

# **Thermodynamics Properties** **Tables and Charts**

to accompany the web learning resource

<http://www.ohio.edu/mechanical/thermo>

## **Engineering Thermodynamics – A Graphical Approach**

By

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## Thermodynamic Properties of Water (Steam Tables)

Critical Pressure: 22.064 MPa, Critical Temperature 373.95°C

Ideal Gas Constant of Steam:  $R = 0.4615 \text{ kJ/kg}\cdot\text{K}$

Specific Heat Capacity of liquid water:  $C_{H_2O} = 4.18 \text{ kJ/kg}\cdot\text{°C}$

### Steam Property Tables:

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

### Steam Property Tables (Excel Version):

- Saturation Properties - Temperature Table
- Saturation Properties - Pressure Table
- Superheated Vapor Properties
- Compressed Liquid Water Properties

Source of data: NIST Chemistry WebBook - accessed Jan 2008

### Steam Property Diagrams:

- Pressure-Enthalpy ( $P-h$ ) Diagram
- Enthalpy-Entropy ( $h-s$ ) Diagram



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### Saturation Properties for Steam - Temperature Table (0.01°C - 150°C)

Temp °C	Pressure MPa	volume (m <sup>3</sup> /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	uf	ug	hf	hfg	hg	sf	sfg	sg
0.01	0.00061	0.00100	205.99	0	2374.9	0.001	2500.9	2500.9	0	9.1555	9.1555
5	0.00087	0.00100	147.01	21.02	2381.8	21.0	2489.1	2510.1	0.0763	8.9485	9.0248
10	0.00123	0.00100	106.30	42.02	2388.6	42.0	2477.2	2519.2	0.1511	8.7487	8.8998
15	0.00171	0.00100	77.875	62.98	2395.5	63.0	2465.3	2528.3	0.2245	8.5558	8.7803
20	0.00234	0.00100	57.757	83.91	2402.3	83.9	2453.5	2537.4	0.2965	8.3695	8.6660
25	0.00317	0.00100	43.337	104.83	2409.1	104.8	2441.7	2546.5	0.3672	8.1894	8.5566
30	0.00425	0.00100	32.878	125.73	2415.9	125.7	2429.8	2555.5	0.4368	8.0152	8.4520
35	0.00563	0.00101	25.205	146.63	2422.7	146.6	2417.9	2564.5	0.5051	7.8466	8.3517
40	0.00739	0.00101	19.515	167.53	2429.4	167.5	2406.0	2573.5	0.5724	7.6831	8.2555
45	0.00960	0.00101	15.252	188.43	2436.1	188.4	2394.0	2582.4	0.6386	7.5247	8.1633
50	0.01235	0.00101	12.027	209.33	2442.7	209.3	2382.0	2591.3	0.7038	7.3710	8.0748
55	0.01576	0.00102	9.5643	230.24	2449.3	230.3	2369.8	2600.1	0.7680	7.2218	7.9898
60	0.01995	0.00102	7.6672	251.16	2455.9	251.2	2357.6	2608.8	0.8313	7.0768	7.9081
65	0.02504	0.00102	6.1935	272.09	2462.4	272.1	2345.4	2617.5	0.8937	6.9359	7.8296
70	0.03120	0.00102	5.0395	293.03	2468.9	293.2	2333.0	2626.1	0.9551	6.7989	7.7540
75	0.03860	0.00103	4.1289	313.99	2475.2	314.0	2320.6	2634.6	1.0158	6.6654	7.6812
80	0.04741	0.00103	3.4052	334.96	2481.6	335.0	2308.0	2643.0	1.0756	6.5355	7.6111
85	0.05787	0.00103	2.8258	355.95	2487.8	356.0	2295.3	2651.3	1.1346	6.4088	7.5434
90	0.07018	0.00104	2.3591	376.97	2494.0	377.0	2282.5	2659.5	1.1929	6.2852	7.4781
95	0.08461	0.00104	1.9806	398.00	2500.0	398.1	2269.5	2667.6	1.2504	6.1647	7.4151
100	0.10142	0.00104	1.6718	419.06	2506.0	419.2	2256.4	2675.6	1.3072	6.0469	7.3541
110	0.14338	0.00105	1.2093	461.26	2517.7	461.4	2229.7	2691.1	1.4188	5.8193	7.2381
120	0.19867	0.00106	0.8912	503.60	2528.9	503.8	2202.1	2705.9	1.5279	5.6012	7.1291
130	0.27028	0.00107	0.66800	546.09	2539.5	546.4	2173.7	2720.1	1.6346	5.3918	7.0264
140	0.36154	0.00108	0.50845	588.77	2549.6	589.2	2144.2	2733.4	1.7392	5.1901	6.9293
150	0.47616	0.00109	0.39245	631.66	2559.1	632.2	2113.7	2745.9	1.8418	4.9953	6.8371

- **Saturation Properties - Temperature Table (0.01°C - 150°C)**
- **Saturation Properties - Temperature Table (150°C - 373.95°C)**
- **Saturation Properties - Pressure Table (1 kPa - 1 MPa)**
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- **Compressed Liquid Water Properties - (5 MPa - 30 MPa)**

Source of data: NIST Chemistry WebBook - accessed Jan 2008



### Saturation Properties for Steam - Temperature Table (150°C - 373.95°C)

Temp	Pressure	volume (m <sup>3</sup> /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
°C	MPa	vf	vg	uf	ug	hf	hfg	hg	sf	sfg	sg
150	0.4762	0.00109	0.39245	631.66	2559.1	632.2	2113.7	2745.9	1.8418	4.9953	6.8371
160	0.6182	0.00110	0.30678	674.79	2567.8	675.5	2081.9	2757.4	1.9426	4.8065	6.7491
170	0.7922	0.00111	0.24259	718.20	2575.7	719.1	2048.8	2767.9	2.0417	4.6233	6.6650
180	1.0028	0.00113	0.19384	761.92	2582.8	763.1	2014.1	2777.2	2.1392	4.4448	6.5840
190	1.2552	0.00114	0.15636	806.00	2589.0	807.4	1977.9	2785.3	2.2355	4.2704	6.5059
200	1.5549	0.00116	0.12721	850.47	2594.2	852.3	1939.7	2792.0	2.3305	4.0997	6.4302
210	1.9077	0.00117	0.10429	895.39	2598.3	897.6	1899.7	2797.3	2.4245	3.9318	6.3563
220	2.3196	0.00119	0.08609	940.82	2601.2	943.6	1857.3	2800.9	2.5177	3.7663	6.2840
230	2.7971	0.00121	0.07150	986.81	2602.9	990.2	1812.7	2802.9	2.6101	3.6027	6.2128
240	3.3469	0.00123	0.05971	1033.4	2603.1	1037.6	1765.4	2803.0	2.7020	3.4403	6.1423
250	3.9762	0.00125	0.05008	1080.8	2601.8	1085.8	1715.1	2800.9	2.7935	3.2786	6.0721
260	4.6923	0.00128	0.04217	1129.0	2598.7	1135.0	1661.6	2796.6	2.8849	3.1167	6.0016
270	5.5030	0.00130	0.03562	1178.1	2593.7	1185.3	1604.4	2789.7	2.9765	2.9539	5.9304
280	6.4166	0.00133	0.03015	1228.3	2586.4	1236.9	1543.0	2779.9	3.0685	2.7894	5.8579
290	7.4418	0.00137	0.02556	1279.9	2576.5	1290.0	1476.7	2766.7	3.1612	2.6222	5.7834
300	8.5879	0.00140	0.02166	1332.9	2563.6	1345.0	1404.6	2749.6	3.2552	2.4507	5.7059
310	9.8651	0.00145	0.01834	1387.9	2547.1	1402.2	1325.7	2727.9	3.3510	2.2734	5.6244
320	11.284	0.00150	0.01547	1445.3	2526.0	1462.2	1238.4	2700.6	3.4494	2.0878	5.5372
330	12.858	0.00156	0.01298	1505.8	2499.2	1525.9	1140.1	2666.0	3.5518	1.8904	5.4422
340	14.601	0.00164	0.01078	1570.6	2464.4	1594.5	1027.3	2621.8	3.6601	1.6755	5.3356
350	16.529	0.00174	0.00880	1642.1	2418.1	1670.9	892.7	2563.6	3.7784	1.4326	5.211
360	18.666	0.00190	0.00695	1726.3	2351.8	1761.7	719.8	2481.5	3.9167	1.1369	5.0536
370	21.044	0.00222	0.00495	1844.1	2230.3	1890.7	443.8	2334.5	4.1112	0.69	4.8012
373.95	22.064	0.00311	0.00311	2015.7	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

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Source of data: NIST Chemistry WebBook - accessed Jan 2008

### Saturation Properties for Steam - Pressure Table (1 kPa - 1 MPa)

Pressure	Temp	volume		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		MPa	°C	vf	vg	uf	ug	hf	hfg	hg	sf
0.001	6.97	0.00100	129.18	29.3	2384.5	29.3	2484.4	2513.7	0.1059	8.8690	8.9749
0.0012	9.65	0.00100	108.67	40.6	2388.2	40.6	2478.0	2518.6	0.1460	8.7622	8.9082
0.0014	11.97	0.00100	93.90	50.3	2391.3	50.3	2472.5	2522.8	0.1802	8.6720	8.8522
0.0016	14.01	0.00100	82.74	58.8	2394.1	58.8	2467.7	2526.5	0.2100	8.5935	8.8035
0.0018	15.84	0.00100	74.01	66.5	2396.6	66.5	2463.4	2529.9	0.2366	8.5242	8.7608
0.002	17.50	0.00100	66.99	73.4	2398.9	73.4	2459.5	2532.9	0.2606	8.4620	8.7226
0.003	24.08	0.00100	45.65	101.0	2407.9	101.0	2443.8	2544.8	0.3543	8.2221	8.5764
0.004	28.96	0.00100	34.79	121.4	2414.5	121.4	2432.3	2553.7	0.4224	8.0510	8.4734
0.006	36.16	0.00101	23.73	151.5	2424.2	151.5	2415.1	2566.6	0.5208	7.8082	8.3290
0.008	41.51	0.00101	18.10	173.8	2431.4	173.8	2402.4	2576.2	0.5925	7.6348	8.2273
0.01	45.81	0.00101	14.67	191.8	2437.2	191.8	2392.1	2583.9	0.6492	7.4996	8.1488
0.012	49.42	0.00101	12.36	206.9	2442.0	206.9	2383.4	2590.3	0.6963	7.3886	8.0849
0.014	52.55	0.00101	10.69	220.0	2446.1	220.0	2375.8	2595.8	0.7366	7.2945	8.0311
0.016	55.31	0.00102	9.431	231.6	2449.8	231.6	2369.0	2600.6	0.7720	7.2126	7.9846
0.018	57.80	0.00102	8.443	242.0	2453.0	242.0	2363.0	2605.0	0.8036	7.1401	7.9437
0.02	60.06	0.00102	7.648	251.4	2456.0	251.4	2357.5	2608.9	0.8320	7.0752	7.9072
0.03	69.10	0.00102	5.228	289.2	2467.7	289.3	2335.2	2624.5	0.9441	6.8234	7.7675
0.04	75.86	0.00103	3.993	317.6	2476.3	317.6	2318.5	2636.1	1.0261	6.6429	7.6690
0.06	85.93	0.00103	2.732	360.0	2489.0	359.9	2293.0	2652.9	1.1454	6.3857	7.5311
0.08	93.49	0.00104	2.087	391.6	2498.2	391.7	2273.5	2665.2	1.2330	6.2009	7.4339
0.1	99.61	0.00104	1.694	417.4	2505.6	417.5	2257.4	2674.9	1.3028	6.0560	7.3588
0.12	104.78	0.00105	1.428	439.2	2511.7	439.4	2243.7	2683.1	1.3609	5.9368	7.2977
0.14	109.29	0.00105	1.2366	458.3	2516.9	458.4	2231.6	2690.0	1.4110	5.8351	7.2461
0.16	113.30	0.00105	1.0914	475.2	2521.4	475.4	2220.6	2696.0	1.4551	5.7463	7.2014
0.18	116.91	0.00106	0.9775	490.5	2525.5	490.7	2210.7	2701.4	1.4945	5.6676	7.1621
0.2	120.21	0.00106	0.8857	504.5	2529.1	504.7	2201.5	2706.2	1.5302	5.5967	7.1269
0.3	133.52	0.00107	0.6058	561.1	2543.2	561.4	2163.5	2724.9	1.6717	5.3199	6.9916
0.4	143.61	0.00108	0.4624	604.2	2553.1	604.7	2133.4	2738.1	1.7765	5.1190	6.8955
0.6	158.83	0.00110	0.3156	669.7	2566.8	670.4	2085.7	2756.1	1.9308	4.8284	6.7592
0.8	170.41	0.00112	0.2403	720.0	2576.0	720.9	2047.4	2768.3	2.0457	4.6159	6.6616
1	179.88	0.00113	0.1944	761.4	2582.7	762.5	2014.6	2777.1	2.1381	4.4469	6.5850

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### Saturation Properties for Steam - Pressure Table (1 MPa - 22.064 MPa)

Pressure MPa	Temp °C	volume (m <sup>3</sup> /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	uf	ug	hf	hfg	hg	sf	sfg	sg
1	179.88	0.00113	0.1944	761.4	2582.7	762.5	2014.6	2777.1	2.1381	4.4469	6.5850
1.2	187.96	0.00114	0.1633	797.0	2587.8	798.3	1985.4	2783.7	2.2159	4.3058	6.5217
1.4	195.04	0.00115	0.1408	828.4	2591.8	830.0	1958.8	2788.8	2.2835	4.1840	6.4675
1.6	201.37	0.00116	0.1237	856.6	2594.8	858.5	1934.3	2792.8	2.3435	4.0764	6.4199
1.8	207.11	0.00117	0.1104	882.4	2597.2	884.5	1911.4	2795.9	2.3975	3.9800	6.3775
2	212.38	0.00118	0.0996	906.1	2599.1	908.5	1889.8	2798.3	2.4468	3.8922	6.3390
3	233.85	0.00122	0.0667	1004.7	2603.2	1008.3	1794.9	2803.2	2.6455	3.5401	6.1856
4	250.35	0.00125	0.0498	1082.5	2601.7	1087.5	1713.3	2800.8	2.7968	3.2728	6.0696
6	275.58	0.00132	0.0325	1206.0	2589.9	1213.9	1570.7	2784.6	3.0278	2.8623	5.8901
8	295.01	0.00139	0.0235	1306.2	2570.5	1317.3	1441.4	2758.7	3.2081	2.5369	5.7450
10	311.00	0.00145	0.0180	1393.5	2545.2	1408.1	1317.4	2725.5	3.3606	2.2554	5.6160
12	324.68	0.00153	0.0143	1473.1	2514.3	1491.5	1193.9	2685.4	3.4967	1.9972	5.4939
14	336.67	0.00161	0.0115	1548.4	2477.1	1571.0	1066.9	2637.9	3.6232	1.7495	5.3727
16	347.35	0.00171	0.0093	1622.3	2431.8	1649.7	931.1	2580.8	3.7457	1.5006	5.2463
18	356.99	0.00184	0.0075	1699.0	2374.8	1732.1	777.7	2509.8	3.8718	1.2343	5.1061
20	365.75	0.00204	0.0059	1786.4	2295.0	1827.2	585.1	2412.3	4.0156	0.9158	4.9314
22.064	373.95	0.00311	0.00311	2015.7	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

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Source of data: NIST Chemistry WebBook - accessed Jan 2008

