27	=C27*B$36/C15	=C9*D34
35		=SUM(B29:B34)	=SUM(C29:C34)		=SUM(E29:E34)
36	ρ	=1/B35			
37	α = k/(ρCp)	=E35/(B36*C35*10^3)			
38					

APPENDIX A.12

Correlation Equations for Heat Transfer Coefficients

Correlation equations for heat transfer coefficients:

Very viscious fluids flowing inside horizontal tubes

$$Nu = 1.62\left[prRe\frac{d}{L}\right]^{0.33}[1 + 0.015(Gr)^{0.33}]\left[\frac{\mu_f}{\mu_n}\right]^{0.33}$$

Very viscous fluids flowing inside vertical tubes

$$\mathrm{Nu} = 0.255Gr^{0.25}Re^{0.07}Pr^{0.37}$$

Fluids in laminar flow inside bent tubes

$$h = h_r\left[\frac{1+21}{Re^{0.14}}\right]\left[\frac{d}{D}\right]$$

$h_r = h$ in straight tube, $d =$ tube diameter, $D =$ diameter of curvature of bend.

Evaporation from heat exchange surfaces

$$\frac{q}{A} = 15.6P^{1.156}(T_w - T_s)^{2.30/p^{0.24}}$$

$q/A =$ heat flux, $T_w =$ wall temperature, $T_s =$ saturated temperature of vapor at pressure P.

Condensing vapors outside vertical tubes

$$Nu_L = 0.925\left[\frac{L^3\rho^2 g\lambda}{\mu k\Delta T}\right]^{0.25}$$

Condensation outside horizontal tubes

$$Nu_{D0} = 0.73\left[\frac{Do^3\rho^2 g\lambda}{k\mu\Delta T}\right]^{0.25}$$

Condensation inside horizontal tubes

$$Nu_{Di} = 0.612\left[\frac{Di^3\rho_1(\rho_1 - \rho_v)g}{k\mu\Delta T}\right]^{0.25}$$

Condensation inside horizontal tubes

$$Nu_{Di} = 0.024(Re)^{0.8}(Pr)^{0.43}\rho_{corr}$$

Re is based on the total mass of steam entering the pipe. $\rho_{corr} = [0.5/\rho_i](\rho_1 - \rho_v)(x_t - x_0).x =$ steam quality, subscripts *i* and *o* refer to inlet and exit, and 1 and *v* refer to condensate and vapor.
Fluids in cross-flow to a bank of tubes
Re is based on fluid velocity at the entrance to the tube bank.

Tubes in line: $a =$ diameter to diameter distance between tubes.

$$Nu = [1.517 + 205Re^{0.38}]^2\left[\frac{4a}{(4a-\pi)}\right]$$

Tubes staggered, hexagonal centers; $a =$ distance between tube rows.

$$Nu = [1.878 + 0.256Re^{0.36}]\left[\frac{4a}{(4a-\pi)}\right]$$

Laminar flow in annuli

$$Nu = 1.02Re^{0.45}Pr^{0.5}\left(\frac{De}{L}\right)^{0.4}\left(\frac{D_2}{D_1}\right)^{0.8}Gr^{0.05}\left(\frac{\mu}{\mu_1}^{0.14}\right)$$

$De =$ hydraulic diameter; subscripts 1 and 2 refer to outside diameter of inner cylinder and inside diameter of outer cylinder, respectively.

Turbulent flow in annuli

$$Nu = 0.02Re^{0.8}Pr^{0.33}\left(\frac{D_2}{D_1}\right)^{0.53}$$

Finned tubes

Nu_d, Re_d, and A_0 use the outside diameter of the bare tube. $A =$ total area of tube wall and fin.

Tubes in line: $Nu_d = 0.3\,Re_d^{0.625}\left(\frac{A_0}{A}\right)^{0.375}Pr^{0.33}$

Staggered tubes: $Hu_d = 0.45\,Re_d^{0.625}\left(\frac{A_0}{A}\right)^{0.375}Pr^{0.33}$

Swept surface heat exchangers
$N =$ rotational speed of blades, $D =$ inside diameter of heat exchanger, $V =$ average fluid velocity, $L =$ swept surface length.

$$Nu = 4.9Re^{9.57}Pr^{0.47}\left(D\frac{N}{V}\right)^{0.17}\left(\frac{D}{L}\right)^{0.37}$$

Individual particles
The Nusselt number and the Reynolds number are based on the particle characteristic diameter and the fluid velocity over the particle.

