Refrigerant Piping

The following recommendations are given for ammonia piping. Local codes or ordinances governing ammonia mains should also be followed, in addition to the recommendations here.

Recommended Material

Because copper and copper-bearing materials are attacked by ammonia, they are not used in ammonia piping systems. Steel piping, fittings, and valves of the proper pressure rating are suitable for ammonia gas and liquid.

Ammonia piping should conform to ASME Standard B31.5, Refrigerant Piping and IIAR Standard 2, which states the following:

1. Liquid lines 1.5 inches and smaller shall be not less than Schedule 80 carbon steel pipe.
2. Liquid lines 2 through 6 inches shall be not less than Schedule 40 carbon steel pipe.
3. Liquid lines 8 through 12 inches shall be not less than Schedule 20 carbon steel pipe.
4. Vapor lines 6 inches and smaller shall be not less than Schedule 40 carbon steel pipe.
5. Vapor lines 8 through 12 inches shall be not less than Schedule 20 carbon steel pipe.
6. Vapor lines 14 inches and larger shall be not less than Schedule 10 carbon steel pipe.
7. All threaded pipe shall be Schedule 80.
8. Carbon steel pipe shall be ASTM Standard A 53 Grade A or B, Type E (electric resistance welded) or Type S (seamless); or ASTM Standard A 106 (seamless), except where temperature-pressure criteria mandate a higher specification material. Standard A 53 Type F is not permitted for ammonia piping.

Fittings

Couplings, elbows, and tees for threaded pipe are for a minimum of 3000 psi design pressure and constructed of forged steel. Fittings for welded pipe should match the type of pipe used (i.e., standard fittings for standard pipe and extra-heavy fittings for extra-heavy pipe).

Tongue and groove or ANSI flanges should be used in ammonia piping. Welded flanges for low-side piping can have a minimum 150 psi design pressure rating. On systems located in high ambients, low-side piping and vessels should be designed for 200 to 225 psig. The high side should be 250 psig if the system uses water-cooled or evaporative cooled condensing. Use 300 psig minimum for air-cooled designs.

Refrigerant Piping

Steel Line Size		Saturated Suction Temperature, ˚F					
		-60		-40		-20	
IPS	SCH	Δt = 0.25˚F Δp = 0.046	Δt = 0.50˚F Δp = 0.092	Δt = 0.25˚F Δp = 0.077	Δt = 0.50˚F Δp = 0.155	Δt = 0.25˚F Δp = 0.123	Δt = 0.50˚F Δp = 0.245
3/8	80	0.03	0.05	0.06	0.09	0.11	0.16
1/2	80	0.06	0.10	0.12	0.18	0.22	0.32
3/4	80	0.15	0.22	0.28	0.42	0.50	0.73
1	40	0.30	0.45	0.57	0.84	0.99	1.44
1 /14	40	0.82	1.21	1.53	2.24	2.65	3.84
1 1/2	40	1.25	1.83	2.32	3.38	4.00	5.80
2	40	2.43	3.57	4.54	6.59	7.79	11.26
2 1/2	40	3.94	5.78	7.23	10.56	12.50	18.03
3	40	7.10	10.30	13.00	18.81	22.23	32.09
4	40	14.77	21.21	26.81	38.62	45.66	65.81
5	40	26.66	38.65	48.68	70.07	82.70	119.60
6	40	43.48	62.83	79.18	114.26	134.37	193.44
8	40	90.07	129.79	163.48	235.38	277.80	397.55
10	40	164.26	236.39	297.51	427.71	504.98	721.08
12	ID*	264.07	379.88	477.55	686.10	808.93	1,157.59

Steel Line Size		Saturated Suction Temperature, ˚F					
		0		20		40	
IPS	SCH	Δt = 0.25˚F Δp = 0.184	Δt = 0.50˚F Δp = 0.368	Δt = 0.25˚F Δp = 0.265	Δt = 0.50˚F Δp = 0.530	Δt = 0.25˚F Δp = 0.366	Δt = 0.50˚F Δp = 0.582
3/8	80	0.18	0.26	0.28	0.40	0.41	0.53
1/2	80	0.36	0.52	0.55	0.80	0.82	1.05
3/4	80	0.82	1.18	1.26	1.83	1.87	2.38
1	40	1.62	2.34	2.50	3.60	3.68	4.69
1 /14	40	4.30	6.21	6.63	9.52	9.76	12.42
1 1/2	40	6.49	9.34	9.98	14.34	14.68	18.64
2	40	12.57	18.12	19.35	27.74	28.45	36.08
2 1/2	40	20.19	28.94	30.98	44.30	45.37	57.51
3	40	35.87	51.35	54.98	78.50	80.40	101.93
4	40	73.56	105.17	112.34	160.57	164.44	208.34
5	40	133.12	190.55	203.53	289.97	296.88	376.18
6	40	216.05	308.62	329.59	469.07	480.96	609.57
8	40	444.56	633.82	676.99	962.47	985.55	1,250.34
10	40	806.47	1,148.72	1,226.96	1,744.84	1,786.55	2,263.99
12	ID*	1,290.92	1,839.28	1,964.56	2,790.37	2,862.23	3,613.23

Table 1 Suction Line Capacities in Tons for Ammonia with Pressure Drops of 0.25 and 0.50°F per 100 ft Equivalent

NOTE: Capacities are in tons of refrigeration resulting in a line friction loss (Δp in psi per 100 ft equivalent pipe length), with corresponding change (Δt in ˚F per 100 ft) in saturation temperature.*

* The inside diameter of the pipe is the same as the nominal pipe size.