**Superheated Vapor Properties for Steam - (0.01 MPa - 0.4 MPa)**

<b>P=0.010 MPa (45.8°C)</b>					<b>P=0.050 MPa (81.3°C)</b>				<b>P=0.10 MPa (99.6°C)</b>			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	14.67	2437.2	2583.9	8.149	3.240	2483.2	2645.2	7.593	1.694	2505.6	2674.9	7.359
50	14.87	2443.3	2592.0	8.174	-	-	-	-	-	-	-	-
100	17.20	2515.5	2687.5	8.449	3.419	2511.5	2682.4	7.695	1.696	2506.2	2675.8	7.361
150	19.51	2587.9	2783.0	8.689	3.890	2585.7	2780.2	7.941	1.937	2582.9	2776.6	7.615
200	21.83	2661.3	2879.6	8.905	4.356	2660.0	2877.8	8.159	2.172	2658.2	2875.5	7.836
250	24.14	2736.1	2977.4	9.102	4.821	2735.1	2976.1	8.357	2.406	2733.9	2974.5	8.035
300	26.45	2812.3	3076.7	9.283	5.284	2811.6	3075.8	8.539	2.639	2810.6	3074.5	8.217
350	28.76	2890.0	3177.5	9.451	5.747	2889.4	3176.8	8.708	2.871	2888.7	3175.8	8.387
400	31.06	2969.3	3279.9	9.609	6.209	2968.9	3279.3	8.866	3.103	2968.3	3278.6	8.545
450	33.37	3050.3	3384.0	9.758	6.672	3049.9	3383.5	9.015	3.334	3049.4	3382.8	8.695
500	35.68	3132.9	3489.7	9.900	7.134	3132.6	3489.3	9.157	3.566	3132.2	3488.7	8.836
600	40.30	3303.3	3706.3	10.163	8.058	3303.1	3706.0	9.420	4.028	3302.8	3705.6	9.100
700	44.91	3480.8	3929.9	10.406	8.981	3480.6	3929.7	9.663	4.490	3480.4	3929.4	9.342
800	49.53	3665.3	4160.6	10.631	9.905	3665.2	4160.4	9.888	4.952	3665.0	4160.2	9.568
900	54.14	3856.9	4398.3	10.843	10.828	3856.8	4398.2	10.100	5.414	3856.6	4398.0	9.780
1000	58.76	4055.2	4642.8	11.043	11.751	4055.1	4642.7	10.300	5.875	4055.0	4642.6	9.980

<b>P=0.20 MPa (120.2°C)</b>					<b>P=0.30 MPa (133.5°C)</b>				<b>P=0.40 MPa (143.6°C)</b>			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.8857	2529.1	2706.2	7.127	0.6058	2543.2	2724.9	6.992	0.4624	2553.1	2738.1	6.896
150	0.9599	2577.1	2769.1	7.281	0.6340	2571.0	2761.2	7.079	0.4709	2564.4	2752.8	6.931
200	1.0805	2654.6	2870.7	7.508	0.7164	2651.0	2865.9	7.313	0.5343	2647.2	2860.9	7.172
250	1.1989	2731.4	2971.2	7.710	0.7964	2728.9	2967.9	7.518	0.5952	2726.4	2964.5	7.380
300	1.3162	2808.8	3072.1	7.894	0.8753	2807.0	3069.6	7.704	0.6549	2805.1	3067.1	7.568
350	1.4330	2887.3	3173.9	8.064	0.9536	2885.9	3172.0	7.875	0.7140	2884.4	3170.0	7.740
400	1.5493	2967.1	3277.0	8.224	1.0315	2966.0	3275.5	8.035	0.7726	2964.9	3273.9	7.900
450	1.6655	3048.5	3381.6	8.373	1.1092	3047.5	3380.3	8.185	0.8311	3046.6	3379.0	8.051
500	1.7814	3131.4	3487.7	8.515	1.1867	3130.6	3486.6	8.327	0.8894	3129.8	3485.5	8.193
600	2.0130	3302.2	3704.8	8.779	1.3414	3301.6	3704.0	8.591	1.0056	3301.0	3703.2	8.458
700	2.2443	3479.9	3928.8	9.022	1.4958	3479.5	3928.2	8.834	1.1215	3479.0	3927.6	8.701
800	2.4755	3664.7	4159.8	9.248	1.6500	3664.3	4159.3	9.060	1.2373	3663.9	4158.8	8.927
900	2.7066	3856.3	4397.6	9.460	1.8042	3856.0	4397.3	9.272	1.3530	3855.7	4396.9	9.139
1000	2.9375	4054.8	4642.3	9.660	1.9582	4054.5	4642.0	9.473	1.4686	4054.3	4641.7	9.340

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

Source of data: NIST Chemistry WebBook - accessed Jan 2008

**Superheated Vapor Properties for Steam (0.5 MPa - 1.4 MPa)**

P=0.50 MPa (151.8°C)					P=0.60 MPa (158.8°C)				P=0.80 MPa (170.4°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.3748	2560.7	2748.1	6.821	0.3156	2566.8	2756.1	6.759	0.2403	2576.0	2768.3	6.662
200	0.4250	2643.3	2855.8	7.061	0.3521	2639.3	2850.6	6.968	0.2609	2631.0	2839.7	6.818
250	0.4744	2723.8	2961.0	7.272	0.3939	2721.2	2957.6	7.183	0.2932	2715.9	2950.4	7.040
300	0.5226	2803.2	3064.6	7.461	0.4344	2801.4	3062.0	7.374	0.3242	2797.5	3056.9	7.235
350	0.5702	2883.0	3168.1	7.635	0.4743	2881.6	3166.1	7.548	0.3544	2878.6	3162.2	7.411
400	0.6173	2963.7	3272.3	7.796	0.5137	2962.5	3270.8	7.710	0.3843	2960.2	3267.6	7.573
450	0.6642	3045.6	3377.7	7.947	0.5530	3044.7	3376.5	7.861	0.4139	3042.8	3373.9	7.726
500	0.7109	3129.0	3484.5	8.089	0.5920	3128.2	3483.4	8.004	0.4433	3126.6	3481.3	7.869
600	0.8041	3300.4	3702.5	8.354	0.6698	3299.8	3701.7	8.270	0.5019	3298.7	3700.1	8.135
700	0.8970	3478.5	3927.0	8.598	0.7473	3478.1	3926.4	8.513	0.5601	3477.2	3925.3	8.379
800	0.9897	3663.6	4158.4	8.824	0.8246	3663.2	4157.9	8.740	0.6182	3662.4	4157.0	8.606
900	1.0823	3855.4	4396.6	9.036	0.9018	3855.1	4396.2	8.952	0.6762	3854.5	4395.5	8.819
1000	1.1748	4054.0	4641.4	9.236	0.9789	4053.7	4641.1	9.152	0.7341	4053.2	4640.5	9.019

P=1.00 MPa (179.9°C)					P=1.20 MPa (188.0°C)				P=1.40 MPa (195.0°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.1944	2582.7	2777.1	6.585	0.1633	2587.8	2783.7	6.522	0.1408	2591.8	2788.8	6.468
200	0.2060	2622.2	2828.3	6.696	0.1693	2612.9	2816.1	6.591	0.1430	2602.7	2803.0	6.498
250	0.2328	2710.4	2943.1	6.927	0.1924	2704.7	2935.6	6.831	0.1636	2698.9	2927.9	6.749
300	0.2580	2793.6	3051.6	7.125	0.2139	2789.7	3046.3	7.034	0.1823	2785.7	3040.9	6.955
350	0.2825	2875.7	3158.2	7.303	0.2346	2872.7	3154.2	7.214	0.2003	2869.7	3150.1	7.138
400	0.3066	2957.9	3264.5	7.467	0.2548	2955.5	3261.3	7.379	0.2178	2953.1	3258.1	7.305
450	0.3305	3040.9	3371.3	7.620	0.2748	3038.9	3368.7	7.533	0.2351	3037.0	3366.1	7.459
500	0.3541	3125.0	3479.1	7.764	0.2946	3123.4	3476.9	7.678	0.2522	3121.8	3474.8	7.605
600	0.4011	3297.5	3698.6	8.031	0.3339	3296.3	3697.0	7.946	0.2860	3295.1	3695.4	7.873
700	0.4478	3476.2	3924.1	8.276	0.3730	3475.3	3922.9	8.190	0.3195	3474.4	3921.7	8.118
800	0.4944	3661.7	4156.1	8.502	0.4118	3661.0	4155.2	8.418	0.3529	3660.2	4154.3	8.346
900	0.5408	3853.9	4394.8	8.715	0.4506	3853.3	4394.0	8.630	0.3861	3852.7	4393.3	8.559
1000	0.5872	4052.7	4639.9	8.916	0.4893	4052.2	4639.4	8.831	0.4193	4051.7	4638.8	8.759

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

Source of data: NIST Chemistry WebBook - accessed Jan 2008

**Superheated Vapor Properties for Steam - (1.6 MPa - 3.5 MPa)**

P=1.60 MPa (201.4°C)					P=1.80 MPa (207.1°C)				P=2.00 MPa (212.4°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.1237	2594.8	2792.8	6.420	0.1104	2597.2	2795.9	6.378	0.0996	2599.1	2798.3	6.339
225	0.1329	2645.1	2857.8	6.554	0.1168	2637.0	2847.2	6.482	0.1038	2628.5	2836.1	6.416
250	0.1419	2692.9	2919.9	6.675	0.1250	2686.7	2911.7	6.609	0.1115	2680.2	2903.2	6.548
300	0.1587	2781.6	3035.4	6.886	0.1403	2777.4	3029.9	6.825	0.1255	2773.2	3024.2	6.768
350	0.1746	2866.6	3146.0	7.071	0.1546	2863.6	3141.8	7.012	0.1386	2860.5	3137.7	6.958
400	0.1901	2950.7	3254.9	7.239	0.1685	2948.3	3251.6	7.181	0.1512	2945.9	3248.3	7.129
450	0.2053	3035.0	3363.5	7.395	0.1821	3033.1	3360.9	7.338	0.1635	3031.1	3358.2	7.287
500	0.2203	3120.1	3472.6	7.541	0.1955	3118.5	3470.4	7.485	0.1757	3116.9	3468.2	7.434
600	0.2500	3293.9	3693.9	7.810	0.2220	3292.7	3692.3	7.754	0.1996	3291.5	3690.7	7.704
700	0.2794	3473.5	3920.5	8.056	0.2482	3472.6	3919.4	8.000	0.2233	3471.6	3918.2	7.951
800	0.3087	3659.5	4153.3	8.283	0.2743	3658.8	4152.4	8.228	0.2467	3658.0	4151.5	8.179
900	0.3378	3852.1	4392.6	8.497	0.3002	3851.5	4391.9	8.442	0.2701	3850.9	4391.1	8.393
1000	0.3669	4051.2	4638.2	8.697	0.3261	4050.7	4637.6	8.643	0.2934	4050.2	4637.0	8.594

P=2.5 MPa (224.0°C)					P=3.0 MPa (233.9°C)				P=3.5 MPa (242.6°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.0800	2602.1	2801.9	6.256	0.0667	2603.2	2803.2	6.186	0.0571	2602.9	2802.6	6.124
250	0.0871	2663.3	2880.9	6.411	0.0706	2644.7	2856.5	6.289	0.0588	2624.0	2829.7	6.176
300	0.0989	2762.2	3009.6	6.646	0.0812	2750.8	2994.3	6.541	0.0685	2738.8	2978.4	6.448
350	0.1098	2852.5	3127.0	6.842	0.0906	2844.4	3116.1	6.745	0.0768	2836.0	3104.8	6.660
400	0.1201	2939.8	3240.1	7.017	0.0994	2933.5	3231.7	6.923	0.0846	2927.2	3223.2	6.843
450	0.1302	3026.2	3351.6	7.177	0.1079	3021.2	3344.8	7.086	0.0920	3016.1	3338.0	7.007
500	0.1400	3112.8	3462.7	7.325	0.1162	3108.6	3457.2	7.236	0.0992	3104.5	3451.6	7.159
600	0.1593	3288.5	3686.8	7.598	0.1325	3285.5	3682.8	7.510	0.1133	3282.5	3678.9	7.436
700	0.1784	3469.3	3915.2	7.846	0.1484	3467.0	3912.2	7.759	0.1270	3464.7	3909.3	7.685
800	0.1972	3656.2	4149.2	8.074	0.1642	3654.3	4146.9	7.989	0.1406	3652.5	4144.6	7.916
900	0.2160	3849.4	4389.3	8.288	0.1799	3847.9	4387.5	8.203	0.1541	3846.4	4385.7	8.130
1000	0.2347	4048.9	4635.6	8.490	0.1955	4047.7	4634.1	8.405	0.1675	4046.4	4632.7	8.332

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

Source of data: NIST Chemistry WebBook - accessed Jan 2008



**Superheated Vapor Properties for Steam - (4 MPa - 8 MPa)**

P=4.0 MPa (250.4°C)					P=4.5 MPa (257.4°C)				P=5.0 MPa (263.9°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.0498	2601.7	2800.8	6.070	0.0441	2599.7	2797.9	6.020	0.0395	2597.0	2794.2	5.974
275	0.0546	2668.9	2887.3	6.231	0.0473	2651.3	2864.3	6.143	0.0414	2632.3	2839.5	6.057
300	0.0589	2726.2	2961.7	6.364	0.0514	2713.0	2944.2	6.285	0.0454	2699.0	2925.7	6.211
350	0.0665	2827.4	3093.3	6.584	0.0584	2818.6	3081.5	6.515	0.0520	2809.5	3069.3	6.452
400	0.0734	2920.7	3214.5	6.771	0.0648	2914.2	3205.6	6.707	0.0578	2907.5	3196.7	6.648
450	0.0800	3011.0	3331.2	6.939	0.0708	3005.8	3324.2	6.877	0.0633	3000.6	3317.2	6.821
500	0.0864	3100.3	3446.0	7.092	0.0765	3096.0	3440.4	7.032	0.0686	3091.7	3434.7	6.978
600	0.0989	3279.4	3674.9	7.371	0.0877	3276.4	3670.9	7.313	0.0787	3273.3	3666.8	7.261
700	0.1110	3462.4	3906.3	7.621	0.0985	3460.0	3903.3	7.565	0.0885	3457.7	3900.3	7.514
800	0.1229	3650.6	4142.3	7.852	0.1092	3648.8	4140.0	7.796	0.0982	3646.9	4137.7	7.746
900	0.1348	3844.8	4383.9	8.067	0.1197	3843.3	4382.1	8.012	0.1077	3841.8	4380.2	7.962
1000	0.1465	4045.1	4631.2	8.270	0.1302	4043.9	4629.8	8.214	0.1172	4042.6	4628.3	8.165

P=6.0 MPa (275.6°C)					P=7.0 MPa (285.8°C)				P=8.0 MPa (295.0°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.0325	2589.9	2784.6	5.890	0.0274	2581.0	2772.6	5.815	0.0235	2570.5	2758.7	5.745
300	0.0362	2668.4	2885.5	6.070	0.0295	2633.5	2839.9	5.934	0.0243	2592.3	2786.5	5.794
350	0.0423	2790.4	3043.9	6.336	0.0353	2770.1	3016.9	6.230	0.0300	2748.3	2988.1	6.132
400	0.0474	2893.7	3178.2	6.543	0.0400	2879.5	3159.2	6.450	0.0343	2864.6	3139.4	6.366
450	0.0522	2989.9	3302.9	6.722	0.0442	2979.0	3288.3	6.635	0.0382	2967.8	3273.3	6.558
500	0.0567	3083.1	3423.1	6.883	0.0482	3074.3	3411.4	6.800	0.0418	3065.4	3399.5	6.727
600	0.0653	3267.2	3658.7	7.169	0.0557	3260.9	3650.6	7.091	0.0485	3254.7	3642.4	7.022
700	0.0736	3453.0	3894.3	7.425	0.0629	3448.3	3888.2	7.349	0.0548	3443.6	3882.2	7.282
800	0.0817	3643.2	4133.1	7.658	0.0699	3639.5	4128.4	7.584	0.0610	3635.7	4123.8	7.518
900	0.0896	3838.8	4376.6	7.875	0.0768	3835.7	4373.0	7.801	0.0671	3832.6	4369.3	7.737
1000	0.0976	4040.1	4625.4	8.079	0.0836	4037.5	4622.5	8.006	0.0731	4035.0	4619.6	7.942