Particles in a packed bed: $Nu = 0.015\,Re^{1.6}Pr^{0.67}$

Particles in a gas stream: $Nu = 2 + 0.6\,Re^{0.5}Pr^{0.33}$

Sources: Perry and Chilton, *Chemical Engineers Handbook*, 5th ed., McGraw-Hill Book Co., New York; Rohsenow and Hartnett, *Handbook of Heat Transfer*, McGraw-Hill Book Co., New York; Hausen, *Heat Transfer in Counterflow, Parallel Flow and Cross Flow*, McGraw-Hill Book Co., New York; Schmidt, *Kaltechn.* 15:98, 1963 and 15:370, 1963; Ranz and Marshall, *Chem. Eng. Prog.* 48(3):141 1952.

Appendix A.13

Visual BASIC Program for Evaluating Temperature Response of a Brick-Shaped Solid

```
Option Explicit
Dim X
Dim i As Integer
Dim BI(3) As Single
Dim Delta1(6) As Single
Dim Delta2(6) As Single
Dim Delta3(6) As Single
Dim YS, YC, TS, TC

Const TM = 177
Const T0 = 4
Const L1 = 0.0245
Const L2 = 0.0256
Const L3 = 0.0254
Const H1 = 6.5
Const H2 = 6.5
Const H3 = 6.5
Const K = 0.455
Const Rho = 1085
Const Cp = 4100

Dim TIMX
Dim d1, d2, d3
Dim YS1, YC1, YS2, YC2, YS3, YC3
Dim YXn, YCN, YCXn

Dim test
Dim Numx(6), DeNumx(6)
Dim YX(6), YCX(6)
```

(*Continued*)

```
Dim j As Integer
Dim fh
Dim LPHA As Variant

Sub TEMPSLAB()

LPHA = K / Rho / Cp
Debug.Print "alpha=" & LPHA

Worksheets("sheet1").Cells.Clear
BI(1) = H1 * L1 / K
Debug.Print “BI(1)” & BI(1)

BI(2) = H2 * L2 / K
Debug.Print "bi = " & BI(2)
BI(3) = H3 * L3 / K
Debug.Print "bi =" & BI(3)
Call toexc
j = 1

For TIMX = 0 To 4800 Step 600
Call DELN(BI(1), L1)
YS1 = YXn
YC1 = YCXn
d1 = Delta1(1)

Call DELN(BI(2), L2)
YS2 = YXn
YC2 = YCXn
d2 = Delta1(1)

Call DELN(BI(3), L3)
YS3 = YXn
YC3 = YCXn
d3 = Delta1(1)

YS = YS1 * YS2 * YS3
YC = YC1 * YC2 * YC3

TS = TM - YS * (TM - T0)
TC = TM - YC * (TM - T0)
If TIMX <> 0 Then Debug.Print "TIME =" & TIMX, "TS =" & TS, "TC =" & TC

Call toexcel(j, TIMX / 60, Format(TS, "0.000"), Format(TC, "0.000"))
j = j + 1
Next TIMX
fh = 1 / (LPHA * 0.4343 * ((d1ˆ 2 / L1 ˆ 2) + (d2 ˆ 2 / L2 ˆ 2) + (d3 ˆ 2 / L3 ˆ 2)))
Debug.Print "FH=", fh
Call toexc1(fh, TM, T0, L1, L2, L3)
```

```
End Sub
Sub DELN(BI, L) 'DETERMINE ROOTS OF DELTA1
Delta1(1) = DntanDn(0, 1.57, BI)
Delta1(2) = DntanDn(3.14, 4.71, BI)
Delta1(3) = DntanDn(6.28, 7.85, BI)
Delta1(4) = DntanDn(9.42, 11, BI)
Delta1(5) = DntanDn(12.5, 14.1, BI)
Delta1(6) = DntanDn(15.7, 17.3, BI)

For i = 1 To 6
Numx(i) = 2 * Sin(Delta1(i)) * Cos(Delta1(i))
DeNumx(i) = Delta1(i) + Sin(Delta1(i)) * Cos(Delta1(i))
YX(i) = (Numx(i) / DeNumx(i)) * Exp(-LPHA * TIMX * Delta1(i) ^ 2 / L ^ 2)
YCX(i) = YX(i) / Cos(Delta1(i))

Next i

YXn = YX(1) + YX(2) + YX(3) + YX(4) + YX(5) + YX(6)
YCXn = YCX(1) + YCX(2) + YCX(3) + YCX(4) + YCX(5) + YCX(6)

If YXn > 1 Then YXn = 1
If YCXn > 1 Then YCXn = 1

End Sub
Function DntanDn(Lo, Hi, BI)
Do
X = 0.5 * (Lo + Hi)
test = X * Tan(X) - BI
If test > 0 Then Hi = X Else Lo = X
If Abs(Hi - Lo) < 0.00001 Then GoTo LABEL
Loop While Abs(test) > 0.001
LABEL:
DntanDn = X
End Function

Sub toexc()
With Sheets("sheet1")
.Cells(1, 1).Value = "alpha= "
.Cells(1, 2).Value = LPHA
.Cells(2, 1).Value = "bi(1)"
.Cells(2, 2).Value = BI(1)
.Cells(3, 1).Value = "bi(2)"
.Cells(3, 2).Value = BI(2)
.Cells(4, 1).Value = "(bi(3)"
.Cells(4, 2).Value = BI(3)
.Cells(5, 1).Value = "time": .Cells(5, 2).Value = "tsurf": .Cells(5, 3).Value = "tcent"
End With
End Sub
```