Pipe Joints

Joints between lengths of pipe or between pipe and fittings can be threaded if the pipe size is 1.25 in. or smaller. Pipe 1.5 inches or larger should be welded. An all-welded piping system is superior.

Threaded Joints. Many sealants and compounds are available for sealing threaded joints. The manufacturer's instructions cover compatibility and application method. Do not use excessive amounts or apply on female threads because any excess can contaminate the system.

Welded Joints. Pipe should be cut and beveled before welding. Use pipe alignment guides to align the pipe and provide a proper gap between pipe ends so that a full penetration weld is obtained. The weld should be made by a qualified welder, using proper procedures such as the Welding Procedure Specifications, prepared by the National Certified Pipe Welding Bureau (NCPWB).

Gasketed Joints. A compatible fiber gasket should be used with flanges. Before tightening flange bolts to valves, controls, or flange unions, properly align the pipe and bolt holes. When flanges are are used to straighten pipe, they put stress on adjacent valves, compressors, and controls, causing the operating mechanism to bind. To prevent leaks, flange bolts are drawn up evenly when connecting the flanges. Flanges at compressors and other system components must not move or indicate stress when all bolts are loosened.

Union Joints. Steel (3000 psi) ground joint unions are used for gage and pressure control lines with screwed valves and for joints up to 0.75 in. When tightening this type of joint, the two pipes must be axially aligned. To be effective, the two parts of the union must match perfectly. Ground joint unions should be avoided if at all possible.

Pipe Location

Piping should be at least 7.5 ft above the floor. Locate pipes carefully in relation to other piping and structural members, especially when the lines are to be insulated. The distance between insulated lines should be at least three times the thickness of the insulation for screwed fittings, and four times for flange fittings. The space between the pipe and adjacent surfaces should be three-fourths of these amounts.

Hangers located close to the vertical risers to and from compressors keep the piping weight off the compressor. Pipe hangers should be placed no more than 8 to 10 ft apart and with in 2 ft of a change in direction of the piping. Hangers should be designed to bear on the outside of insulated lines. Sheet metal sleeves on the lower half of the insulation are usually sufficient. Where piping penetrates a wall, a sleeve should be installed and where the pipe penetrating the wall is insulated, it must be adequately sealed.

Piping to and from compressors and to other components must provide for expansion and contraction. Sufficient flange or union joints should be located in the piping that components can be assembled easily during initial installation and also disassembled for servicing.

Refrigerant Piping

System Practices for Ammonia Refrigerant

Steel Line Size		Suction Lines (Δt = 1˚F) Saturated Suction Temperature, ˚F					Discharge Lines	Steel Line Size		Liquid Lines	
IPS	SCH	-40 Δp = 0.31	-20 Δp = 0.49	0 Δp = 0.73	20 Δp = 1.06	40 Δp = 1.46	Δt = 1˚F Δp = 2.95	IPS	SCH	Velocity = 100 fpm	Δp = 2.0 psi Δt = 0.7˚F
3/8	80	-	-	-	-	-	-	3/8	80	8.6	12.1
1/2	80	-	-	-	-	-	3.1	1/2	80	14.2	24.0
3/4	80	-	-	-	2.6	3.8	7.1	3/4	80	26.3	54.2
1	40	-	2.1	3.4	5.2	7.6	13.9	1	80	43.8	106.4
1 /14	40	3.2	5.6	8.9	13.6	19.9	36.5	1 1/4	80	78.1	228.6
1 1/2	40	4.9	8.4	13.4	20.5	29.9	54.8	1 1/2	80	107.5	349.2
2	40	9.5	16.2	26.0	39.6	57.8	105.7	2	40	204.2	811.4
2 1/2	40	15.3	25.9	41.5	63.2	92.1	168.5	2 1/2	40	291.1	1292.6
3	40	27.1	46.1	73.5	111.9	163.0	297.6	3	40	449.6	2287.8
4	40	55.7	94.2	150.1	228.7	333.0	606.2	4	40	774.7	4662.1
5	40	101.1	170.4	271.1	412.4	600.9	1095.2	5	40	-	-
6	40	164.0	276.4	439.2	667.5	971.6	1771.2	6	40	-	-
8	40	337.2	566.8	901.1	1366.6	1989.4	3623.0	8	40	-	-
10	40	611.6	1027.2	1634.3	2474.5	3598.0	-	10	40	-	-
12	ID*	981.6	1644.5	2612.4	3963.5	5464.6	-	12	ID*	-	-

Table 2. Suction, Discharge, and Liquid Line Capacities in Tons for Ammonia (Single- or High-Stage Applications)

Notes:

1. Table capacities are in tons of refrigeration.
   Δp = pressure drop due to line friction, psi per 100 ft of equivalent line length
   Δt = corresponding change in saturation temperature, ˚F per 100 ft
2. Line capacity for other saturation temperatures Δt and equivalent lengths Lc

$$\text{Line capacity} = \text{Table capacity} \left(\frac{\text{Table Lc}}{\text{Actual Lc}} \times \frac{\text{Actual } \Delta t}{\text{Table } \Delta t} \right)^{0.55}$$