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

Source of data: NIST Chemistry WebBook accessed Jan 2008

**Superheated Vapor Properties for Steam - (9 MPa - 40 MPa)**

P=9.0 MPa (303.3°C)					P=10.0 MPa (311.0°C)				P=12.5 MPa (327.8°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.0205	2558.5	2742.9	5.679	0.0180	2545.2	2725.5	5.616	0.0135	2505.6	2674.3	5.464
350	0.0258	2724.9	2957.3	6.038	0.0224	2699.6	2924.0	5.946	0.0161	2624.8	2826.6	5.713
400	0.0300	2849.2	3118.8	6.288	0.0264	2833.1	3097.4	6.214	0.0200	2789.6	3040.0	6.043
450	0.0335	2956.3	3258.0	6.487	0.0298	2944.5	3242.3	6.422	0.0230	2913.7	3201.4	6.275
500	0.0368	3056.3	3387.4	6.660	0.0328	3047.0	3375.1	6.600	0.0256	3023.2	3343.6	6.465
600	0.0429	3248.4	3634.1	6.961	0.0384	3242.0	3625.8	6.905	0.0303	3225.8	3604.6	6.783
700	0.0486	3438.8	3876.1	7.223	0.0436	3434.0	3870.0	7.169	0.0346	3422.0	3854.6	7.054
800	0.0541	3632.0	4119.1	7.461	0.0486	3628.2	4114.5	7.409	0.0387	3618.7	4102.8	7.297
900	0.0596	3829.6	4365.7	7.680	0.0536	3826.5	4362.0	7.629	0.0427	3818.9	4352.9	7.519
1000	0.0649	4032.4	4616.7	7.886	0.0584	4029.9	4613.8	7.835	0.0466	4023.5	4606.5	7.727

P=15.0 MPa (342.16°C)					P=17.5 MPa (354.7°C)				P=20.0 MPa (365.8°C)			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.0103	2455.6	2610.7	5.311	0.00793	2390.5	2529.3	5.143	0.00587	2295	2412.3	4.931
375	0.0139	2650.4	2858.9	5.705	0.01056	2567.5	2752.3	5.494	0.00768	2449.1	2602.6	5.228
400	0.0157	2740.6	2975.7	5.882	0.01246	2684.3	2902.4	5.721	0.00995	2617.9	2816.9	5.553
450	0.0185	2880.7	3157.9	6.143	0.01520	2845.4	3111.4	6.021	0.01272	2807.2	3061.7	5.904
500	0.0208	2998.4	3310.8	6.348	0.01739	2972.4	3276.7	6.242	0.01479	2945.3	3241.2	6.145
600	0.0249	3209.3	3583.1	6.680	0.02107	3192.5	3561.3	6.589	0.01819	3175.3	3539.0	6.508
700	0.0286	3409.8	3839.1	6.957	0.02434	3397.5	3823.5	6.873	0.02113	3385.1	3807.8	6.799
800	0.0321	3609.2	4091.1	7.204	0.02741	3599.7	4079.3	7.124	0.02387	3590.1	4067.5	7.053
900	0.0355	3811.2	4343.7	7.429	0.03035	3803.4	4334.5	7.351	0.02648	3795.7	4325.4	7.283
1000	0.0388	4017.1	4599.2	7.638	0.03322	4010.7	4592.0	7.562	0.02902	4004.3	4584.7	7.495

**Supercritical Vapor**

P=25.0 MPa					P=30.0 MPa				P=40.0 MPa			
Temp	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy	volume	energy	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	v(m <sup>3</sup> /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
375	0.00196	1799.9	1849.4	4.034	0.00179	1738.1	1791.8	3.931	0.00164	1677	1742.6	3.829
400	0.00601	2428.5	2578.6	5.140	0.00280	2068.9	2152.8	4.476	0.00191	1854.9	1931.4	4.115
450	0.00918	2721.2	2950.6	5.676	0.00674	2618.9	2821.0	5.442	0.00369	2364.2	2511.8	4.945
500	0.01114	2887.3	3165.9	5.964	0.00869	2824.0	3084.7	5.796	0.00562	2681.6	2906.5	5.474
600	0.01414	3140.0	3493.5	6.364	0.01145	3103.4	3446.7	6.237	0.00809	3026.8	3350.4	6.017
700	0.01664	3359.9	3776.0	6.670	0.01365	3334.3	3743.9	6.560	0.00993	3282.0	3679.1	6.374
800	0.01892	3570.7	4043.8	6.932	0.01563	3551.2	4020.0	6.830	0.01152	3511.8	3972.6	6.661
900	0.02108	3780.2	4307.1	7.167	0.01747	3764.6	4288.8	7.070	0.01298	3733.3	4252.5	6.911
1000	0.02315	3991.5	4570.2	7.382	0.01924	3978.6	4555.8	7.288	0.01436	3952.9	4527.3	7.136

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)



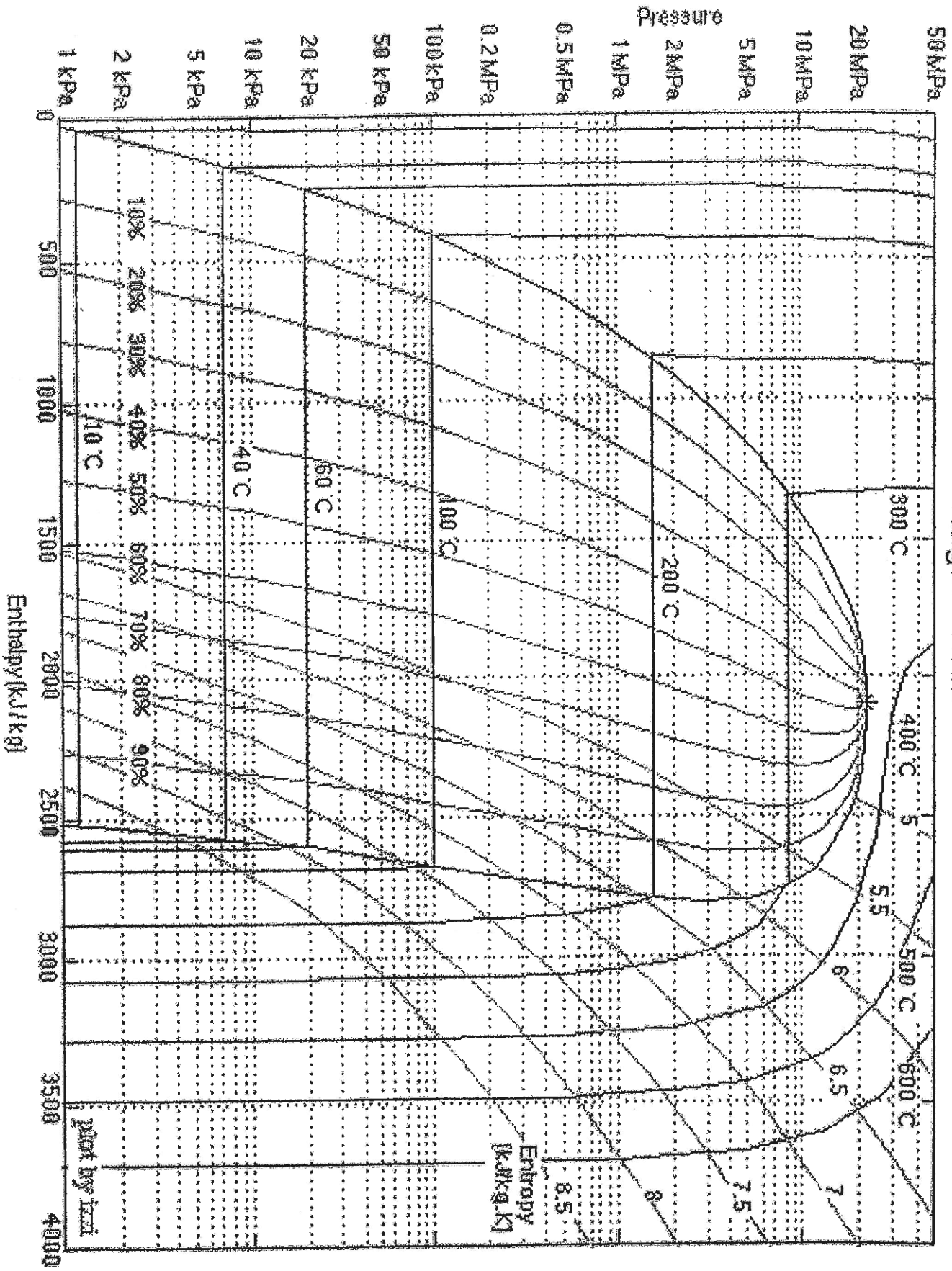
**Compressed Liquid Water Properties - (5 MPa - 30 MPa)**

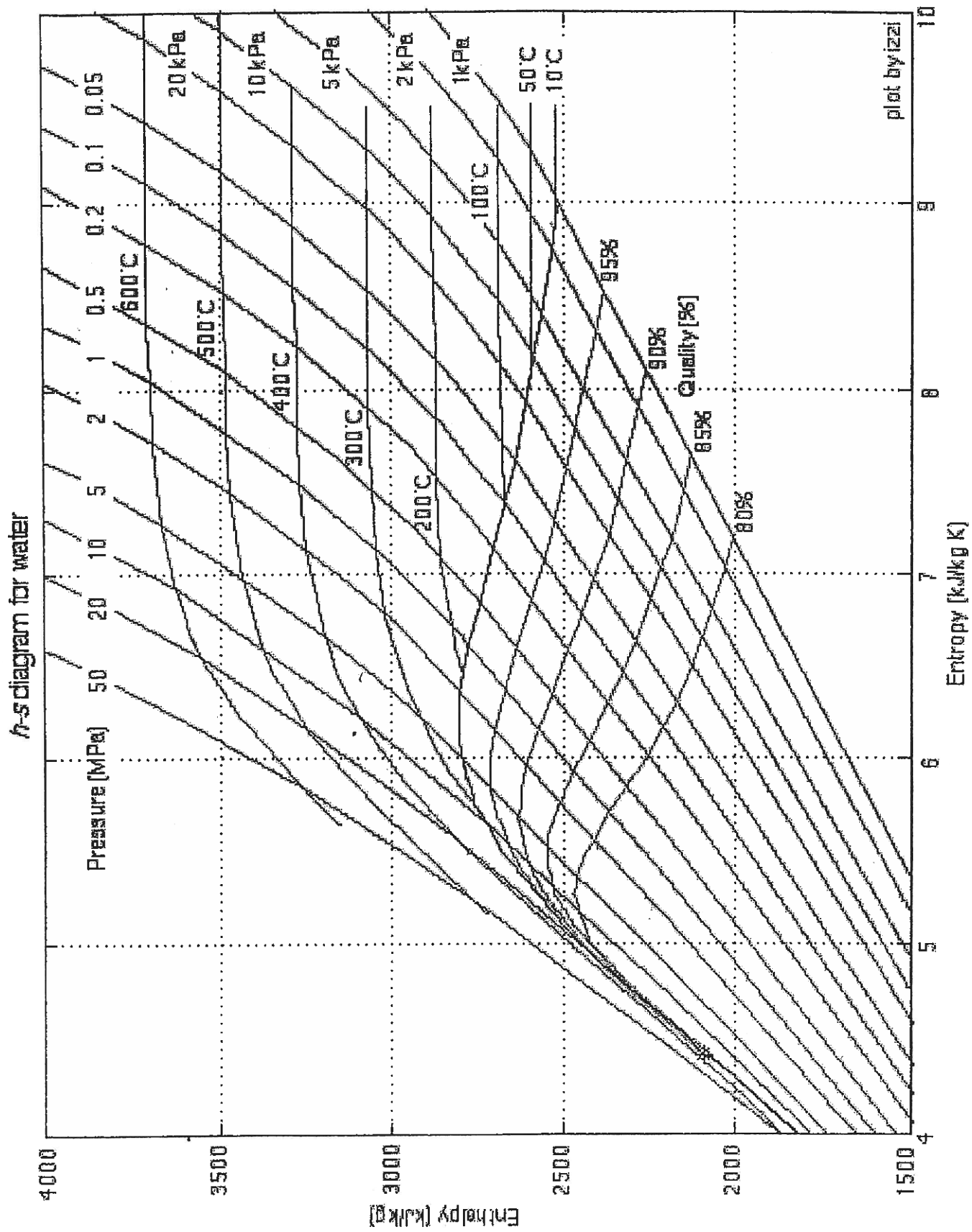
P = 5 MPa					P = 10 MPa				P = 15 MPa			
Temp	density	energy	enthalpy	entropy	density	energy	enthalpy	entropy	density	energy	enthalpy	entropy
°C	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
20	1000.4	83.6	88.6	0.2954	1002.7	83.3	93.3	0.2944	1004.9	83.0	97.9	0.2932
40	994.4	166.9	172.0	0.5705	996.5	166.3	176.4	0.5685	998.7	165.8	180.8	0.5666
60	985.3	250.3	255.4	0.8287	987.5	249.4	259.5	0.8260	989.6	248.6	263.7	0.8234
80	974.0	333.8	339.0	1.0723	976.2	332.7	342.9	1.0691	978.4	331.6	346.9	1.0659
100	960.6	417.6	422.9	1.3034	962.9	416.2	426.6	1.2996	965.2	414.9	430.4	1.2958
120	945.5	501.9	507.2	1.5236	947.9	500.2	510.7	1.5191	950.4	498.5	514.3	1.5148
140	928.6	586.8	592.2	1.7344	931.3	584.7	595.5	1.7293	933.9	582.7	598.8	1.7243
160	910.1	672.6	678.0	1.9374	913.0	670.1	681.0	1.9315	915.8	667.6	684.0	1.9259
180	889.7	759.5	765.1	2.1338	892.9	756.5	767.7	2.1271	896.0	753.6	770.3	2.1206
200	867.3	847.9	853.7	2.3251	870.9	844.3	855.8	2.3174	874.5	840.8	858.0	2.3100
220	842.6	938.4	944.3	2.5127	846.8	934.0	945.8	2.5037	851.0	929.8	947.4	2.4951
240	815.1	1031.6	1037.7	2.6983	820.2	1026.1	1038.3	2.6876	825.0	1021.0	1039.2	2.6774
260	784.0	1128.5	1134.9	2.8841	790.3	1121.6	1134.3	2.8710	796.2	1115.1	1134.0	2.8586