(*Continued*)

```
Sub toexcel(j, tx, surf, cent)
With Sheets("sheet1")
.Cells(j + 5, 1).Value = tx
.Cells(j + 5, 2).Value = surf
.Cells(j + 5, 3).Value = cent
End With
End Sub
Sub toexc1(fh, TM, T0, L1, L2, L3)
With Sheets("sheet1")
.Cells(j + 5, 1).Value = "fh = ": .Cells(j + 5, 2).Value = fh
.Cells(j + 6, 1).Value = "Tm = ": .Cells(j + 6, 2).Value = TM
.Cells(j + 7, 1).Value = "T0 = ": .Cells(j + 7, 2).Value = T0
.Cells(j + 8, 1).Value = "L1 =": .Cells(j + 8, 2) = L1
.Cells(j + 9, 1).Value = "L2 = ": .Cells(j + 9, 2).Value = L2
.Cells(j + 10, 1).Value = "L3 = ": .Cells(j + 10, 2).Value = L3
End With
End Sub
```

Appendix A.14

Visual BASIC Program for Evaluating Local Heat Transfer Coefficient from Temperature Response of a Brick-Shaped Solid

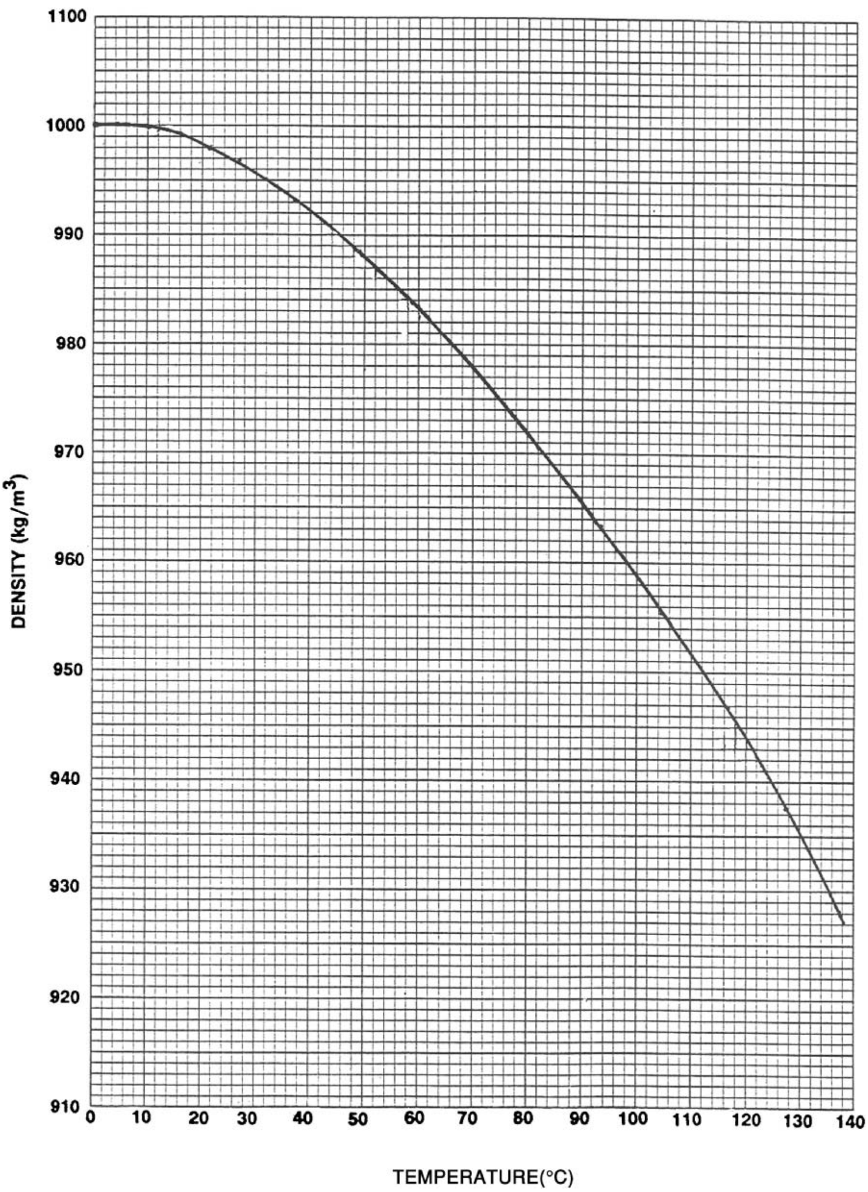
```
Sub localh()
'calculate h from Fh