3. Saturation temperature Δt for other capacities and equivalent lengths Lc

$$\Delta t = \text{Table } \Delta t \; \frac{\text{Actual Lc}}{\text{Table Lc}} \times \left(\frac{\text{Actual Capacity}}{\text{Table Capacity}} \right)^{1.8}$$

4. Values in the table are based on 90˚F condensing temperature. Multiply table capacities by the following factors for other condensing temperatures:

Condensing Temperature, ˚F	Suction Lines	Discharge Lines
70	1.05	0.78
80	1.02	0.89
90	1.00	1.00
100	0.98	1.11

5. Discharge and liquid line capacities are based on 20˚F suction. Evaporator temperature is 0˚F. The capacity is affected less than 3% when applied from -40 to +40˚F extremes.

*The inside diameter of the pipe is the same as the nominal pipe size.

Nominal Size, in.	Pumped Liquid Overfeed Ratio			High-Pressure Liquid at 3 psi [a]	Hot-Gas Defrost [a]	Equalizer High Side [b]	Thermosiphon Lubricant Cooling Lines Gravity Flow, [c] 1000 Btu/h		
	3:1	4:1	5:1				Supply	Return	Vent
1/2	10	7.5	6	30	-	-	-	-	-
3/4	22	16.5	13	69	4	50	-	-	-
1	43	32.5	26	134	8	100	-	-	-
1 1/4	93.5	70	56	286	20	150	-	-	-
1 1/2	146	110	87.5	439	30	225	200	120	203
2	334	250	200	1016	50	300	470	300	362
2 1/2	533	400	320	1616	92	500	850	530	638
3	768	576	461	2886	162	1000	1312	870	1102
4	1365	1024	819	-	328	2000	2261	1410	2000
5	-	-	-	-	594	-	3550	2214	3624
6	-	-	-	-	970	-	5130	3200	6378
8	-	-	-	-	-	-	8874	5533	11596

Table 3. Liquid Ammonia line capacities (capacity in tons of refrigeration, except as noted)

Source: Wile (1977)

a. Hot-gas line sizes are based on 1.5 psi pressure drop per 100 ft of equivalent length at 100 psig discharge pressure and 3 times the evaporator refrigeration capacity.
b. Line sizes are based on experience using total system evaporator tons.
c. From Frick Co. (1995). Values for line sizes above 4 in are extrapolated.

Pipe Sizing

Table 1 presents practical suction line sizing data based on 0.25˚F and 0.50˚F differential pressure drop equivalent per 100 ft for the total equivalent length of pipe, assuming no liquid in the suction line. **Table 2** lists data for sizing suction and discharge lines at 1˚F differential pressure drop equivalent per 100 ft equivalent length of pipe, and for sizing liquid lines at 100 fpm. Charts prepared by Wile (1977) present pressure drops in saturation temperature equivalents. For a complete discussion of the basis of these line sizing charts, see Timm (1991). **Table 3** presents line sizing information for pumped liquid lines, high-pressure liquid lines, hot-gas defrost lines, equalizing lines, and thermosiphon lubricant cooling ammonia lines.

Valves

Stop Valves. These valves, also commonly called shutoff or isolation valves, are generally manually operated, although motor-actuated units are available. ASHRAE *Standard 15* requires these valves in the inlet and outlet lines to all condensers, compressors, and liquid receivers. Additional valves are installed on vessels, evaporators, and long lengths of pipe so they can be isolated in case of leaks and to facilitates pumping out for servicing and evacuation. Sections of liquid piping that can experience hydraulic lockup in normal operation must be protected with a relief device (preferably vented back into the system). Only qualified personnel should be allowed to operate stop valves.

Installing globe-type stop valves with the valve stems horizontal lessens the chance (1) for dirt or scale to lodge on the valve seat or disk and cause it to leak or (2) for liquid or lubricant to pocket in the area below the seat. Wet suction return lines (recirculation system) should use angle valves or globe valves (with their stems horizontal) to reduce the possibility of liquid pockets and to reduce pressure drop.

Refrigerant Piping

Welded flanged or weld-in-line valves are desirable for all line sizes; however, screwed valves may be used for 1 1/4" and smaller lines. Ammonia globe and angle valves should have the following features:

- Soft seating surfaces for positive shutoff (no copper or copper alloy)
- Back seating to permit repacking the valve stem while in service
- Arrangement that allows packing to be tightened easily
- All-steel construction (preferable)
- Bolted bonnets above 1 in., threaded bonnets for 1 in. and smaller

Consider seal cap valves in refrigerated areas and for all ammonia piping. To keep pressure drop to a minimum, consider angle valves (as opposed to globe valves).

Control Valves. Pressure regulators, solenoid valves, check valves, gas-powered suction stop valves, and thermostatic expansion valves can be flanged for easy assembly and removal. Alternative weld-in line valves with nonwearing body parts are available. Valves 1.5 in. and larger should have welded companion flanges. Smaller valves can have threaded companion flanges.

A strainer should be used in front of self-contained control valves to protect them from pipe construction material and dirt.

Solenoid Valves. Solenoid Valve stems should be upright with their coils protected from moisture. They should have flexible conduit connections, where allowed by codes, and an electric pilot light wired in parallel to indicate when the coil is energized.

