

CHAPTER 30

THERMOPHYSICAL PROPERTIES OF REFRIGERANTS

THIS chapter presents data for thermodynamic and transport properties of refrigerants, arranged for the occasional user. The refrigerants have a thermodynamic property chart on pressure-enthalpy coordinates with an abbreviated set of tabular data for saturated liquid and vapor on the facing page. In addition, tabular data in the superheated vapor region are given for R-134a to assist students working on compression cycle examples.

For each cryogenic fluid, a second table of properties is provided for vapor at a pressure of one standard atmosphere; these data are needed when such gases are used in heat transfer or purge gas applications. For zeotropic blends, including R-729 (air), tables are incremented in pressure, with properties given for liquid on the bubble line and vapor on the dew line. This arrangement is used because pressure is more commonly measured in the field while servicing equipment; it also highlights the difference between bubble and dew-point temperatures (the “temperature glide” experienced with blends).

Most CFC refrigerants have been deleted. Tables for R-11, R-13, R-113, R-114, R-141b, R-142b, R-500, R-502, R-503, and R-720 (neon) may be found in the 1997 *ASHRAE Handbook—Fundamentals*. R-12 has been retained to assist in making comparisons. Revised formulations have been used for many refrigerants; these conform to international standards, where applicable. Thermodynamic properties of R-12, R-22, R-32, R-123, R-125, R-134a, R-143a, R-152a, R-717 (ammonia), and R-744 (carbon dioxide) and refrigerant blends R-404A, R-407C, R-410A, and R-507 conform to ISO/DIS *Draft Standard 17584, Refrigerant Properties*.

Reference states used for most refrigerants correspond to the American convention of 0 Btu/lb for enthalpy and 0 Btu/lb·°F for entropy for saturated liquid at -40°F. Exceptions are water and fluids with very low critical temperatures (e.g., ethylene, cryogenics).

These data are intended to help engineers make preliminary comparisons among unfamiliar fluids. For greater detail and a wider range of data, see the sources in the References.

Refrigerant	Page	Refrigerant	Page
Halocarbon Refrigerants		R-718 (water/steam)	30.36
<i>Methane Series</i>		R-744 (carbon dioxide)	30.38
R-12 (dichlorodifluoromethane)	30.2	Hydrocarbon Refrigerants	
R-22 (chlorodifluoromethane)	30.4	R-50 (methane)	30.40
R-23 (trifluoromethane)	30.6	R-170 (ethane)	30.42
R-32 (difluoromethane)	30.8	R-290 (propane)	30.44
<i>Ethane Series</i>		R-600 (<i>n</i> -butane)	30.46
R-123 (2,2-dichloro-1,1,1-trifluoroethane)	30.10	R-600a (isobutane)	30.48
R-124 (2-chloro-1,1,1,2-tetrafluoroethane)	30.12	R-1150 (ethylene)	30.50
R-125 (pentafluoroethane)	30.14	R-1270 (propylene)	30.52
R-134a (1,1,1,2-tetrafluoroethane)	30.16	Cryogenic Fluids	
R-143a (1,1,1-trifluoroethane)	30.20	R-702 (normal hydrogen)	30.54
R-152a (1,1-difluoroethane)	30.22	R-702p (parahydrogen)	30.56
<i>Propane Series</i>		R-704 (helium)	30.58
R-245fa (1,1,1,3,3-pentafluoropropane)	30.24	R-728 (nitrogen)	30.60
<i>Zeotropic Blends (% by mass)</i>		R-729 (air)	30.62
R-404A [R-125/143a/134a (44/52/4)]	30.26	R-732 (oxygen)	30.64
R-407C [R-32/125/134a (23/25/52)]	30.28	R-740 (argon)	30.66
R-410A [R-32/125 (50/50)]	30.30	Absorption Solutions	
<i>Azeotropic Blends</i>		Ammonia/Water	30.68
R-507A [R-125/143a (50/50)]	30.32	Water/Lithium Bromide	30.70
Inorganic Refrigerants			
R-717 (ammonia)	30.34		

The preparation of this chapter is assigned to TC 3.1, Refrigerants and Secondary Coolants.

Licensed for single user. © 2009 ASHRAE, Inc.

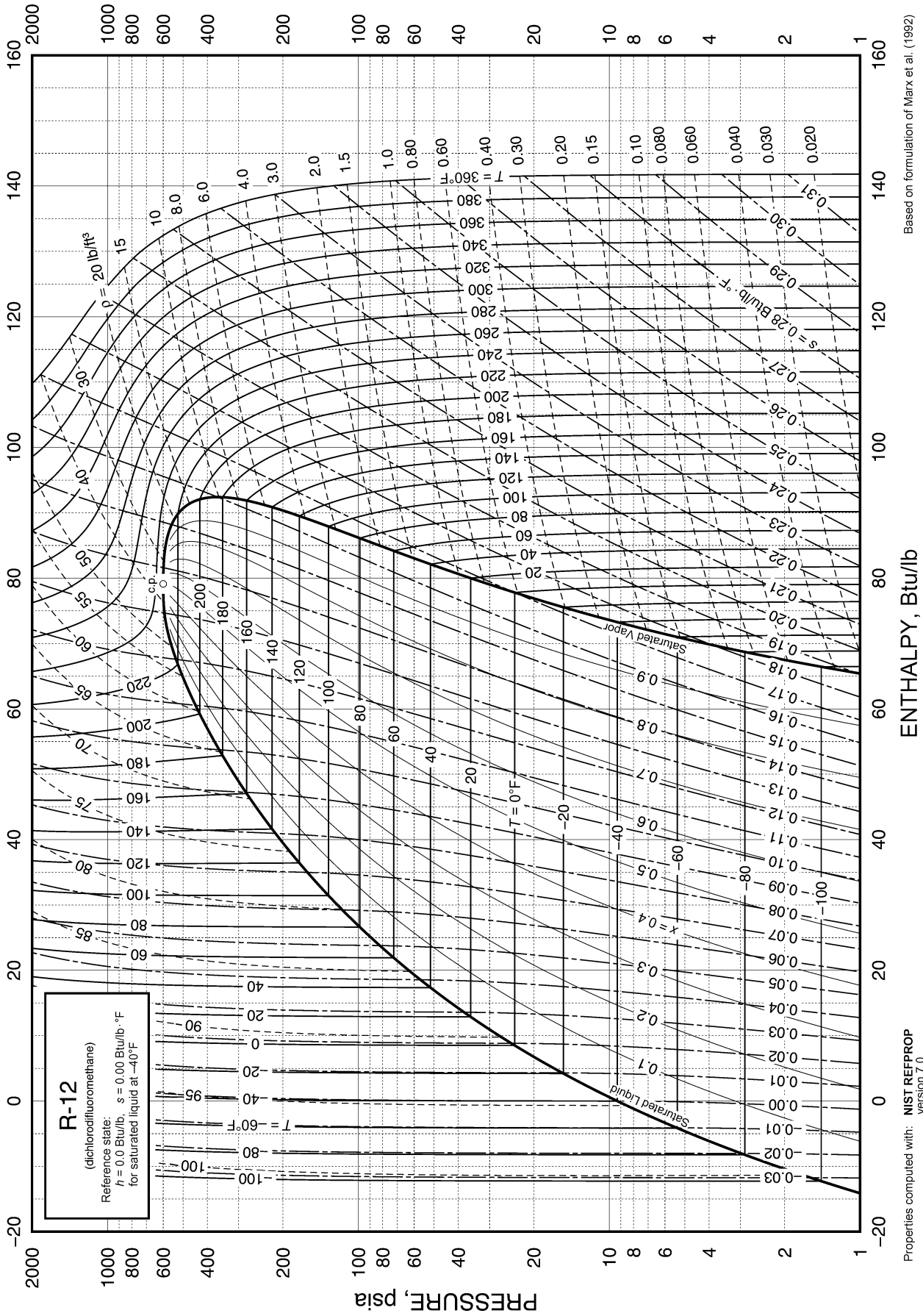


Fig. 1 Pressure-Enthalpy Diagram for Refrigerant 12

Refrigerant 12 (Dichlorodifluoromethane) Properties of Saturated Liquid and Saturated Vapor

Table with columns: Temp., Pres-sure, Density, Volume, Enthalpy, Entropy, Specific Heat, Vel. of Sound, Viscosity, Thermal Cond., Surface Tension. Rows range from -150 to 233.55 degrees Fahrenheit.

*Temperatures on ITS-90 scale

bNormal boiling point

cCritical point

Licensed for single user. © 2009 ASHRAE, Inc.

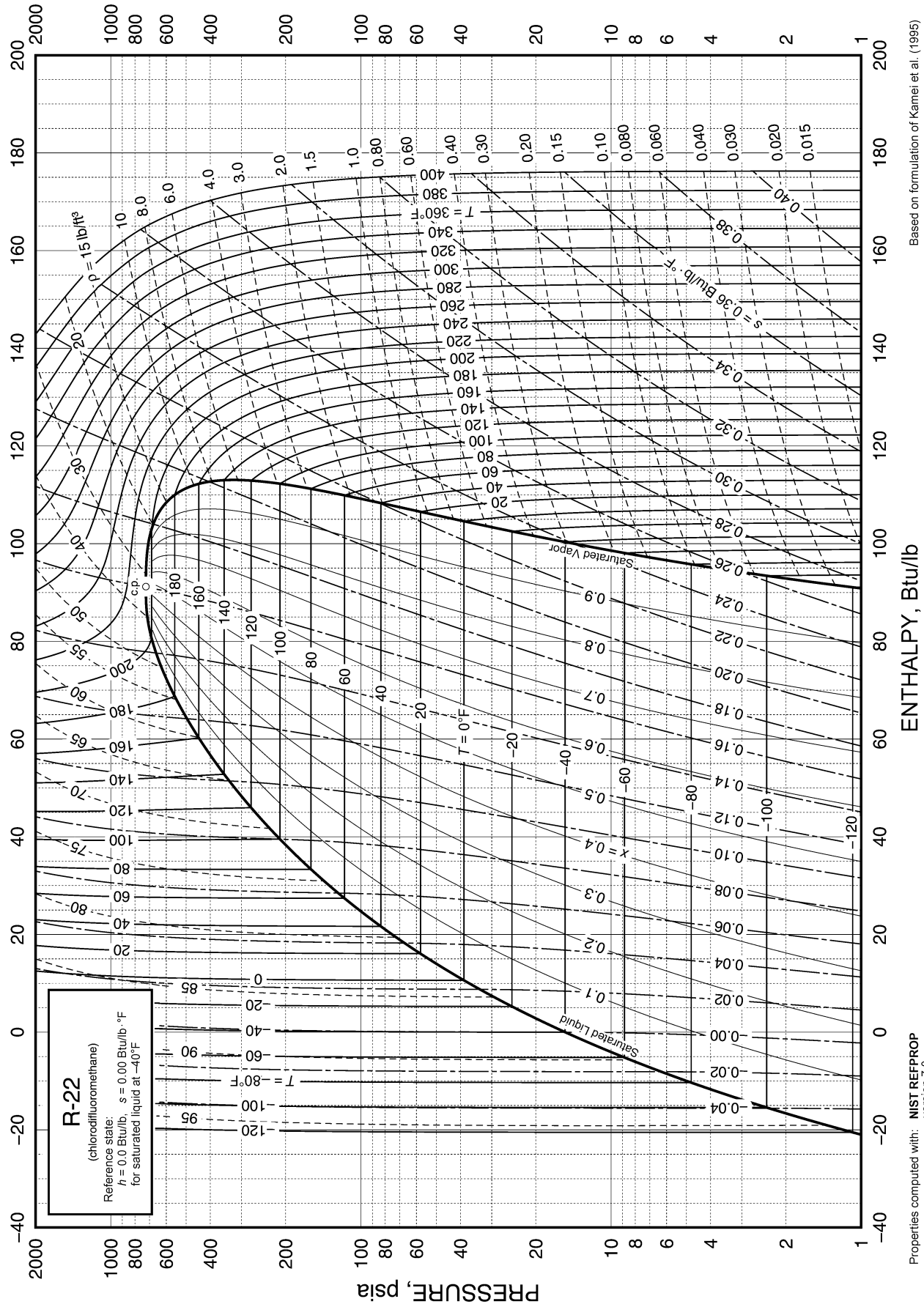


Fig. 2 Pressure-Enthalpy Diagram for Refrigerant 22

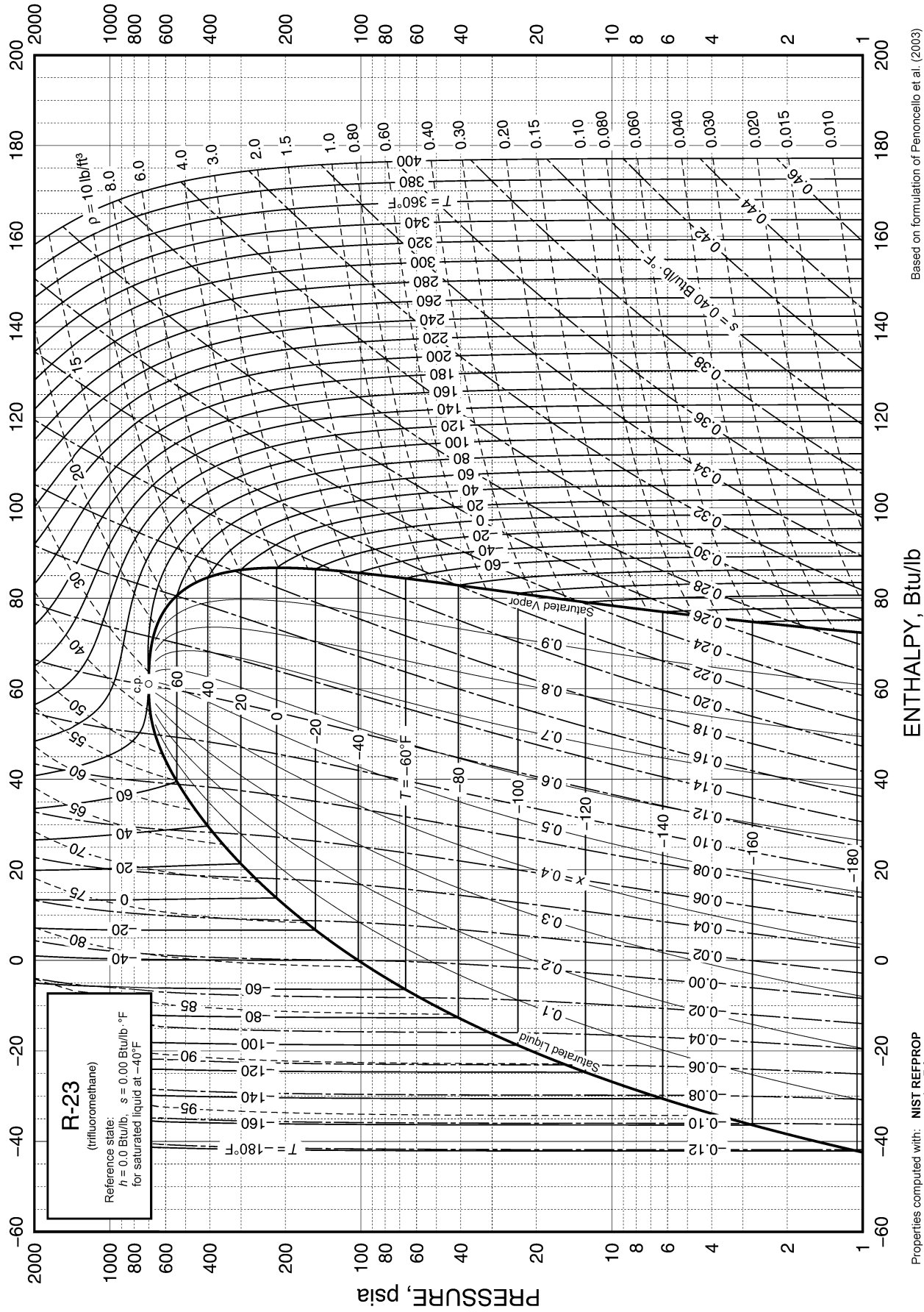
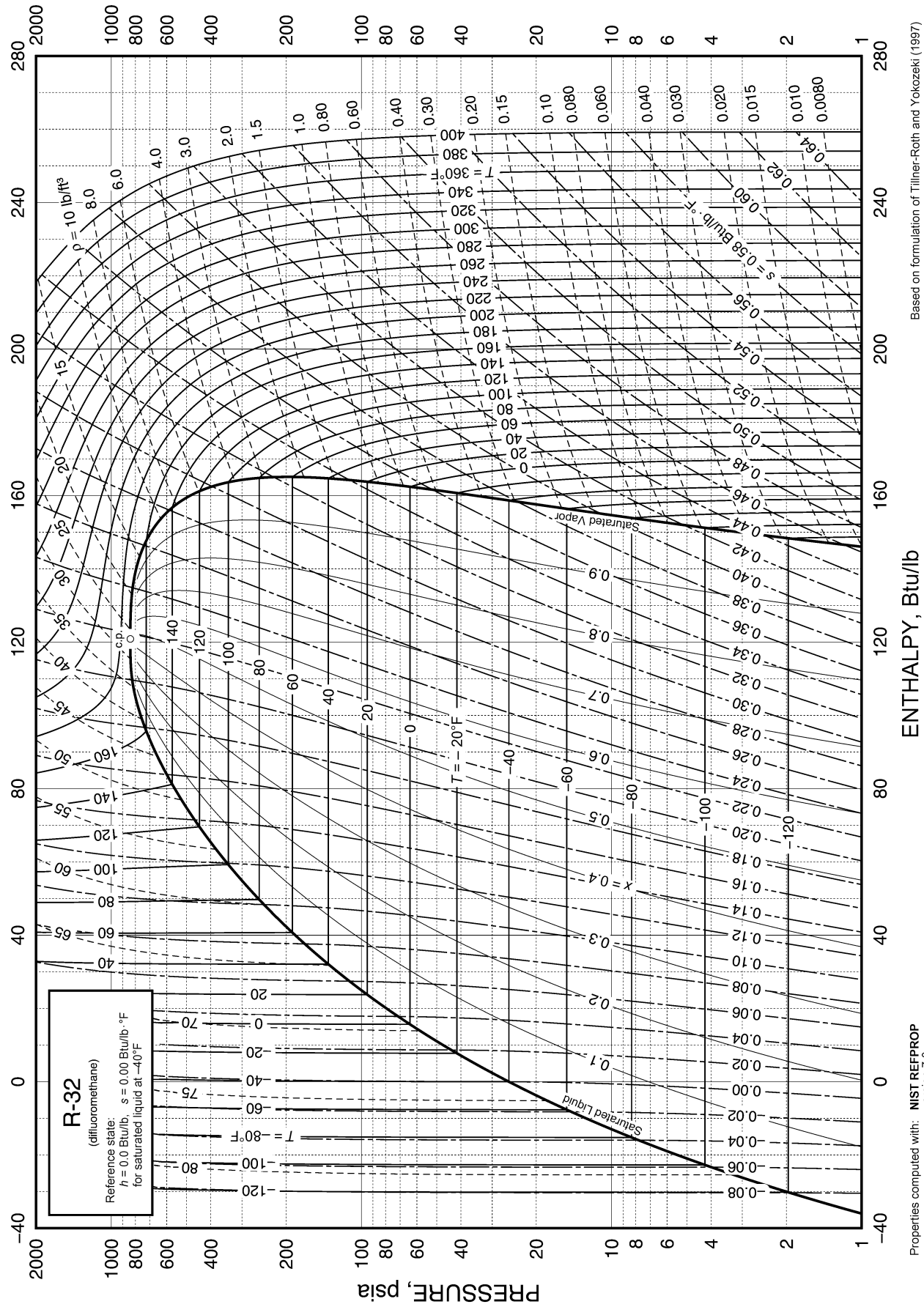


Fig. 3 Pressure-Enthalpy Diagram for Refrigerant 23

Licensed for single user. © 2009 ASHRAE, Inc.



Properties computed with: NIST REFPROP version 7.0

ENTHALPY, Btu/lb

Based on formulation of Tillner-Roth and Yokozeki (1997)

Fig. 4 Pressure-Enthalpy Diagram for Refrigerant 32

Refrigerant 32 (Difluoromethane) Properties of Saturated Liquid and Saturated Vapor

Table with columns: Temp., Pressure, Density, Volume, Enthalpy, Entropy, Specific Heat, Vel. of Sound, Viscosity, Thermal Cond., Surface Tension, Temp. The table lists properties for Refrigerant 32 at various temperatures from -214.26 to 172.59.

*Temperatures on ITS-90 scale

^aTriple point

^bNormal boiling point

^cCritical point

Licensed for single user. © 2009 ASHRAE, Inc.