P = 20 MPa					P = 25 MPa				P = 30 MPa			
Temp	density	energy	enthalpy	entropy	density	energy	enthalpy	entropy	density	energy	enthalpy	entropy
°C	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)	kg/m <sup>3</sup>	u(kJ/kg)	h(kJ/kg)	s(kJ/kg.K)
20	1007.1	82.7	102.6	0.2921	1009.3	82.4	107.2	0.2909	1011.5	82.1	111.8	0.2897
40	1000.8	165.2	185.2	0.5646	1002.9	164.6	189.5	0.5627	1004.9	164.1	193.9	0.5607
60	991.7	247.8	267.9	0.8208	993.8	246.9	272.1	0.8182	995.8	246.1	276.3	0.8156
80	980.5	330.5	350.9	1.0627	982.6	329.4	354.9	1.0595	984.7	328.4	358.9	1.0564
100	967.4	413.5	434.2	1.2920	969.7	412.2	438.0	1.2883	971.8	410.9	441.7	1.2847
120	952.7	496.9	517.8	1.5105	955.1	495.2	521.4	1.5062	957.4	493.7	525.0	1.5020
140	936.4	580.7	602.1	1.7194	938.9	578.8	605.4	1.7146	941.4	576.9	608.8	1.7098
160	918.6	665.3	687.1	1.9203	921.3	663.0	690.1	1.9148	924.0	660.7	693.2	1.9094
180	899.1	750.8	773.0	2.1143	902.1	748.1	775.8	2.1081	905.1	745.4	778.5	2.1020
200	878.0	837.5	860.3	2.3027	881.3	834.2	862.6	2.2956	884.6	831.1	865.0	2.2888
220	854.9	925.8	949.2	2.4867	858.8	921.8	951.0	2.4786	862.5	918.1	952.9	2.4707
240	829.7	1016.1	1040.2	2.6676	834.1	1011.4	1041.3	2.6582	838.4	1006.9	1042.7	2.6491
260	801.8	1109.0	1134.0	2.8469	807.1	1103.2	1134.2	2.8357	812.1	1097.8	1134.7	2.8250
280	770.5	1205.5	1231.5	3.0265	777.0	1198.3	1230.5	3.0129	783.1	1191.5	1229.8	3.0001
300	734.7	1307.1	1334.4	3.2091	743.0	1297.6	1331.3	3.1919	750.7	1288.9	1328.9	3.1760
320	692.1	1416.6	1445.5	3.3996	703.5	1403.4	1438.9	3.3764	713.6	1391.6	1433.7	3.3557
340	637.2	1540.2	1571.6	3.6086	655.1	1519.4	1557.5	3.5731	669.7	1502.3	1547.1	3.5438
360	548.0	1703.6	1740.1	3.8787	589.3	1656.2	1698.6	3.7993	614.4	1626.7	1675.6	3.7498

- Saturation Properties - Temperature Table (0.01°C - 150°C)
- Saturation Properties - Temperature Table (150°C - 373.95°C)
- Saturation Properties - Pressure Table (1 kPa - 1 MPa)
- Saturation Properties - Pressure Table (1 MPa - 22.064 MPa)
- Superheated Vapor Properties - (0.01 MPa - 0.4 MPa)
- Superheated Vapor Properties - (0.5 MPa - 1.4 MPa)
- Superheated Vapor Properties - (1.6 MPa - 3.5 MPa)
- Superheated Vapor Properties - (4 MPa - 8 MPa)
- Superheated Vapor Properties - (9 MPa - 40 MPa)
- Compressed Liquid Water Properties - (5 MPa - 30 MPa)

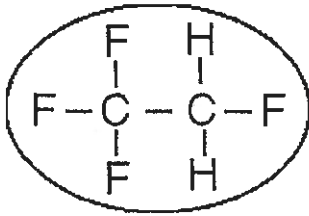
P-h diagram for water





plot by izzi

# Thermodynamic Properties of R134a TetraFlouroEthane - CF<sub>3</sub>CH<sub>2</sub>F



Critical Pressure: 4.059 MPa, Critical Temperature 101.06°C

## R134a Property Tables:

- Saturation Properties - Temperature Table (-40°C - 20°C)
- Saturation Properties - Temperature Table (20°C - 101.06°C)
- Saturation Properties - Pressure Table (60 kPa - 3 MPa)
- Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)
- Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)
- Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)
- Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)

## R134a Property Tables (Excel Version)

- Saturation Properties - Temperature Table
- Saturation Properties - Pressure Table
- Superheated Vapor Properties

Source of data: NIST Chemistry WebBook - accessed Jan 2008

## R134a Property Diagrams:

- Pressure-Enthalpy (P-h) Diagram
- Enthalpy-Entropy (h-s) Diagram

**Note:** R134a has a Global Warming Potential (GWP) of 1300 with respect to Carbon Dioxide. There is currently serious consideration of replacing it with R744 (Carbon Dioxide) in refrigeration and heat pump applications.



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**R134a - TetraFlouroEthane Saturation Properties - Temperature Table (-40°C - 20°C)**

Temp °C	Pressure kPa	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
-40	51.2	0.0007054	0.3611	0.00	225.86	225.86	0.0000	0.9687	0.9687
-36	62.9	0.0007112	0.2977	5.04	223.35	228.39	0.0214	0.9418	0.9632
-32	76.7	0.0007172	0.2473	10.10	220.81	230.92	0.0425	0.9157	0.9582
-28	92.7	0.0007234	0.2068	15.20	218.23	233.43	0.0634	0.8902	0.9536
-26	101.7	0.0007265	0.1896	17.76	216.92	234.68	0.0738	0.8777	0.9515
-24	111.3	0.0007297	0.1741	20.33	215.60	235.93	0.0841	0.8653	0.9495
-22	121.7	0.0007329	0.1601	22.91	214.26	237.17	0.0944	0.8531	0.9476
-20	132.7	0.0007362	0.1474	25.49	212.92	238.41	0.1046	0.8411	0.9457
-18	144.6	0.0007396	0.1359	28.09	211.55	239.64	0.1148	0.8292	0.9440
-16	157.3	0.0007430	0.1255	30.69	210.18	240.87	0.1250	0.8174	0.9423
-14	170.8	0.0007464	0.1161	33.30	208.79	242.09	0.1350	0.8057	0.9407
-12	185.2	0.0007499	0.1074	35.92	207.39	243.31	0.1451	0.7941	0.9392
-10	200.6	0.0007535	0.0996	38.55	205.97	244.52	0.1550	0.7827	0.9377
-8	216.9	0.0007571	0.0924	41.19	204.53	245.72	0.1650	0.7714	0.9364
-6	234.3	0.0007608	0.0859	43.84	203.08	246.92	0.1749	0.7602	0.9351
-4	252.7	0.0007646	0.0799	46.50	201.61	248.11	0.1848	0.7490	0.9338
-2	272.2	0.0007684	0.0744	49.17	200.12	249.29	0.1946	0.7380	0.9326
0	292.8	0.0007723	0.0693	51.86	198.60	250.46	0.2044	0.7271	0.9315
2	314.6	0.0007763	0.0647	54.55	197.07	251.62	0.2142	0.7162	0.9304
4	337.7	0.0007804	0.0604	57.25	195.53	252.78	0.2239	0.7055	0.9294
6	362.0	0.0007845	0.0564	59.97	193.95	253.92	0.2336	0.6948	0.9284
8	387.6	0.0007887	0.0528	62.69	192.36	255.05	0.2432	0.6842	0.9274
12	443.0	0.0007975	0.0463	68.19	189.11	257.29	0.2625	0.6632	0.9256
16	504.3	0.0008066	0.0408	73.73	185.74	259.47	0.2816	0.6424	0.9240
20	571.7	0.0008161	0.0360	79.32	182.28	261.6	0.3006	0.6218	0.9224

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: NIST Chemistry WebBook - accessed Jan 2008

**R134a - TetraFlouroEthane Saturation Properties - Temperature Table (20°C - 101.06°C)**

Temp °C	Pressure kPa	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
20	571.7	0.0008161	0.0360	79.32	182.26	261.60	0.3006	0.6218	0.9224
24	645.8	0.0008261	0.0319	84.98	178.70	263.68	0.3196	0.6014	0.9210
26	685.4	0.0008313	0.0300	87.83	176.87	264.7	0.3290	0.5912	0.9203
28	726.9	0.0008367	0.0283	90.70	175.00	265.69	0.3385	0.5811	0.9196
30	770.2	0.0008421	0.0266	93.58	173.09	266.67	0.3479	0.5710	0.9189
32	815.4	0.0008478	0.0251	96.48	171.16	267.64	0.3573	0.5609	0.9182
34	862.6	0.0008536	0.0237	99.40	169.18	268.58	0.3667	0.5508	0.9175
36	911.9	0.0008595	0.0224	102.33	167.17	269.50	0.3761	0.5407	0.9168
38	963.2	0.0008657	0.0211	105.29	165.12	270.41	0.3855	0.5307	0.9162
40	1016.6	0.0008720	0.0200	108.27	163.01	271.28	0.3949	0.5206	0.9155
42	1072.2	0.0008786	0.0189	111.26	160.88	272.14	0.4043	0.5105	0.9147
44	1130.1	0.0008854	0.0178	114.28	158.69	272.97	0.4136	0.5004	0.9140
48	1252.9	0.0008997	0.0160	120.39	154.16	274.55	0.4324	0.4800	0.9125
52	1385.4	0.0009150	0.0143	126.60	149.41	276.01	0.4513	0.4595	0.9108
56	1528.2	0.0009317	0.0128	132.92	144.40	277.32	0.4702	0.4387	0.9089
60	1681.8	0.0009498	0.0114	139.36	139.13	278.49	0.4892	0.4176	0.9068
70	2116.8	0.0010038	0.0087	156.14	124.37	280.51	0.5376	0.3624	0.9000
80	2633.2	0.0010773	0.0064	174.25	106.42	280.67	0.5880	0.3014	0.8894
90	3244.2	0.0011936	0.0046	194.78	82.49	277.27	0.6434	0.2272	0.8706
100	3972.4	0.0015357	0.0027	225.15	34.39	259.54	0.7232	0.0921	0.8153
101.06	4059.1	0.0019535	0.0020	241.49	0	241.49	0.7665	0	0.7665

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: NIST Chemistry WebBook - accessed Jan 2008

**R134a - TetraFlouroEthane Saturation Properties - Pressure Table (60 kPa - 3 MPa)**

Pressure kPa	Temp °C	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
60	-36.9	0.0007098	0.3112	3.9	223.9	227.8	0.0164	0.9481	0.9645
80	-31.1	0.0007185	0.2376	11.3	220.2	231.5	0.0472	0.9100	0.9572
100	-26.4	0.0007259	0.1926	17.3	217.2	234.5	0.0720	0.8799	0.9519
120	-22.3	0.0007324	0.1621	22.5	214.5	237.0	0.0928	0.8550	0.9478
140	-18.8	0.0007383	0.1402	27.1	212.1	239.2	0.1110	0.8337	0.9446
160	-15.6	0.0007437	0.1235	31.2	209.9	241.1	0.1270	0.8150	0.9420
180	-12.7	0.0007487	0.1104	35.0	207.9	242.9	0.1415	0.7982	0.9397
200	-10.1	0.0007534	0.0999	38.5	206.0	244.5	0.1547	0.7831	0.9378
220	-7.6	0.0007578	0.0912	41.7	204.3	245.9	0.1668	0.7693	0.9361
240	-5.4	0.0007620	0.0839	44.7	202.6	247.3	0.1780	0.7566	0.9347
260	-3.2	0.0007661	0.0777	47.5	201.0	248.6	0.1885	0.7448	0.9333
280	-1.2	0.0007699	0.0724	50.2	199.5	249.7	0.1984	0.7338	0.9322
300	0.7	0.0007737	0.0677	52.8	198.1	250.9	0.2077	0.7234	0.9311
320	2.5	0.0007773	0.0636	55.2	196.7	251.9	0.2165	0.7137	0.9301
340	4.2	0.0007808	0.0600	57.5	195.4	252.9	0.2248	0.7044	0.9293
360	5.8	0.0007842	0.0567	59.8	194.1	253.8	0.2328	0.6956	0.9284
400	8.9	0.0007907	0.0512	64.0	191.6	255.6	0.2477	0.6793	0.9270
500	15.7	0.0008060	0.0411	73.4	186.0	259.3	0.2803	0.6438	0.9241
600	21.6	0.0008200	0.0343	81.5	180.9	262.4	0.3081	0.6138	0.9219
700	26.7	0.0008332	0.0294	88.8	176.2	265.1	0.3324	0.5876	0.9200
800	31.3	0.0008459	0.0256	95.5	171.8	267.3	0.3541	0.5643	0.9184
900	35.5	0.0008581	0.0227	101.6	167.7	269.3	0.3739	0.5431	0.9170
1000	39.4	0.0008701	0.0203	107.4	163.7	271.0	0.3920	0.5237	0.9157
1200	46.3	0.0008935	0.0167	117.8	156.1	273.9	0.4245	0.4886	0.9131
1400	52.4	0.0009167	0.0141	127.3	148.9	276.2	0.4533	0.4573	0.9106
1600	57.9	0.0009401	0.0121	136.0	141.9	277.9	0.4792	0.4287	0.9080
1800	62.9	0.0009640	0.0106	144.1	135.1	279.2	0.5031	0.4020	0.9051
2000	67.5	0.0009888	0.0093	151.8	128.3	280.1	0.5252	0.3767	0.9020
2500	77.6	0.0010569	0.0069	169.7	111.2	280.9	0.5755	0.3170	0.8925
3000	86.2	0.0011413	0.0053	186.6	92.6	279.2	0.6215	0.2578	0.8792

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: NIST Chemistry WebBook - accessed Jan 2008

**Superheated Vapor Properties for R134a - (0.06 MPa - 0.24 MPa)**

P=0.06 MPa (-36.9°C)				P=0.10 MPa (-26.4°C)				P=0.14 MPa (-18.8°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.3112	227.8	0.964	Sat.	0.1926	234.5	0.952	Sat.	0.1402	239.18	0.94462
-20	0.3361	240.8	1.018	-20	0.1984	239.5	0.972	-10	0.1461	246.4	0.972
-10	0.3505	248.6	1.048	-10	0.2074	247.5	1.003	0	0.1526	254.6	1.003
0	0.3648	256.5	1.077	0	0.2163	255.6	1.033	10	0.1591	262.9	1.033
10	0.3789	264.7	1.107	10	0.2251	263.8	1.063	20	0.1654	271.4	1.062
20	0.3930	272.9	1.135	20	0.2337	272.2	1.092	30	0.1717	280.0	1.091
30	0.4071	281.4	1.164	30	0.2423	280.7	1.120	40	0.1780	288.7	1.120
40	0.4210	290.0	1.192	40	0.2509	289.3	1.149	50	0.1841	297.6	1.147
50	0.4350	298.7	1.219	50	0.2594	298.2	1.176	60	0.1903	306.6	1.175
60	0.4488	307.7	1.246	60	0.2678	307.1	1.204	70	0.1964	315.8	1.202
70	0.4627	316.8	1.273	70	0.2763	316.3	1.231	80	0.2024	325.1	1.229
80	0.4765	326.0	1.300	80	0.2847	325.6	1.257	90	0.2085	334.6	1.255
90	0.4903	335.4	1.326	90	0.2930	335.0	1.284	100	0.2145	344.2	1.282
100	0.5041	345.0	1.352	100	0.3014	344.6	1.310				

P=0.18 MPa (-12.7°C)				P=0.20 MPa (-10.1°C)				P=0.24 MPa (-5.4°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.1104	242.9	0.940	Sat.	0.0999	244.5	0.938	Sat.	0.0839	247.3	0.935
-10	0.1119	245.2	0.948	0	0.1048	253.1	0.970	0	0.0862	252.0	0.952
0	0.1172	253.6	0.980	10	0.1096	261.6	1.001	10	0.0903	260.7	0.983
10	0.1224	262.0	1.010	20	0.1142	270.2	1.030	20	0.0942	269.4	1.013
20	0.1275	270.6	1.040	30	0.1187	278.9	1.060	30	0.0981	278.2	1.043
30	0.1325	279.3	1.069	40	0.1232	287.7	1.088	40	0.1019	287.1	1.072
40	0.1374	288.1	1.098	50	0.1277	296.7	1.116	50	0.1057	296.1	1.100
50	0.1423	297.0	1.126	60	0.1321	305.8	1.144	60	0.1094	305.2	1.128
60	0.1472	306.1	1.153	70	0.1364	315.0	1.171	70	0.1131	314.5	1.156
70	0.1520	315.3	1.181	80	0.1407	324.4	1.198	80	0.1168	323.9	1.183
80	0.1567	324.6	1.207	90	0.1451	333.9	1.225	90	0.1204	333.5	1.209
90	0.1615	334.1	1.234	100	0.1493	343.6	1.251	100	0.1240	343.2	1.236
100	0.1662	343.8	1.260								

