Appendix A tables A.5-A.10 from L. R. Wilhelm, D. A. Suter, and G. H. Brusewitz. 2004. Food & Process Engineering Technology. ASABE.

A Precautionary Note!

This appendix contains tables listing selected properties of biological materials. We know that there is great variability in biological materials. Thermal and mechanical properties of apples, for example, vary greatly with maturity, and also among cultivars. Two apples of the same apparent maturity, harvested from the same tree at the same time, will almost certainly have somewhat different properties. Keep this variability in mind as you use the tables in this appendix. Some property values may be expressed to as many as four significant digits. However, actual values for any give sample of the material may differ from these tabulated values by 10%, 20%, or more, depending upon the product and the property being measured.

Table A.5. Thermal properties of selected food products.

Commodity	% water	Sp. Heat at Freezing: Above (kJ/kg K)	Sp. Heat at Freezing: Below (kJ/kg K)	Freezing Point (°C)	Latent Heat of Fusion† (kJ/kg)
Vegetables					
Asparagus	92.4	3.94	2.01	-0.6	310
Beans, snap	90.3	3.94	2.39	-0.7	303
Brussels sprouts	86.0	3.68	1.67	-0.8	288
Cabbage	92.2	3.94	1.97	-0.9	309
Carrots	87.8	3.77	1.93	-1.4	294
Cauliflower	91.9	3.89	1.97	-0.8	308
Corn, sweet yellow	76.0	3.32	1.77	-0.6	255
Lettuce, iceberg	95.9	4.02	2.01	-0.2	321
Onions	89.7	3.77	1.93	-0.9	300
Peas, green	78.9	3.31	1.76	-0.6	264
Peppers, sweet green	92.2	3.94	1.97	-0.7	309
Potatoes, main crop	79.0	3.63	1.82	-0.6	265
Potatoes, sweet	72.8	3.14	1.68	-1.3	244
Tomatoes, mature green	93.0	3.98	2.01	-0.6	312
Tomatoes, ripe	93.8	3.98	2.01	-0.5	314
Fruits					
Apples, dried	31.8	2.27	1.14	-	107
Apples, fresh	83.9	3.60	1.84	-1.1	281
Apricots	86.3	3.68	1.93	-1.1	289
Bananas	74.3	3.35	1.76	-0.8	249
Blackberries	85.6	3.68	1.68	-0.8	287
Blueberries	84.6	3.60	1.88	-1.6	283
Oranges	82.3	3.77	1.93	-0.8	276
Peaches, fresh	87.7	3.77	1.93	-0.9	294
Raisins, seedless	15.4	1.97	1.07		52
Strawberries	91.6	3.89	1.94	-0.8	307
Meats					
Beef, sirloin, lean	71.7	3.08	1.55	-1.7	240
Beef, veal, lean	75.9	3.35	1.93		254
Bacon	31.6	2.09	1.26		106
Ham, country cured	55.9	2.72	1.37		187
Shoulder, whole lean	72.6	2.90	1.46	-2.2	243
Chicken	66.0	3.31	1.55	-2.8	221
Salmon, pink	76.4	2.97	1.63	-2.2	256
Dairy					
Butter	17.9	1.38	1.05		60
Cheese, cheddar	36.8	2.60	1.31	-12.9	123

Commodity	% water	Sp. Heat at Freezing		Freezing Point (°C)	Latent Heat of Fusion† (kJ/kg)
		Above (kJ/kg K)	Below (kJ/kg K)		
Cream, half and half	80.6	3.68	1.85		270
Ice cream, vanilla	61.0	3.27	1.88	-5.6	204
Milk, skim	90.8	4.00	2.51		304
Milk, whole	87.7	3.85	1.94	-0.6	294
Other					
Eggs, whole	75.3	3.18	1.68	-0.6	252
Honey‡	17.1	2.10	1.68		57
Maple syrup	32.0	2.05	1.30		107
Orange Juice	89.0	3.82	1.96	-0.4	298
Pecans	4.8	1.75	0.88		16

*Properties of selected commodities taken from ASHRAE. 1998. ASHRAE Handbook of Refrigeration, Chapter 8. Courtesy of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

†Computed from product of the latent heat of fusion (335 kJ/kg) and the moisture content shown (in decimal form).

‡Specific heat values for honey were taken from ASHRAE. 1993. ASHRAE. Handbook of Fundamentals, Chapter 30.

Table A.6. Composition of selected fruit products[*].