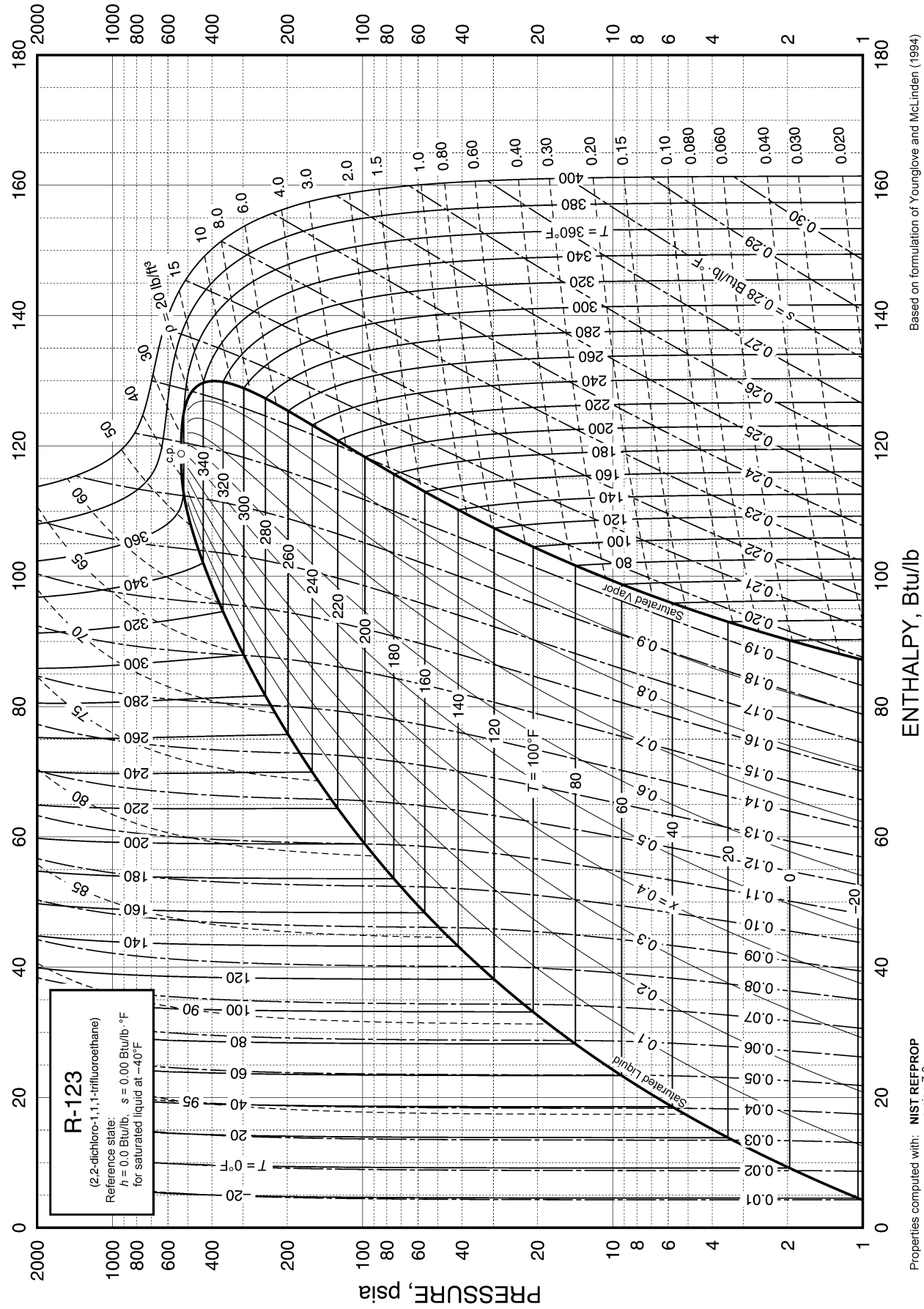
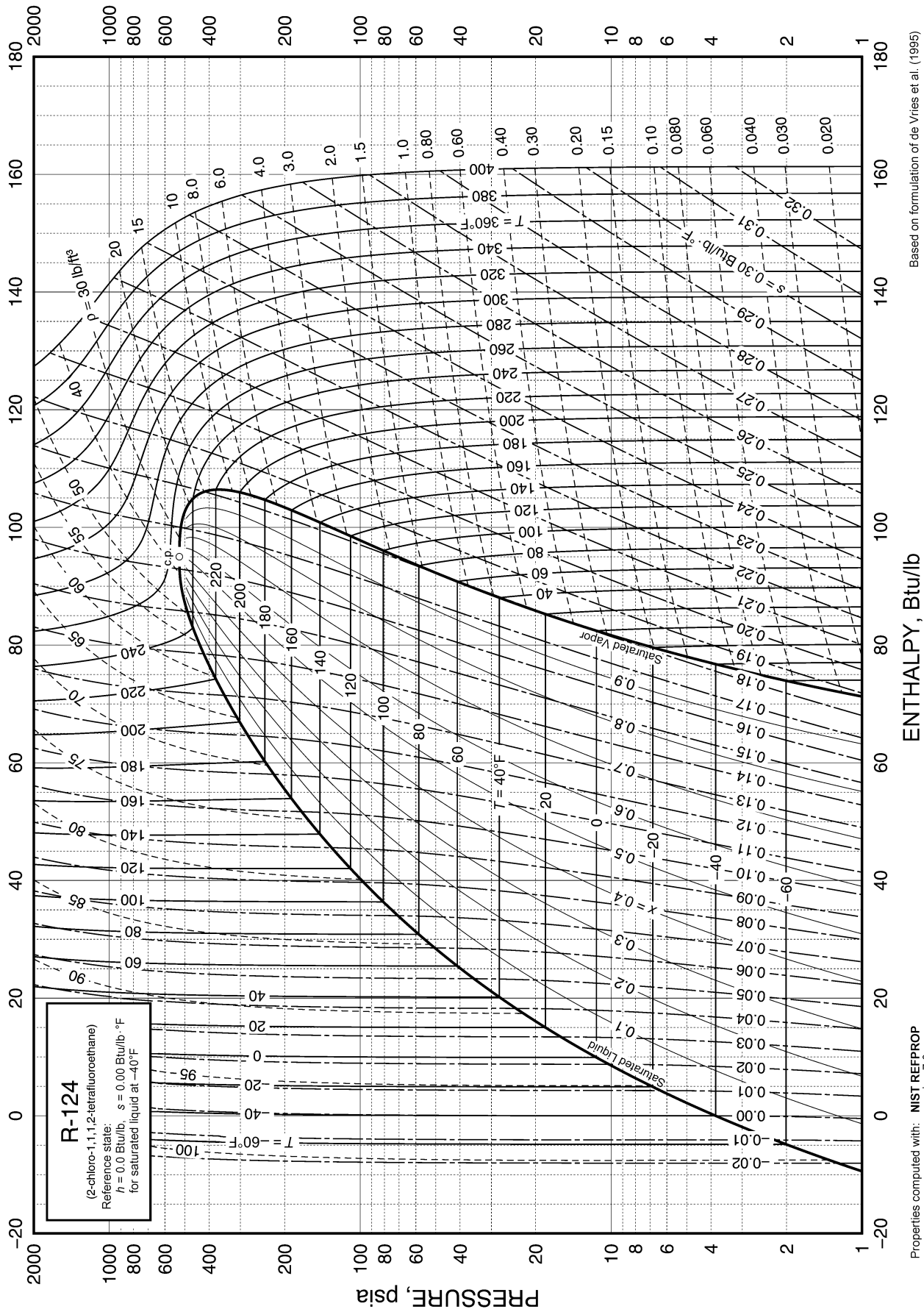


Fig. 5 Pressure-Enthalpy Diagram for Refrigerant 123



Based on formulation of de Vries et al. (1995)

Properties computed with: NIST REFPROP version 7.0

Fig. 6 Pressure-Enthalpy Diagram for Refrigerant 124

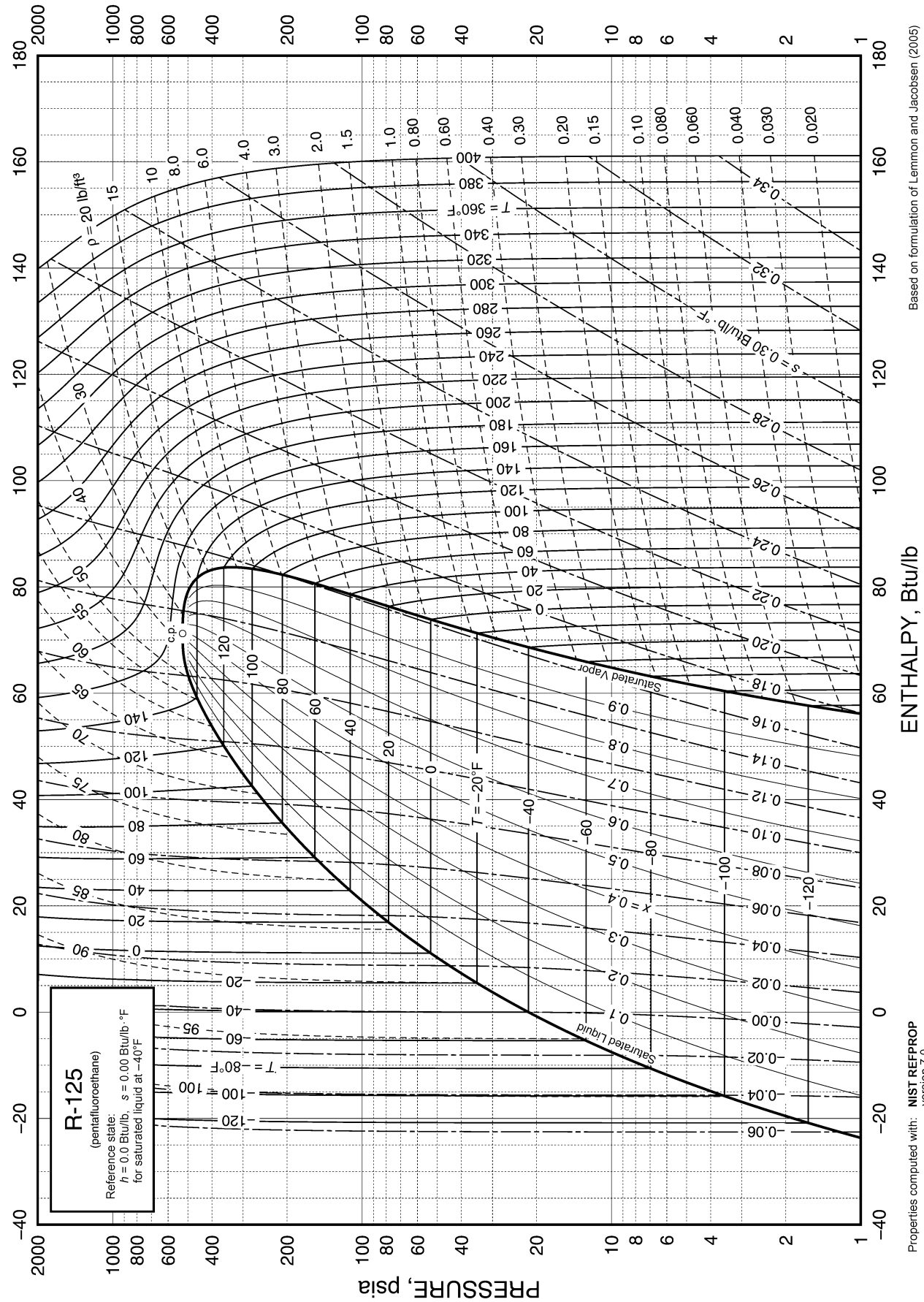


Fig. 7 Pressure-Enthalpy Diagram for Refrigerant 125

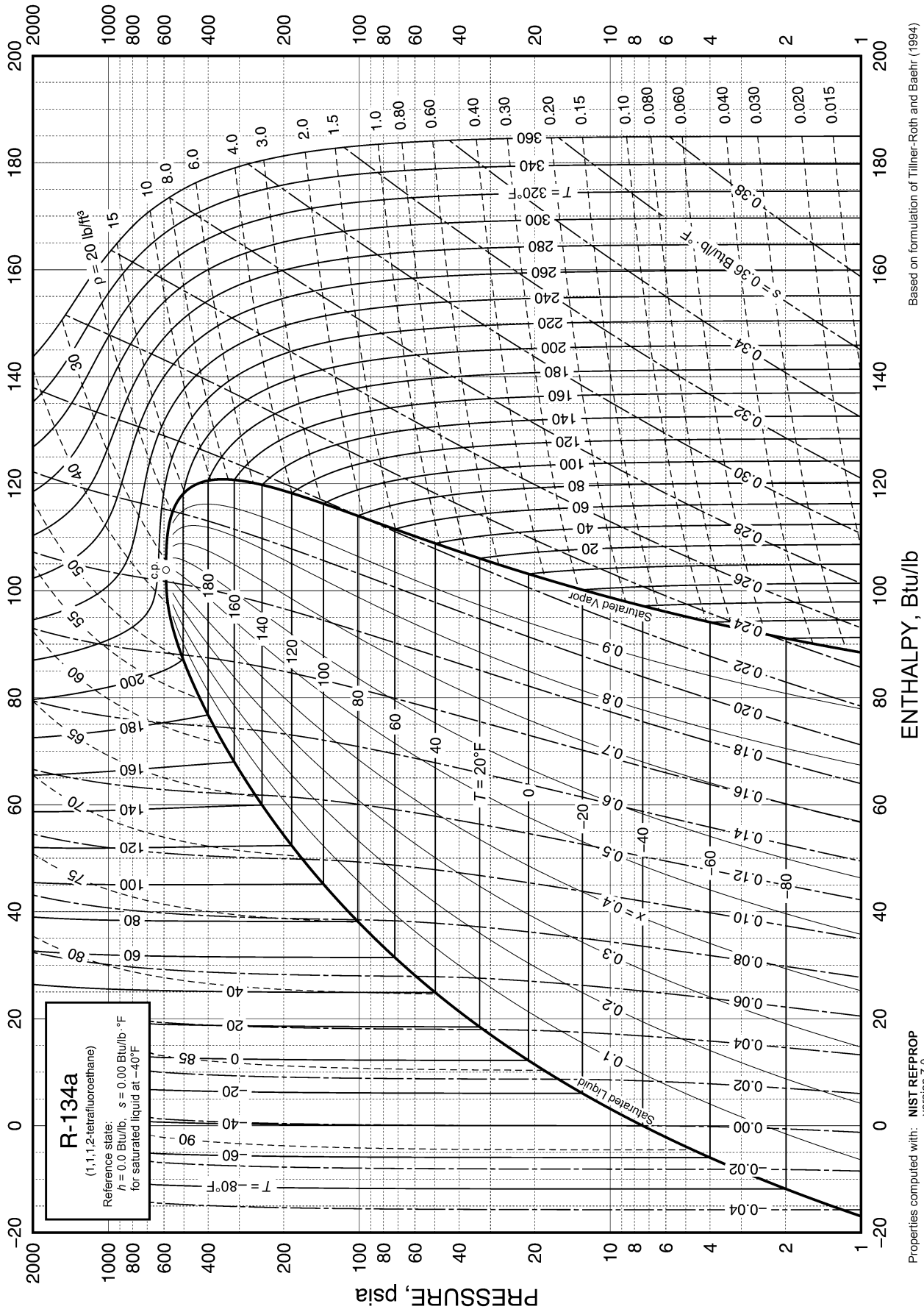


Fig. 8 Pressure-Enthalpy Diagram for Refrigerant 134a

Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor

Table with columns: Temp., Pressure, Density, Volume, Enthalpy, Entropy, Specific Heat, Vel. of Sound, Viscosity, Thermal Cond., Surface Tension, Temp. Sub-headers: Liquid, Vapor. Rows range from -153.94 to 213.91 degrees Fahrenheit.

*Temperatures on ITS-90 scale

^aTriple point

^bNormal boiling point

^cCritical point

Refrigerant 134a Properties of Superheated Vapor

Pressure = 14.696 psia Saturation temperature = -14.92 °F					Pressure = 25.00 psia Saturation temperature = 7.22 °F					Pressure = 50.00 psia Saturation temperature = 40.29 °F				
Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s
Saturated					Saturated					Saturated				
Liquid	85.7972	7.53	0.01739	2451.2	Liquid	83.4823	14.32	0.03224	2263.9	Liquid	79.8125	24.79	0.05377	1982.3
Vapor	0.3283	100.81	0.22713	478.0	Vapor	0.5426	104.07	0.22446	481.5	Vapor	1.0545	108.74	0.22170	481.7
0	0.3158	103.62	0.23335	487.2										
20	0.3008	107.45	0.24149	499.0	20	0.5245	106.60	0.22982	489.9	60	0.9982	113.00	0.23005	496.2
40	0.2874	111.34	0.24944	510.2	40	0.4991	110.61	0.23800	502.4	80	0.9489	117.32	0.23822	509.8
60	0.2753	115.31	0.25723	521.0	60	0.4765	114.66	0.24596	514.1	100	0.9055	121.68	0.24614	522.5
80	0.2642	119.35	0.26486	531.5	80	0.4563	118.78	0.25373	525.4	120	0.8670	126.07	0.25385	534.5
100	0.2541	123.47	0.27236	541.6	100	0.4379	122.96	0.26135	536.2	140	0.8322	130.51	0.26139	545.8
120	0.2448	127.68	0.27974	551.4	120	0.4212	127.22	0.26881	546.6	160	0.8008	135.01	0.26877	556.7
140	0.2362	131.96	0.28700	561.0	140	0.4058	131.55	0.27615	556.7	180	0.7718	139.57	0.27601	567.2
160	0.2282	136.32	0.29416	570.4	160	0.3916	135.95	0.28337	566.5	200	0.7454	144.20	0.28313	577.4
180	0.2208	140.77	0.30122	579.5	180	0.3786	140.43	0.29048	576.0	220	0.7208	148.89	0.29014	587.2
200	0.2139	145.30	0.30819	588.5	200	0.3663	144.98	0.29750	585.3	240	0.6980	153.65	0.29704	596.8
220	0.2074	149.90	0.31507	597.3	220	0.3549	149.61	0.30441	594.4	260	0.6768	158.48	0.30385	606.1
240	0.2013	154.59	0.32187	606.0	240	0.3443	154.32	0.31124	603.3	280	0.6569	163.38	0.31056	615.2
260	0.1955	159.36	0.32858	614.5	260	0.3343	159.10	0.31798	612.0	300	0.6383	168.35	0.31719	624.1
280	0.1901	164.20	0.33522	622.8	280	0.3248	163.96	0.32464	620.6					
300	0.1850	169.12	0.34178	631.1	300	0.3160	168.90	0.33122	629.0					
Pressure = 75.00 psia Saturation temperature = 62.24 °F					Pressure = 100.00 psia Saturation temperature = 79.17 °F					Pressure = 125.00 psia Saturation temperature = 93.15 °F				
Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s
Saturated					Saturated					Saturated				
Liquid	77.1862	31.98	0.06775	1793.6	Liquid	75.0245	37.69	0.07840	1646.8	Liquid	73.1279	42.53	0.08715	1524.7
Vapor	1.5686	111.67	0.22042	478.1	Vapor	2.0917	113.78	0.21960	472.8	Vapor	2.6279	115.41	0.21898	466.7
80	1.4873	115.74	0.22809	492.7	80	2.0858	113.98	0.21998	473.6					
100	1.4092	120.30	0.23639	507.7	100	1.9576	118.80	0.22874	491.6	100	2.5638	117.16	0.22212	473.9
120	1.3416	124.85	0.24439	521.6	120	1.8509	123.55	0.23709	507.8	120	2.4025	122.16	0.23090	492.9
140	1.2822	129.43	0.25215	534.5	140	1.7597	128.29	0.24512	522.4	140	2.2694	127.08	0.23924	509.7
160	1.2294	134.04	0.25971	546.6	160	1.6800	133.02	0.25288	536.0	160	2.1561	131.96	0.24725	525.0
180	1.1817	138.69	0.26710	558.2	180	1.6094	137.78	0.26044	548.8	180	2.0577	136.83	0.25498	539.0
200	1.1383	143.39	0.27434	569.2	200	1.5463	142.57	0.26781	560.8	200	1.9710	141.71	0.26250	552.2
220	1.0984	148.15	0.28145	579.8	220	1.4891	147.40	0.27502	572.3	220	1.8935	146.62	0.26983	564.6
240	1.0620	152.97	0.28843	590.1	240	1.4368	152.27	0.28210	583.3	240	1.8233	151.56	0.27700	576.4
260	1.0280	157.85	0.29531	600.0	260	1.3886	157.21	0.28905	593.9	260	1.7592	156.55	0.28402	587.6
280	0.9966	162.79	0.30208	609.7	280	1.3444	162.19	0.29588	604.1	280	1.7006	161.59	0.29093	598.4
300	0.9671	167.80	0.30876	619.0	300	1.3031	167.24	0.30261	614.0	300	1.6463	166.67	0.29771	608.8
320	0.9398	172.87	0.31535	628.2	320	1.2647	172.35	0.30925	623.6	320	1.5959	171.82	0.30440	618.9
340	0.9138	178.01	0.32186	637.1	340	1.2287	177.52	0.31579	632.9	340	1.5492	177.02	0.31098	628.7
360	0.8895	183.21	0.32828	645.9	360	1.1950	182.75	0.32225	642.1	360	1.5055	182.27	0.31747	638.2
380	0.8665	188.48	0.33463	654.5	380	1.1633	188.04	0.32863	651.0	380	1.4644	187.59	0.32388	647.5
400	0.8448	193.82	0.34091	662.9	400	1.1334	193.39	0.33494	659.8	400	1.4258	192.97	0.33021	656.6
Pressure = 150.00 psia Saturation temperature = 105.17 °F					Pressure = 175.00 psia Saturation temperature = 115.76 °F					Pressure = 200.00 psia Saturation temperature = 125.27 °F				
Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s
Saturated					Saturated					Saturated				
Liquid	71.4013	46.78	0.09464	1419.1	Liquid	69.7902	50.62	0.10126	1325.3	Liquid	68.2602	54.14	0.10721	1240.5
Vapor	3.1801	116.71	0.21844	460.0	Vapor	3.7511	117.76	0.21794	453.0	Vapor	4.3437	118.61	0.21743	445.6
120	3.0077	120.64	0.22530	476.6	120	3.6836	118.95	0.21999	458.4					
140	2.8181	125.78	0.23403	496.0	140	3.4148	124.38	0.22921	481.3	140	4.0726	122.86	0.22460	465.2
160	2.6620	130.83	0.24231	513.3	160	3.2025	129.64	0.23783	500.9	160	3.7850	128.36	0.23363	487.8
180	2.5295	135.83	0.25026	528.9	180	3.0271	134.79	0.24602	518.3	180	3.5561	133.70	0.24210	507.2
200	2.4146	140.82	0.25794	543.3	200	2.8785	139.90	0.25388	534.0	200	3.3656	138.94	0.25018	524.5
220	2.3132	145.82	0.26539	556.7	220	2.7494	144.99	0.26148	548.5	220	3.2036	144.14	0.25793	540.2
240	2.2223	150.83	0.27267	569.3	240	2.6349	150.08	0.26887	562.1	240	3.0623	149.31	0.26544	554.7
260	2.1401	155.88	0.27978	581.3	260	2.5328	155.19	0.27607	574.8	260	2.9371	154.50	0.27274	568.3
280	2.0658	160.97	0.28675	592.7	280	2.4403	160.34	0.28312	586.9	280	2.8247	159.69	0.27987	581.1
300	1.9971	166.10	0.29360	603.7	300	2.3558	165.51	0.29003	598.5	300	2.7234	164.92	0.28684	593.2
320	1.9338	171.28	0.30033	614.2	320	2.2785	170.73	0.29681	609.5	320	2.6305	170.18	0.29368	604.8
340	1.8751	176.51	0.30696	624.5	340	2.2071	176	0.30348	620.2	340	2.5455	175.49	0.30039	615.9
360	1.8208	181.80	0.31349	634.4	360	2.1411	181.32	0.31004	630.5	360	2.4668	180.83	0.30700	626.7
380	1.7695	187.14	0.31993	644.0	380	2.0795	186.69	0.31651	640.5	380	2.3934	186.23	0.31350	637.0
400	1.7216	192.54	0.32628	653.4	400	2.0216	192.11	0.32290	650.3	400	2.3254	191.68	0.31991	647.1
420	1.6766	198.00	0.33256	662.6	420	1.9675	197.59	0.32920	659.7	420	2.2614	197.18	0.32624	656.9
440	1.6341	203.51	0.33876	671.6	440	1.9164	203.12	0.33542	669.0	440	2.2017	202.73	0.33248	666.4
460	1.5940	209.08	0.34488	680.4	460	1.8683	208.71	0.34156	678.0	460	2.1453	208.34	0.33864	675.7
480	1.5558	214.71	0.35094	689.0	480	1.8228	214.36	0.34763	686.9	480	2.0920	214.00	0.34473	684.8
500	1.5197	220.40	0.35692	697.4	500	1.7797	220.05	0.35363	695.6	500	2.0417	219.71	0.35075	693.7

*Temperatures on ITS-90 scale

Refrigerant 134a Properties of Superheated Vapor (Concluded)