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: [NIST Chemistry WebBook](#) - accessed Jan 2008



**Superheated Vapor Properties for R134a - (0.28 MPa - 0.70 MPa)**

<b>P=0.28 MPa (-1.2°C)</b>				<b>P=0.32 MPa (2.5°C)</b>				<b>P=0.40 MPa (8.9°C)</b>			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.0724	249.7	0.932	Sat.	0.0636	251.9	0.930	Sat.	0.0512	255.6	0.927
10	0.0765	259.7	0.968	10	0.0661	258.7	0.954	10	0.0515	256.6	0.931
20	0.0800	268.5	0.999	20	0.0693	267.7	0.986	20	0.0542	265.9	0.963
30	0.0834	277.4	1.029	30	0.0723	276.7	1.016	30	0.0568	275.1	0.994
40	0.0867	286.4	1.058	40	0.0753	285.7	1.045	40	0.0593	284.3	1.024
50	0.0900	295.5	1.086	50	0.0782	294.9	1.074	50	0.0617	293.6	1.053
60	0.0932	304.7	1.114	60	0.0811	304.1	1.102	60	0.0641	301.0	1.081
70	0.0964	314.0	1.142	70	0.0839	313.5	1.130	70	0.0664	312.4	1.109
80	0.0996	323.5	1.169	80	0.0868	323.0	1.157	80	0.0687	322.0	1.137
90	0.1028	333.1	1.196	90	0.0895	332.6	1.184	90	0.0710	331.7	1.164
100	0.1059	342.8	1.222	100	0.0923	342.4	1.211	100	0.0735	341.6	1.191
110	0.1090	352.7	1.248	110	0.0950	352.3	1.237	110	0.0755	351.5	1.217
120	0.1121	362.7	1.274	120	0.0978	362.4	1.263	120	0.0777	361.6	1.243

<b>P=0.50 MPa (15.7°C)</b>				<b>P=0.60 MPa (21.6°C)</b>				<b>P=0.70 MPa (26.7°C)</b>			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.0411	259.3	0.924	Sat.	0.0343	262.43	0.922	Sat.	0.0294	265.05	0.920
20	0.0421	263.5	0.938	30	0.0360	270.8	0.950	30	0.0300	268.45	0.931
30	0.0443	273.0	0.970	40	0.0379	280.6	0.982	40	0.0317	278.58	0.964
40	0.0465	282.5	1.001	50	0.0397	290.3	1.012	50	0.0333	288.53	0.995
50	0.0485	292.0	1.031	60	0.0414	300.0	1.042	60	0.0349	298.43	1.026
60	0.0505	301.5	1.060	70	0.0431	309.7	1.071	70	0.0364	308.33	1.055
70	0.0524	311.1	1.088	80	0.0447	319.6	1.099	80	0.0379	318.28	1.084
80	0.0543	320.8	1.116	90	0.0463	329.5	1.126	90	0.0393	328.3	1.111
90	0.0562	330.6	1.144	100	0.0479	339.5	1.154	100	0.0406	338.4	1.139
100	0.0583	340.5	1.171	110	0.0495	349.6	1.180	110	0.0420	348.6	1.166
110	0.0600	350.6	1.197	120	0.0510	359.8	1.207	120	0.0434	358.91	1.192
120	0.0617	360.7	1.223	130	0.0525	370.2	1.233	130	0.0447	369.32	1.219
130	0.0635	371.0	1.249	140	0.0540	380.7	1.258	140	0.0460	379.86	1.244
140	0.0653	381.5	1.275								

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: [NIST Chemistry WebBook](#) - accessed Jan 2008

**Superheated Vapor Properties for R134a - (0.80 MPa - 1.60 MPa)**

P=0.80 MPa (31.3°C)				P=0.90 MPa (35.5°C)				P=1.00 MPa (39.4°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.0256	267.3	0.918	Sat.	0.0227	269.3	0.917	Sat.	0.0203	271.0	0.916
40	0.0270	276.5	0.948	40	0.0234	274.2	0.933	40	0.0204	271.7	0.918
50	0.0285	286.7	0.980	50	0.0248	284.8	0.966	50	0.0218	282.7	0.953
60	0.0300	296.8	1.011	60	0.0261	295.1	0.998	60	0.0231	293.4	0.985
70	0.0313	306.9	1.041	70	0.0274	305.4	1.028	70	0.0243	303.9	1.016
80	0.0327	317.0	1.070	80	0.0286	315.6	1.057	80	0.0254	314.3	1.046
90	0.0339	327.1	1.098	90	0.0298	325.9	1.086	90	0.0265	324.7	1.075
100	0.0352	337.3	1.126	100	0.0310	336.2	1.114	100	0.0276	335.1	1.103
110	0.0364	347.6	1.153	110	0.0321	346.6	1.141	110	0.0286	345.5	1.131
120	0.0376	358.0	1.180	120	0.0332	357.0	1.168	120	0.0296	356.1	1.158
130	0.0388	368.5	1.206	130	0.0342	367.6	1.195	130	0.0306	366.7	1.185
140	0.0400	379.1	1.232	140	0.0353	378.2	1.221	140	0.0316	377.4	1.211
150	0.0411	389.8	1.258	150	0.0363	389.0	1.247	150	0.0325	388.2	1.237
160	0.0423	400.6	1.283	160	0.0374	399.9	1.272	160	0.0335	399.2	1.262

P=1.20 MPa (46.3°C)				P=1.40 MPa (52.4°C)				P=1.60 MPa (57.9°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.0167	273.9	0.913	Sat.	0.0141	276.2	0.911	Sat.	0.0121	277.9	0.908
50	0.0172	278.3	0.927	60	0.0150	285.5	0.939	60	0.0124	280.7	0.916
60	0.0184	289.6	0.961	70	0.0161	297.1	0.973	70	0.0134	293.3	0.954
70	0.0195	300.6	0.994	80	0.0170	308.3	1.006	80	0.0144	305.1	0.987
80	0.0205	311.4	1.025	90	0.0179	319.4	1.036	90	0.0152	316.5	1.019
90	0.0215	322.1	1.056	100	0.0188	330.3	1.066	100	0.0160	327.8	1.050
100	0.0224	332.7	1.084	110	0.0196	341.2	1.095	110	0.0168	338.9	1.080
110	0.0233	343.4	1.112	120	0.0204	352.1	1.123	120	0.0175	350.0	1.108
120	0.0242	354.1	1.139	130	0.0212	363.0	1.150	130	0.0182	361.1	1.136
130	0.0251	364.9	1.166	140	0.0219	374.0	1.177	140	0.0189	372.3	1.163
140	0.0259	375.7	1.193	150	0.0226	385.1	1.204	150	0.0195	383.5	1.190
150	0.0268	386.7	1.219	160	0.0234	396.2	1.230	160	0.0202	394.7	1.216
160	0.0276	397.7	1.245	170	0.0241	407.4	1.255	170	0.0208	406.0	1.242
170	0.0284	408.8	1.270	180	0.0247	418.8	1.281	180	0.0215	417.4	1.268
180	0.0292	420.1	1.295								

- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

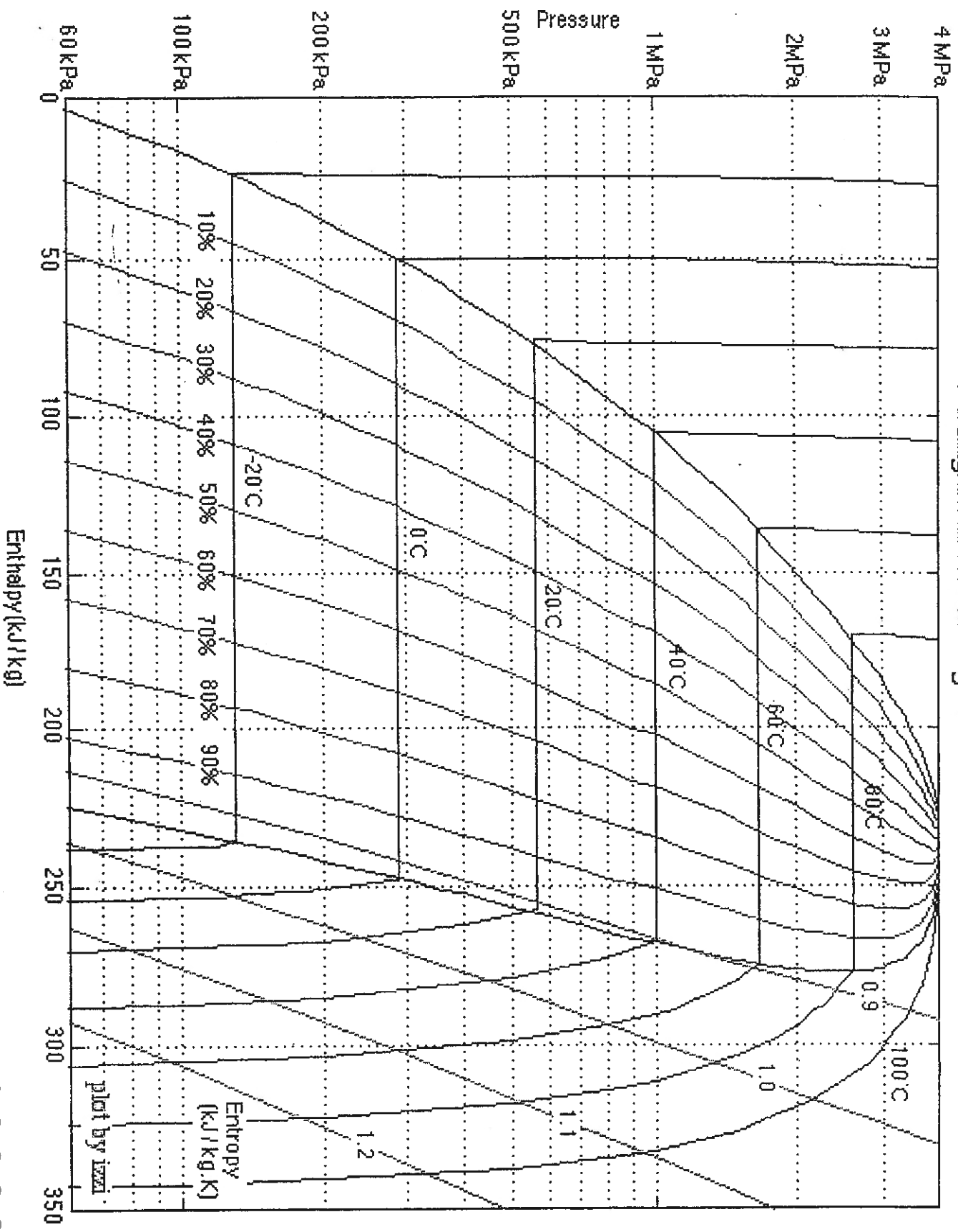
**Superheated Vapor Properties for R134a - (1.8 MPa - 2.0 MPa)**

<b>P=1.8 MPa (62.9°C)</b>				<b>P=2.0 MPa (67.5°C)</b>			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)	°C	v (m <sup>3</sup> /kg)	h(kJ/kg)	s (kJ/kg.K)
Sat.	0.0106	279.2	0.905	Sat.	0.0093	280.1	0.902
70	0.0113	288.9	0.934	70	0.0096	283.9	0.913
80	0.0123	301.5	0.970	80	0.0105	297.6	0.952
90	0.0131	313.5	1.003	90	0.0114	310.2	0.988
100	0.0139	325.1	1.035	100	0.0121	322.3	1.020
110	0.0146	336.5	1.065	110	0.0128	334.1	1.052
120	0.0152	347.9	1.094	120	0.0134	345.7	1.081
130	0.0159	359.2	1.123	130	0.0141	357.2	1.110
140	0.0165	370.5	1.150	140	0.0146	368.6	1.138
150	0.0171	381.6	1.177	150	0.0152	380.1	1.166
160	0.0177	393.2	1.204	160	0.0158	391.6	1.193
170	0.0183	404.6	1.230	170	0.0163	403.1	1.219
180	0.0189	416.1	1.256	180	0.0168	414.8	1.245

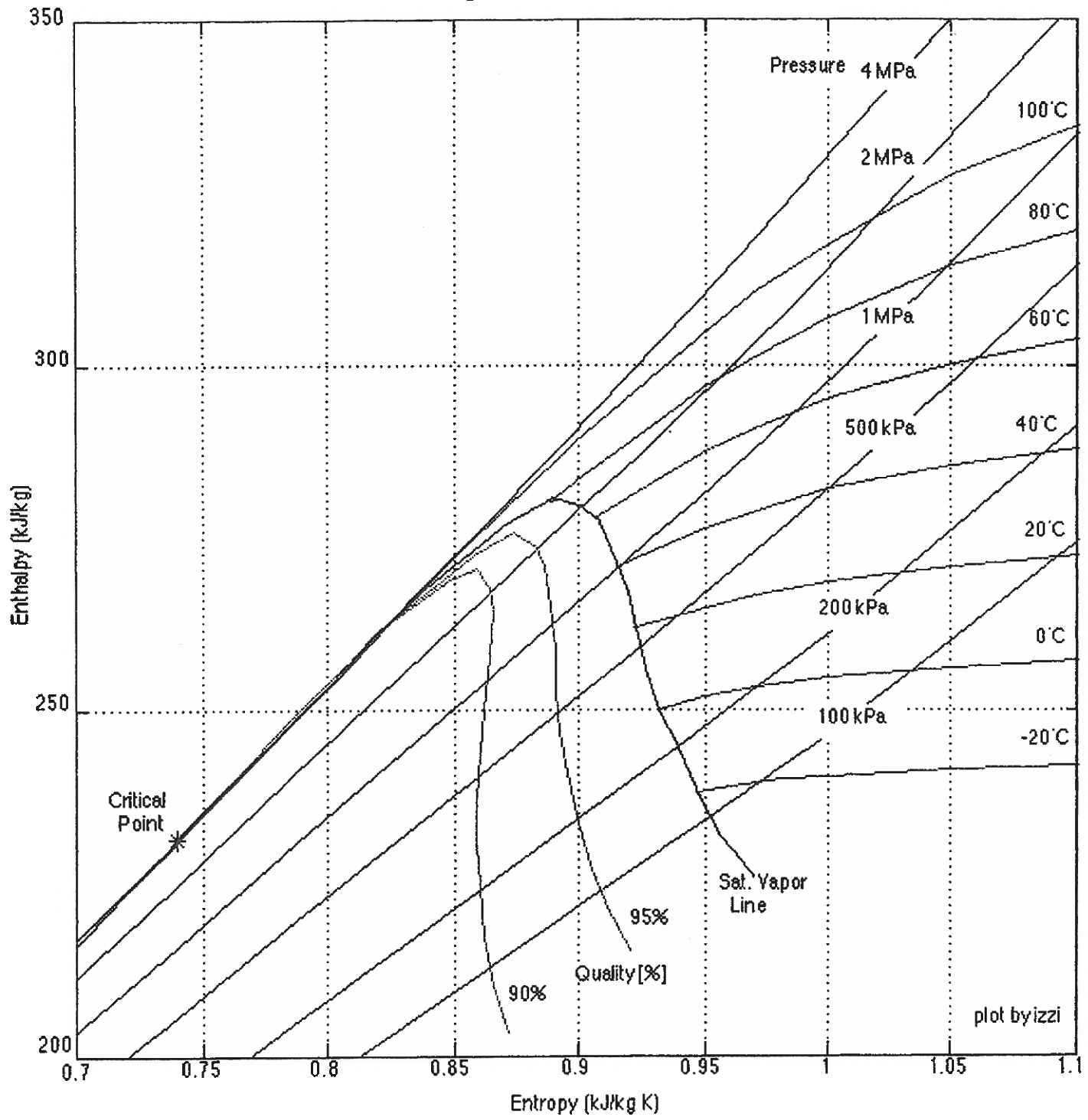
- **Saturation Properties - Temperature Table (-40°C - 20°C)**
- **Saturation Properties - Temperature Table (20°C - 101.06°C)**
- **Saturation Properties - Pressure Table (60 kPa - 3 MPa)**
- **Superheated Vapor Properties - (0.06 MPa - 0.24 MPa)**
- **Superheated Vapor Properties - (0.28 MPa - 0.7 MPa)**
- **Superheated Vapor Properties - (0.8 MPa - 1.6 MPa)**
- **Superheated Vapor Properties - (1.8 MPa - 2.0 MPa)**