Solenoid valves for high-pressure liquid feed to evaporators should have soft seats for positive shutoff. Solenoid valves for other applications, such as in suction lines, hot-gas lines, or gravity feed lines, should be selected for the pressure and temperature of the fluid flowing and for the pressure drop available.

Relief Valves. Safety Valves must be provided in conformance with ASHRAE *Standard 15* and Section VIII, Division 1, of the ASME *Boiler and Pressure Vessel Code*. For ammonia systems, IIAR Bulletin 109 also addresses the subject of safety valves.

Dual relief valve arrangements enable testing of the relief valves (**Figure 1**). The three-way stop valve is constructed so that it is always open to one of the relief valves if the other is removed to be checked or repaired.

Isolated Line Sections

Sections of piping that can be isolated between hand valves or check valves can be subjected to extreme hydraulic pressures if cold liquid refrigerant is trapped in them and subsequently warmed. Additional safety valves for such piping must be provided.

Insulation and Vapor Retarders

Insulation and effective vapor retarders on low-temperature systems are very important. At low temperatures, the smallest leak in the vapor retarder can allow ice to from inside the insulation, which can totally destroy the integrity of the entire insulation system. The result can cause a significant increase in load and power usage.

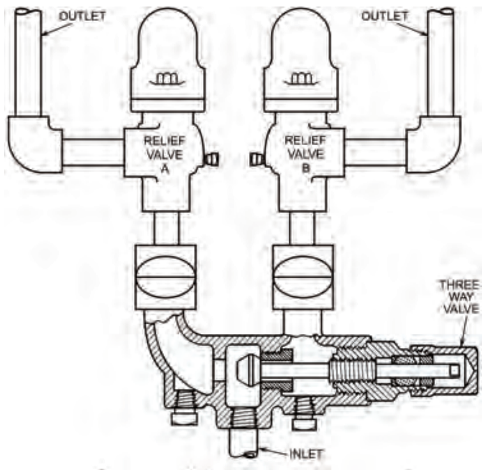

Figure 1. Dual Relief Valve Fitting For Ammonia

Table 3 Unfrozen Composition Data, Initial Freezing Point, and Specific Heats of Foods*