Pressure = 225.00 psia Saturation temperature = 133.93°F					Pressure = 250.00 psia Saturation temperature = 141.89°F					Pressure = 275.00 psia Saturation temperature = 149.27°F				
Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s	Temp.,* °F	Density, lb/ft ³	Enthalpy, Btu/lb	Entropy, Btu/lb·°F	Vel. Sound, ft/s
Saturated														
Liquid	66.7870	57.42	0.11266	1162.8	Liquid	65.3526	60.50	0.11770	1090.7	Liquid	63.9423	63.43	0.12241	1023.4
Vapor	4.9609	119.30	0.21690	438.1	Vapor	5.6060	119.84	0.21634	430.3	Vapor	6.2831	120.25	0.21572	422.3
140	4.8123	121.16	0.22002	447.3										
160	4.4191	126.99	0.22959	473.6	160	5.1189	125.49	0.22560	458.2	160	5.9060	123.82	0.22155	441.2
180	4.1206	132.54	0.23840	495.5	180	4.7275	131.31	0.23484	483.1	180	5.3869	129.98	0.23133	469.9
200	3.8796	137.94	0.24671	514.6	200	4.4239	136.89	0.24343	504.2	200	5.0031	135.78	0.24026	493.4
220	3.6784	143.25	0.25465	531.6	220	4.1756	142.34	0.25156	522.8	220	4.6978	141.38	0.24862	513.7
240	3.5058	148.52	0.26229	547.2	240	3.9664	147.71	0.25935	539.5	240	4.4465	146.87	0.25658	531.7
260	3.3542	153.78	0.26970	561.6	260	3.7854	153.05	0.26688	554.9	260	4.2314	152.30	0.26423	548.0
280	3.2202	159.04	0.27691	575.1	280	3.6265	158.37	0.27418	569.2	280	4.0446	157.69	0.27162	563.1
300	3.0995	164.32	0.28395	587.9	300	3.4847	163.71	0.28129	582.6	300	3.8803	163.08	0.27881	577.2
320	2.9899	169.62	0.29084	600.0	320	3.3571	169.06	0.28824	595.3	320	3.7317	168.49	0.28583	590.5
340	2.8897	174.97	0.29761	611.7	340	3.2408	174.44	0.29506	607.4	340	3.5987	173.91	0.29270	603.1
360	2.7978	180.35	0.30425	622.8	360	3.1342	179.85	0.30175	618.9	360	3.4764	179.36	0.29943	615.1
380	2.7122	185.77	0.31079	633.6	380	3.0359	185.31	0.30832	630.1	380	3.3646	184.84	0.30604	626.6
400	2.6330	191.24	0.31723	644.0	400	2.9451	190.81	0.31479	640.8	400	3.2612	190.37	0.31254	637.7
420	2.5592	196.77	0.32358	654.0	420	2.8604	196.35	0.32117	651.2	420	3.1653	195.93	0.31894	648.4
440	2.4900	202.34	0.32984	663.9	440	2.7813	201.94	0.32745	661.3	440	3.0758	201.55	0.32525	658.8
460	2.4249	207.96	0.33603	673.4	460	2.7072	207.58	0.33365	671.1	460	2.9922	207.20	0.33147	668.9
480	2.3636	213.64	0.34213	682.8	480	2.6374	213.27	0.33977	680.7	480	2.9136	212.91	0.33761	678.7
500	2.3057	219.36	0.34816	691.9	500	2.5717	219.02	0.34582	690.1	500	2.8397	218.67	0.34368	688.3
Saturated														
Liquid	62.5436	66.23	0.12686	959.8	Liquid	61.1446	68.92	0.13110	899.5	Liquid	59.7334	71.54	0.13516	841.7
Vapor	6.9967	120.54	0.21505	414.2	Vapor	7.7526	120.71	0.21431	405.9	Vapor	8.5577	120.76	0.21349	397.5
160	6.8168	121.92	0.21730	422.0										
180	6.1118	128.55	0.22782	455.8	180	6.9220	126.96	0.22423	440.3	180	7.8491	125.18	0.22046	423.2
200	5.6239	134.61	0.23715	482.1	200	6.2928	133.36	0.23408	470.2	200	7.0242	132.01	0.23098	457.6
220	5.2494	140.39	0.24578	504.3	220	5.8341	139.34	0.24301	494.5	220	6.4561	138.24	0.24029	484.4
240	4.9472	146.00	0.25393	523.7	240	5.4723	145.10	0.25136	515.5	240	6.0219	144.17	0.24888	507.1
260	4.6939	151.52	0.26171	541.1	260	5.1741	150.73	0.25930	534.0	260	5.6728	149.91	0.25698	526.9
280	4.4758	157.00	0.26921	557.0	280	4.9208	156.29	0.26692	550.9	280	5.3805	155.56	0.26472	544.7
300	4.2852	162.45	0.27649	571.8	300	4.7017	161.81	0.27428	566.4	300	5.1295	161.15	0.27218	561.0
320	4.1160	167.90	0.28357	585.7	320	4.5082	167.31	0.28144	580.9	320	4.9098	166.72	0.27941	576.1
340	3.9631	173.37	0.29049	598.8	340	4.3352	172.82	0.28841	594.5	340	4.7148	172.27	0.28644	590.2
360	3.8247	178.85	0.29727	611.2	360	4.1790	178.35	0.29524	607.4	360	4.5396	177.84	0.29332	603.6
380	3.6981	184.37	0.30392	623.1	380	4.0368	183.90	0.30193	619.7	380	4.3807	183.42	0.30005	616.3
400	3.5816	189.92	0.31045	634.6	400	3.9063	189.48	0.30849	631.5	400	4.2355	189.03	0.30665	628.4
420	3.4737	195.51	0.31688	645.6	420	3.7859	195.09	0.31495	642.8	420	4.1019	194.67	0.31313	640.1
440	3.3735	201.15	0.32321	656.3	440	3.6743	200.75	0.32131	653.8	440	3.9784	200.35	0.31952	651.4
460	3.2799	206.83	0.32945	666.6	460	3.5703	206.44	0.32757	664.4	460	3.8636	206.06	0.32580	662.2
480	3.1922	212.55	0.33561	676.7	480	3.4731	212.19	0.33375	674.7	480	3.7564	211.82	0.33199	672.8
500	3.1098	218.32	0.34169	686.5	500	3.3819	217.97	0.33984	684.7	500	3.6561	217.62	0.33811	683.0
Saturated														
Liquid	58.2974	74.09	0.13908	785.9	Liquid	56.8213	76.60	0.14289	731.8	Liquid				
Vapor	9.4209	120.69	0.21256	389.0	Vapor	10.3541	120.50	0.21152	380.6	Vapor				
180	8.9498	123.10	0.21634	403.8	180	10.3454	120.53	0.21158	380.6					
200	7.8311	130.54	0.22781	444.1	200	8.7370	128.93	0.22451	429.5					
220	7.1211	137.08	0.23758	474.0	220	7.8399	135.85	0.23484	463.0	220	19.6784	118.27	0.20421	340.3
240	6.6028	143.19	0.24644	498.5	240	7.2145	142.18	0.24403	489.7	240	14.2159	131.50	0.22343	409.1
260	6.1926	149.07	0.25473	519.6	260	6.7351	148.21	0.25252	512.3	260	12.2674	139.92	0.23530	449.7
280	5.8555	154.82	0.26260	538.4	280	6.3472	154.06	0.26055	532.1	280	11.0672	147.15	0.24522	480.8
300	5.5694	160.49	0.27016	555.5	300	6.0221	159.81	0.26821	550.0	300	10.2049	153.83	0.25413	506.7
320	5.3212	166.11	0.27747	571.3	320	5.7425	165.49	0.27560	566.5	320	9.5351	160.21	0.26241	529.2
340	5.1022	171.72	0.28457	586.0	340	5.4977	171.15	0.28277	581.7	340	8.9895	166.39	0.27024	549.2
360	4.9066	177.32	0.29149	599.8	360	5.2802	176.80	0.28975	596.0	360	8.5305	172.45	0.27774	567.5
380	4.7300	182.94	0.29826	612.9	380	5.0848	182.45	0.29656	609.5	380	8.1351	178.45	0.28496	584.4
400	4.5692	188.58	0.30490	625.4	400	4.9075	188.12	0.30323	622.4	400	7.7885	184.40	0.29197	600.1
420	4.4217	194.24	0.31141	637.4	420	4.7454	193.82	0.30978	634.7	420	7.4804	190.34	0.29879	615.0
440	4.2857	199.94	0.31782	648.9	440	4.5964	199.54	0.31621	646.5	440	7.2035	196.26	0.30546	629.0
460	4.1596	205.68	0.32413	660.1	460	4.4584	205.30	0.32254	657.9	460	6.9523	202.20	0.31198	642.4
480	4.0421	211.46	0.33034	670.8	480	4.3303	211.09	0.32878	669.0	480	6.7229	208.15	0.31838	655.3
500	3.9323	217.28	0.33647	681.3	500	4.2107	216.93	0.33492	679.6	500	6.5118	214.12	0.32467	667.6

*Temperatures on ITS-90 scale

Licensed for single user. © 2009 ASHRAE, Inc.

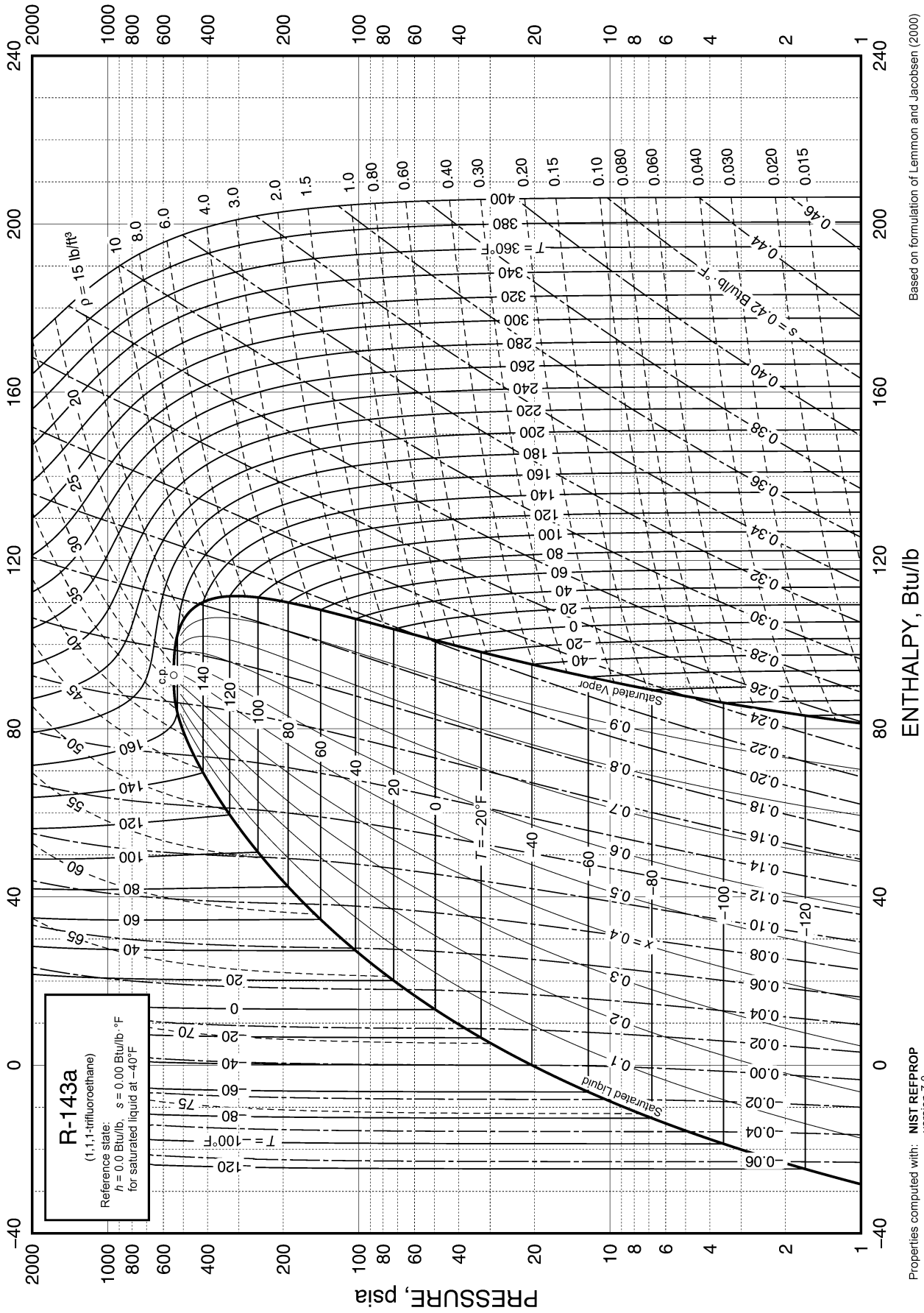


Fig. 9 Pressure-Enthalpy Diagram for Refrigerant 143a

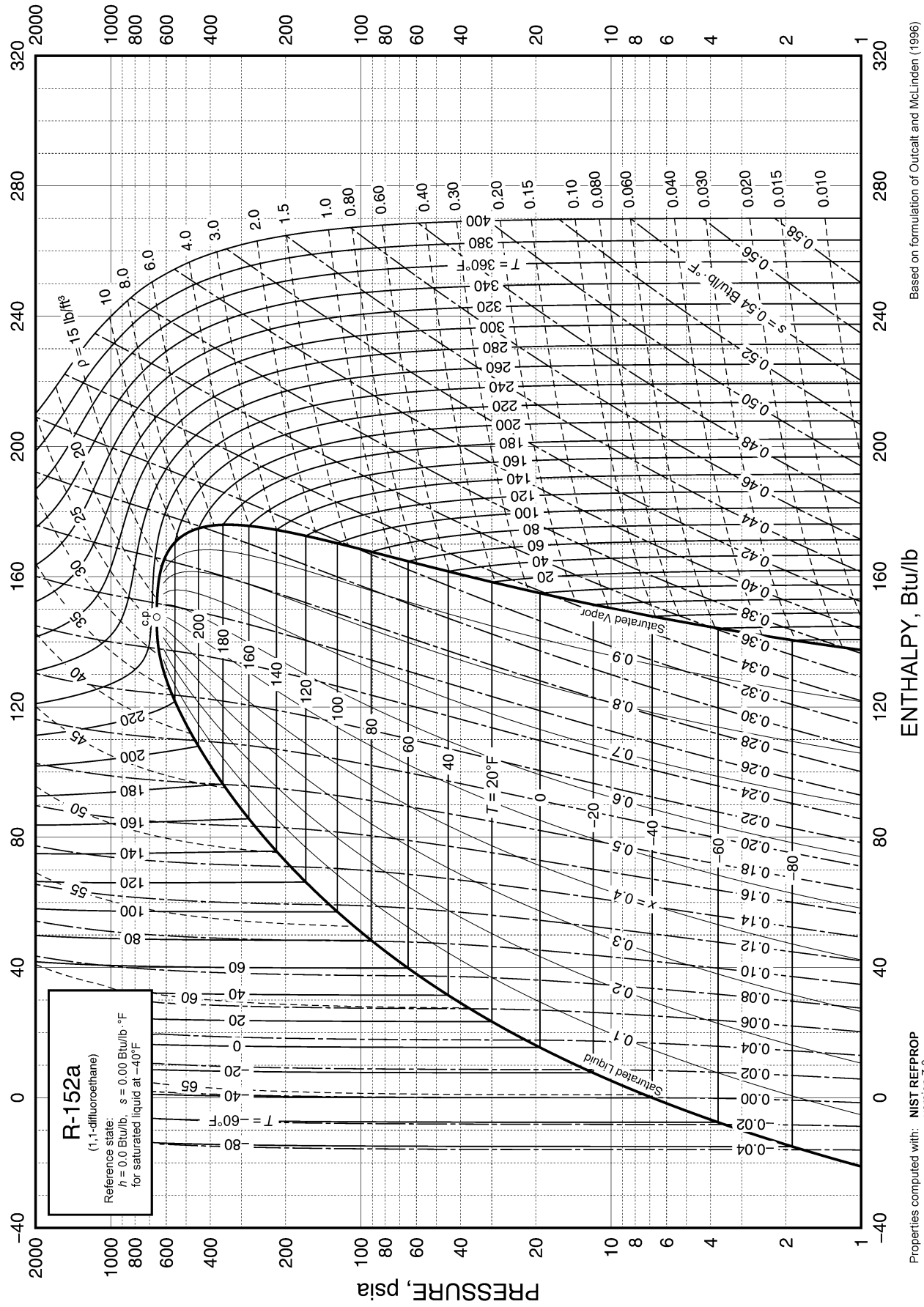


Fig. 10 Pressure-Enthalpy Diagram for Refrigerant 152a

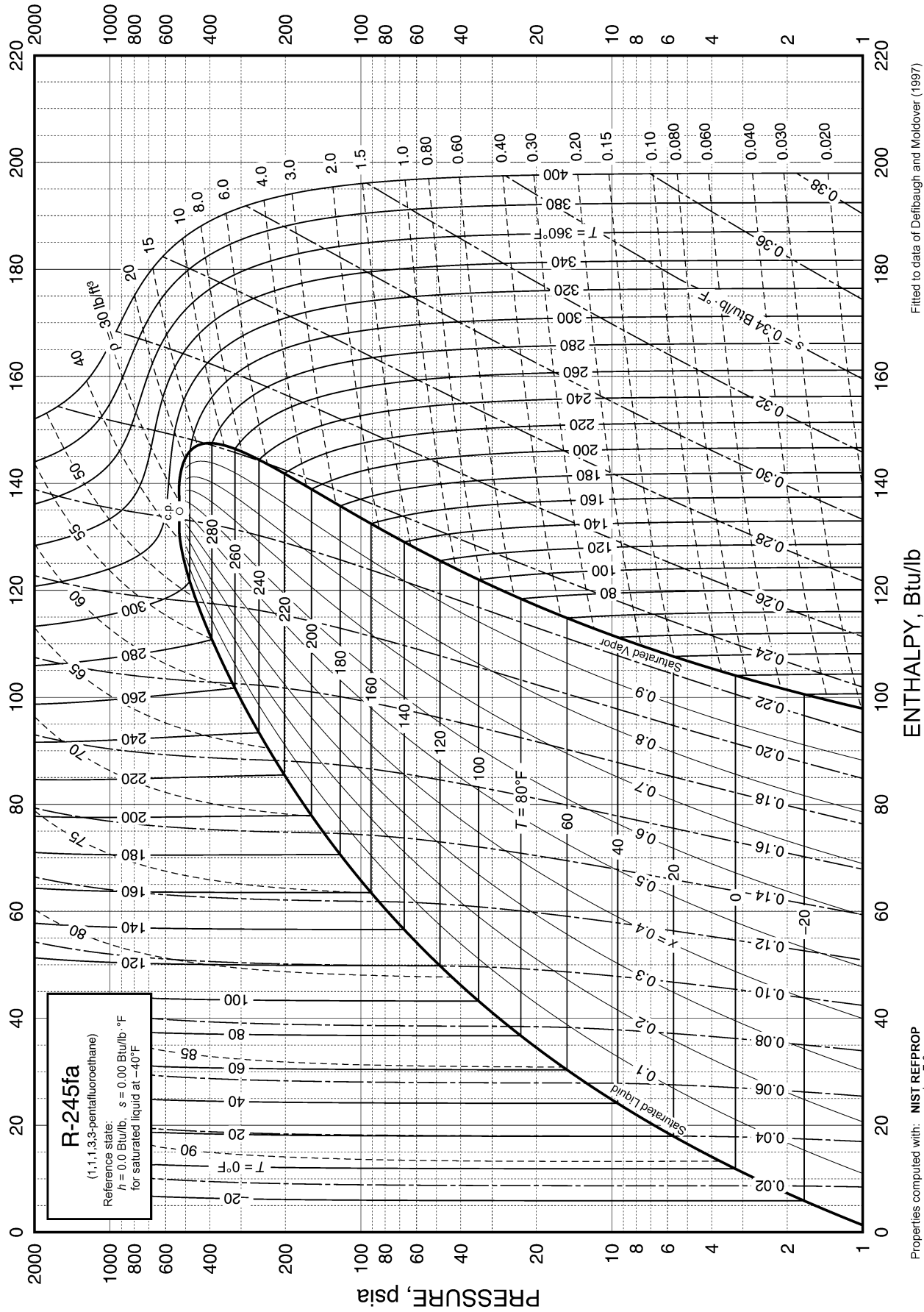


Fig. 11 Pressure-Enthalpy Diagram for Refrigerant 245fa

Licensed for single user. © 2009 ASHRAE, Inc.

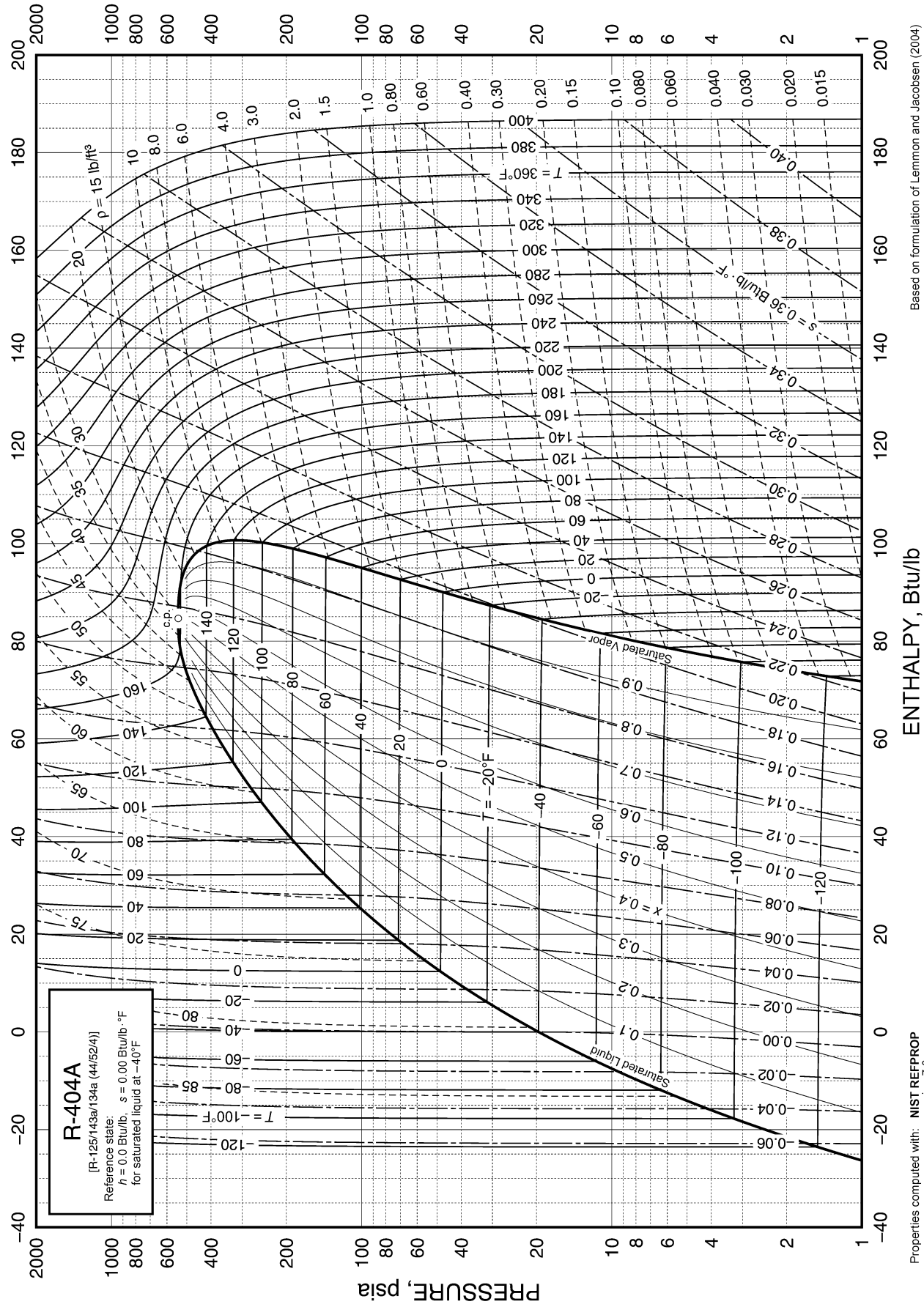


Fig. 12 Pressure-Enthalpy Diagram for Refrigerant 404A

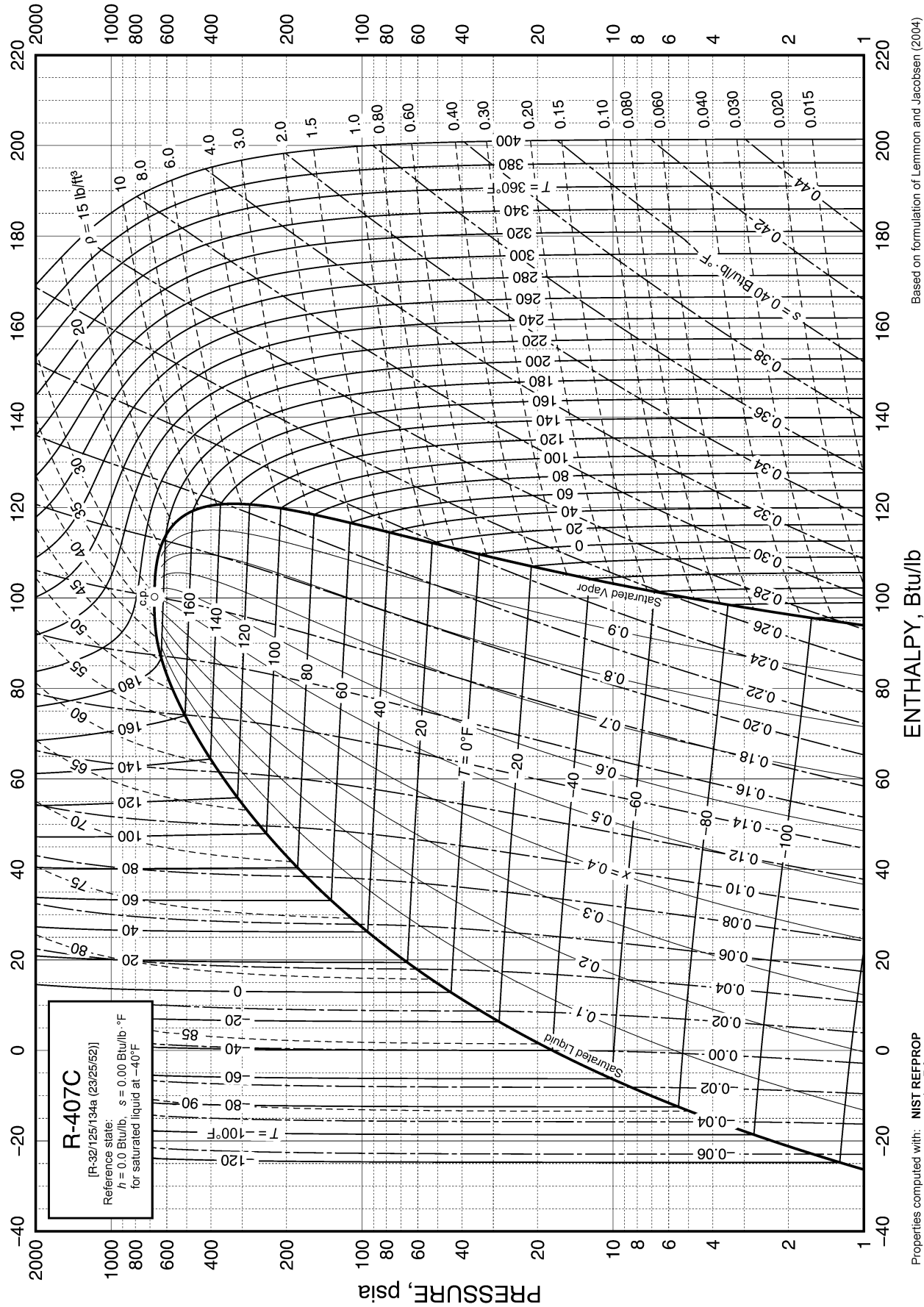
Refrigerant 404A [R-125/143a/134a (44/52/4)] Properties of Liquid on Bubble Line and Vapor on Dew Line

Table with 20 columns: Pressure (psia), Temp. (°F), Density, Volume, Enthalpy, Entropy, Specific Heat, Vel. of Sound, Viscosity, Thermal Cond., Surface Tension, and Pressure. It lists thermophysical data for Refrigerant 404A across various temperature and pressure points.