Fh = 33596
L1 = 0.0254
L2 = 0.0508
L3 = 0.1016
k = 0.455
RHO = 10855
Cp = 4100
ALPHA = k / (RHO * Cp)
h = 375
Do
Bi1 = h * L1 / k
Bi2 = h * L2 / k
Bi3 = h * L3 / k
Delta1 = getDelta(Bi1)
Delta2 = getDelta(Bi2)
Delta3 = getDelta(Bi3)
testfh2 = testfh
testfh = 1 − (Fh * ALPHA * 0.4343 * ((Delta1 ^ 2 / L1 ^ 2) + (Delta2 ^ 2 /
L2 ^ 2) + (Delta3  2 ^ L3 ^ 2)))
If testfh > 0 Then dh = 0.001 Else dh = −0.001
h = h + dh
Debug.Print h, testfh
If testfh2 <> Empty Then If testfh / testfh2 < 0 Then Exit Do
```

```
Loop While Abs(testfh) > 0.01
MsgBox ″Heat transfer coef, H Test″ & Chr(13) & h − dh & ″ ″ &
testfh2 & Chr(13) & h & ″ ″ & testfh

End Sub
Function getDelta(Bi)
Lo = 0
Hi = 2
Do
x = 0.5 * (Lo + Hi)
Test = x * Tan(x) − Bi
If Test > 0 Then Hi = x Else Lo = x
If Abs(Hi - Lo) < 0.00001 Then Exit Do
Loop
getDelta = x
End Function
```