Product	Percent Mass[†]						Energy[§] (kJ/100g)
	Water	Protein	Fat	Carbo-hydrate	Fiber[‡]	Ash	
Apples, raw, with skin	83.93	0.19	0.36	15.25	0.77	0.26	245
Apples, dried, sulfured, uncooked	31.76	0.93	0.32	65.89	2.87	1.10	1,017
Applesauce, unsweetened	88.35	0.17	0.05	11.29	0.53	0.15	181
Applesauce, sweetened	79.58	0.18	0.18	19.91	0.46	0.14	318
Bananas, raw	74.26	1.03	0.48	23.43	0.50	0.80	384
Blueberries, raw	84.61	0.67	0.38	14.13	1.30	0.21	236
Blueberries, frozen, unsweetened	86.59	0.42	0.64	12.17	1.50	0.18	212
Dates	22.50	1.97	0.45	73.51	2.20	1.58	1,151
Melons, cantaloupe, raw	89.78	0.88	0.28	8.36	0.36	0.71	148
Oranges, raw	86.75	0.94	0.12	11.75	0.43	0.44	197
Peaches, raw	87.66	0.70	0.09	11.10	0.64	0.46	180
Peaches, canned, water pack	93.13	0.44	0.06	6.11	0.31	0.27	100
Peaches, canned, heavy syrup	79.28	0.45	0.10	19.94	0.29	0.24	310
Peaches, dehydrated, sulfured, cooked	62.04	2.01	0.42	34.14	1.63	1.39	557
Pears, raw	83.81	0.39	0.40	15.11	1.40	0.28	247
Strawberries, raw	91.57	0.61	0.37	7.02	0.53	0.43	127
Strawberries, frozen, unsweetened	89.97	0.43	0.11	9.13	0.79	0.37	147
Watermelon, raw	91.51	0.62	0.43	7.18	0.30	0.26	132

[*]From Gebhardt, Cutrufelli, and Matthews. 1982. Composition of Foods: Fruits and Fruit Juices. Agricultural Handbook Number 8-9, USDA, GPO, Washington.

[†]Rounded to two decimal places. The sum of values may not always be 100%.

[‡]Fiber is included in the carbohydrate value. Thus, values in this column should not be added separately to obtain the 100% total content.

[§]The energy value provided is physiological energy. Some energy is required for metabolism and for digestion of the product. The energy remaining after these losses is the physiological energy.

Table A.7. Composition of selected vegetable products[*].

Product	Percent Mass[†]						Energy[§]
	Water	Protein	Fat	Carbo-hydrate	Fiber[‡]	Ash	(kJ/100g)
Beans, snap, raw	90.27	1.82	0.12	7.14	1.10	0.66	129
Beans, snap, cooked, boiled, drained	89.22	1.89	0.28	7.89	1.43	0.73	147
Broccoli, raw	90.69	2.98	0.35	5.24	1.11	0.92	116
Broccoli, cooked, boiled, drained	90.20	2.97	0.28	5.57	1.20	0.99	123
Broccoli, frozen, chopped	91.46	2.81	0.29	4.79	1.10	0.66	110
Cabbage, raw	92.52	1.21	0.18	5.37	0.80	0.72	99
Cabbage, cooked, boiled, drained	93.60	0.96	0.25	4.77	0.60	0.43	90
Carrots, raw	87.79	1.03	0.19	10.14	1.04	0.87	181
Carrots, cooked, boiled, drained	87.38	1.09	0.18	10.48	1.47	0.87	188
Carrots, frozen, cooked, boiled, drained	89.88	1.19	0.11	8.25	1.18	0.58	150
Corn, sweet, raw	75.96	3.22	1.18	19.02	0.70	0.62	358
Corn, sweet, cooked, boiled, drained	69.57	3.32	1.28	25.11	0.60	0.72	454
Corn, sweet, canned, solids and liquid	81.90	1.94	0.45	14.83	0.49	0.89	257
Corn, sweet, canned, cream style	78.73	1.74	0.42	18.13	0.49	0.98	303
Corn, sweet, frozen, kernels, cut off cob, unprepared	74.92	3.02	0.77	20.80	0.62	0.48	369
Okra, raw	89.58	2.00	0.10	7.63	0.94	0.70	158
Okra, cooked, boiled, drained	89.91	1.87	0.17	7.21	0.90	0.84	133
Okra, frozen, unprepared	90.82	1.69	0.25	6.64	0.83	0.61	125
Onions, raw	90.82	1.18	0.26	7.32	0.44	0.42	141
Potatoes, raw, fresh	78.96	2.07	0.10	17.98	0.44	0.89	331
Potatoes, baked, flesh and skin	71.20	2.30	0.10	25.23	0.66	1.16	456
Potatoes, baked, flesh	75.42	1.96	0.10	21.56	0.38	0.97	390
Potatoes, baked, skin	47.31	4.29	0.10	46.07	2.28	2.24	830
Potatoes, mashed, from dehydrated flakes	76.3	1.90	5.60	15.02	0.47	1.18	472
Squash, summer, all varieties, raw	93.68	1.18	0.21	4.35	0.60	0.58	84
Squash, summer, all varieties, cooked, boiled, drained	93.70	0.91	0.31	4.31	0.60	0.77	85
Tomato paste	74.06	3.78	0.89	18.82	0.95	2.45	351
Tomato sauce	89.07	1.33	0.17	7.18	0.71	2.25	127
Tomatoes, green, raw	93.00	1.20	0.20	5.10	0.50	0.50	100
Tomatoes, red, ripe, raw	93.95	0.89	0.21	4.34	0.47	0.61	81
Tomatoes, red, ripe, cooked, boiled	92.40	1.12	0.27	5.63	0.77	0.58	105
Turnip greens, raw	91.07	1.50	0.30	5.73	0.80	1.40	111
Turnip greens, cooked, boiled, drained	93.20	1.14	0.23	4.36	0.61	1.07	85
Turnip greens, canned, solids and liquid	94.69	1.36	0.30	2.42	0.61	1.23	61