*Temperatures on ITS-90 scale

^bBubble and dew points at one standard atmosphere

^cCritical point



Properties computed with: NIST REFPROP version 7.0

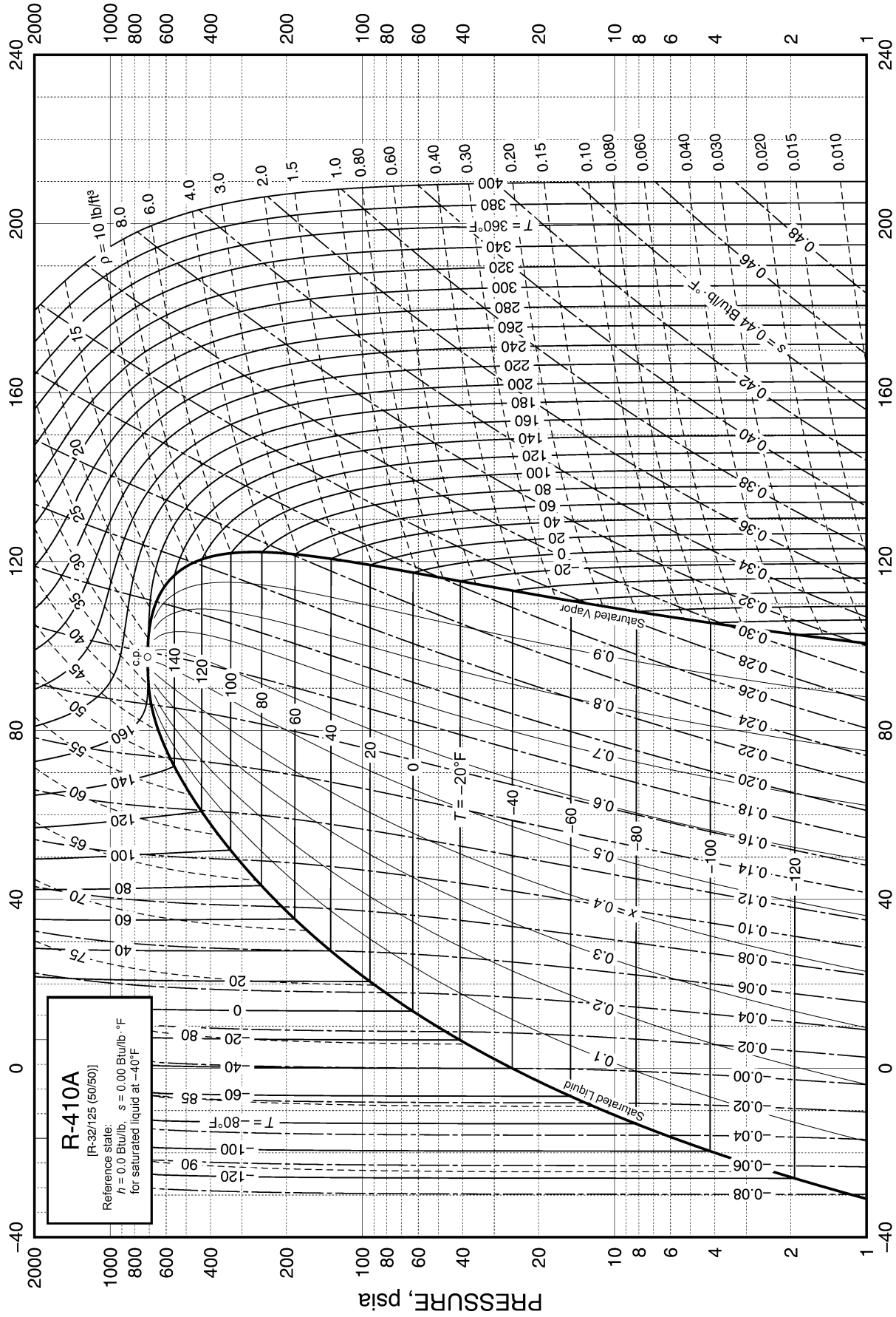
ENTHALPY, Btu/lb

Fig. 13 Pressure-Enthalpy Diagram for Refrigerant 407C

Based on formulation of Lemmon and Jacobsen (2004)

Licensed for single user. © 2009 ASHRAE, Inc.

Licensed for single user. © 2009 ASHRAE, Inc.



Properties computed with: NIST REFPROP version 7.0

Based on formulation of Lemmon and Jacobsen (2004)

Fig. 14 Pressure-Enthalpy Diagram for Refrigerant 410A

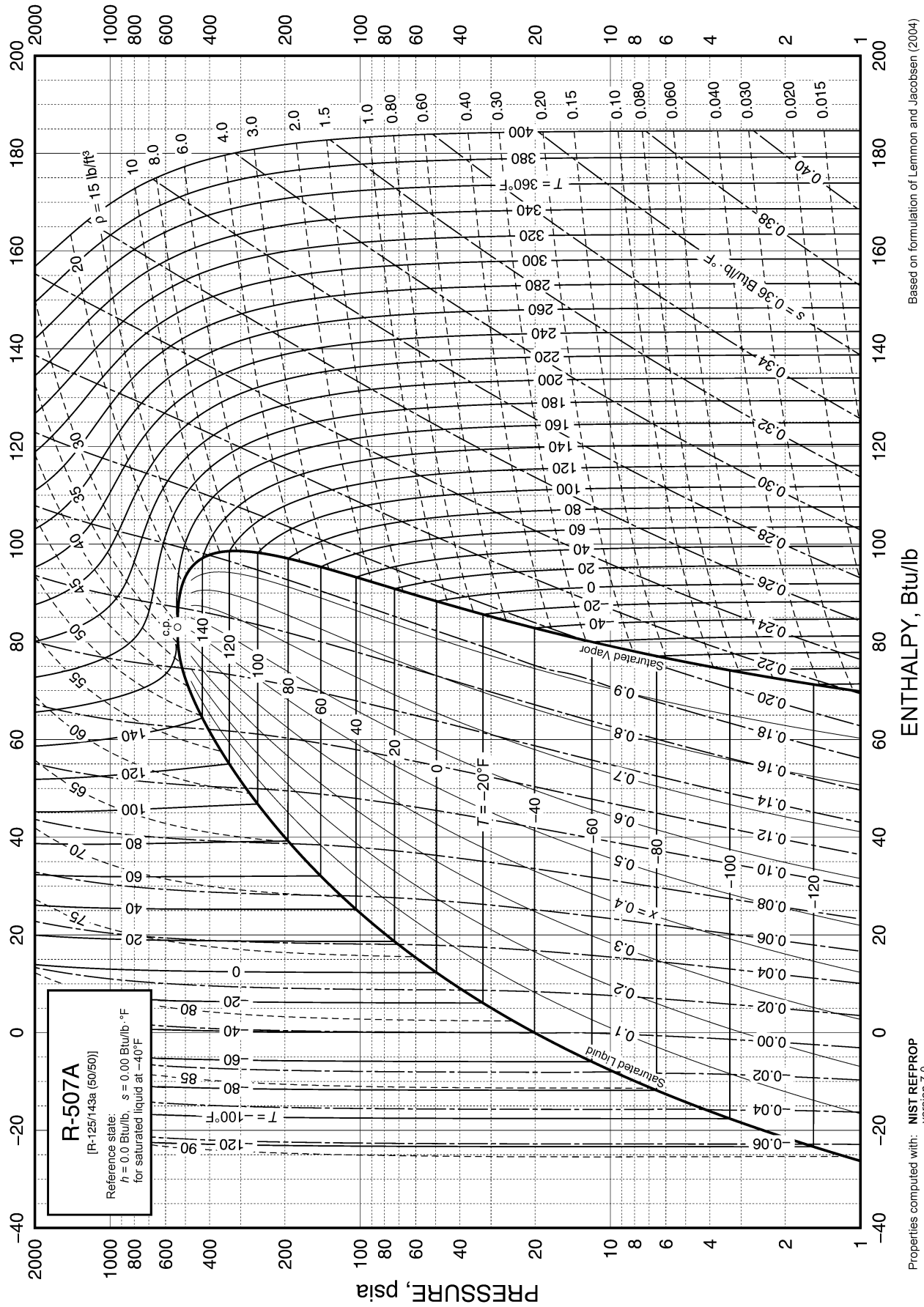


Fig. 15 Pressure-Enthalpy Diagram for Refrigerant 507A

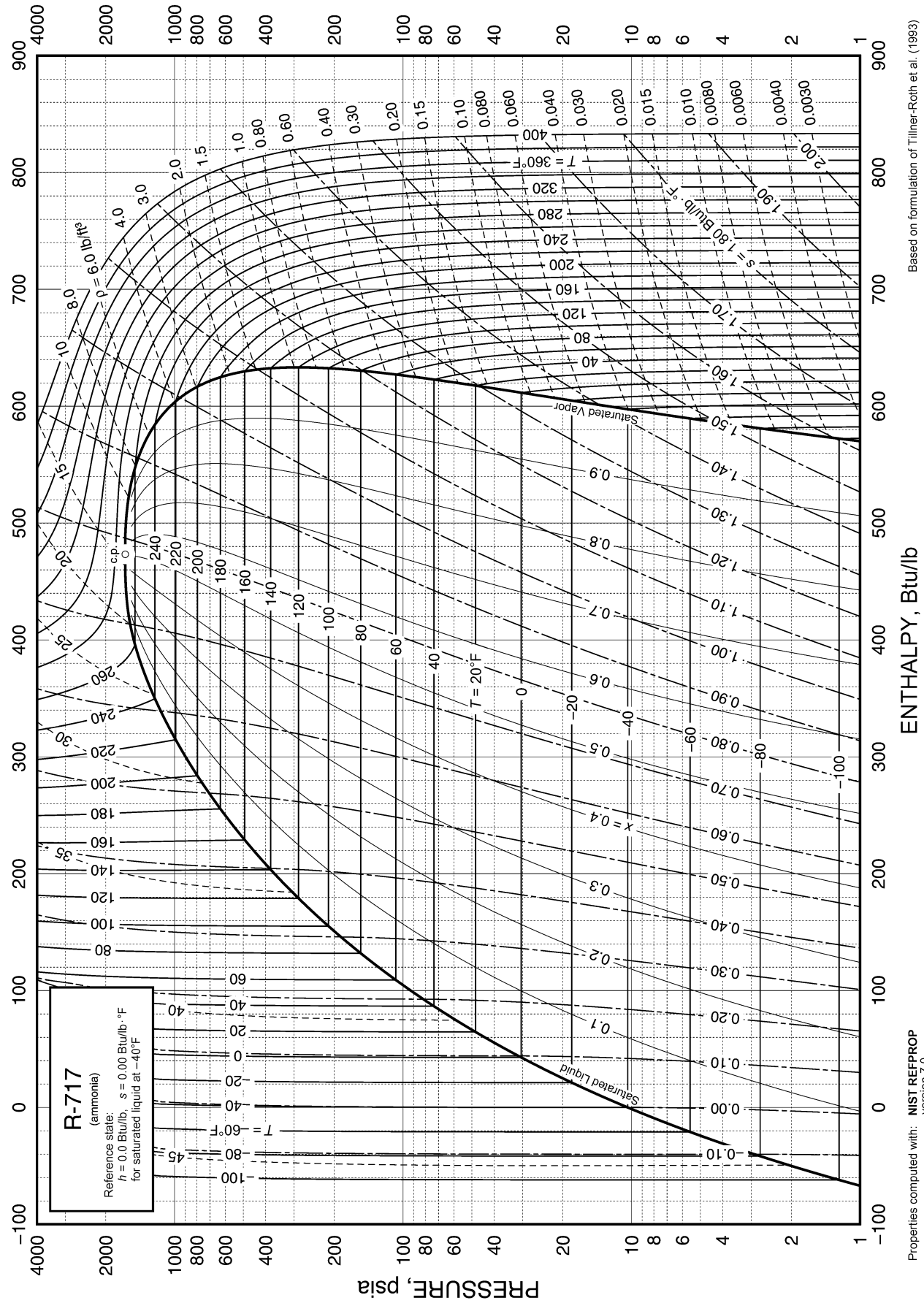


Fig. 16 Pressure-Enthalpy Diagram for Refrigerant 717 (Ammonia)

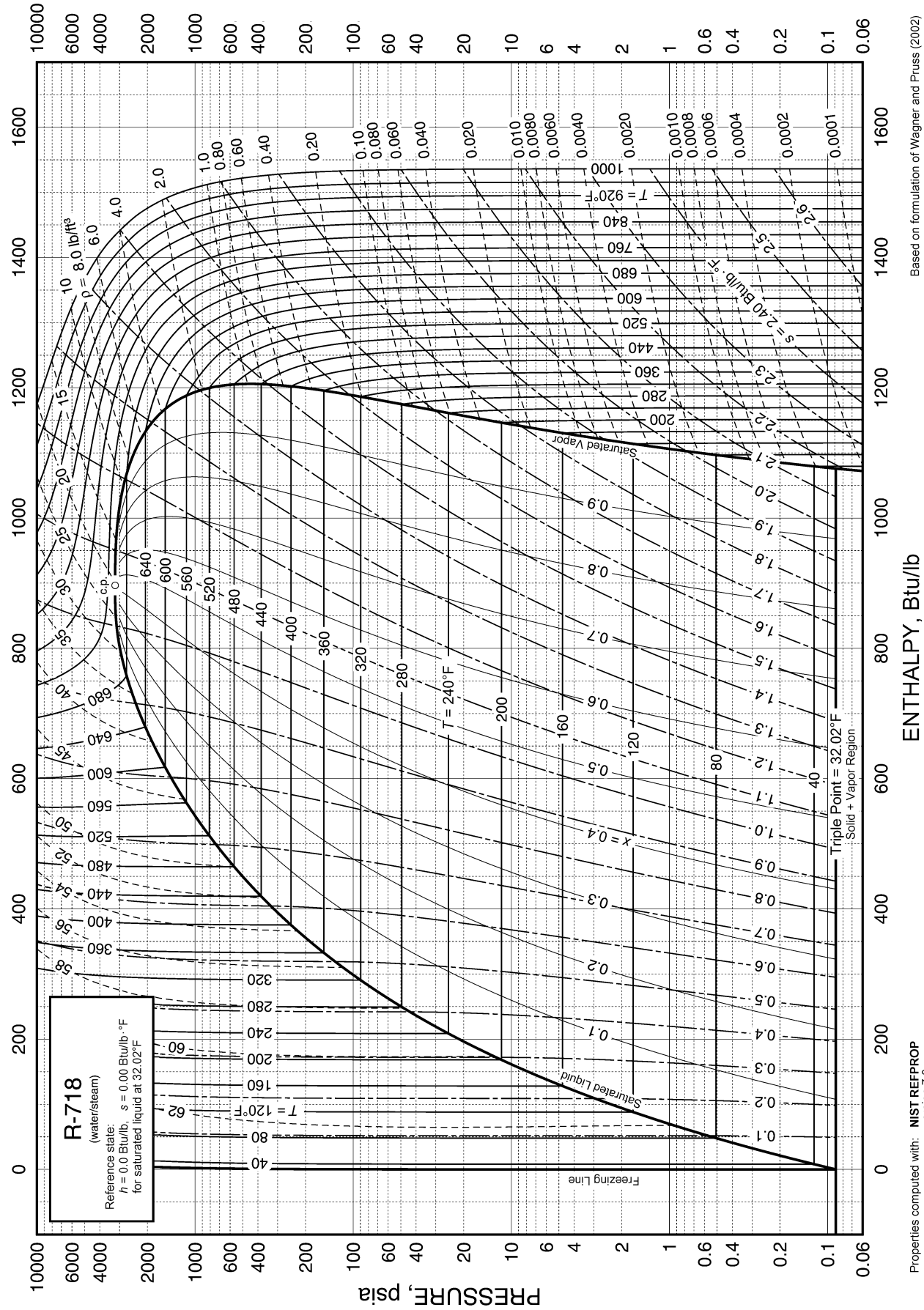


Fig. 17 Pressure-Enthalpy Diagram for Refrigerant 718 (Water/Steam)

Licensed for single user. © 2009 ASHRAE, Inc.

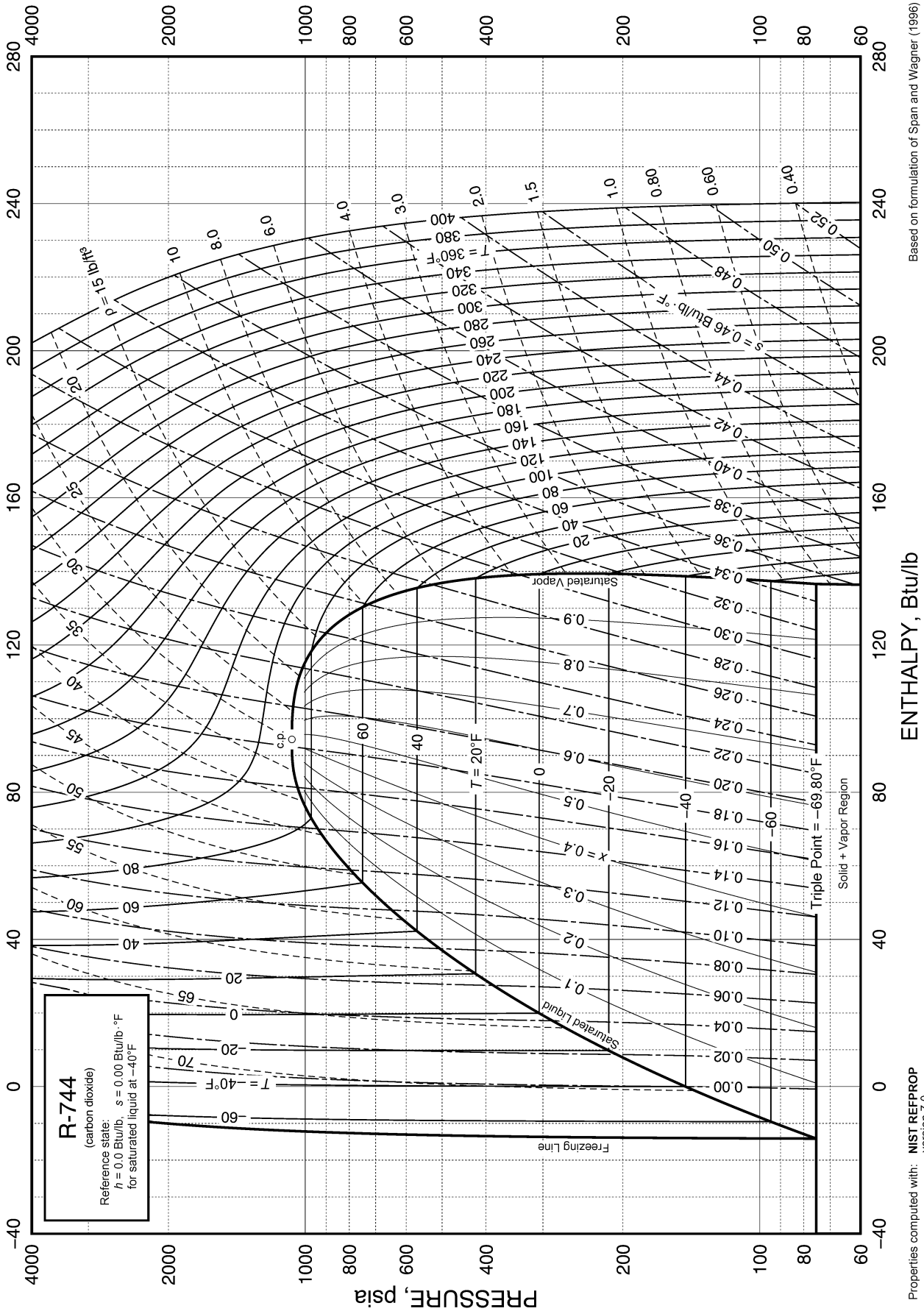


Fig. 18 Pressure-Enthalpy Diagram for Refrigerant 744 (Carbon Dioxide)