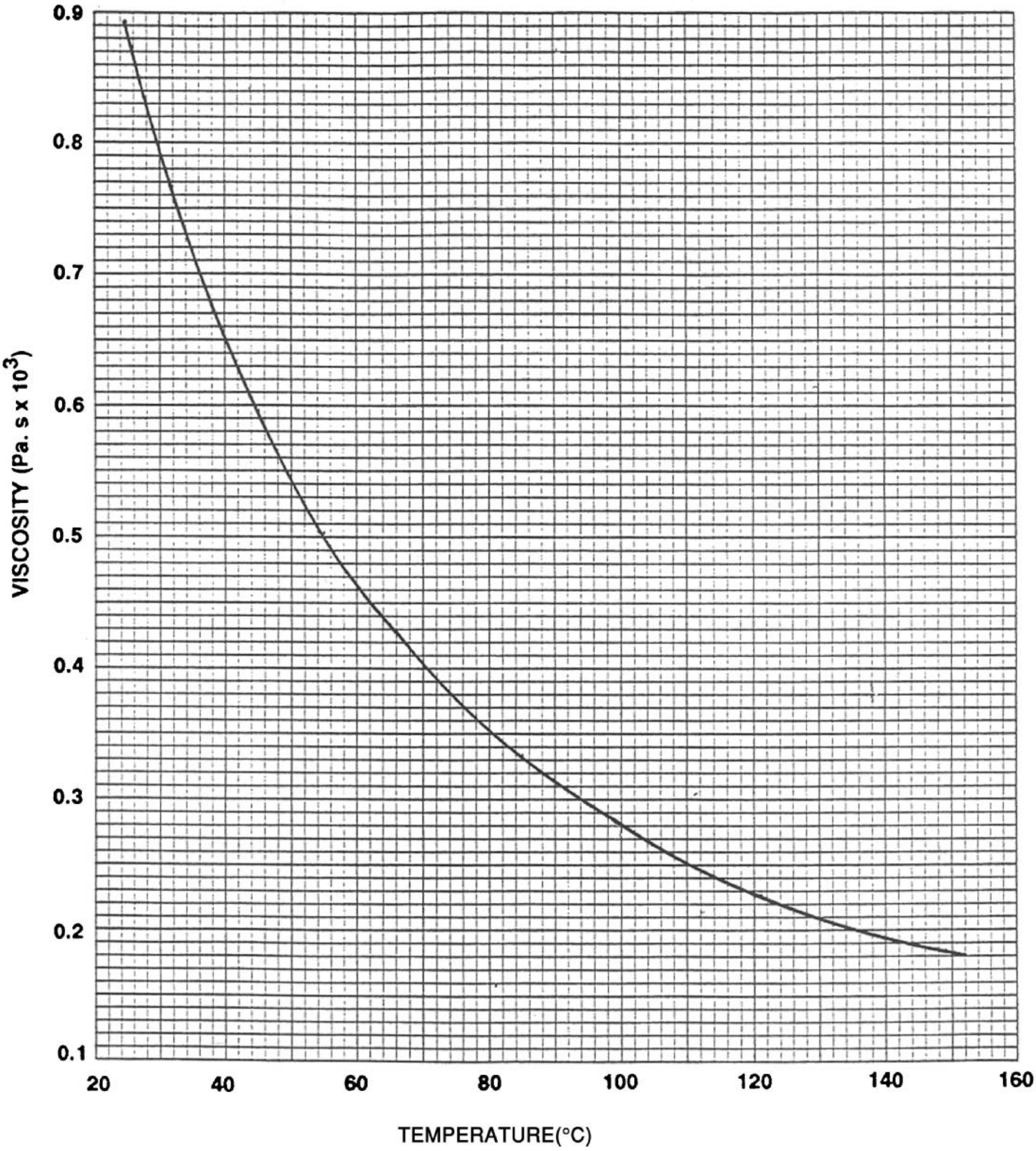
Appendix A.15

Thermal Conductivity of Water as a Function of Temperature


1100
1000
990
980
970
960
950
940
930
920
910
DENSITY (kg/m3)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TEMPERATURE(°C)