Source of data: NIST Chemistry WebBook - accessed Oct 2010

P-h diagram for R134a refrigerant



*h-s* diagram for R134a refrigerant



## Thermodynamic Properties of R744 (Carbon Dioxide - CO<sub>2</sub>)

Critical Pressure: 7.377 MPa, Critical Temperature 30.978°C

Ideal Gas Constant of Carbon Dioxide:  $R = 0.1889 \text{ kJ/kg.K}$

### CO<sub>2</sub> Property Tables:

- Saturation Properties - Temperature Table (-20°C - 5°C)
- Saturation Properties - Temperature Table (5°C - 30.978°C)
- Saturation Properties - Pressure Table (2 MPa - 5 MPa)
- Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)
- Superheated Vapor Properties - (2.0 MPa - 7.0 MPa)
- Transcritical Vapor Properties - (8.0 MPa - 13.0 MPa)
- Transcritical Vapor Properties - (14.0 MPa - 20.0 MPa)

### CO<sub>2</sub> Property Tables (Excel Version)

- Saturation Properties - Temperature Table
- Saturation Properties - Pressure Table
- Superheated and Transcritical Vapor Properties

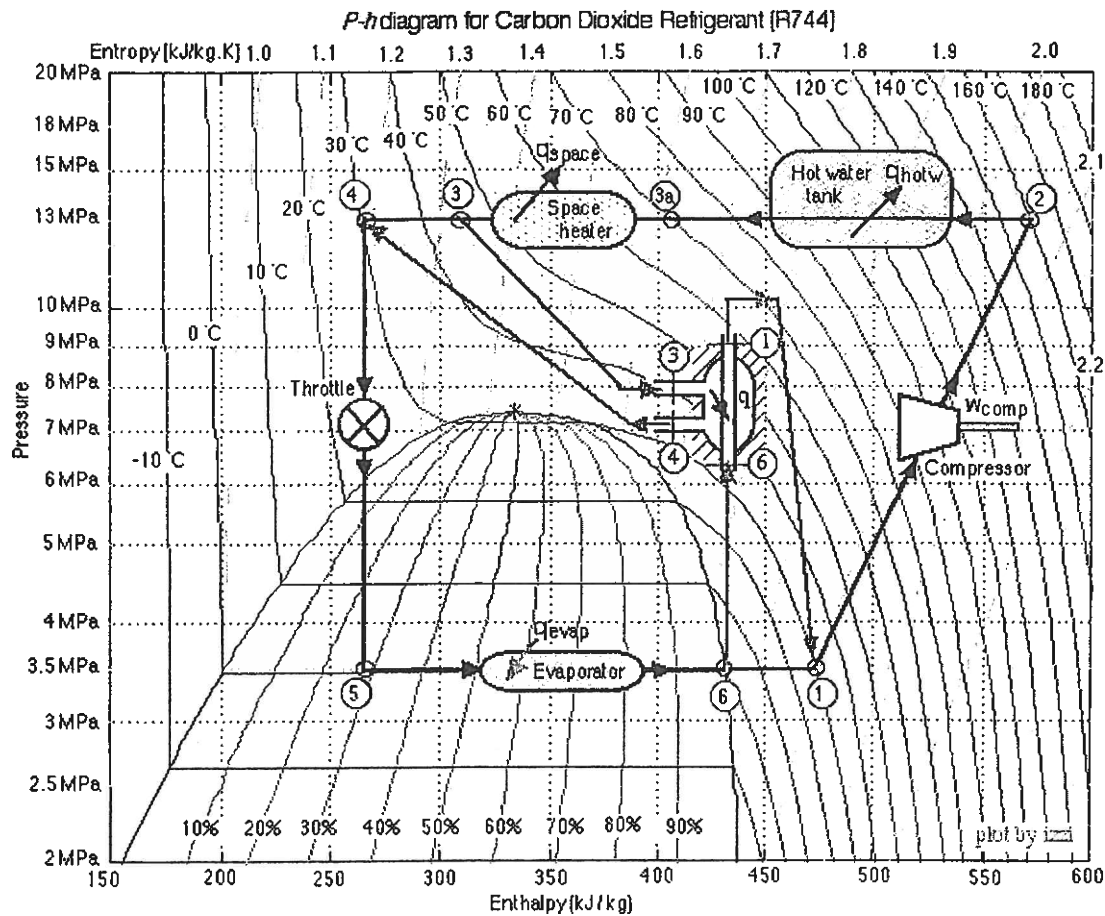
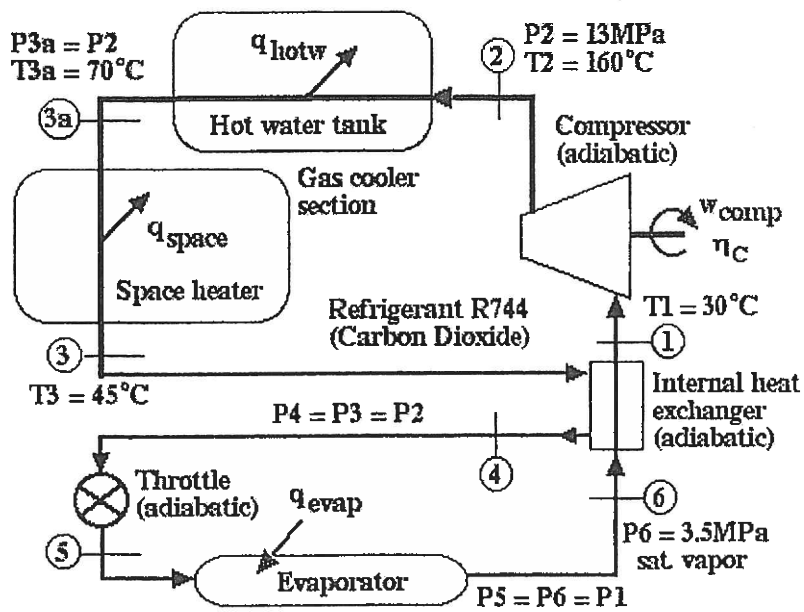
Source of data: NIST Chemistry WebBook - accessed March 2007

### CO<sub>2</sub> Property Diagrams:

- Pressure-Enthalpy ( $P-h$ ) Diagram
- Enthalpy-Entropy ( $h-s$ ) Diagram

**Note:** The current refrigerant R134a has a Global Warming Potential (GWP) of 1300 with respect to CO<sub>2</sub>. There is currently serious consideration of replacing it with R744 (Carbon Dioxide) in refrigeration and heat pump applications, as well as automotive air conditioning systems..

A typical home heat pump system is shown below, followed by the  $P-h$  plot. Notice how the transcritical cycle conveniently allows hot water heating together with space heating and air conditioning.



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**R744 - Carbon Dioxide Saturation Properties - Temperature Table (-20°C - 5°C)**

Temp °C	Pressure MPa	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
-20	1.9696	0.000969	0.019343	154.45	282.44	436.89	0.8328	1.1157	1.9485
-19	2.0310	0.000974	0.018726	156.61	280.20	436.81	0.8411	1.1025	1.9436
-18	2.0938	0.000978	0.018131	158.77	277.93	436.70	0.8494	1.0892	1.9386
-17	2.1581	0.000983	0.017557	160.95	275.63	436.58	0.8577	1.0761	1.9337
-16	2.2237	0.000987	0.017002	163.14	273.30	436.44	0.8659	1.0628	1.9287
-15	2.2908	0.000992	0.016467	165.34	270.93	436.27	0.8742	1.0495	1.9237
-14	2.3593	0.000997	0.015950	167.55	268.54	436.09	0.8825	1.0362	1.9187
-13	2.4294	0.001002	0.015450	169.78	266.11	435.89	0.8908	1.0229	1.9137
-12	2.5010	0.001007	0.014967	172.01	263.65	435.66	0.8991	1.0095	1.9086
-11	2.5740	0.001012	0.014500	174.26	261.15	435.41	0.9074	0.9962	1.9036
-10	2.6487	0.001017	0.014048	176.52	258.62	435.14	0.9157	0.9828	1.8985
-9	2.7249	0.001023	0.013611	178.80	256.04	434.84	0.9241	0.9694	1.8934
-8	2.8027	0.001028	0.013188	181.09	253.42	434.51	0.9324	0.9558	1.8882
-7	2.8821	0.001034	0.012778	183.39	250.78	434.17	0.9408	0.9422	1.8830
-6	2.9632	0.001040	0.012381	185.71	248.08	433.79	0.9492	0.9287	1.8778
-5	3.0459	0.001046	0.011996	188.05	245.33	433.38	0.9576	0.9149	1.8725
-4	3.1303	0.001052	0.011624	190.40	242.55	432.95	0.9660	0.9012	1.8672
-3	3.2164	0.001058	0.011262	192.77	239.71	432.48	0.9744	0.8874	1.8618
-2	3.3042	0.001065	0.010911	195.16	236.83	431.99	0.9829	0.8734	1.8563
-1	3.3938	0.001071	0.010571	197.57	233.89	431.46	0.9915	0.8595	1.8509
0	3.4851	0.001078	0.010241	200.00	230.89	430.89	1.0000	0.8453	1.8453
1	3.5783	0.001085	0.009920	202.45	227.84	430.29	1.0086	0.8311	1.8397
2	3.6733	0.001093	0.009609	204.93	224.72	429.65	1.0172	0.8168	1.8340
3	3.7701	0.001100	0.009306	207.43	221.54	428.97	1.0259	0.8023	1.8282
4	3.8688	0.001108	0.009011	209.95	218.3	428.25	1.0346	0.7877	1.8223
5	3.9695	0.001116	0.008724	212.50	214.98	427.48	1.0434	0.7729	1.8163

Source of data: NIST Chemistry WebBook accessed March 2007



**R744 - Carbon Dioxide Saturation Properties - Temperature Table (5°C - 30.978°C)**

Temp °C	Pressure MPa	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
5	3.9695	0.001116	0.008724	212.50	214.98	427.48	1.0434	0.7729	1.8163
6	4.0720	0.001124	0.008445	215.08	211.59	426.67	1.0523	0.7579	1.8102
7	4.1765	0.001133	0.008174	217.69	208.12	425.81	1.0612	0.7429	1.8041
8	4.2831	0.001142	0.007909	220.34	204.55	424.89	1.0702	0.7275	1.7977
9	4.3916	0.001152	0.007651	223.01	200.91	423.92	1.0792	0.7121	1.7913
10	4.5022	0.001161	0.007399	225.73	197.15	422.88	1.0884	0.6963	1.7847
11	4.6149	0.001172	0.007153	228.49	193.30	421.79	1.0976	0.6803	1.7779
12	4.7297	0.001182	0.006913	231.29	189.33	420.62	1.1070	0.6640	1.7710
13	4.8466	0.001193	0.006677	234.13	185.24	419.37	1.1165	0.6473	1.7638
14	4.9658	0.001205	0.006447	237.03	181.02	418.05	1.1261	0.6304	1.7565
15	5.0871	0.001218	0.006222	239.99	176.65	416.64	1.1359	0.6130	1.7489
16	5.2108	0.001231	0.006000	243.01	172.11	415.12	1.1458	0.5953	1.7411
17	5.3368	0.001245	0.005783	246.10	167.40	413.50	1.1559	0.5770	1.7329
18	5.4651	0.001260	0.005569	249.26	162.50	411.76	1.1663	0.5581	1.7244
19	5.5958	0.001276	0.005358	252.52	157.37	409.89	1.1769	0.5386	1.7155
20	5.7291	0.001293	0.005149	255.87	152.00	407.87	1.1877	0.5185	1.7062
21	5.8648	0.001312	0.004943	259.33	146.34	405.67	1.1989	0.4975	1.6964
22	6.0031	0.001332	0.004738	262.93	140.33	403.26	1.2105	0.4755	1.6860
23	6.1440	0.001354	0.004533	266.68	133.95	400.63	1.2225	0.4524	1.6749
24	6.2877	0.001379	0.004327	270.61	127.09	397.70	1.2352	0.4277	1.6629
25	6.4342	0.001408	0.004120	274.78	119.65	394.43	1.2485	0.4013	1.6498
26	6.5837	0.001440	0.003908	279.26	111.45	390.71	1.2627	0.3726	1.6353
27	6.7361	0.001479	0.003690	284.14	102.25	386.39	1.2783	0.3406	1.6189
28	6.8918	0.001526	0.003459	289.62	91.58	381.20	1.2958	0.3041	1.5999
29	7.0509	0.001589	0.003205	296.07	78.54	374.61	1.3163	0.2600	1.5763
30	7.2137	0.001686	0.002898	304.55	60.58	365.13	1.3435	0.1998	1.5433
30.978	7.3773	0.002139	0.002139	332.25	0.00	332.25	1.4336	0.0000	1.4336

- Saturation Properties - Temperature Table (-20°C - 5°C)
- Saturation Properties - Temperature Table (5°C - 30.978°C)
- Saturation Properties - Pressure Table (2 MPa - 5 MPa)
- Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)
- Superheated Vapor Properties - (2.0 MPa - 7.0 MPa)
- Transcritical Vapor Properties - (8.0 MPa - 13.0 MPa)
- Transcritical Vapor Properties - (14.0 MPa - 20.0 MPa)