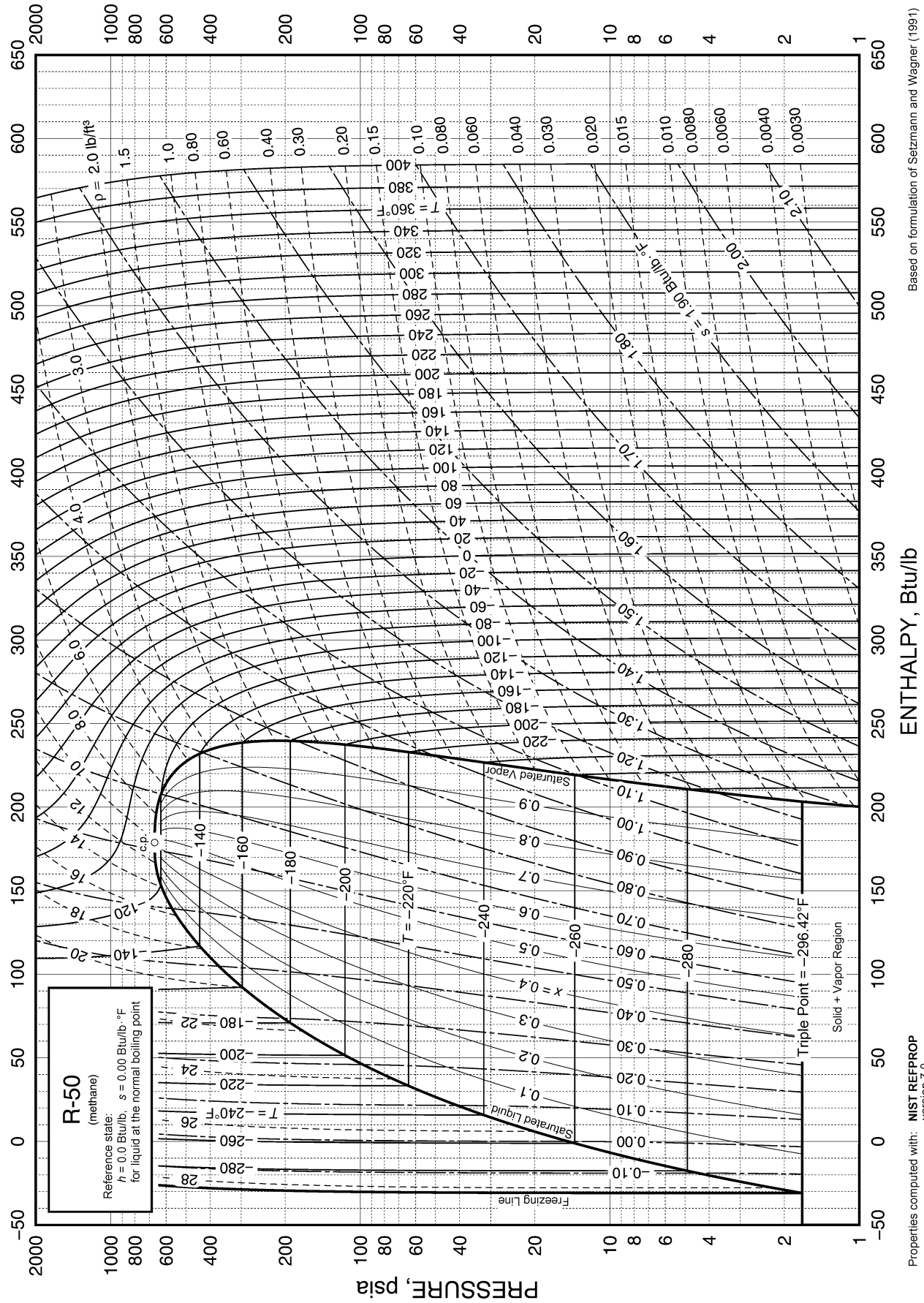
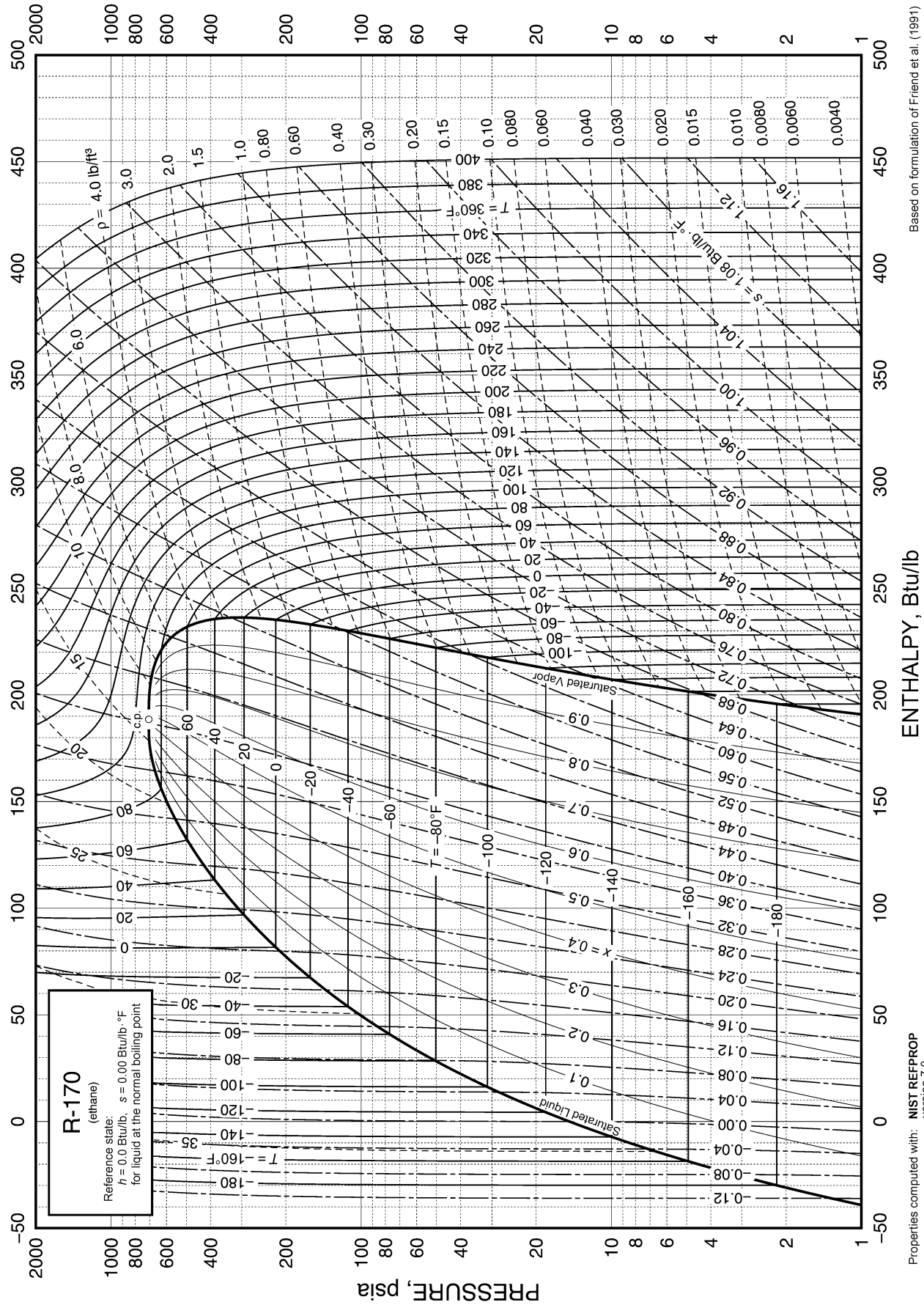


Fig. 19 Pressure-Enthalpy Diagram for Refrigerant 50 (Methane)

Properties computed with: NIST REFPROP version 7.0

Based on formulation of Setzmann and Wagner (1991)

Licensed for single user. © 2009 ASHRAE, Inc.



Properties computed with: NIST REFPROP version 7.0

ENTHALPY, Btu/lb

Based on formulation of Friend et al. (1991)

Fig. 20 Pressure-Enthalpy Diagram for Refrigerant 170 (Ethane)

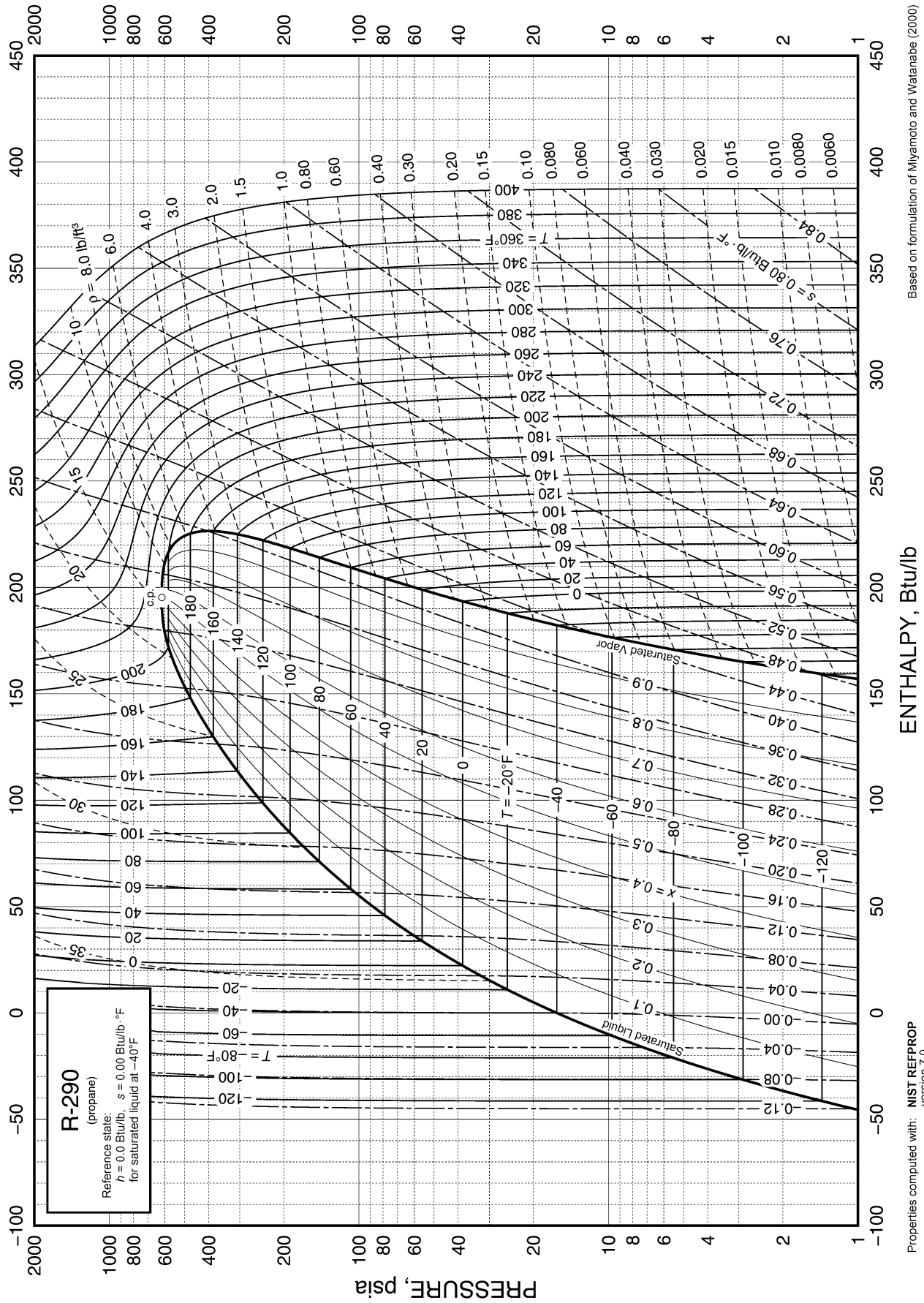
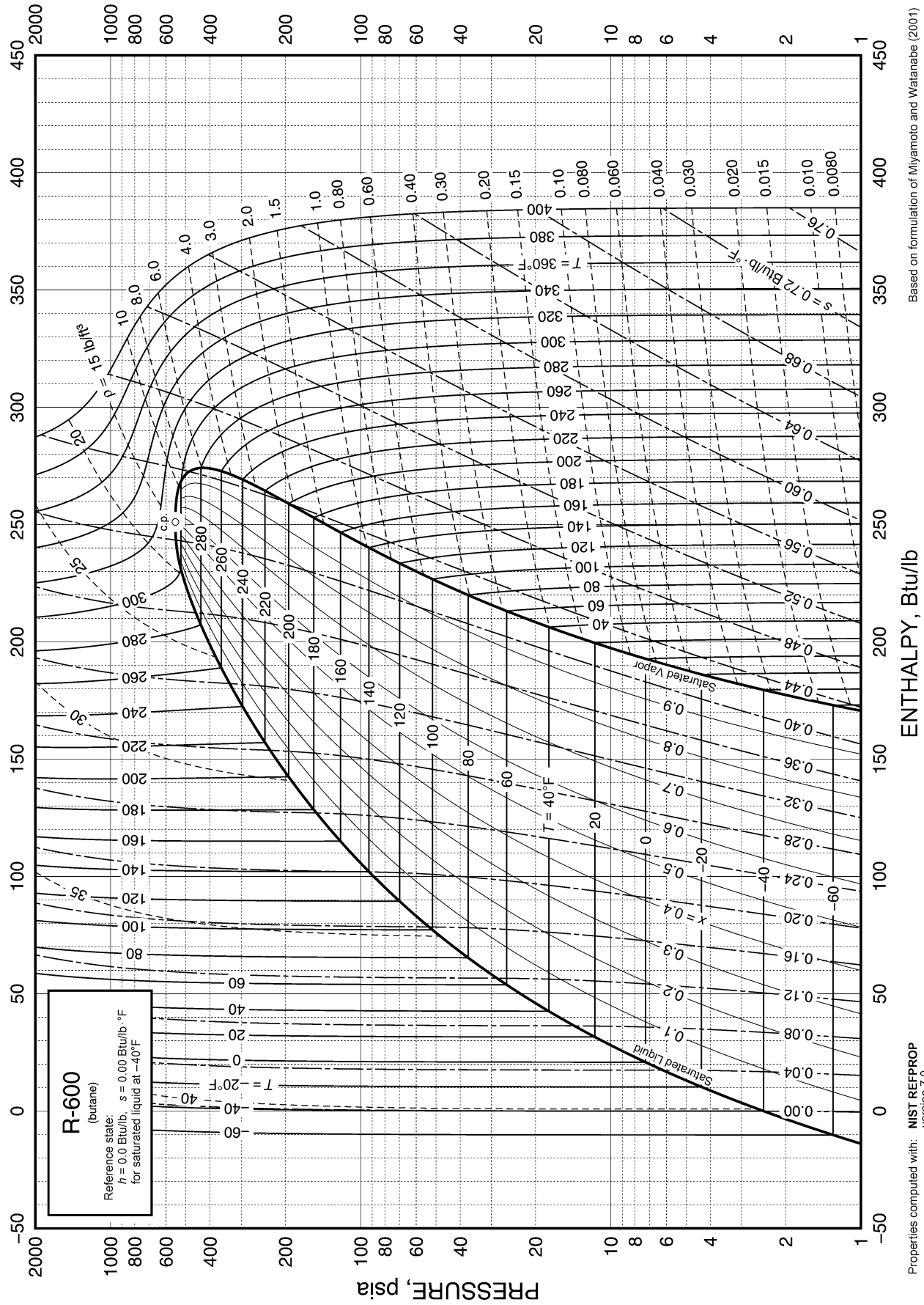


Fig. 21 Pressure-Enthalpy Diagram for Refrigerant 290 (Propane)



Based on formulation of Miyamoto and Watanabe (2001)

ENTHALPY, Btu/lb

Fig. 22 Pressure-Enthalpy Diagram for Refrigerant 600 (*n*-Butane)

Properties computed with: NIST REFPROP version 7.0

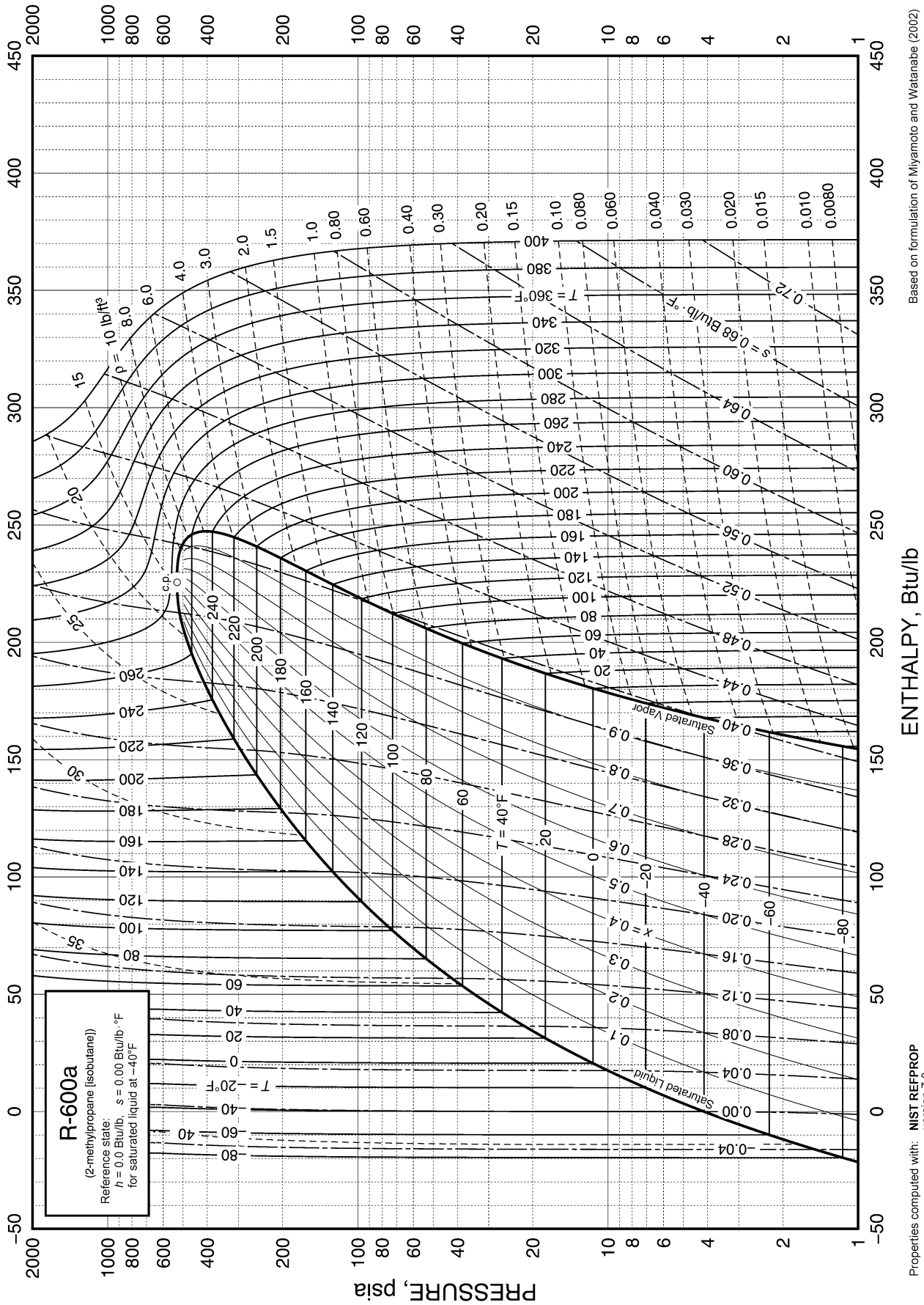
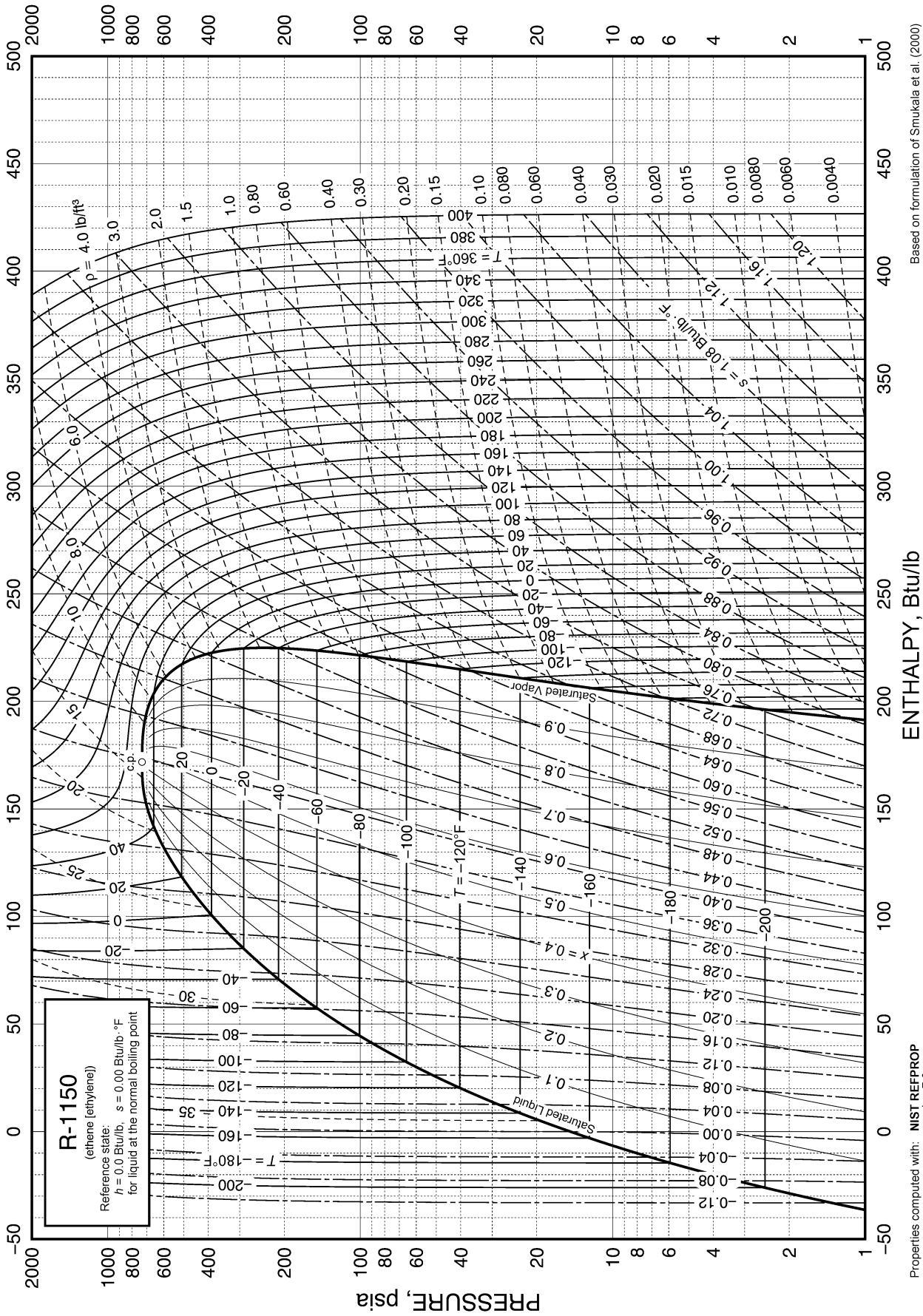


Fig. 23 Pressure-Enthalpy Diagram for Refrigerant 600a (Isobutane)

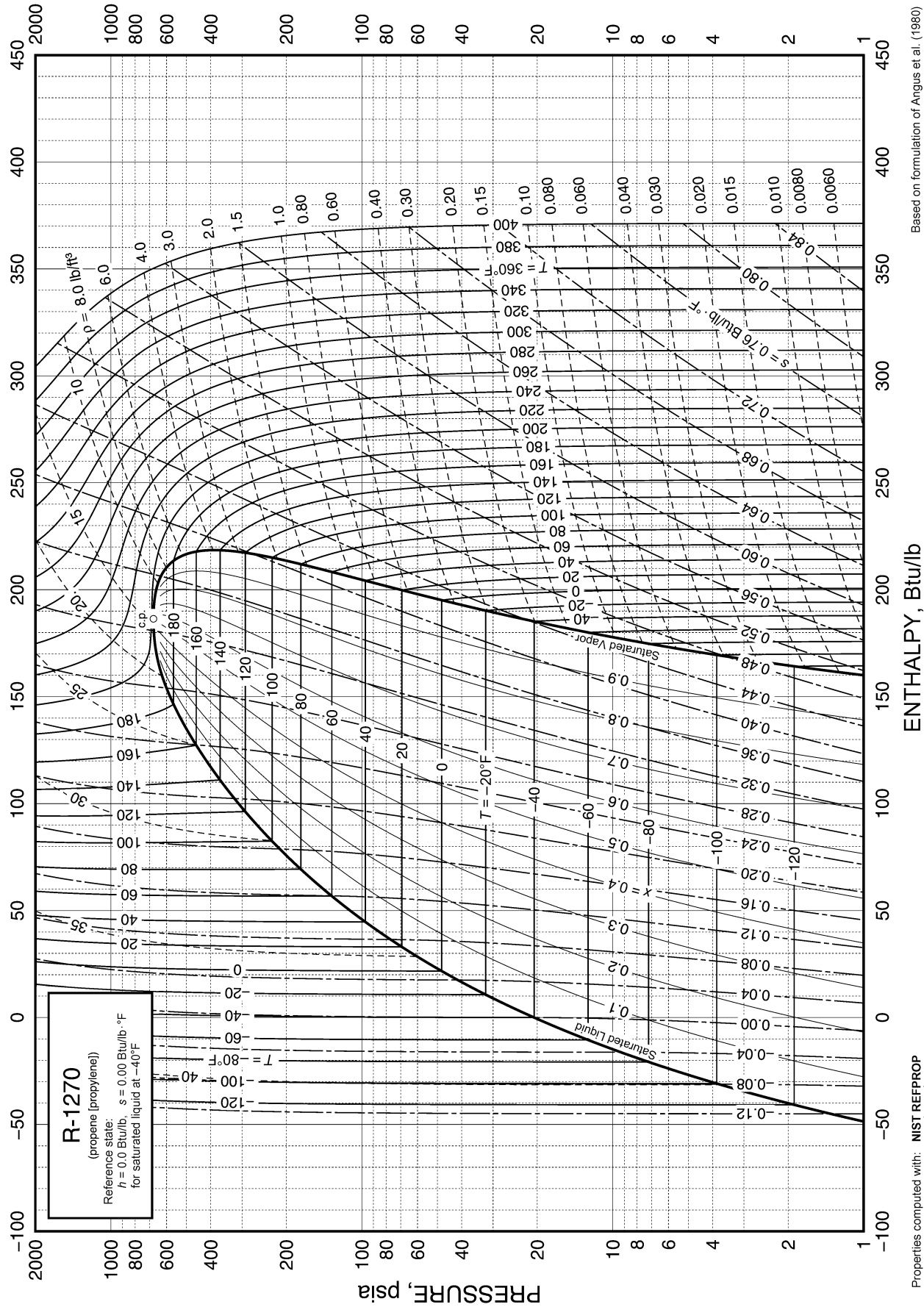
Licensed for single user. © 2009 ASHRAE, Inc.