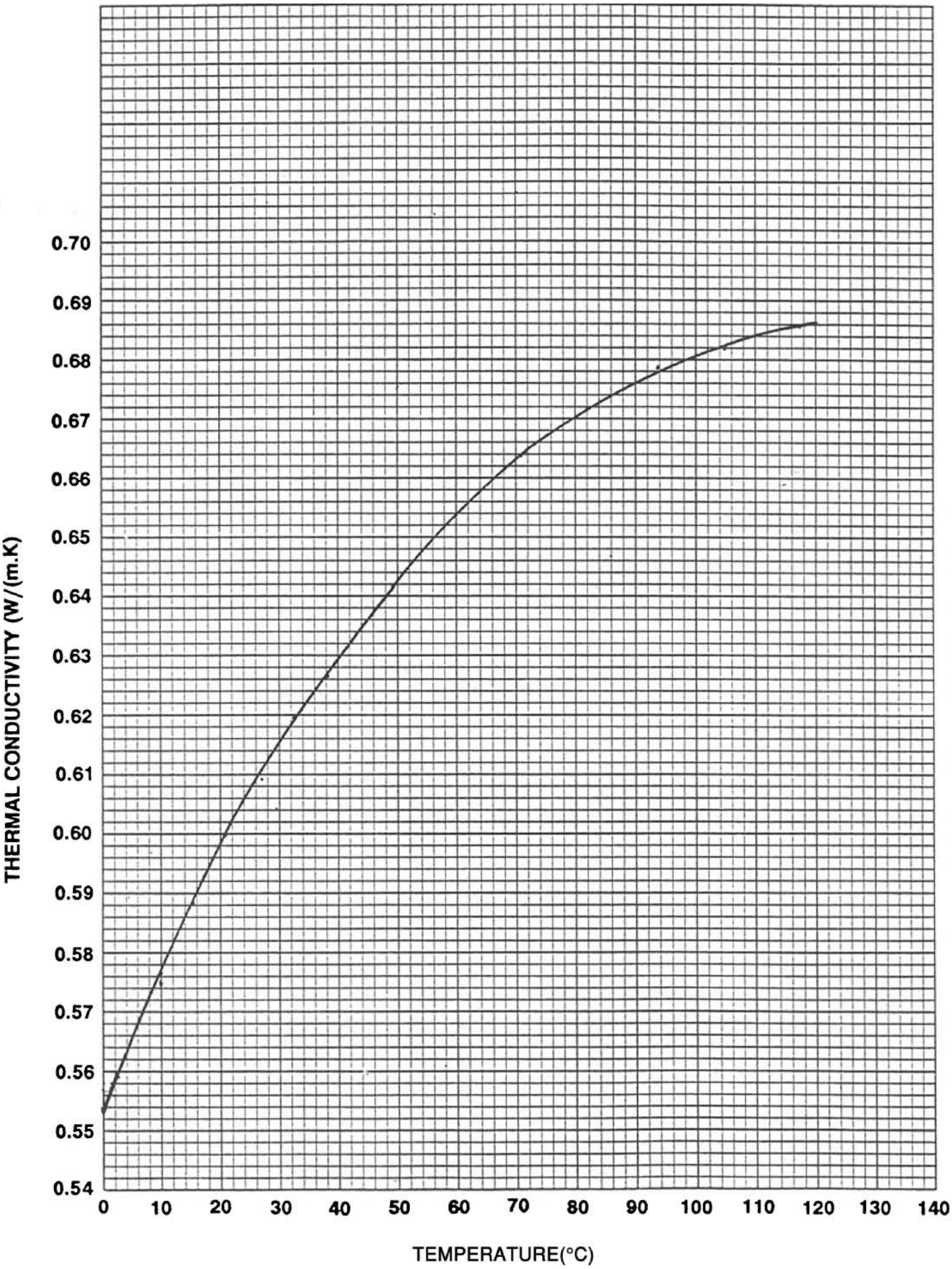
Appendix A.16

Density of Water as a Function of Temperature


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
VISCOSITY (Pa. s x 10³)
20
40
60
80
100
120
140
160
TEMPERATURE(°C)

Appendix A.17

Viscosity of Water as a Function of Temperature


0.70
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.60
0.59
0.58
0.57
0.56
0.55
0.54
THERMAL CONDUCTIVITY (W/(m.K)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TEMPERATURE(°C)

Index