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate Total, % x_c	Carbohydrate Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °F	Specific Heat Above Freezing, Btu/lb·°F	Specific Heat Below Freezing, Btu/lb·°F	Latent Heat of Fusion, Btu/lb
Vegetables										
Artichokes, globe	84.94	3.27	0.15	10.51	5.40	1.13	29.8	0.93	0.48	122
Jerusalem	78.01	2.00	0.01	17.44	1.60	2.54	27.5	0.87	0.54	112
Asparagus	92.40	2.28	0.20	4.54	2.10	0.57	30.9	0.96	0.43	133
Beans, snap	90.27	1.82	0.12	7.14	3.40	0.66	30.7	0.95	0.44	130
lima	70.24	6.84	0.86	20.16	4.90	1.89	30.9	0.84	0.49	101
Beets	87.58	1.61	0.17	9.56	2.80	1.08	30.0	0.93	0.46	126
Broccoli	90.69	2.98	0.35	5.24	3.00	0.92	30.9	0.96	0.43	130
Brussels sprouts	86.00	3.38	0.30	8.96	3.80	1.37	30.6	0.93	0.46	123
Cabbage	92.15	1.44	0.27	5.43	2.30	0.71	30.4	0.96	0.44	132
Carrots	87.79	1.03	0.19	10.14	3.00	0.87	29.5	0.94	0.48	126
Cauliflower	91.91	1.98	0.21	5.20	2.50	0.71	30.6	0.96	0.44	132
Celeriac	88.00	1.50	0.30	9.20	1.80	1.00	30.4	0.93	0.45	126
Celery	94.64	0.75	0.14	3.65	1.70	0.82	31.1	0.97	0.42	136
Collards	90.55	1.57	0.22	7.11	3.60	0.55	30.6	0.96	0.44	130
Corn, sweet, yellow	75.96	3.22	1.18	19.02	2.70	0.62	30.9	0.86	0.47	109
Cucumbers	96.01	0.69	0.13	2.76	0.80	0.41	31.1	0.98	0.41	138
Eggplant	92.03	1.02	0.18	6.07	2.50	0.71	30.6	0.96	0.44	132
Endive	93.79	1.25	0.20	3.35	3.10	1.41	31.8	0.97	0.40	135
Garlic	58.58	6.36	0.50	33.07	2.10	1.50	30.6	0.76	0.52	84
Ginger, root	81.67	1.74	0.73	15.09	2.00	0.77	—	0.90	0.46	117
Horseradish	78.66	9.40	1.40	8.28	2.00	2.26	28.8	0.88	0.51	113
Kale	84.46	3.30	0.70	10.01	2.00	1.53	31.1	0.91	0.44	121
Kohlrabi	91.00	1.70	0.10	6.20	3.60	1.00	30.2	0.96	0.45	131
Leeks	83.00	1.50	0.30	14.15	1.80	1.05	30.7	0.90	0.46	119
Lettuce, iceberg	95.89	1.01	0.19	2.09	1.40	0.48	31.6	0.98	0.39	138
Mushrooms	91.81	2.09	0.42	4.65	1.20	0.89	30.4	0.95	0.44	132
Okra	89.58	2.00	0.10	7.63	3.20	0.70	28.8	0.95	0.49	129
Onions	89.68	1.16	0.16	8.63	1.80	0.37	30.4	0.94	0.45	129
dehydrated flakes	3.93	8.95	0.46	83.28	9.20	3.38	—	—	—	6
Parsley	87.71	2.97	0.79	6.33	3.30	2.20	30.0	0.94	0.46	126
Parsnips	79.53	1.20	0.30	17.99	4.90	0.98	30.4	0.89	0.48	114
Peas, green	78.86	5.42	0.40	14.46	5.10	0.87	30.9	0.90	0.47	113
Peppers, freeze-dried	2.00	17.90	3.00	68.70	21.30	8.40	—	—	—	3
sweet, green	92.19	0.89	0.19	6.43	1.80	0.30	30.7	0.96	0.43	132
Potatoes, main crop	78.96	2.07	0.10	17.98	1.60	0.89	30.9	0.88	0.46	113
sweet	72.84	1.65	0.30	24.28	3.00	0.95	29.7	0.83	0.50	104
Pumpkins	91.60	1.00	0.10	6.50	0.50	0.80	30.6	0.95	0.43	132
Radishes	94.84	0.60	0.54	3.59	1.60	0.54	30.7	0.97	0.42	136
Rhubarb	93.61	0.90	0.20	4.54	1.80	0.76	30.4	0.97	0.44	135
Rutabaga	89.66	1.20	0.20	8.13	2.50	0.81	30.0	0.94	0.46	129
Salsify (vegetable oyster)	77.00	3.30	0.20	18.60	3.30	0.90	30.0	0.87	0.49	110
Spinach	91.58	2.86	0.35	3.50	2.70	1.72	31.5	0.96	0.42	132
Squash, summer	94.20	0.94	0.24	4.04	1.90	0.58	31.1	0.97	0.42	135
winter	87.78	0.80	0.10	10.42	1.50	0.90	30.6	0.93	0.45	126
Tomatoes, mature green	93.00	1.20	0.20	5.10	1.10	0.50	30.9	0.96	0.42	134
ripe	93.76	0.85	0.33	4.64	1.10	0.42	31.1	0.97	0.43	135
Turnip	91.87	0.90	0.10	6.23	1.80	0.70	30.0	0.96	0.45	132
greens	91.07	1.50	0.30	5.73	3.20	1.40	31.6	0.96	0.42	131
Watercress	95.11	2.30	0.10	1.29	1.50	1.20	31.5	0.97	0.40	137
Yams	69.60	1.53	0.17	27.89	4.10	0.82	—	0.83	0.49	100
Fruits										
Apples, fresh	83.93	0.19	0.36	15.25	2.70	0.26	30.0	0.91	0.47	120
dried	31.76	0.93	0.32	65.89	8.70	1.10	—	0.61	0.68	46
Apricots	86.35	1.40	0.39	11.12	2.40	0.75	30.0	0.92	0.47	124
Avocados	74.27	1.98	15.32	7.39	5.00	1.04	31.5	0.88	0.47	107
Bananas	74.26	1.03	0.48	23.43	2.40	0.80	30.6	0.85	0.48	107
Blackberries	85.64	0.72	0.39	12.76	5.30	0.48	30.6	0.93	0.46	123
Blueberries	84.61	0.67	0.38	14.13	2.70	0.21	29.1	0.91	0.49	122
Cantaloupes	89.78	0.88	0.28	8.36	0.80	0.71	29.8	0.94	0.46	129
Cherries, sour	86.13	1.00	0.30	12.18	1.60	0.40	28.9	0.92	0.49	124
sweet	80.76	1.20	0.96	16.55	2.30	0.53	28.8	0.89	0.51	116
Cranberries	86.54	0.39	0.20	12.68	4.20	0.19	30.4	0.93	0.46	124

Table 3 Unfrozen Composition Data, Initial Freezing Point, and Specific Heats of Foods* (*Continued*)