Properties computed with: NIST REFPROP version 7.0

Based on formulation of Smukala et al. (2000)

Fig. 24 Pressure-Enthalpy Diagram for Refrigerant 1150 (Ethylene)



Properties computed with: NIST REFPROP version 7.0

ENTHALPY, Btu/lb

Based on formulation of Angus et al. (1980)

Fig. 25 Pressure-Enthalpy Diagram for Refrigerant 1270 (Propylene)

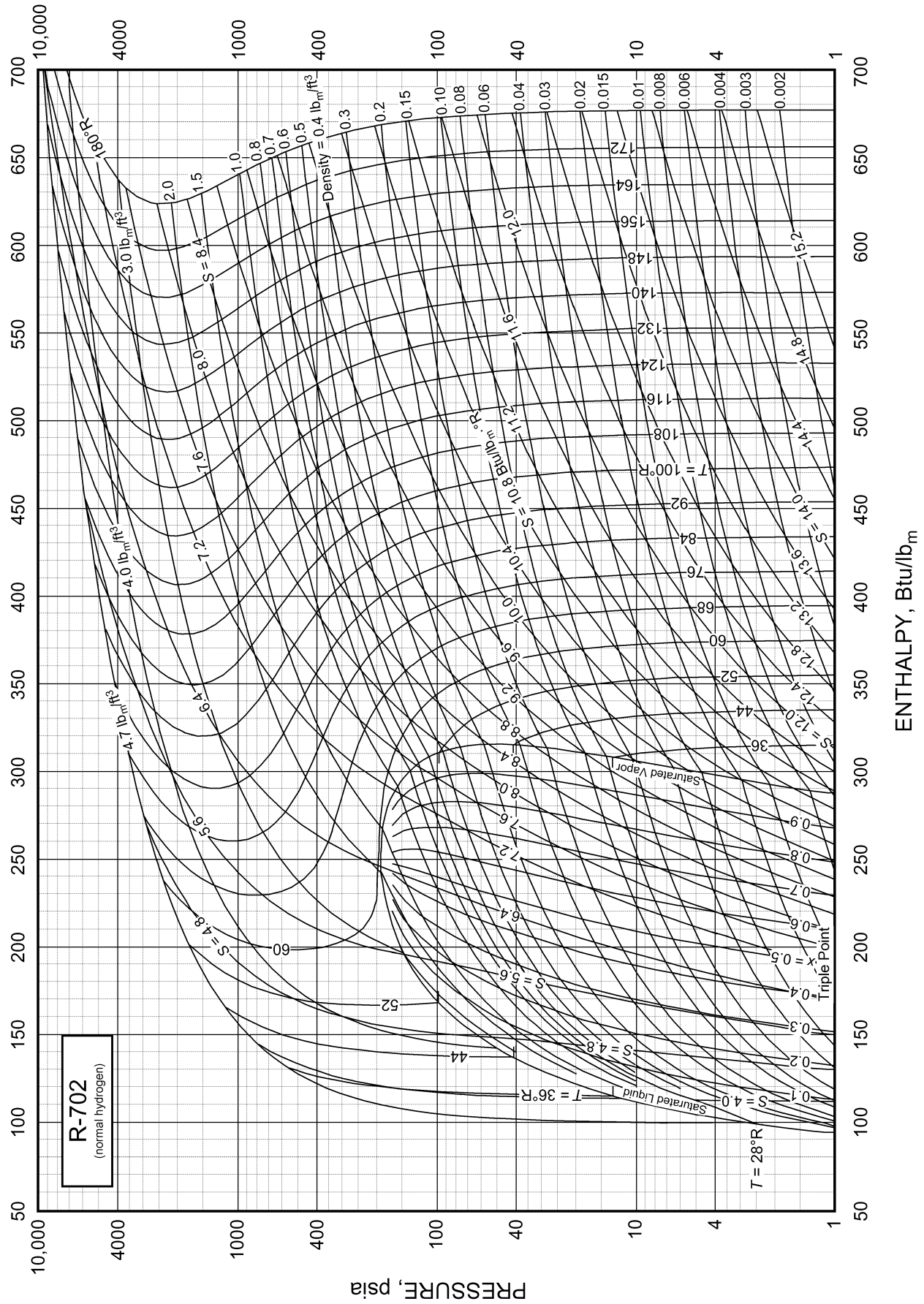


Fig. 26 Pressure-Enthalpy Diagram for Refrigerant 702 (Normal Hydrogen)

Licensed for single user. © 2009 ASHRAE, Inc.

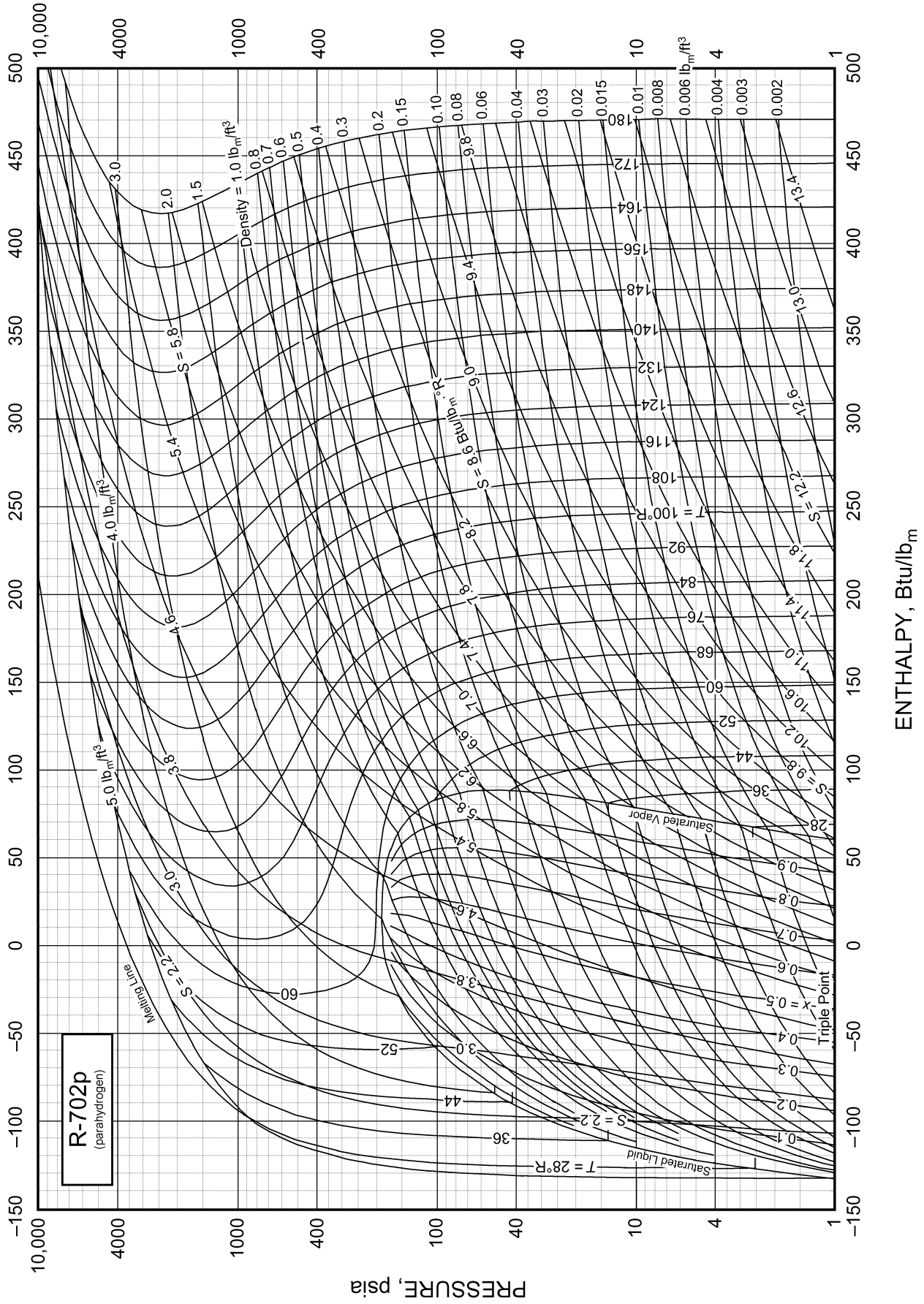


Fig. 27 Pressure-Enthalpy Diagram for Refrigerant 702p (Parahydrogen)

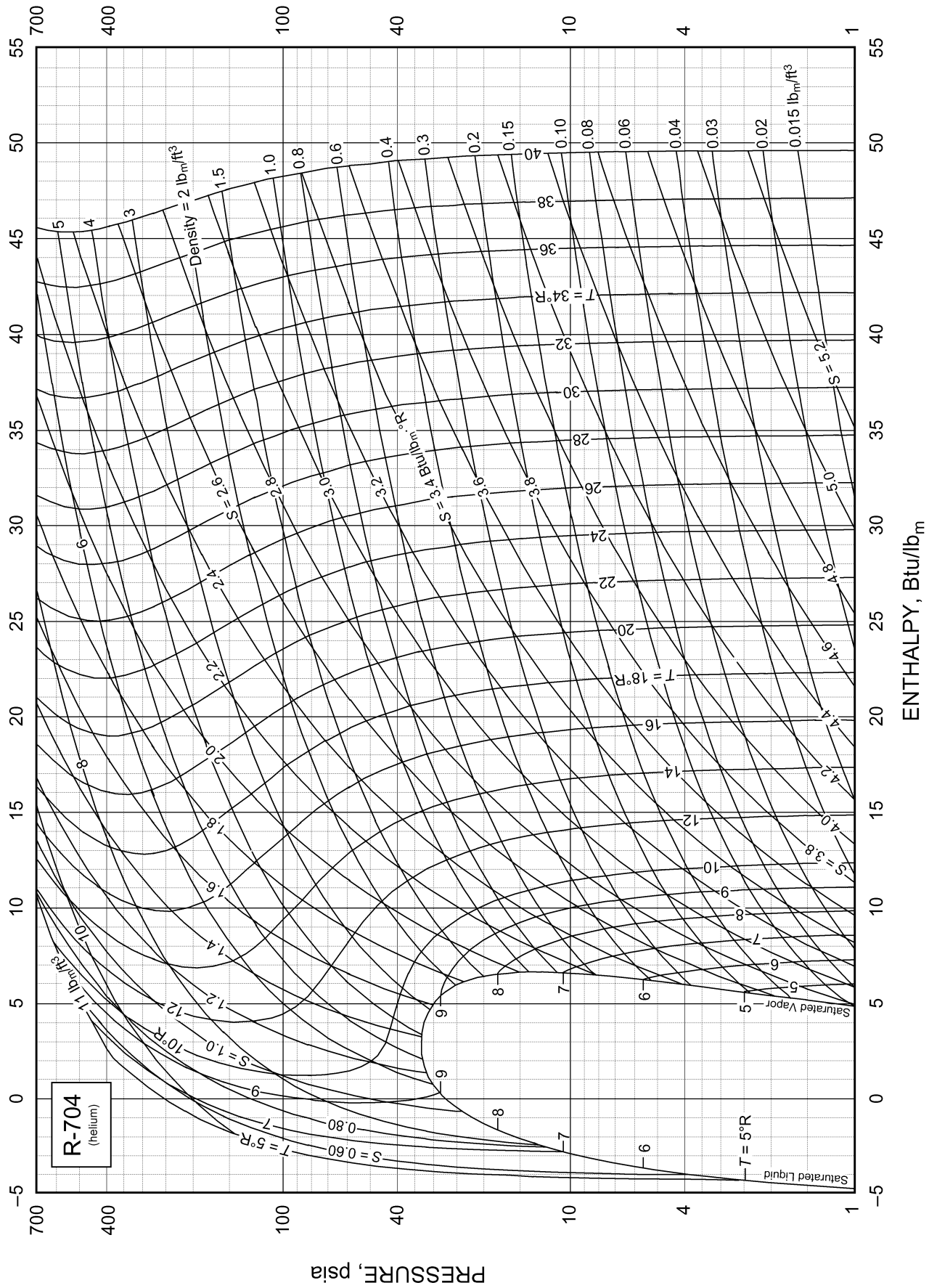
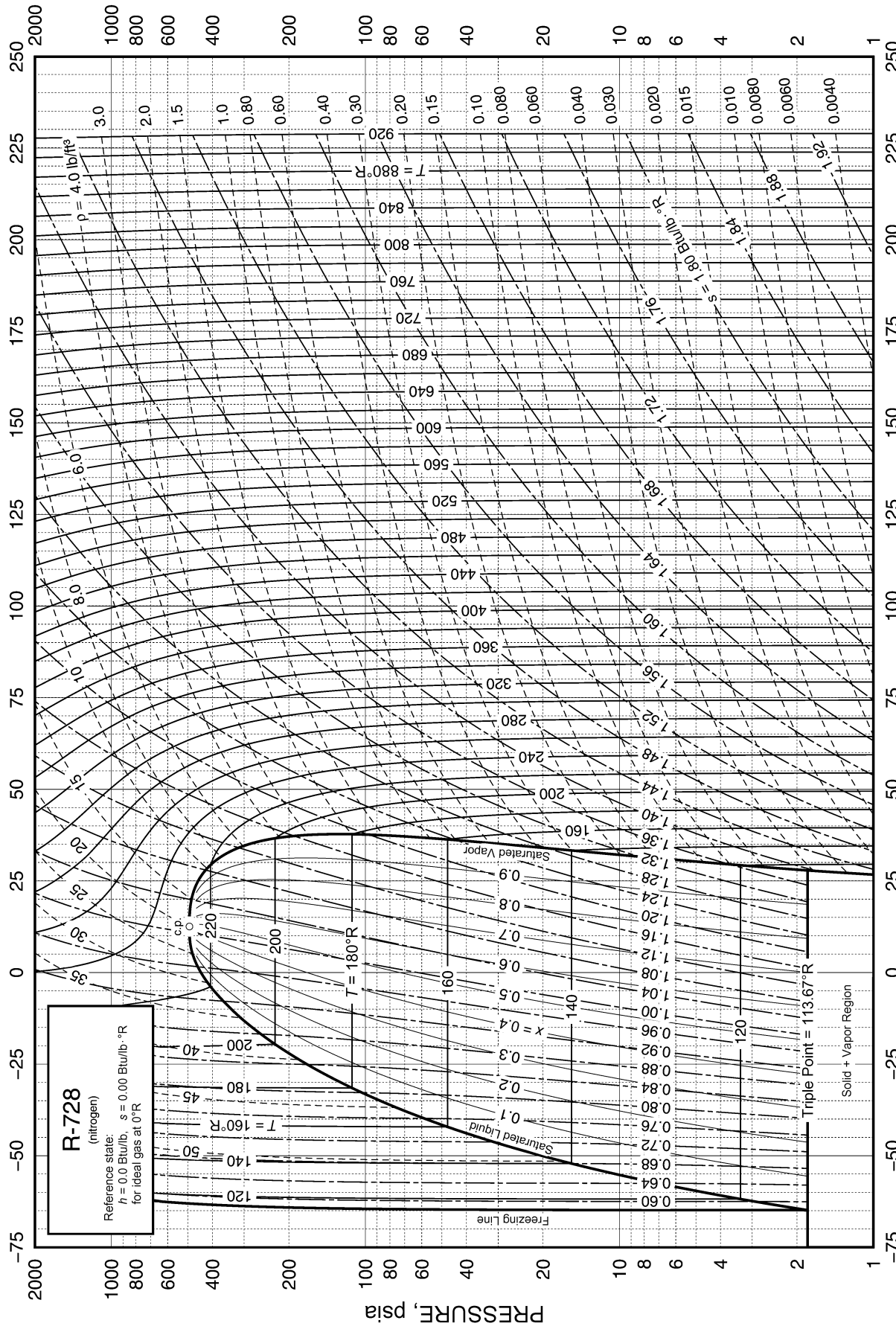


Fig. 28 Pressure-Enthalpy Diagram for Refrigerant 704 (Helium)
 Note: The reference states for enthalpy and entropy differ from those in the table.



Properties computed with: NIST REFPROP version 7.0

Based on formulation of Span et al. (2000)

Fig. 29 Pressure-Enthalpy Diagram for Refrigerant 728 (Nitrogen)

Licensed for single user. © 2009 ASHRAE, Inc.

Refrigerant 728 (Nitrogen) Properties of Saturated Liquid and Saturated Vapor

Table with 18 columns: Temp., Pressure, Density, Volume, Enthalpy, Entropy, Specific Heat, Velocity of Sound, Viscosity, Thermal Cond., Surface Tension, Temp. (repeated). Rows range from 113.67 to 227.15 degrees R.

*Temperatures on ITS-90 scale

^aTriple point

^bNormal boiling point

^cCritical point

Refrigerant 728 (Nitrogen) Properties of Gas at 14.696 psia (one standard atmosphere)

Table with 18 columns: Temp., Density, Enthalpy, Entropy, Cp, Cp/Cv, Vel. of Sound, Viscosity, Thermal Cond., Temp., Density, Enthalpy, Entropy, Cp, Cp/Cv, Vel. of Sound, Viscosity, Thermal Cond. Rows range from -320.4 to 180 degrees F.

^bSaturated vapor at normal boiling point

ASHRAE, Inc. © 2009

Licensed for single user. © 2009 ASHRAE, Inc.

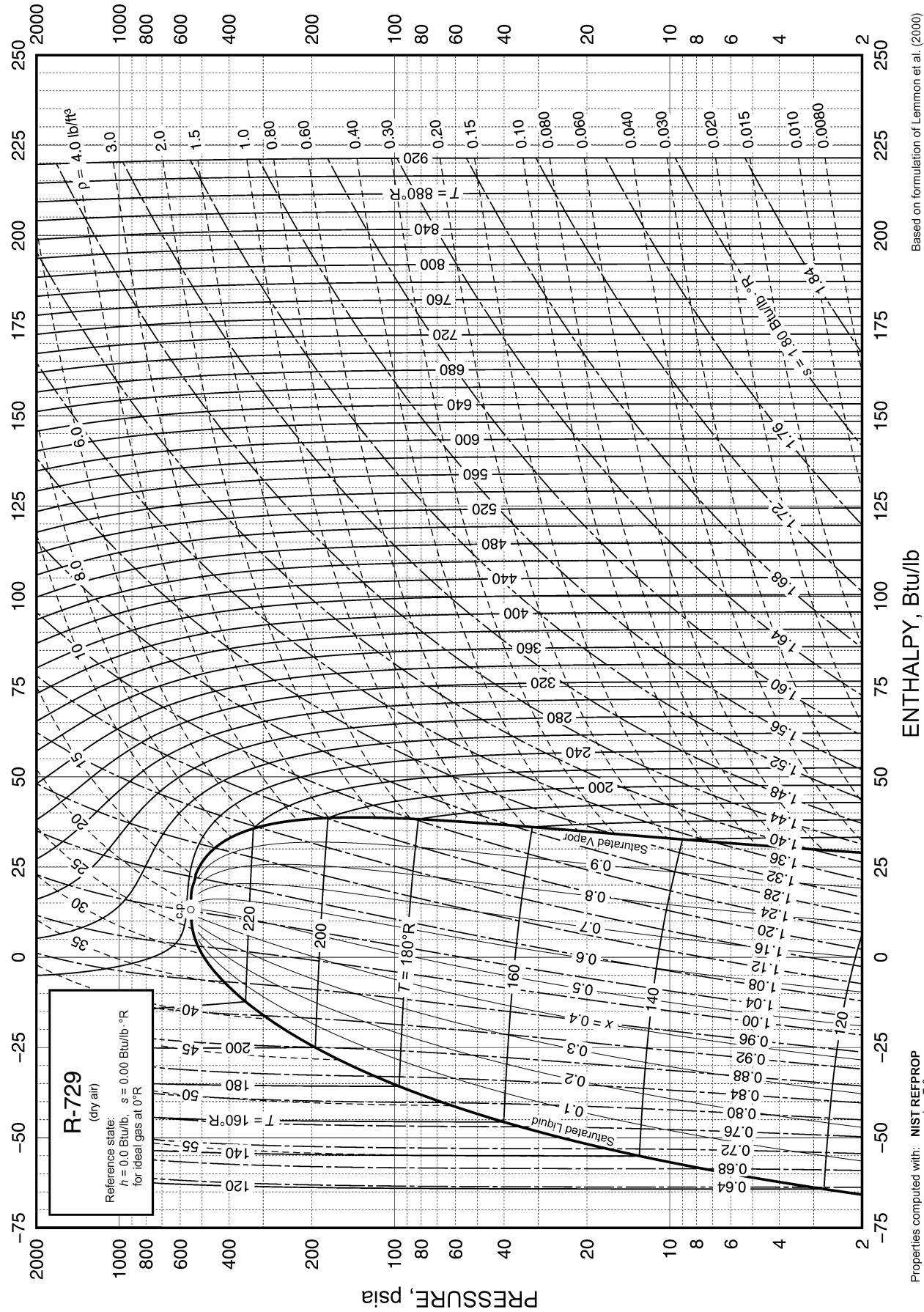


Fig. 30 Pressure-Enthalpy Diagram for Refrigerant 729 (Air)