Source of data: NIST Chemistry WebBook - accessed March 2007

### R744 - Carbon Dioxide Saturation Properties - Pressure Table (2 MPa - 5 MPa)

Pressure MPa	Temp °C	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
2.0	-19.50	0.000971	0.019033	155.52	281.33	436.85	0.8369	1.1092	1.9461
2.1	-17.90	0.000979	0.018074	158.99	277.70	436.69	0.8502	1.0880	1.9382
2.2	-16.36	0.000986	0.017199	162.36	274.13	436.49	0.8630	1.0675	1.9305
2.3	-14.86	0.000993	0.016396	165.64	270.61	436.25	0.8753	1.0477	1.9230
2.4	-13.42	0.001000	0.015656	168.85	267.12	435.97	0.8873	1.0285	1.9158
2.5	-12.01	0.001007	0.014973	171.98	263.68	435.66	0.8990	1.0097	1.9087
2.6	-10.65	0.001014	0.014340	175.05	260.27	435.32	0.9103	0.9915	1.9018
2.7	-9.32	0.001021	0.013751	178.06	256.88	434.94	0.9213	0.9737	1.8950
2.8	-8.03	0.001028	0.013202	181.01	253.52	434.53	0.9321	0.9563	1.8884
2.9	-6.78	0.001035	0.012688	183.90	250.18	434.08	0.9426	0.9392	1.8818
3.0	-5.55	0.001043	0.012207	186.75	246.86	433.61	0.9529	0.9225	1.8754
3.1	-4.36	0.001050	0.011755	189.56	243.55	433.11	0.9630	0.9061	1.8691
3.2	-3.19	0.001057	0.011329	192.32	240.25	432.57	0.9729	0.8900	1.8628
3.3	-2.05	0.001064	0.010928	195.05	236.96	432.01	0.9825	0.8741	1.8566
3.4	-0.93	0.001072	0.010548	197.74	233.68	431.42	0.9920	0.8585	1.8505
3.5	0.16	0.001079	0.010189	200.39	230.41	430.80	1.0014	0.8430	1.8444
3.6	1.23	0.001087	0.009848	203.02	227.13	430.15	1.0106	0.8278	1.8384
3.7	2.28	0.001095	0.009524	205.62	223.85	429.47	1.0196	0.8128	1.8324
3.8	3.30	0.001103	0.009215	208.19	220.57	428.76	1.0286	0.7978	1.8264
3.9	4.31	0.001111	0.008921	210.74	217.28	428.02	1.0374	0.7830	1.8204
4.0	5.30	0.001119	0.008640	213.27	213.98	427.25	1.0461	0.7684	1.8145
4.1	6.27	0.001127	0.008372	215.78	210.66	426.44	1.0547	0.7539	1.8086
4.2	7.22	0.001135	0.008114	218.28	207.33	425.61	1.0632	0.7395	1.8027
4.3	8.16	0.001144	0.007868	220.75	203.99	424.74	1.0716	0.7251	1.7967
4.4	9.08	0.001152	0.007631	223.22	200.62	423.84	1.0799	0.7109	1.7908
4.5	9.98	0.001161	0.007404	225.68	197.22	422.90	1.0882	0.6966	1.7848
4.6	10.87	0.001170	0.007185	228.12	193.81	421.93	1.0964	0.6824	1.7788
4.7	11.74	0.001179	0.006974	230.56	190.36	420.92	1.1046	0.6682	1.7728
4.8	12.60	0.001189	0.006770	233.00	186.88	419.88	1.1127	0.6540	1.7667
4.9	13.45	0.001199	0.006573	235.43	183.36	418.79	1.1208	0.6398	1.7606
5.0	14.28	0.001209	0.006383	237.87	179.79	417.66	1.1289	0.6255	1.7544

- Saturation Properties - Temperature Table (-20°C - 5°C)
- Saturation Properties - Temperature Table (5°C - 30.978°C)
- Saturation Properties - Pressure Table (2 MPa - 5 MPa)
- Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)
- Superheated Vapor Properties - (2.0 MPa - 7.0 MPa)
- Transcritical Vapor Properties - (8.0 MPa - 13.0 MPa)
- Transcritical Vapor Properties - (14.0 MPa - 20.0 MPa)

**R744 - Carbon Dioxide Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)**

Pressure MPa	Temp °C	volume (m <sup>3</sup> /kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	hf	hfg	hg	sf	sfg	sg
5.0	14.28	0.001209	0.006383	237.87	179.79	417.66	1.1289	0.6255	1.7544
5.1	15.12	0.001219	0.006198	240.30	176.18	416.48	1.1369	0.6112	1.7481
5.2	15.91	0.001230	0.006019	242.74	172.52	415.26	1.1449	0.5968	1.7417
5.3	16.71	0.001241	0.005846	245.19	168.80	413.99	1.1530	0.5823	1.7353
5.4	17.50	0.001252	0.005677	247.65	165.01	412.66	1.1610	0.5677	1.7287
5.5	18.27	0.001264	0.005512	250.13	161.15	411.28	1.1691	0.5530	1.7221
5.6	19.03	0.001276	0.005351	252.62	157.21	409.83	1.1772	0.5381	1.7153
5.7	19.78	0.001289	0.005194	255.13	153.19	408.32	1.1854	0.5229	1.7083
5.8	20.53	0.001303	0.005041	257.67	149.06	406.73	1.1936	0.5075	1.7011
5.9	21.26	0.001317	0.004890	260.24	144.83	405.07	1.2019	0.4919	1.6938
6.0	21.98	0.001332	0.004742	262.85	140.47	403.32	1.2102	0.4760	1.6862
6.1	22.69	0.001347	0.004596	265.49	135.98	401.47	1.2188	0.4596	1.6784
6.2	23.39	0.001364	0.004452	268.19	131.33	399.52	1.2274	0.4429	1.6703
6.3	24.08	0.001382	0.004310	270.96	126.48	397.44	1.2363	0.4255	1.6618
6.4	24.77	0.001401	0.004168	273.79	121.43	395.22	1.2453	0.4076	1.6529
6.5	25.44	0.001421	0.004027	276.72	116.12	392.84	1.2547	0.3889	1.6436
6.6	26.11	0.001444	0.003885	279.76	110.51	390.27	1.2644	0.3692	1.6336
6.7	26.77	0.001469	0.003742	282.95	104.52	387.47	1.2745	0.3485	1.6230
6.8	27.41	0.001497	0.003597	286.32	98.05	384.37	1.2852	0.3263	1.6115
6.9	28.05	0.001529	0.003446	289.93	90.97	380.90	1.2967	0.3021	1.5988
7.0	28.68	0.001567	0.003289	293.88	83.03	376.91	1.3093	0.2751	1.5844
7.1	29.30	0.001613	0.003120	298.35	73.81	372.16	1.3236	0.2440	1.5676
7.2	29.92	0.001675	0.002927	303.71	62.41	366.12	1.3407	0.2060	1.5467
7.3	30.52	0.001774	0.002680	311.12	46.06	357.18	1.3646	0.1517	1.5163
7.377	30.98	0.002139	0.002139	332.25	00.00	332.25	1.4336	0.0000	1.4336

- Saturation Properties - Temperature Table (-20°C - 5°C)
- Saturation Properties - Temperature Table (5°C - 30.978°C)
- Saturation Properties - Pressure Table (2 MPa - 5 MPa)
- Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)
- Superheated Vapor Properties - (2.0 MPa - 7.0 MPa)
- Transcritical Vapor Properties - (8.0 MPa - 13.0 MPa)
- Transcritical Vapor Properties - (14.0 MPa - 20.0 MPa)

Source of data: NIST Chemistry WebBook - accessed March 2007

**Carbon Dioxide Refrigerant (R744) - Superheated Vapor Properties (2 MPa -7 MPa)**

P = 2.0 MPa (-19.5°C)				P = 3.0 MPa (-5.55°C)				P = 4.0 MPa (5.3°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.019033	436.85	1.9461	Sat.	0.012207	433.61	1.8754	Sat.	0.008640	427.25	1.8145
-10	0.020507	448.58	1.9915	0	0.012931	442.22	1.9072	10	0.009224	436.55	1.8477
0	0.021926	460.00	2.0341	10	0.014082	455.98	1.9567	20	0.010257	452.99	1.9047
10	0.023257	470.84	2.0731	20	0.015116	468.46	2.0001	30	0.011141	467.15	1.9523
20	0.024526	481.32	2.1095	30	0.016074	480.20	2.0395	40	0.011939	480.10	1.9943
30	0.025748	491.57	2.1438	40	0.01698	491.46	2.0760	50	0.012681	492.31	2.0327
40	0.026934	501.65	2.1766	50	0.017847	502.39	2.1104	60	0.013382	504.02	2.0684
50	0.028091	511.63	2.2079	60	0.018683	513.09	2.1430	70	0.014053	515.39	2.1020
60	0.029224	521.54	2.2381	70	0.019495	523.64	2.1742	80	0.014699	526.51	2.1339
70	0.030337	531.41	2.2673	80	0.020287	534.07	2.2041	90	0.015326	537.45	2.1645
80	0.031434	541.26	2.2956	90	0.021063	544.42	2.2330	100	0.015937	548.26	2.1939
90	0.032516	551.11	2.3231	100	0.021824	554.73	2.2610	110	0.016534	558.97	2.2222
100	0.033586	560.97	2.3499	110	0.022574	565.00	2.2882	120	0.017120	569.62	2.2496
110	0.034646	570.85	2.3760	120	0.023313	575.26	2.3146	130	0.017695	580.22	2.2763
120	0.035696	580.76	2.4015	130	0.024043	585.51	2.3404	140	0.018263	590.80	2.3022
130	0.036738	590.69	2.4265	140	0.024766	595.77	2.3655	150	0.018823	601.35	2.3274
140	0.037773	600.66	2.4509	150	0.025481	606.05	2.3901	160	0.019376	611.90	2.3521
150	0.038802	610.68	2.4749	160	0.026191	616.35	2.4142	170	0.019924	622.46	2.3762
160	0.039825	620.73	2.4984	170	0.026895	626.67	2.4377				
170	0.040842	630.84	2.5214								

P = 5.0 MPa (14.3°C)				P = 6.0 MPa (22.0°C)				P=7.0 MPa (28.7°C)			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
Sat.	0.006383	417.66	1.7544	Sat.	0.004742	403.32	1.6862	Sat.	0.003289	376.91	1.5844
20	0.007110	432.38	1.8051	30	0.005833	430.71	1.7779	30	0.003752	392.71	1.6367
30	0.008063	451.44	1.8691	40	0.006700	451.72	1.8462	40	0.005050	432.12	1.7649
40	0.008846	467.13	1.9200	50	0.007396	468.57	1.8992	50	0.005814	453.99	1.8337
50	0.009538	481.15	1.9641	60	0.008006	483.44	1.9445	60	0.006430	471.53	1.8872
60	0.010173	494.19	2.0039	70	0.008561	497.16	1.9851	70	0.006969	486.98	1.9329
70	0.010768	506.59	2.0405	80	0.009079	510.11	2.0223	80	0.007459	501.18	1.9737
80	0.011334	518.54	2.0749	90	0.009569	522.55	2.0570	90	0.007916	514.57	2.0111
90	0.011876	530.16	2.1073	100	0.010037	534.60	2.0898	100	0.008347	527.38	2.0459
100	0.012399	541.55	2.1383	110	0.010488	546.36	2.1209	110	0.008759	539.77	2.0787
110	0.012907	552.76	2.1679	120	0.010924	557.92	2.1507	120	0.009155	551.85	2.1098
120	0.013403	563.84	2.1965	130	0.011349	569.31	2.1793	130	0.009537	563.70	2.1396
130	0.013887	574.82	2.2240	140	0.011764	580.59	2.2069	140	0.009909	575.36	2.1681
140	0.014363	585.73	2.2508	150	0.012170	591.77	2.2336	150	0.010272	586.88	2.1957
150	0.014830	596.59	2.2767	160	0.012569	602.88	2.2596	160	0.010627	598.30	2.2223
160	0.015290	607.41	2.3020	170	0.012961	613.94	2.2848	170	0.010976	609.63	2.2482
170	0.015745	618.22	2.3267								

**Carbon Dioxide Refrigerant (R744) - Transcritical Vapor Properties (8 MPa -13 MPa)**

P = 8.0 MPa				P = 9.0 MPa				P = 10.0 MPa			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
10	0.001107	220.04	1.0543	10	0.001096	218.97	1.0467	10	0.001086	218.06	1.0396
20	0.001208	246.91	1.1475	20	0.001186	244.58	1.1355	20	0.001168	242.70	1.1251
30	0.001425	284.04	1.2719	30	0.001344	276.32	1.2419	30	0.001296	271.62	1.2220
40	0.003599	402.90	1.6578	40	0.002060	343.78	1.4600	40	0.001591	313.04	1.3563
50	0.004562	436.37	1.7632	50	0.003509	413.81	1.6810	50	0.002602	384.07	1.5795
60	0.005219	458.13	1.8296	60	0.004248	442.78	1.7693	60	0.003449	425.02	1.7045
70	0.005760	475.93	1.8822	70	0.004807	463.86	1.8317	70	0.004036	450.65	1.7804
80	0.006237	491.69	1.9275	80	0.005280	481.59	1.8827	80	0.004513	470.85	1.8384
90	0.006672	506.21	1.9681	90	0.005703	497.46	1.9270	90	0.004928	488.31	1.8872
100	0.007078	519.90	2.0053	100	0.006092	512.15	1.9669	100	0.005303	504.14	1.9302
110	0.007462	532.99	2.0399	110	0.006455	526.02	2.0036	110	0.005651	518.88	1.9692
120	0.007828	545.65	2.0725	120	0.006798	539.32	2.0378	120	0.005977	532.86	2.0052
130	0.008180	557.98	2.1035	130	0.007127	552.17	2.0701	130	0.006287	546.28	2.0389
140	0.008521	570.06	2.1331	140	0.007443	564.70	2.1008	140	0.006584	559.28	2.0708
150	0.008852	581.95	2.1615	150	0.007749	576.97	2.1302	150	0.006870	571.95	2.1011
160	0.009174	593.68	2.1889	160	0.008046	589.03	2.1584	160	0.007147	584.37	2.1301
170	0.009489	605.29	2.2154	170	0.008336	600.94	2.1855	170	0.007416	596.58	2.1580
180	0.009799	616.82	2.2411	180	0.008619	612.73	2.2118	180	0.007679	608.64	2.1849

P = 11.0 MPa				P = 12.0 MPa				P=13.0 MPa			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
10	0.001078	217.26	1.0330	10	0.001069	216.57	1.0267	10	0.001062	215.97	1.0208
20	0.001152	241.14	1.1158	20	0.001139	239.82	1.1074	20	0.001127	238.68	1.0996
30	0.001263	268.21	1.2066	30	0.001236	265.57	1.1937	30	0.001215	263.41	1.1826
40	0.001463	302.38	1.3173	40	0.001393	296.06	1.2926	40	0.001346	291.61	1.2741
50	0.001990	354.37	1.4806	50	0.001710	336.41	1.4194	50	0.001572	326.00	1.3821
60	0.002795	404.93	1.6349	60	0.002302	384.62	1.5663	60	0.001979	367.69	1.5091
70	0.003405	436.31	1.7278	70	0.002892	421.19	1.6746	70	0.002489	406.21	1.6231
80	0.003886	459.49	1.7944	80	0.003370	447.64	1.7506	80	0.002948	435.59	1.7075
90	0.004296	478.80	1.8483	90	0.003774	468.98	1.8102	90	0.003342	459.00	1.7729
100	0.004661	495.90	1.8948	100	0.004131	487.47	1.8604	100	0.003689	478.93	1.8271
110	0.004996	511.59	1.9363	110	0.004455	504.18	1.9046	110	0.004003	496.70	1.8741
120	0.005308	526.31	1.9742	120	0.004755	519.68	1.9446	120	0.004292	513.01	1.9161
130	0.005603	540.32	2.0094	130	0.005037	534.32	1.9814	130	0.004562	528.30	1.9545
140	0.005884	553.82	2.0425	140	0.005304	548.33	2.0157	140	0.004818	542.84	1.9902
150	0.006154	566.91	2.0738	150	0.005560	561.86	2.0480	150	0.005062	556.81	2.0236
160	0.006414	579.69	2.1036	160	0.005807	575.00	2.0788	160	0.005296	570.33	2.0552
170	0.006667	592.21	2.1322	170	0.006045	587.86	2.1081	170	0.005522	583.51	2.0853
180	0.006912	604.55	2.1598	180	0.006276	600.47	2.1362	180	0.005741	596.42	2.1140
190	0.007152	616.72	2.1863	190	0.006502	612.90	2.1634	190	0.005954	609.09	2.1417