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate: Total, % x_c	Carbohydrate: Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °F	Specific Heat Above Freezing, Btu/lb·°F	Specific Heat Below Freezing, Btu/lb·°F	Latent Heat of Fusion, Btu/lb
Currants, European black	81.96	1.40	0.41	15.38	0.00	0.86	30.2	0.89	0.47	118
red and white	83.95	1.40	0.20	13.80	4.30	0.66	30.2	0.92	0.47	120
Dates, cured	22.50	1.97	0.45	73.51	7.50	1.58	3.7	0.55	0.55	32
Figs, fresh	79.11	0.75	0.30	19.18	3.30	0.66	27.7	0.88	0.54	113
dried	28.43	3.05	1.17	65.35	9.30	2.01	—	0.60	0.98	41
Gooseberries	87.87	0.88	0.58	10.18	4.30	0.49	30.0	0.94	0.47	126
Grapefruit	90.89	0.63	0.10	8.08	1.10	0.31	30.0	0.95	0.45	131
Grapes, American	81.30	0.63	0.35	17.15	1.00	0.57	29.1	0.89	0.49	117
European type	80.56	0.66	0.58	17.77	1.00	0.44	28.2	0.88	0.52	116
Lemons	87.40	1.20	0.30	10.70	4.70	0.40	29.5	0.94	0.48	126
Limes	88.26	0.70	0.20	10.54	2.80	0.30	29.1	0.94	0.48	127
Mangos	81.71	0.51	0.27	17.00	1.80	0.50	30.4	0.89	0.47	117
Melons, casaba	92.00	0.90	0.10	6.20	0.80	0.80	30.0	0.95	0.45	132
honeydew	89.66	0.46	0.10	9.18	0.60	0.60	30.4	0.94	0.44	129
watermelon	91.51	0.62	0.43	7.18	0.50	0.26	31.3	0.95	0.42	132
Nectarines	86.28	0.94	0.46	11.78	1.60	0.54	30.4	0.92	0.45	124
Olives	79.99	0.84	10.68	6.26	3.20	2.23	29.5	0.90	0.49	115
Oranges	82.30	1.30	0.30	15.50	4.50	0.60	30.6	0.91	0.47	118
Peaches, fresh	87.66	0.70	0.90	11.10	2.00	0.46	30.4	0.93	0.45	126
dried	31.80	3.61	0.76	61.33	8.20	2.50	—	0.61	0.83	46
Pears	83.81	0.39	0.40	15.11	2.40	0.28	29.1	0.91	0.49	120
Persimmons	64.40	0.80	0.40	33.50	0.00	0.90	28.0	0.78	0.55	92
Pineapples	86.50	0.39	0.43	12.39	1.20	0.29	30.2	0.92	0.46	124
Plums	85.20	0.79	0.62	13.01	1.50	0.39	30.6	0.91	0.45	123
Pomegranates	80.97	0.95	0.30	17.17	0.60	0.61	26.6	0.88	0.55	116
Prunes, dried	32.39	2.61	0.52	62.73	7.10	1.76	—	0.61	0.84	46
Quinces	83.80	0.40	0.10	15.30	1.90	0.40	28.4	0.91	0.51	120
Raisins, seedless	15.42	3.22	0.46	79.13	4.00	1.77	—	0.49	0.49	22
Raspberries	86.57	0.91	0.55	11.57	6.80	0.40	30.9	0.95	0.46	124
Strawberries	91.57	0.61	0.37	7.02	2.30	0.43	30.6	0.96	0.44	132
Tangerines	87.60	0.63	0.19	11.19	2.30	0.39	30.0	0.93	0.46	126
Whole Fish										
Cod	81.22	17.81	0.67	0.0	0.0	1.16	28.0	0.90	0.51	117
Haddock	79.92	18.91	0.72	0.0	0.0	1.21	28.0	0.90	0.51	115
Halibut	77.92	20.81	2.29	0.0	0.0	1.36	28.0	0.89	0.52	112
Herring, kippered	59.70	24.58	12.37	0.0	0.0	1.94	28.0	0.78	0.54	86
Mackerel, Atlantic	63.55	18.60	13.89	0.0	0.0	1.35	28.0	0.80	0.53	91
Perch	78.70	18.62	1.63	0.0	0.0	1.20	28.0	0.89	0.51	113
Pollock, Atlantic	78.18	19.44	0.98	0.0	0.0	1.41	28.0	0.88	0.51	112
Salmon, pink	76.35	19.94	3.45	0.0	0.0	1.22	28.0	0.88	0.52	110
Tuna, bluefin	68.09	23.33	4.90	0.0	0.0	1.18	28.0	0.82	0.52	98
Whiting	80.27	18.31	1.31	0.0	0.0	1.30	28.0	0.90	0.51	115
Shellfish										
Clams	81.82	12.77	0.97	2.57	0.0	1.87	28.0	0.90	0.51	117
Lobster, American	76.76	18.80	0.90	0.50	0.0	2.20	28.0	0.87	0.51	110
Oysters	85.16	7.05	2.46	3.91	0.0	1.42	28.0	0.91	0.51	122
Scallop, meat	78.57	16.78	0.76	2.36	0.0	1.53	28.0	0.89	0.51	113
Shrimp	75.86	20.31	1.73	0.91	0.0	1.20	28.0	0.87	0.52	109
Beef										
Brisket	55.18	16.94	26.54	0.0	0.0	0.80	—	0.76	0.56	79
Carcass, choice	57.26	17.32	24.05	0.0	0.0	0.81	28.0	0.77	0.55	82
select	58.21	17.48	22.55	0.0	0.0	0.82	28.9	0.78	0.54	83
Liver	68.99	20.00	3.85	5.82	0.0	1.34	28.9	0.83	0.52	99
Ribs, whole (ribs 6-12)	54.54	16.37	26.98	0.0	0.0	0.77	—	0.75	0.55	78
Round, full cut, lean and fat	64.75	20.37	12.81	0.0	0.0	0.97	—	0.81	0.52	93
full cut, lean	70.83	22.03	4.89	0.0	0.0	1.07	—	0.84	0.51	102
Sirloin, lean	71.70	21.24	4.40	0.0	0.0	1.08	28.9	0.84	0.50	103
Short loin, porterhouse steak, lean	69.59	20.27	8.17	0.0	0.0	1.01	—	0.83	0.51	100
T-bone steak, lean	69.71	20.78	7.27	0.0	0.0	1.27	—	0.83	0.51	100
Tenderloin, lean	68.40	20.78	7.90	0.0	0.0	1.04	—	0.82	0.51	98
Veal, lean	75.91	20.20	2.87	0.0	0.0	1.08	—	0.87	0.50	109

Table 3 Unfrozen Composition Data, Initial Freezing Point, and Specific Heats of Foods* (*Continued*)