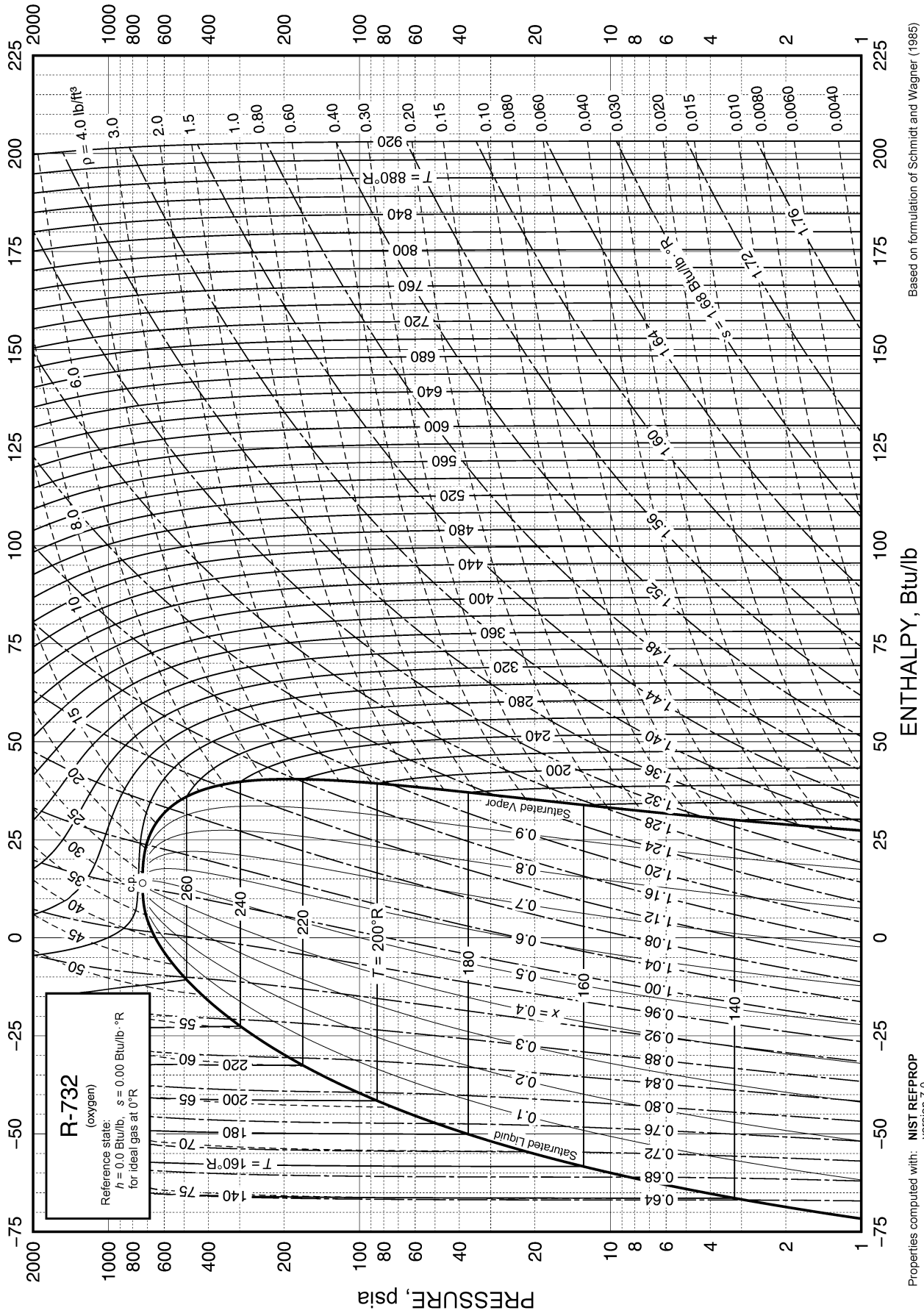
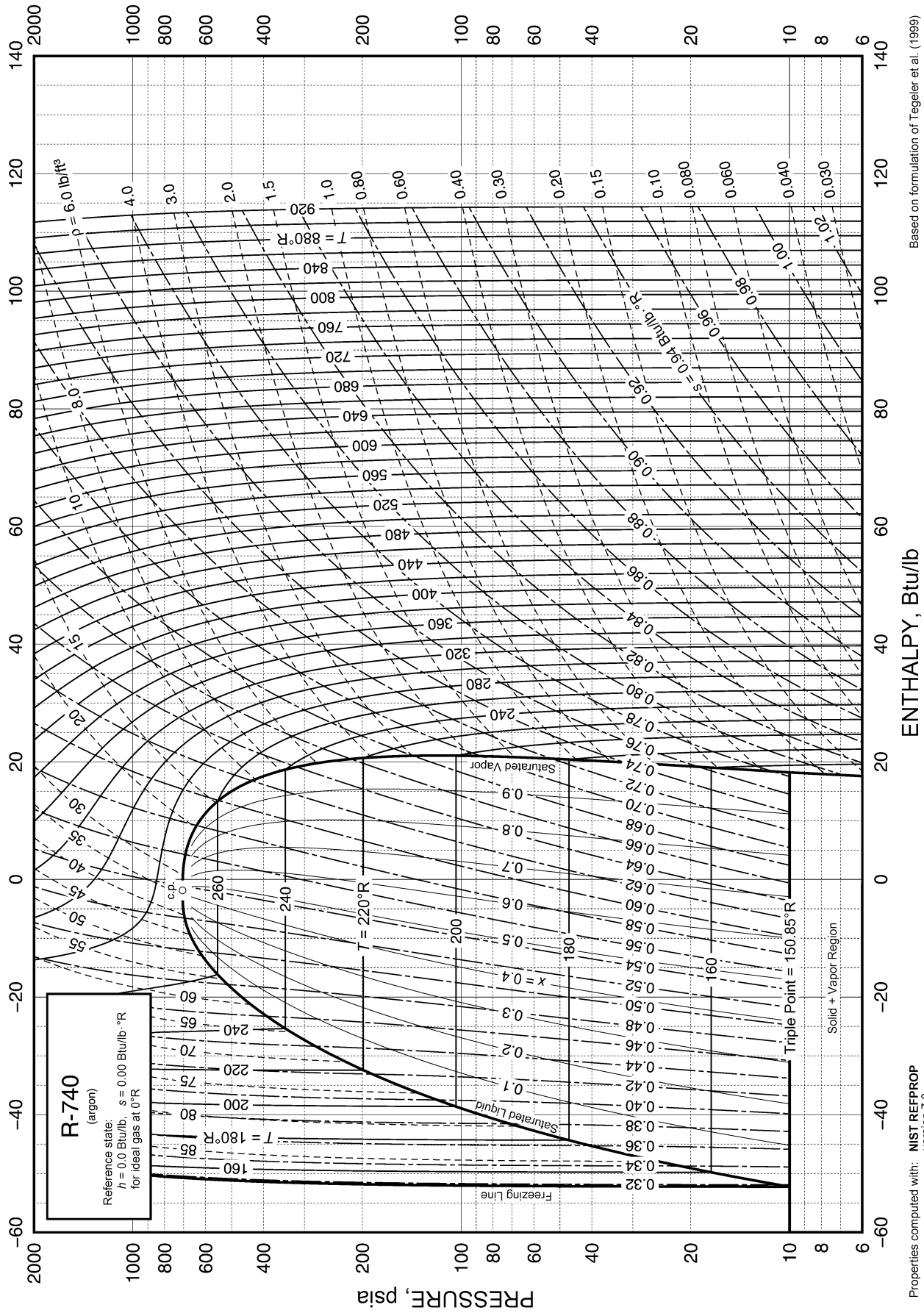


Fig. 31 Pressure-Enthalpy Diagram for Refrigerant 732 (Oxygen)

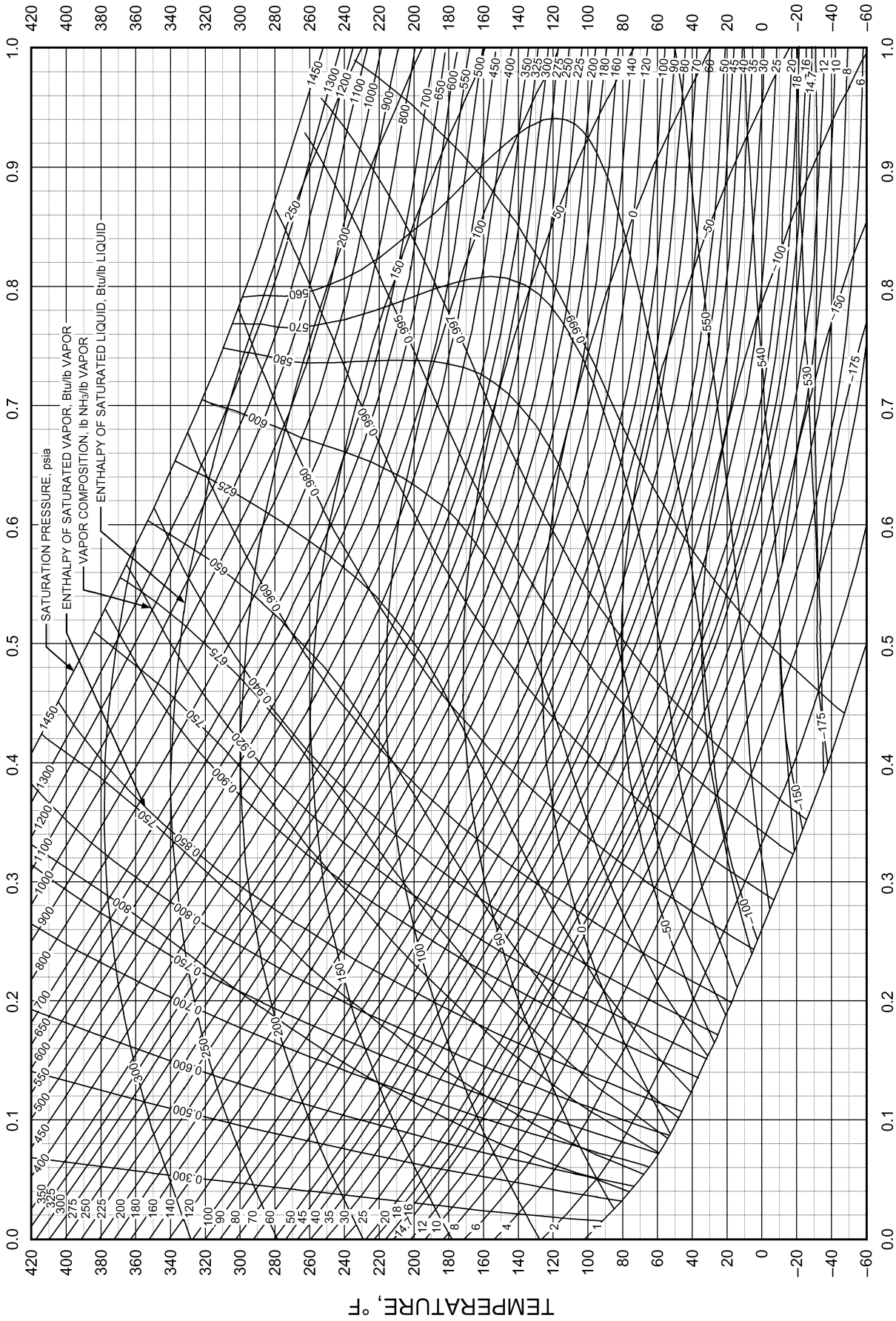


Based on formulation of Tegeler et al. (1999)

Fig. 32 Pressure-Enthalpy Diagram for Refrigerant 740 (Argon)

Properties computed with: NIST REFPROP version 7.0

Licensed for single user. © 2009 ASHRAE, Inc.



AMMONIA IN SATURATED LIQUID, lb NH₃/lb LIQUID

Fig. 33 Enthalpy-Concentration Diagram for Ammonia/Water Solutions

Prepared by Kwang Kim and Keith Herold, Center for Environmental Energy Engineering, University of Maryland at College Park

Specific Volume of Saturated Ammonia-Water Solutions, ft³/lb

Temp., °F	Concentration, Ammonia (Mass Basis)											Temp., °F
	0	10	20	30	40	50	60	70	80	90	100	
20	0.0160	0.0165	0.0170	0.0176	0.0182	0.0190	0.0197	0.0207	0.0217	0.0230	0.0245	20
40	0.0160	0.0165	0.0171	0.0177	0.0184	0.0191	0.0200	0.0209	0.0221	0.0236	0.0253	40
60	0.0160	0.0166	0.0172	0.0178	0.0186	0.0193	0.0202	0.0212	0.0225	0.0241	0.0260	60
80	0.0161	0.0167	0.0173	0.0180	0.0188	0.0196	0.0205	0.0216	0.0230	0.0247	0.0267	80
100	0.0161	0.0168	0.0174	0.0182	0.0190	0.0198	0.0208	0.0220	0.0235	0.0254	0.0275	100
120	0.0162	0.0169	0.0176	0.0184	0.0192	0.0201	0.0211	0.0224	0.0241	0.0261	0.0284	120
140	0.0163	0.0170	0.0177	0.0185	0.0194	0.0203	0.0215	0.0229	0.0247	0.0268	0.0294	140
160	0.0164	0.0172	0.0179	0.0187	0.0196	0.0206	0.0219	0.0235	0.0254	0.0277	0.0306	160
180	0.0165	0.0173	0.0181	0.0190	0.0199	0.0210	0.0223	0.0241	0.0262	0.0286	0.0320	180
200	0.0166	0.0175	0.0183	0.0192	0.0202	0.0213	0.0228	0.0247	0.0270	0.0298	0.0338	200
220	0.0168	0.0176	0.0185	0.0194	0.0205	0.0217	0.0234	0.0255	0.0279	0.0312	0.0361	220

Prepared under ASHRAE research project RP-271, sponsored by TC 8.3.
Data reference: B.H. Jennings, Ammonia water properties (paper presented at ASHRAE meeting, January 1965).

Refrigerant Temperature (*t'* = °F) and Enthalpy (*h* = Btu/lb) of Lithium Bromide Solutions

Temp., (<i>t</i> = °F)		Percent LiBr										
		0	10	20	30	40	45	50	55	60	65	70
80	<i>t'</i>	80.0	78.2	75.6	70.5	60.9	53.5	42.1	28.6	13.8	-0.2#	-11.6#
	<i>h</i>	48.0	39.2	31.8	25.6	21.6	21.2	23.0	28.7	38.9	52.7#	67.1#
100	<i>t'</i>	100.0	98.1	95.3	89.9	79.6	71.8	60.0	46.1	30.9	16.2#	3.8#
	<i>h</i>	68.0	56.6	47.0	38.7	33.2	32.1	33.2	38.2	47.8	61.1#	75.1#
120	<i>t'</i>	120.0	117.9	114.9	109.2	98.3	90.1	77.9	63.6	48.1	32.7	19.1#
	<i>h</i>	87.9	73.6	61.7	51.7	44.7	43.0	43.6	48.0	56.9	69.4	83.0#
140	<i>t'</i>	140.0	137.8	134.6	128.5	117.1	108.5	95.8	81.2	65.2	49.1	34.4#
	<i>h</i>	107.9	91.0	77.0	65.1	56.5	54.1	54.1	57.9	66.1	78.0	91.1#
160	<i>t'</i>	160.0	157.7	154.3	147.9	135.8	126.8	113.8	98.7	82.3	65.6	49.7#
	<i>h</i>	127.9	108.2	92.0	78.2	68.1	65.1	64.7	67.9	75.4	86.6	99.2#
180	<i>t'</i>	180.0	177.5	173.9	167.2	154.5	145.1	131.7	116.2	99.5	82.0	65.1#
	<i>h</i>	147.9	125.4	107.9	91.9	80.4	76.6	75.3	77.7	84.6	95.1	107.2#
200	<i>t'</i>	200.0	197.4	193.6	186.5	173.3	163.5	149.6	133.7	116.6	98.5	80.4#
	<i>h</i>	168.0	143.4	123.3	105.3	92.1	87.4	85.9	87.8	94.1	104.0	115.6#
220	<i>t'</i>	220.0	217.2	213.3	205.8	192.0	181.8	167.5	151.3	133.7	114.9	95.7
	<i>h</i>	188.1	160.7	138.2	119.0	104.1	99.0	96.5	97.8	103.3	112.5	123.6
240	<i>t'</i>	240.0*	237.1*	232.9	225.2	210.7	200.2	185.4	168.8	150.9	131.4	111.0
	<i>h</i>	208.3*	178.4*	154.0	132.6	116.0	110.3	107.1	107.7	112.5	121.1	131.6
260	<i>t'</i>	260.0*	256.9*	252.6*	244.5*	229.4	218.5	203.3	186.3	168.0	147.9	126.4
	<i>h</i>	228.6*	195.7*	169.1*	146.2*	128.1	121.6	117.6	117.6	121.6	129.5	139.5
280	<i>t'</i>	280.0*	276.8*	272.3*	263.8*	248.2*	236.8*	221.2	203.9	185.1	164.3	141.7
	<i>h</i>	249.1*	213.8*	185.1*	159.7*	140.0*	132.8*	128.1	127.5	130.6	137.9	147.6
300	<i>t'</i>	300.0*	296.7*	291.9*	283.1*	266.9*	255.2*	239.2*	221.4	202.3	180.8	157.0
	<i>h</i>	269.6*	231.6*	200.7*	173.5*	152.1*	144.1*	138.9*	137.3	139.8	146.5	155.5
320	<i>t'</i>	320.0*	316.5*	311.6*	302.5*	285.6*	273.5*	257.1*	238.9*	219.4	197.2	172.4
	<i>h</i>	290.3*	249.7*	216.3*	187.2*	164.2*	155.3*	149.5*	147.1*	148.8	154.9	163.4
340	<i>t'</i>	340.0*	336.4*	331.3*	321.8*	304.4*	291.9*	275.0*	256.4*	236.5*	213.7	187.7
	<i>h</i>	311.1*	267.9*	232.1*	201.0*	176.1*	166.6*	160.1*	157.0*	158.0*	163.5	171.0
360	<i>t'</i>	360.0*	356.2*	350.9*	341.1*	323.1*	310.2*	292.9*	274.0*	253.7*	230.1	203.0
	<i>h</i>	332.2*	286.1*	248.0*	214.9*	188.2*	178.0*	170.6*	166.8*	167.0*	171.9	178.3

*Extensions of data above 235°F are well above the original data and should be used with care.
#Supersaturated solution.

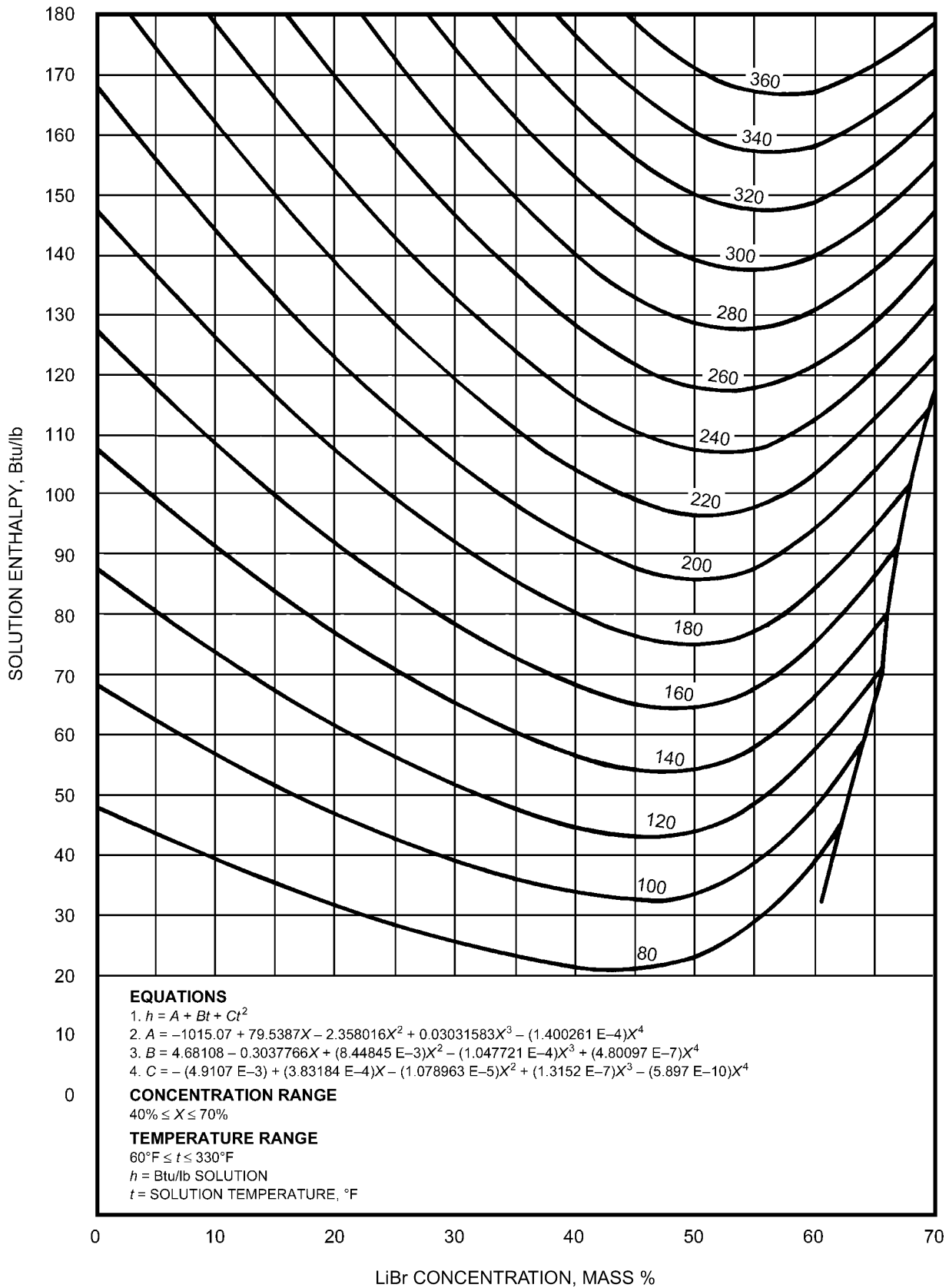


Fig. 34 Enthalpy-Concentration Diagram for Water/Lithium Bromide Solutions

EQUATIONS

1. $t = At' + B$
2. $t' = (t - B)/A$
3. $A = -2.00755 + 0.16976X - (3.133362 E-3)X^2 + (1.97668 E-5)X^3$
4. $B = 321.128 - 19.322X + 0.374382X^2 - (2.0637 E-3)X^3$
5. $\log_{10} P = C + D/(t' + 459.72) + E/(t' + 459.72)^2$
6. $t' = \frac{-2E}{D + [D^2 - 4E(C - \log_{10} P)]^{0.5}} - 459.72$

Temperature Range (Refrigerant) $0 < t' \leq 230^\circ\text{F}$
 Temperature Range (Solution) $40 < t \leq 350^\circ\text{F}$
 Concentration Range $45\% < X \leq 70\%$

$C = 6.21147$
 $D = -2886.373$
 $E = -337269.46$
 t' = Refrigerant Temperature, °F
 t = Solution Temperature, °F
 X = Percent LiBr
 P = psia

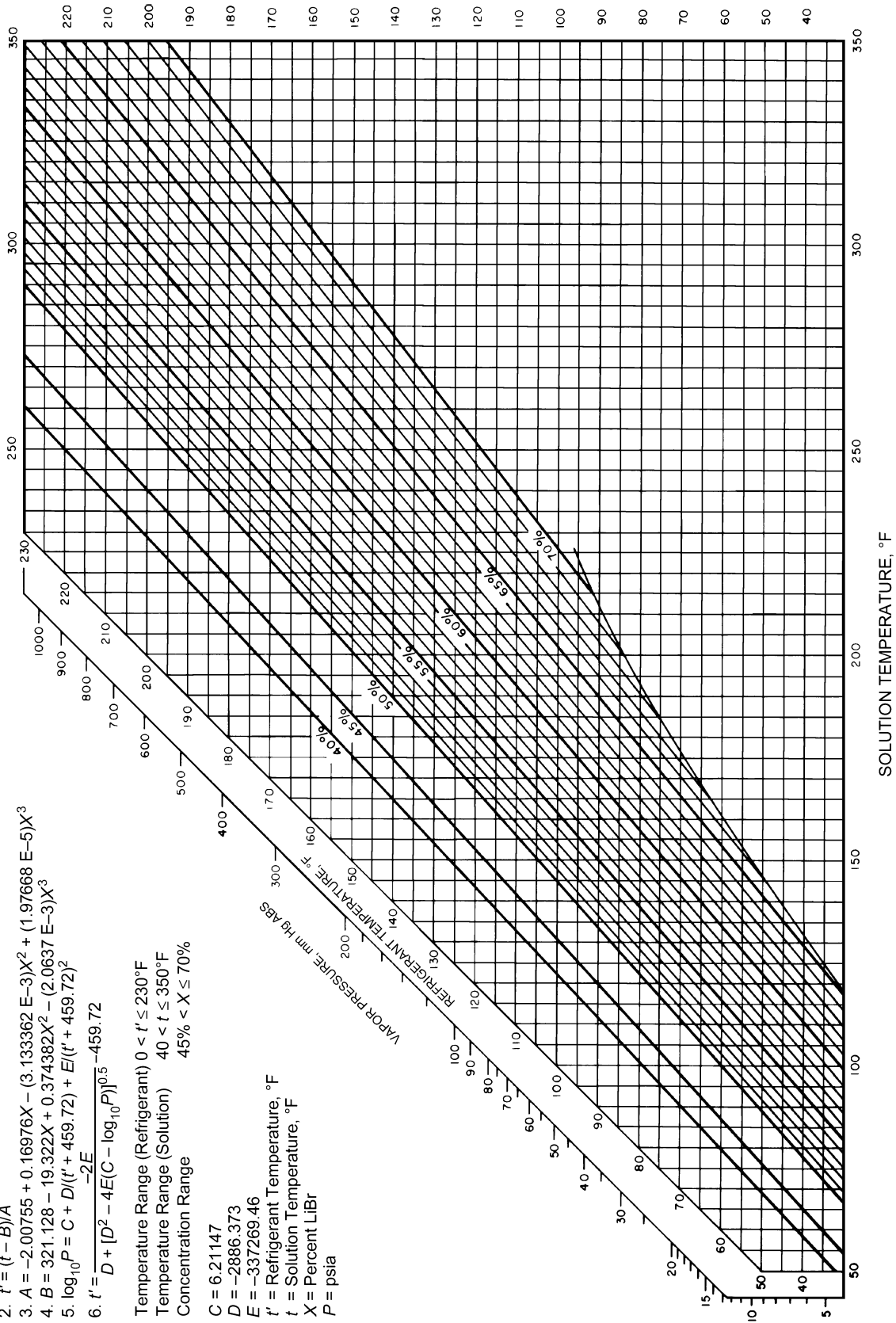


Fig. 35 Equilibrium Chart for Aqueous Lithium Bromide Solutions
 Reprinted by permission of Carrier Corp.

REFERENCES

Tables revised for this edition (R-125, R-170, R-245fa, R-290, R-600, and R-600a) have been calculated using

Lemmon, E.W., M.L. Huber, and M.O. McLinden. 2007. *NIST standard reference database 23, NIST reference fluid thermodynamic and transport properties—REFPROP*, v. 8.0. Standard Reference Data Program, National Institute of Standards and Technology, Gaithersburg, MD.