[*]From Haytowitz and Matthews. 1984. Composition of Foods: Vegetables and Vegetable Products. Agricultural Handbook Number 8-11, USDA, GPO, Washington.

[†]Rounded to two decimal places. The sum of values may not always be 100%.

[‡]Fiber is included in the carbohydrate value. Thus, values in this column should not be added separately to obtain the 100% total content.

[§]The energy value provided is physiological energy. Some energy is required for metabolism and for digestion of the product. The energy remaining after these losses is the physiological energy.

Table A.8. Heat of respiration for selected fresh fruits and vegetables at various temperatures.

Commodity	0□C	5□C	10□C	15□C	20□C	25□C
Apples, early cultivars	9.7-18	16-32	41-32	54-92	58-121	
Apples, late cultivars	5.3-11	14-21	20-31	28-58	351-386	
Apricots	16-17	19-27	33-56	63-102	303-581	
Asparagus	81-238	162-404	318-904	472-971	809-1484	
Beans, snap		101-104	162-173	252-276	351-386	
Berries, blackberries	47-68	85-136	155-281	208-432	388-582	
Berries, raspberries	52-74	92-114	82-165	244-301	400-727	
Berries, Strawberries	36-52	48-98	146-281	210-274	303-581	501-626
Brussels Spouts	46-71	96-144	187-251	283-317	267-564	
Carrots, Imperator, TX	46	58	93	117	209	
Carrots, Roots, Nantes, Can.	9.2	20		64-84		
Cauliflower, TX	53	61	100	1377	238	
Corn, sweet with husk, TX	126	230	332	483	856	1208
Lettuce, head, CA.	27-50	40-59	81-119	114-121	178	
Lettuce, leaf, TX	68	87	117	187	298	434
Peaches	12-19	19-27		98-126	176-304	242-361
Pears, late ripening	7.8-11	18-41	23-56	82-126	97-218	
Pears, early ripening	7.8-14	22-46	22-63	102-160	116-267	
Peas, green-in pod	90-139	163-226		530-600	728-1072	1018-1118
Tomatoes, TX, mature green				61	103	127 (27□C)
Tomatoes, TX, ripening				79	120	143 (27□C)
Tomatoes, CA, mature green					71-104	89-143

*Properties of selected commodities taken from ASHRAE. 1998. ASHRAE Refrigeration Handbook, Chapter 8. Courtesy of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Table A.9. Thermal properties of selected products.[*]

Product	t (ºC)	k (W/m K)	□ (kg/m^3)	c_p (kJ/kg K)	□ (m^2/s)
Air[†] (at 101.3 kPa)	20	0.024	1.293	1.005	18.6×10^{-6}
Ice[†]	-20	2.43	948	1.95	1.32×10^{-6}
Ice[†]	0	2.22	917	2.10	1.14×10^{-6}
Water[†]	0	0.533	999.8	4.21	0.135×10^{-6}
Water[†]	20	0.599	998.2	4.18[**]	0.143×10^{-6}
Water[†]	100	0.684	958.4	4.21	0.170×10^{-6}
Steam[†] (at 101.3 kPa)	100	0.0242	0.60	2.03	19.0×10^{-6}
Mercury	20	8.2	13 546	0.139	4.36×10^{-6}
Half & half[‡,§]	20	0.47	1025	3.8	0.12×10^{-6}
Milk, whole[‡,§]	20	0.53	1029	3.9	0.13×10^{-6}
Milk, skimmed[‡,§]	20	0.57	1033	3.94	0.14×10^{-6}
Sucrose[||], 20% solution	20	0.535	1079.9	3.72	0.133×10^{-6}
Sucrose[||], 40%	20	0.470	1175.4	3.22	0.124×10^{-6}
Sucrose[||], 60%	20	0.404	1285.4	2.76	0.114×10^{-6}
Beef fat[†]	20	0.18	950	2.00	0.095×10^{-6}
Starch[†]	20	0.15	1500	1.25	0.08×10^{-6}