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate Total, % x_c	Carbohydrate Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °F	Specific Heat Above Freezing, Btu/lb·°F	Specific Heat Below Freezing, Btu/lb·°F	Latent Heat of Fusion, Btu/lb
Pork										
Backfat	7.69	2.92	88.69	0.0	0.0	0.70	—	0.52	0.71	11
Bacon	31.58	8.66	57.54	0.09	0.0	2.13	—	0.64	0.64	45
Belly	36.74	9.34	53.01	0.0	0.0	0.49	—	0.67	0.80	53
Carcass	49.83	13.91	35.07	0.0	0.0	0.72	—	0.74	0.74	71
Ham, cured, whole, lean	68.26	22.32	5.71	0.05	0.0	3.66	—	0.83	0.53	98
country cured, lean	55.93	27.80	8.32	0.30	0.0	7.65	—	0.75	0.55	80
Shoulder, whole, lean	72.63	19.55	7.14	0.0	0.0	1.02	28.0	0.86	0.53	104
Sausage										
Braunschweiger	48.01	13.50	32.09	3.13	0.0	3.27	—	0.72	0.57	69
Frankfurter	53.87	11.28	29.15	2.55	0.0	3.15	28.9	0.75	0.55	77
Italian	51.08	14.25	31.33	0.65	0.0	2.70	—	0.74	0.57	74
Polish	53.15	14.10	28.72	1.63	0.0	2.40	—	0.75	0.56	77
Pork	44.52	11.69	40.29	1.02	0.0	2.49	—	0.70	0.58	64
Smoked links	39.30	22.20	31.70	2.10	0.0	4.70	—	0.67	0.59	56
Poultry Products										
Chicken	65.99	18.60	15.06	0.0	0.0	0.79	27.0	0.79	0.42	95
Duck	48.50	11.49	39.34	0.0	0.0	0.68	—	0.73	0.59	70
Turkey	70.40	20.42	8.02	0.0	0.0	0.88	—	0.84	0.54	101
Egg										
White	87.81	10.52	0.0	1.03	0.0	0.64	30.9	0.93	0.43	126
dried	14.62	76.92	0.04	4.17	0.0	4.25	—	0.55	0.50	21
Whole	75.33	12.49	10.02	1.22	0.0	0.94	30.9	0.87	0.47	108
dried	3.10	47.35	40.95	4.95	0.0	3.65	—	0.49	0.48	4
Yolk	48.81	16.76	30.87	1.78	0.0	1.77	30.9	0.73	0.54	70
salted	50.80	14.00	23.00	1.60	0.0	10.60	1.0	0.72	0.91	73
sugared	51.25	13.80	22.75	10.80	0.0	1.40	25.0	0.73	0.61	74
Lamb										
Composite of cuts, lean	73.42	20.29	5.25	0.0	0.0	1.06	28.6	0.86	0.51	105
Leg, whole, lean	74.11	20.56	4.51	0.0	0.0	1.07	—	0.86	0.51	107
Dairy Products										
Butter	17.94	0.85	81.11	0.06	0.0	0.04	—	0.57	0.63	26
Cheese										
Camembert	51.80	19.80	24.26	0.46	0.0	3.68	—	0.74	0.80	74
Cheddar	36.75	24.90	33.14	1.28	0.0	3.93	8.8	0.66	0.73	53
Cottage, uncreamed	79.77	17.27	0.42	1.85	0.0	0.69	29.8	0.89	0.48	114
Cream	53.75	7.55	34.87	2.66	0.0	1.17	—	0.75	0.70	77
Gouda	41.46	24.94	27.44	2.22	0.0	3.94	—	0.69	0.66	59
Limburger	48.42	20.05	27.25	0.49	0.0	3.79	18.7	0.72	0.67	70
Mozzarella	54.14	19.42	21.60	2.22	0.0	2.62	—	0.75	0.59	78
Parmesan, hard	29.16	35.75	25.83	3.22	0.0	6.04	—	0.62	0.70	42
Processed American	39.16	22.15	31.25	1.30	0.0	5.84	19.6	0.67	0.66	56
Roquefort	39.38	21.54	30.64	2.00	0.0	6.44	2.7	0.67	0.80	57
Swiss	37.21	28.43	27.45	3.38	0.0	3.53	14.0	0.66	0.69	53
Cream										
Half and half	80.57	2.96	11.50	4.30	0.0	0.67	—	0.89	0.52	116
Table	73.75	2.70	19.31	3.66	0.0	0.58	28.0	0.86	0.53	106
Heavy whipping	57.71	2.05	37.00	2.79	0.0	0.45	—	0.78	0.55	83
Ice Cream										
Chocolate	55.70	3.80	11.0	28.20	1.20	1.00	21.9	0.74	0.66	80
Strawberry	60.00	3.20	8.40	27.60	0.30	0.70	21.9	0.76	0.65	86
Vanilla	61.00	3.50	11.00	23.60	0.0	0.90	21.9	0.77	0.65	88
Milk										
Canned, condensed, sweetened	27.16	7.91	8.70	54.40	0.0	1.83	5.0	0.56	—	39
Evaporated	74.04	6.81	7.56	10.04	0.0	1.55	29.5	0.85	0.50	106
Skim	90.80	3.41	0.18	4.85	0.0	0.76	—	0.94	0.43	130
dried	3.16	36.16	0.77	51.98	0.0	7.93	—	0.43	—	5
Whole	87.69	3.28	3.66	4.65	0.0	0.72	30.9	0.93	0.43	126
dried	2.47	26.32	26.71	38.42	0.0	6.08	—	0.44	—	3
Whey, acid, dried	3.51	11.73	0.54	73.45	0.0	10.77	—	0.40	—	5
sweet, dried	3.19	12.93	1.07	74.46	0.0	8.35	—	0.40	—	5