Many tables (indicated with a ‡ after the fluid name) have not changed from the 2005 *ASHRAE Handbook—Fundamentals*. These tables were calculated using

Lemmon, E.W., M.O. McLinden, and M.L. Huber. 2002. *NIST standard reference database 23, NIST reference fluid thermodynamic and transport properties—REFPROP*, v. 7.0. Standard Reference Data Program, National Institute of Standards and Technology, Gaithersburg, MD.

Some tables (indicated with a † following the fluid name) have not changed from the 2001 *ASHRAE Handbook—Fundamentals*. These tables were calculated using

McLinden, M.O., S.A. Klein, E.W. Lemmon, and A.P. Peskin. 2000a. *NIST standard reference database 23: Thermodynamic and transport properties of refrigerants and refrigerant mixtures—REFPROP*, v. 6.10. Standard Reference Data Program, National Institute of Standards and Technology, Gaithersburg, MD.

Tables for R-702, R-702p, and R-704 have not changed from the 1997 *ASHRAE Handbook—Fundamentals*; these tables were calculated using the programs noted for each fluid.

The underlying sources for these computer packages are listed as follows by fluid and property. The reference listed under “Equation of state” was used for vapor pressure, liquid density, vapor volume, enthalpy, entropy, specific heat, and velocity of sound.

R-12†*Equation of state*

Marx, V., A. Pruss, and W. Wagner. 1992. Neue Zustandsgleichungen für R-12, R-22, R-11 und R-113. Beschreibung des thermodynamischen Zustandsverhaltens bei Temperaturen bis 525 K und Drücken bis 200 MPa. *VDI-Fortschritt-Ber Wärmetechnik/Kältetechnik* 19(57). VDI Verlag, Düsseldorf.

Viscosity

Klein, S.A., M.O. McLinden, and A. Laesecke. 1997. An improved extended corresponding states method for estimation of viscosity of pure refrigerants and mixtures. *International Journal of Refrigeration* 20:208-217.

Thermal conductivity

McLinden, M.O., S.A. Klein, and R.A. Perkins. 2000b. An extended corresponding states model for the thermal conductivity of refrigerants and refrigerant mixtures. *International Journal of Refrigeration* 23:43-63.

Surface tension

Okada, M. and K. Watanabe. 1988. Surface tension correlations for several fluorocarbon refrigerants. *Heat Transfer—Japanese Research* 17:35-52.

R-22†*Equation of state*

Kamei, A., S.W. Beyerlein, and R.T. Jacobsen. 1995. Application of nonlinear regression in the development of a wide range formulation for HCFC-22. *International Journal of Thermophysics* 16(5):1155-1164.

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Okada, M. and K. Watanabe. 1988. op. cit. (See R-12.)

R-23‡*Equation of state*

Penoncello, S.G., E.W. Lemmon, Z. Shan, and R.T. Jacobsen. 2003. An equation of state for the calculation of the thermodynamic properties of trifluoromethane (R-23). *Journal of Physical and Chemical Reference Data* 32:1473.

Viscosity and thermal conductivity

Shan, Z., S.G. Penoncello, and R.T. Jacobsen. 2000. A generalized model for viscosity and thermal conductivity of trifluoromethane (R-23). *ASHRAE Transactions* 106(1):757-767.

Surface tension

Penoncello, S.G. 1999. Thermophysical properties of trifluoromethane (R-23). ASHRAE Research Project RP-997, *Final Report*.

R-32‡*Equation of state*

Tillner-Roth, R. and A. Yokozeki. 1997. An international standard equation of state for difluoromethane (R-32) for temperatures from the triple point at 136.34 K to 435 K and pressures up to 70 MPa. *Journal of Physical and Chemical Reference Data* 26:1273-1328.

Viscosity

Huber, M.L., A. Laesecke, and R.A. Perkins. 2003. Estimation of the viscosity and thermal conductivity of refrigerants including a new correlation for the viscosity of R134a. *Industrial & Engineering Chemistry Research* 42:3163-3178.

Thermal conductivity

Perkins, R.A. 2002. Personal communication, correlation to data as implemented in the NIST REFPROP Database. National Institute of Standards and Technology, Boulder, CO.

Surface tension

Okada, M. and Y. Higashi. 1995. Experimental surface tensions for HFC-32, HCFC-124, HFC-125, HCFC-141b, HCFC-142b, and HFC-152a. *International Journal of Thermophysics* 16(3):791-800.

R-123†*Equation of state*

Younglove, B.A. and M.O. McLinden. 1994. An international standard equation-of-state formulation of the thermodynamic properties of refrigerant 123 (2,2-dichloro-1,1,1-trifluoroethane). *Journal of Physical and Chemical Reference Data* 23(5):731-779.

Viscosity

Tanaka, Y. and T. Sotani. 1995. *Thermodynamic and physical properties*, Chapter 2: Transport properties (thermal conductivity and viscosity), R-123. International Institute of Refrigeration, Paris.

Thermal conductivity

Laesecke, A., R.A. Perkins, and J.B. Howley. 1996. An improved correlation for the thermal conductivity of HCFC-123 (2,2-dichloro-1,1,1-trifluoroethane). *International Journal of Refrigeration* 19:231-238.

Surface tension

Okada and Higashi. 1995. op. cit. (See R-32.)

R-124‡*Equation of state*

de Vries, B., R. Tillner-Roth, and H.D. Baehr. 1995. Thermodynamic properties of HCFC-124. *19th International Congress of Refrigeration, International Institute of Refrigeration* IVa:582-589.

Viscosity and thermal conductivity

Huber et al. 2003. op. cit. (See R-32.)

Surface tension

Okada and Higashi. 1995. op. cit. (See R-32.)

R-125*Equation of state*

Lemmon, E.W. and R.T. Jacobsen. 2005. A new functional form and new fitting techniques for equations of state with application to pentafluoroethane (HFC-125). *Journal of Physical and Chemical Reference Data* 34(1):69-108.

Viscosity

Huber, M.L. and A. Laesecke. 2006. Correlation for the viscosity of pentafluoroethane (R-125) from the triple point to 500 K at pressures up to 60 MPa. *Industrial & Engineering Chemistry Research* 45(12):4447-4453.

Thermal conductivity

Perkins, R.A. and M.L. Huber. 2006. Measurement and correlation of the thermal conductivity of pentafluoroethane (R-125) from 190 K to 512 K at pressures to 70 MPa. *Journal of Chemical & Engineering Data* 51(3):898-904.

Surface tension

Okada and Higashi. 1995. op. cit. (See R-32.)

R-134a†*Equation of state*

Tillner-Roth, R. and H.D. Baehr. 1994. An international standard formulation of the thermodynamic properties of 1,1,1,2-tetrafluoroethane (HFC-134a) covering temperatures from 170 K to 455 K at pressures up to 70 MPa. *Journal of Physical and Chemical Reference Data* 23:657-729.

Viscosity

Huber et al. 2003. op. cit. (See R-32.)

Thermal conductivity

Perkins, R.A., A. Laesecke, J. Howley, M.L.V. Ramires, A.N. Gurova, and L. Cusco. 2000. Experimental thermal conductivity values for the IUPAC round-robin sample of 1,1,1,2-tetrafluoroethane (R134a). NISTIR 6605.

Surface tension

Okada, M. and Y. Higashi. 1994. Surface tension correlation of HFC-134a and HCFC-123. *CFCs, the Day After: Proceedings of Joint Meeting of IIR Commissions B1, B2, E1, and E2*, 541-548.

R-143a†*Equation of state*

Lemmon, E.W. and R.T. Jacobsen. 2001. An international standard formulation for the thermodynamic properties of 1,1,1-trifluoroethane (HFC-143a) for temperatures from 161 to 500 K and pressures to 60 MPa. *Journal of Physical and Chemical Reference Data* 29(4):521-552.

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Schmidt, J.W., E. Carrillo-Nava, and M.R. Moldover. 1996. Partially halogenated hydrocarbons CHFCI-CF₃, CF₃-CH₃, CF₃-CHF-CHF₂, CF₃-CH₂-CF₃, CHF₂-CF₂-CH₂F, CF₃-CH₂-CHF₂, CF₃-O-CHF₂: Critical temperature, refractive indices, surface tension and estimates of liquid, vapor and critical densities. *Fluid Phase Equilibria* 122:187-206.

R-152a‡*Equation of state*

Outcalt, S.L. and M.O. McLinden. 1996. A modified Benedict-Webb-Rubin equation of state for the thermodynamic properties of R-152a (1,1-difluoroethane). *Journal of Physical and Chemical Reference Data* 25(2):605-636.

Viscosity

Klein et al. 1997. op. cit. (see R-12), ECS model of McLinden et al. (2000b) correlated to data as implemented in NIST REFPROP.

Thermal conductivity

Krauss, R., V.C. Weiss, T.A. Edison, J.V. Sengers, and K. Stephan. 1996. Transport properties of 1,1-difluoroethane (R-152a). *International Journal of Thermophysics* 17:731-757.

Surface tension

Okada and Higashi. 1995. op. cit. (See R-32.)

R-245fa*Equation of state**Extended corresponding states model of*

Lemmon, E.W. and R. Span. 2006. Short fundamental equations of state for 20 industrial fluids. *Journal of Chemical & Engineering Data* 51(3):785-850.

Viscosity and thermal conductivity

Huber, M.L., A. Laesecke, and R.A. Perkins. 2003. Model for the viscosity and thermal conductivity of refrigerants, including a new correlation for the viscosity of R-134a. *Industrial & Engineering Chemistry Research* 42(13):3163-3178.

Surface tension

Schmidt et al. 1996. op. cit. (See R-143a.)

Pressure-enthalpy diagram based on data of

Defibaugh, D.R. and M.R. Moldover. 1997. Compressed and saturated liquid densities for 18 halogenated organic compounds. *Journal of Chemical and Engineering Data* 42:160-168.

R-404A‡*Equation of state*

Lemmon, E.W. and R.T. Jacobsen. 2004a. Equations of state for mixtures of R-32, R-125, R-134a, R-143a, and R-152a. *Journal of Physical and Chemical Reference Data* 33(2):593-620.

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Moldover, M.R. and J.C. Rainwater. 1988. Interfacial tension and vapor-liquid equilibria in the critical region of mixtures. *Journal of Chemical Physics* 88:7772-7780.

R-407C‡*Equation of state*

Lemmon and Jacobsen. 2004a. op. cit. (See R-404A.)

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Moldover and Rainwater. 1988. op. cit. (See R-404A.)

R-410A‡*Equation of state*

Lemmon and Jacobsen. 2004a. op. cit. (See R-404A.)

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Moldover and Rainwater. 1988. op. cit. (See R-404A.)

R-507A‡*Equation of state*

Lemmon and Jacobsen. 2004a. op. cit. (See R-404A.)

Viscosity

Klein et al. 1997. op. cit. (See R-12.)

Thermal conductivity

McLinden et al. 2000b. op. cit. (See R-12.)

Surface tension

Moldover and Rainwater. 1988. op. cit. (See R-404A.)

R-717 (Ammonia)†*Equation of state*

Tillner-Roth, R., F. Harms-Watzenberg, and H.D. Baehr. 1993. Eine neue Fundamentalgleichung für Ammoniak. *DKV-Tagungsbericht* 20(II): 167181.

Viscosity

Fenghour, A., W.A. Wakeham, V. Vesovic, J.T.R. Watson, J. Millat, and E. Vogel. 1995a. The viscosity of ammonia. *Journal of Physical and Chemical Reference Data* 24:1649-1667.

Thermal conductivity

Tufeu, R., D.Y. Ivanov, Y. Garrabos, and B. Le Neindre. 1984. Thermal conductivity of ammonia in a large temperature and pressure range including the critical region. *Berichte der Bunsen-Gesellschaft—Physical Chemistry* 88:422-427.

Surface tension

Stairs, R.A. and M.J. Sienko. 1956. Surface tension of ammonia and of solutions of alkali halides in ammonia. *Journal of American Chemical Society* 78:920-923.

R-718 (Water/Steam)†*Data computed using*

Harvey, A.H., S.A. Klein, and A.P. Peskin. 1999. *NIST Standard Reference Database 10. NIST/ASME steam properties database, v. 2.2.* Standard Reference Data Program.

Equation of state

Wagner, W. and A. Pruss. 2002. The IAPWS formulation 1995 for the thermodynamic properties of ordinary water substance for general and scientific use. *Journal of Physical and Chemical Reference Data* 31:387-535.

Viscosity and thermal conductivity

Kestin, J., J.V. Sengers, B. Kamgar-Parsi, and J.M.H. Levelt Sengers. 1984. Thermophysical properties of fluid H₂O. *Journal of Physical and Chemical Reference Data* 13:175.

Surface tension

IAPWS. 1995. Physical chemistry of aqueous systems: Meeting the needs of industry. *Proceedings of the 12th International Conference on the Properties of Water and Steam*, Orlando. Begell House, Inc., A139-A142. International Association for the Properties of Steam.

R-744 (Carbon Dioxide)†*Equation of state*

Span, R. and W. Wagner. 1996. A new equation of state for carbon dioxide covering the fluid region from the triple-point temperature to 1100 K at pressures up to 800 MPa. *Journal of Physical and Chemical Reference Data* 26:1509-1596.

Viscosity

Fenghour, A., W.A. Wakeham, and V. Vesovic. 1995b. The viscosity of carbon dioxide. *Journal of Physical and Chemical Reference Data* 27: 31-44.

Thermal conductivity

Vesovic, V., W.A. Wakeham, G.A. Olchoway, J.V. Sengers, J.T.R. Watson, and J. Millat. 1990. The transport properties of carbon dioxide. *Journal of Physical and Chemical Reference Data* 19:763-808.

Surface tension

Rathjen, W. and J. Straub. 1977. *Heat transfer in boiling*, Chapter 18, Temperature dependence of surface tension, coexistence curve, and vapor pressure of CO₂, CClF₃, CBrF₃, and SF₆. Academic Press, New York.

R-50 (Methane)†*Equation of state*

Setzmann, U. and W. Wagner. 1991. A new equation of state and tables of thermodynamic properties for methane covering the range from the melting line to 625 K at pressures to 1000 MPa. *Journal of Physical and Chemical Reference Data* 20:1061-1151.

Viscosity

Younglove, B.A. and J.F. Ely. 1987. Thermophysical properties of fluids. II. Methane, ethane, propane, isobutane and normal butane. *Journal of Physical and Chemical Reference Data* 16:577-798.

Thermal conductivity

Friend, D.G., J.F. Ely, and H. Ingham. 1989. Thermophysical properties of methane. *Journal of Physical and Chemical Reference Data* 18(2): 583-638.

Surface tension

Somayajulu, G.R. 1988. A generalized equation for surface tension from the triple point to the critical point. *International Journal of Thermophysics* 9:559-566.

R-170 (Ethane)*Equation of state,*

Bücker, D. and W. Wagner. 2006. A reference equation of state for the thermodynamic properties of ethane for temperatures from the melting line to 675 K and pressures up to 900 MPa. *Journal of Physical and Chemical Reference Data* 35:205.

Viscosity, and thermal conductivity

Friend, D.G., H. Ingham, and J.F. Ely. 1991. Thermophysical properties of ethane. *Journal of Physical and Chemical Reference Data* 20(2): 275-347.

Surface tension

Soares, V.A.M., B.d.J.V.S. Almeida, I.A. McLure, and R.A. Higgins. 1986. Surface tension of pure and mixed simple substances at low temperature. *Fluid Phase Equilibria* 32:9-16.

Pressure-enthalpy diagram based on data of

Friend, D.G., H. Ingham, and J.F. Ely. 1991. Thermophysical properties of ethane. *Journal of Physical and Chemical Reference Data* 20(2): 275-347.

R-290 (Propane)*Equation of state*

Lemmon, E.W., W. Wagner, and M.O. McLinden. 2009. Thermodynamic properties of propane, IV: Equation of state. *Journal of Chemical & Engineering Data* (submitted for publication).

Viscosity

Vogel, E., C. Küchenmeister, E. Bich, and A. Laesecke. 1998. Reference correlation of the viscosity of propane. *Journal of Physical and Chemical Reference Data* 27:947-970.

Thermal conductivity

Marsh, K., R. Perkins, and M.L.V. Ramires. 2002. Measurement and correlation of the thermal conductivity of propane from 86 to 600 K at pressures to 70 MPa. *Journal of Chemical & Engineering Data* 47:932-940.

Surface tension

Baidakov, V.G. and I.I. Sulla. 1985. Surface tension of propane and isobutane at near-critical temperatures. *Russian Journal of Physical Chemistry* 59:551-554.

Pressure-enthalpy diagram based on data of

Miyamoto, H. and K. Watanabe. 2000. A thermodynamic property model for fluid-phase propane. *International Journal of Thermophysics* 21:1045-1072.

R-600 (n-Butane)*Equation of state*

Bücker, D. and W. Wagner. 2006. Reference equations of state for the thermodynamic properties of fluid phase *n*-butane and isobutane. *Journal of Physical and Chemical Reference Data* 35:929.

Viscosity

Vogel, E., C. Küchenmeister, and E. Bich. 1999. Viscosity for *n*-butane in the fluid region. *High Temperatures—High Pressures* 31:173-186.

Thermal conductivity

Perkins, R.A., M.L.V. Ramires, C.A. Nieto de Castro, and L. Cusco. 2002. Measurement and correlation of the thermal conductivity of butane. *Journal of Chemical and Engineering Data* 47:1263-1271.

Surface tension

Calado, J.C.G., I.A. McLure, and V.A.M. Soares. 1978. Surface tension for octafluorocyclobutane, *n*-butane and their mixtures from 233 K to 254 K, and vapour pressure, excess Gibbs function and excess volume for the mixture at 233 K. *Fluid Phase Equilibria* 2:199-213.

Coffin, C.C. and O. Maass. 1928. The preparation and physical properties of α -, β - and γ -butylene and normal and isobutane. *Journal of the American Chemical Society* 50(5):1427-1437.

Pressure-enthalpy diagram based on data of

Miyamoto, H. and K. Watanabe. 2001. Thermodynamic property model for fluid-phase *n*-butane. *International Journal of Thermophysics* 22:459-475.

R-600a (Isobutane)*Equation of state*

Bücker, D. and W. Wagner. 2006. op cit. (See R-600.)

Viscosity

Vogel, E., C. Küchenmeister, and E. Bich. 2000. Viscosity correlation for isobutane over wide ranges of the fluid region. *International Journal of Thermophysics* 21:343-356.

Thermal conductivity

Perkins, R.A. 2002. Measurement and correlation of the thermal conductivity of isobutane. *Journal of Chemical Engineering Data* 47: 1272-1279.

Surface tension

Baidakov and Sulla. 1985. op. cit. (See R-290.)

Pressure-enthalpy diagram based on data of

Miyamoto, H. and K. Watanabe. 2002. A thermodynamic property model for fluid-phase isobutane. *International Journal of Thermophysics* 23:477-499.

R-1150 (Ethylene)†*Equation of state*

Smukala, J., R. Span, and W. Wagner. 2000. A new equation of state for ethylene covering the fluid region for temperatures from the melting line to 450 K and pressures up to 300 MPa. *Journal of Physical and Chemical Reference Data* 29:1053-1122.

Viscosity and thermal conductivity

Holland, P.M., B.E. Eaton, and H.J.M. Hanley. 1983. A correlation of the viscosity and thermal conductivity data of gaseous and liquid ethylene. *Journal of Physical and Chemical Reference Data* 12:917-932.

Surface tension

Soares et al. op. cit. (See R-170.)

R-1270 (Propylene)‡*Equation of state*

Angus, S., B. Armstrong, and K.M. de Reuck. 1980. *International thermodynamic tables of the fluid state—7: Propylene*. Pergamon Press, Oxford, U.K.

Viscosity and thermal conductivity

Huber et al. 2003. op. cit. (See R-32.)

Surface tension

Maass, O. and C.H. Wright. 1921. Some physical properties of hydrocarbons containing two and three carbon atoms. *Journal of the American Chemical Society* 43:1098-1111.

R-702 (Hydrogen)

Thermodynamic data computed using the ALLPROPS database, v. 4.0: Lemmon, E.W., R.T. Jacobsen, S.G. Penoncello, and S.W. Beyerlein. 1994. Computer programs for the calculation of thermodynamic properties of cryogenics and other fluids. *Advances in Cryogenic Engineering* 39:1891-1897.

Transport data computed using the NIST 12 database, v. 3.0: Friend, D.G., R.D. McCarty, and V. Arp. 1992. *NIST thermophysical properties of pure fluids database*, v. 3.0. Standard Reference Data Program.

Equation of state, viscosity, and thermal conductivity

McCarty, R.D. 1975. *Hydrogen: Technology survey—Thermophysical properties*. NASA SP-3089.

Surface tension

Liley, P.E. and P.D. Desai. 1993. *ASHRAE thermophysical properties of refrigerants*.

R-702p (Parahydrogen)

Thermodynamic data computed using the ALLPROPS database, v. 4.0: Lemmon et al. 1994. op. cit. (See R-702.)

Transport data computed using the NIST12 database, v. 3.0: Friend et al. 1992. op. cit. (See R-702.)

Equation of state, viscosity, and thermal conductivity

Younglove, B.A. 1982. Thermophysical properties of fluids. I. Argon, ethylene, parahydrogen, nitrogen, nitrogen trifluoride, and oxygen. *Journal of Physical and Chemical Reference Data* 11(Supplement No. 1).

Surface tension

Liley and Desai. 1993. op. cit. (See R-702.)

R-704 (Helium)

Thermodynamic data computed using the ALLPROPS database, v. 4.0: Lemmon et al. 1994. op. cit. (See R-702.)

Transport data computed using the NIST12 database, v. 3.0: Friend et al. 1992. op. cit. (See R-702.)

Equation of state

Arp, V.D., R.D. McCarty, and D.G. Friend. 1995. Thermophysical properties of helium-4 from 0.8 to 1500 K with pressures to 2000 MPa. *NIST Technical Note* 1334 (revised).

Surface tension

Liley and Desai. 1993. op. cit. (See R-702.)

R-728 (Nitrogen)‡*Equation of state, viscosity, and thermal conductivity*

Span, R., E.W. Lemmon, R.T. Jacobsen, W. Wagner, and A. Yokozeki. 2000. A reference equation of state for the thermodynamic properties of nitrogen for temperatures from 63.151 to 1000 K and pressures to 2200 MPa. *Journal of Physical and Chemical Reference Data* 29:1361-1433.

Viscosity and thermal conductivity

Lemmon, E.W. and R.T. Jacobsen. 2004b. Viscosity and thermal conductivity equations for nitrogen, oxygen, argon, and air. *International Journal of Thermophysics* 25:21-69.

Surface tension

Lemmon, E.W. and S.G. Penoncello. 1994. The surface tension of air and air component mixtures. *Advances in Cryogenic Engineering* 39:1927-1934.

R-729 (Air)‡*Equation of state*

Lemmon, E.W., R.T. Jacobsen, S.G. Penoncello, and D.G. Friend. 2000. Thermodynamic properties of air and mixtures of nitrogen, argon, and oxygen from 60 to 2000 K at pressures to 2000 MPa. *Journal of Physical and Chemical Reference Data* 29:331-385.

Viscosity and thermal conductivity

Lemmon and Jacobsen. 2004b. op. cit. (See R-728.)

Surface tension

Lemmon and Penoncello. 1994. op. cit. (See R-728.)

R-732 (Oxygen)‡*Equation of state*

Schmidt, R. and W. Wagner. 1985. A new form of the equation of state for pure substances and its application to oxygen. *Fluid Phase Equilibria* 19:175-200.

Viscosity and thermal conductivity

Lemmon and Jacobsen. 2004b. op. cit. (See R-728.)

Surface tension

Lemmon and Penoncello. 1994. op. cit. (See R-728.)

R-740 (Argon)‡*Equation of state*

Tegeler, C., R. Span, and W. Wagner. 1999. A new equation of state for argon covering the fluid region for temperatures from the melting line to 700 K at pressures up to 1000 MPa. *Journal of Physical and Chemical Reference Data* 28:779-850.

Viscosity and thermal conductivity

Lemmon and Jacobsen. 2004b. op. cit. (See R-728.)

Surface tension

Lemmon and Penoncello. 1994. op. cit. (See R-728.)