[*]Based upon data from references identified for each product. Note that thermal properties of milk products are highly variable, depending upon fat content.

[†]Locin, M. and R. L. Merson. 1979. Food Engineering Principles and Selected Applications. Academic Press, New York.

[‡]Wong, N. P. 1988. Fundamentals of Dairy Chemistry. Van Nostrand Reinhold Co., New York.

[§]Davies, W. L. 1936. The Chemistry of Milk. Chapman & Hall Ltd. London.

[||]Pancoast H. M. And W. R. Junk. 1980. Handbook of Sugars. AVI, Westport, CT.

[**]The specific heat of water is slightly higher at the freezing and boiling points than at temperatures between those points.

Table A.10. Viscosities of selected materials[*].

Material	t (ºC)	□ (N s/m²)	□ (kg/m³)	□ (m²/s)
Air[†,‡]	0	1.720×10^{-5}	1.290	1.330×10^{-5}
	25	1.839×10^{-5}	1.180	1.552×10^{-5}
	50	1.957×10^{-5}	1.100	1.786×10^{-5}
	100	2.179×10^{-5}	0.957	2.300×10^{-5}
Water[†]	0	1.792×10^{-3}	999.9	1.792×10^{-6}
	25	0.894×10^{-3}	997.1	0.897×10^{-6}
	50	0.549×10^{-3}	988.1	0.556×10^{-6}
	75	0.380×10^{-3}	974.8	0.390×10^{-6}
	100	0.283×10^{-3}	958.4	0.295×10^{-6}
Sucrose solution [§,||] 20%	0	3.818×10^{-3}	1084.4	3.52×10^{-6}
	25	1.710×10^{-3}	1078.4	1.59×10^{-6}
	50	0.974×10^{-3}	1067.9	0.912×10^{-6}
Sucrose solution [§,||] 40%	0	14.82×10^{-3}	1182.3	12.5×10^{-6}
	25	5.206×10^{-3}	1173.3	4.44×10^{-6}
	50	2.506×10^{-3}	1161.4	2.16×10^{-6}
Sucrose solution [§,||] 60%	0	235.7×10^{-3}	1294.7	182×10^{-6}
	25	44.02×10^{-3}	1283.0	34.3×10^{-6}
	50	14.06×10^{-3}	1269.6	11.1×10^{-6}
Milk, whole, homogenized[#,**]	0	4.28×10^{-3}	1032	4.15×10^{-6}
	25	1.85×10^{-3}	1028	1.80×10^{-6}
	50	1.08×10^{-3}	1018	1.06×10^{-6}
Milk, skim[††]	0	3.42×10^{-3}	1041	3.28×10^{-6}
	25	1.54×10^{-3}	1032	1.49×10^{-6}
	50	0.85×10^{-3}	1022	0.832×10^{-6}

[*]Based upon data from references identified for each product. Note that viscosity and density of milk products are highly variable, depending upon fat content.

[†]Geankoplis, C. J. 1993. Transport Processes and Unit Operations. Prentice-Hall, Englewood Cliffs, NJ.

[‡]Holman, J. P. 1972. Heat Transfer. McGraw-Hill, New York.

[§]Pancoast H. M. And W. R. Junk. 1980. Handbook of Sugars. AVI, Westport, CT.

[||]Steffe, J. F. 1992. Rheological Methods in Food Process Engineering. Freeman Press, East Lansing, MI.

[#]Spreer, E. and A. Mixa. 1998. Milk and Dairy Product Technology. Marcel Dekker, Inc., New York

[**]Davies, W. L. 1936. The Chemistry of Milk. Chapman & Hall Ltd. London.

[††]Whittaker, R., J. M. Sherman, and P. F. Sharp. 1927. Effect of Temperature on the Viscosity of Skimmilk. J. Dairy Science X:361-371.