Table 3 Unfrozen Composition Data, Initial Freezing Point, and Specific Heats of Foods* (*Continued*)

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate Total, % x_c	Carbohydrate Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °F	Specific Heat Above Freezing, Btu/lb·°F	Specific Heat Below Freezing, Btu/lb·°F	Latent Heat of Fusion, Btu/lb
Nuts, Shelled										
Almonds	4.42	19.95	52.21	20.40	10.90	3.03	—	0.53	—	6
Filberts	5.42	13.04	62.64	15.30	6.10	3.61	—	0.50	—	8
Peanuts, raw	6.50	25.80	49.24	16.14	8.50	2.33	—	0.53	—	9
dry roasted with salt	1.55	23.68	49.66	21.51	8.00	3.60	—	0.50	—	2
Pecans	4.82	7.75	67.64	18.24	7.60	1.56	—	0.52	—	7
Walnuts, English	3.65	14.29	61.87	18.34	4.80	1.86	—	0.50	—	5
Candy										
Fudge, vanilla	10.90	1.10	5.40	82.30	0.0	0.40	—	0.45	—	15
Marshmallows	16.40	1.80	0.20	81.30	0.10	0.30	—	0.48	—	24
Milk chocolate	1.30	6.90	30.70	59.20	3.40	1.50	—	0.44	—	2
Peanut brittle	1.80	7.50	19.10	69.30	2.00	1.50	—	0.42	—	3
Juice and Beverages										
Apple juice, unsweetened	87.93	0.06	0.11	11.68	0.10	0.22	—	0.92	0.43	126
Grapefruit juice, sweetened	87.38	0.58	0.09	11.13	0.10	0.82	—	0.92	0.43	126
Grape juice, unsweetened	84.12	0.56	0.08	14.96	0.10	0.29	—	0.90	0.43	121
Lemon juice	92.46	0.40	0.29	6.48	0.40	0.36	—	0.95	0.41	133
Lime juice, unsweetened	92.52	0.25	0.23	6.69	0.40	0.31	—	0.95	0.41	133
Orange juice	89.01	0.59	0.14	9.85	0.20	0.41	31.3	0.93	0.42	128
Pineapple juice, unsweetened	85.53	0.32	0.08	13.78	0.20	0.30	—	0.91	0.43	123
Prune juice	81.24	0.61	0.03	17.45	1.00	0.68	—	0.89	0.45	117
Tomato juice	93.90	0.76	0.06	4.23	0.40	1.05	—	0.96	0.41	135
Cranberry-apple juice drink	82.80	0.10	0.0	17.10	0.10	0.0	—	0.89	0.44	119
Cranberry-grape juice drink	85.60	0.20	0.10	14.00	0.10	0.10	—	0.91	0.43	123
Fruit punch drink	88.00	0.0	0.0	11.90	0.10	0.10	—	0.92	0.43	126
Club soda	99.90	0.0	0.0	0.0	0.0	0.10	—	1.00	0.39	144
Cola	89.40	0.0	0.0	10.40	0.0	0.10	—	0.93	0.42	129
Cream soda	86.70	0.0	0.0	13.30	0.0	0.10	—	0.91	0.43	125
Ginger ale	91.20	0.0	0.0	8.70	0.0	0.0	—	0.94	0.41	131
Grape soda	88.80	0.0	0.0	11.20	0.0	0.10	—	0.93	0.42	128
Lemon-lime soda	89.50	0.0	0.0	10.40	0.0	0.10	—	0.93	0.42	129
Orange soda	87.60	0.0	0.0	12.30	0.0	0.10	—	0.92	0.43	126
Root beer	89.30	0.0	0.0	10.60	0.0	0.10	—	0.93	0.42	128
Chocolate milk, 2% fat	83.58	3.21	2.00	10.40	0.50	0.81	—	0.90	0.44	120
Miscellaneous										
Honey	17.10	0.30	0.0	82.40	0.20	0.20	—	0.48	—	25
Maple syrup	32.00	0.00	0.20	67.20	0.0	0.60	—	0.58	—	46
Popcorn, air-popped	4.10	12.00	4.20	77.90	15.10	1.80	—	0.49	—	6
oil-popped	2.80	9.00	28.10	57.20	10.00	2.90	—	0.48	—	4
Yeast, baker's, compressed	69.00	8.40	1.90	18.10	8.10	1.80	—	0.85	0.52	100

*Composition data from USDA (1996). Initial freezing point data from Table 1 in Chapter 30 of the 1993 *ASHRAE Handbook—Fundamentals* and USDA (1968). Specific heats calculated from equations in this chapter. Latent heat of fusion obtained by multiplying water content expressed in fractional form by 144 Btu/lb, the heat of fusion of water (Table 1 in Chapter 30 of the 1993 *ASHRAE Handbook—Fundamentals*).