**Carbon Dioxide Refrigerant (R744) - Transcritical Vapor Properties (14 MPa -20 MPa)**

P = 14.0 MPa				P = 15.0 MPa				P = 16.0 MPa			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
10	0.001055	215.45	1.0152	10	0.001048	214.98	1.0099	10	0.001042	214.58	1.0048
20	0.001116	237.70	1.0925	20	0.001106	236.84	1.0857	20	0.001097	236.09	1.0794
30	0.001197	261.62	1.1727	30	0.001181	260.10	1.1637	30	0.001167	258.79	1.1556
40	0.001310	288.21	1.2590	40	0.001282	285.48	1.2461	40	0.001258	283.22	1.2348
50	0.001488	319.07	1.3559	50	0.001429	314.00	1.3357	50	0.001385	310.07	1.3192
60	0.001781	355.38	1.4665	60	0.001655	346.54	1.4348	60	0.001569	339.95	1.4103
70	0.002190	392.61	1.5767	70	0.001977	381.20	1.5374	70	0.001826	372.04	1.5052
80	0.002608	423.79	1.6663	80	0.002341	412.79	1.6281	80	0.002135	402.98	1.5940
90	0.002984	449.04	1.7368	90	0.002690	439.36	1.7024	90	0.002451	430.23	1.6702
100	0.003319	470.38	1.7948	100	0.003009	461.95	1.7638	100	0.002750	453.79	1.7342
110	0.003622	489.21	1.8446	110	0.003299	481.79	1.8162	110	0.003026	474.53	1.7890
120	0.003900	506.35	1.8888	120	0.003567	499.73	1.8625	120	0.003282	493.22	1.8372
130	0.004160	522.29	1.9288	130	0.003816	516.33	1.9042	130	0.003521	510.44	1.8805
140	0.004405	537.37	1.9658	140	0.004052	531.94	1.9424	140	0.003747	526.57	1.9200
150	0.004638	551.78	2.0003	150	0.004275	546.80	1.9780	150	0.003961	541.87	1.9566
160	0.004861	565.69	2.0327	160	0.004488	561.09	2.0113	160	0.004166	556.54	1.9908
170	0.005077	579.20	2.0636	170	0.004694	574.92	2.0429	170	0.004362	570.70	2.0232
180	0.005285	592.39	2.0930	180	0.004893	588.40	2.0730	180	0.004552	584.46	2.0539
190	0.005487	605.32	2.1212	190	0.005085	601.59	2.1018	190	0.004736	597.90	2.0832
200	0.005684	618.05	2.1484	200	0.005273	614.54	2.1294	200	0.004915	611.08	2.1114

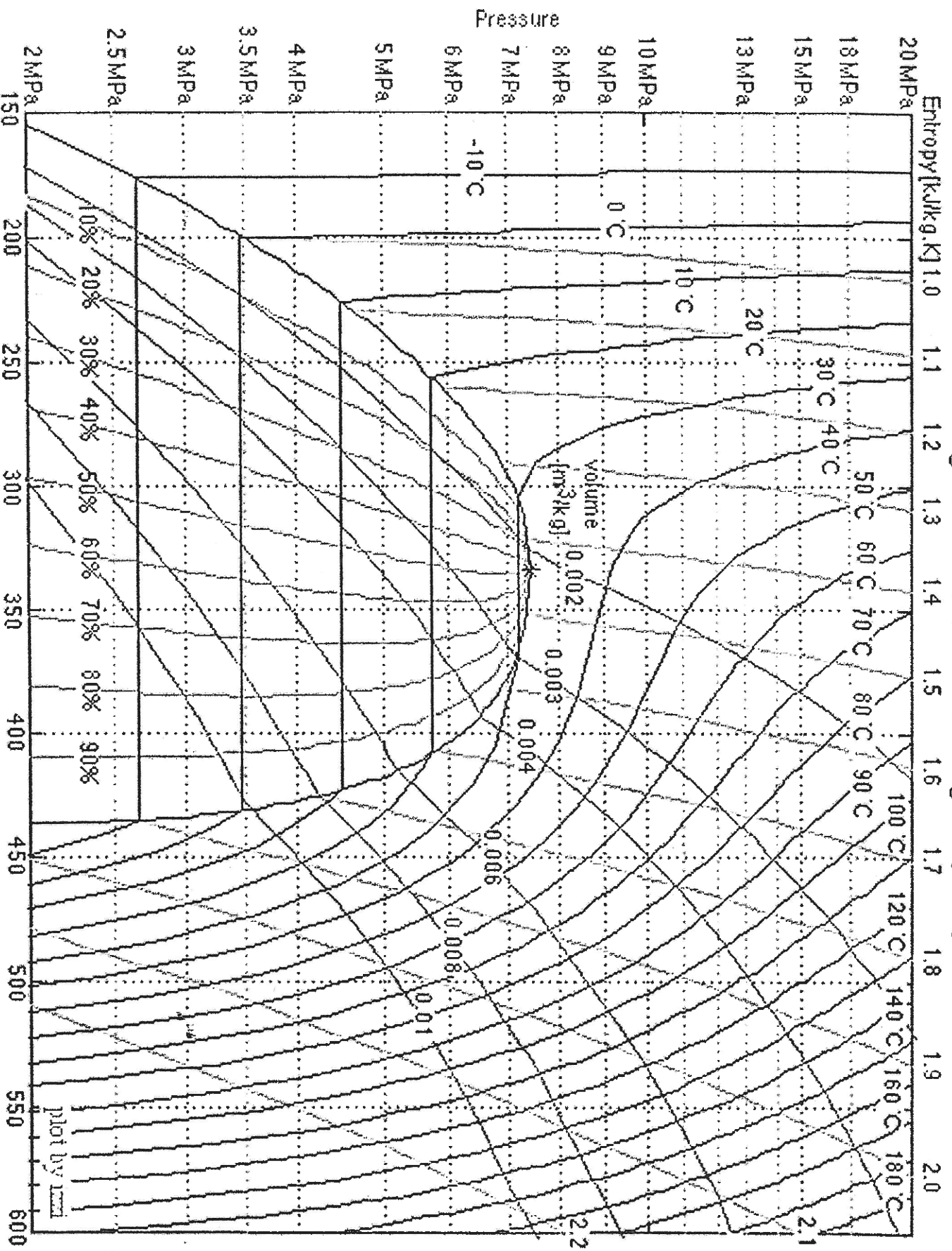
P = 17.0 MPa				P = 18.0 MPa				P = 19.0 MPa			
Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy	Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)	°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
10	0.001036	214.23	0.9999	10	0.001031	213.93	0.9952	10	0.001025	213.66	0.9906
20	0.001089	235.43	1.0734	20	0.001081	234.84	1.0677	20	0.001074	234.33	1.0623
30	0.001154	257.65	1.1480	30	0.001143	256.65	1.1409	30	0.001133	255.78	1.1342
40	0.001238	281.32	1.2248	40	0.001220	279.68	1.2156	40	0.001205	278.26	1.2072
50	0.001350	306.90	1.3052	50	0.001321	304.27	1.2929	50	0.001296	302.04	1.2820
60	0.001505	334.84	1.3903	60	0.001455	330.74	1.3735	60	0.001415	327.35	1.3591
70	0.001716	364.75	1.4788	70	0.001633	358.88	1.4568	70	0.001569	354.08	1.4381
80	0.001977	394.53	1.5643	80	0.001855	387.37	1.5386	80	0.001760	381.34	1.5164
90	0.002258	421.85	1.6406	90	0.002102	414.34	1.6139	90	0.001977	407.71	1.5901
100	0.002534	446.04	1.7063	100	0.002354	438.82	1.6805	100	0.002205	432.20	1.6566
110	0.002794	467.51	1.7631	110	0.002598	460.82	1.7386	110	0.002431	454.53	1.7157
120	0.003038	486.88	1.8130	120	0.002828	480.75	1.7900	120	0.002648	474.9	1.7682
130	0.003267	504.68	1.8578	130	0.003047	499.08	1.8360	130	0.002855	493.67	1.8153
140	0.003483	521.31	1.8985	140	0.003253	516.16	1.8779	140	0.003053	511.17	1.8582
150	0.003688	537.03	1.9361	150	0.003450	532.29	1.9165	150	0.003241	527.67	1.8977
160	0.003885	552.06	1.9712	160	0.003638	547.67	1.9524	160	0.003422	543.38	1.9344
170	0.004073	566.54	2.0043	170	0.003819	562.46	1.9862	170	0.003595	558.46	1.9688
180	0.004255	580.58	2.0356	180	0.003993	576.77	2.0181	180	0.003762	573.03	2.0013
190	0.004431	594.27	2.0655	190	0.004162	590.70	2.0485	190	0.003924	587.19	2.0322
200	0.004602	607.66	2.0941	200	0.004326	604.31	2.0776	200	0.004082	601.01	2.0617

<b>P = 20.0 MPa</b>			
Temp	volume	enthalpy	entropy
°C	v(m <sup>3</sup> /kg)	h(kJ/kg)	s(kJ/kg.K)
10	0.001020	213.44	0.9862
20	0.001067	233.87	1.0571
30	0.001123	255.00	1.1280
40	0.001191	277.02	1.1994
50	0.001275	300.13	1.2721
60	0.001382	324.50	1.3463
70	0.001517	350.07	1.4219
80	0.001684	376.23	1.4971
90	0.001876	401.91	1.5688
100	0.002081	426.19	1.6348
110	0.002289	448.67	1.6942
120	0.002493	469.36	1.7475
130	0.002689	488.49	1.7956
140	0.002877	506.35	1.8394
150	0.003057	523.19	1.8796
160	0.003230	539.21	1.9171
170	0.003396	554.57	1.9521
180	0.003557	569.39	1.9852
190	0.003713	583.77	2.0166
200	0.003864	597.79	2.0465

- Saturation Properties - Temperature Table (-20°C - 5°C)
- Saturation Properties - Temperature Table (5°C - 30.978°C)
- Saturation Properties - Pressure Table (2 MPa - 5 MPa)
- Saturation Properties - Pressure Table (5 MPa - 7.377 MPa)
- Superheated Vapor Properties - (2.0 MPa - 7.0 MPa)
- Transcritical Vapor Properties - (8.0 MPa - 13.0 MPa)
- Transcritical Vapor Properties - (14.0 MPa - 20.0 MPa)

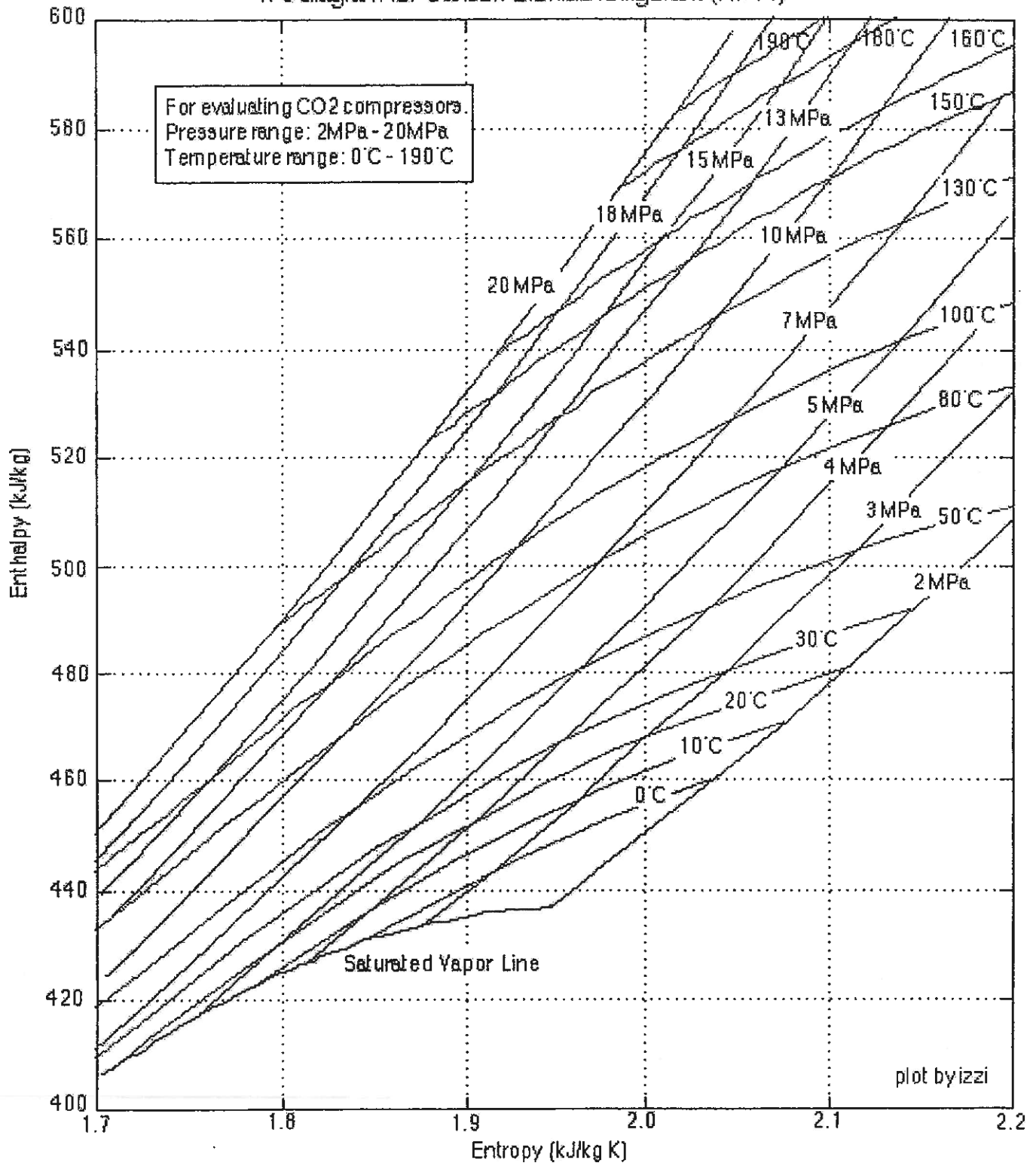
Source of data: NIST Chemistry WebBook - accessed March 2007

*P-h* diagram for Carbon Dioxide Refrigerant (R744)





*h-s* diagram for Carbon Dioxide refrigerant (R744)



## Specific Heat Capacities of an Ideal Gas



Consider a stationary closed system in which the only work interaction is boundary work, thus all other work interactions are excluded.

The differential form of the energy equation is thus:

$$\delta q - \delta w = du \Rightarrow \delta q = du + P dv \quad (1)$$

For a simple system, internal energy ( $u$ ) is a function of two independent variables, thus we assume it to be a function of temperature  $T$  and specific volume  $v$ , hence:

$$u = u(T, v) \Rightarrow du = \left[ \frac{\partial u}{\partial T} \right]_v dT + \left[ \frac{\partial u}{\partial v} \right]_T dv \quad (2)$$

Substituting equation (2) in the energy equation (1) and simplifying, we obtain:

$$\delta q = \left[ \frac{\partial u}{\partial T} \right]_v dT + \left( \left[ \frac{\partial u}{\partial v} \right]_T + P \right) dv \quad (3)$$

Now for a constant volume process ( $dv = 0$ ):

$$\delta q = \left[ \frac{\partial u}{\partial T} \right]_v dT = C_v dT \Leftrightarrow C_v = \left[ \frac{\partial u}{\partial T} \right]_v \quad (4)$$

where  $C_v$  is the specific constant volume heat capacity

That is, the specific constant volume heat capacity of a system is a function only of its internal energy and temperature. Now in his classic experiment of 1843 Joule showed that the internal energy of an ideal gas is a function of temperature only, and not of pressure or specific volume. Thus for an ideal gas the partial derivatives can be replaced by ordinary derivatives, and the change in internal energy can be expressed as:

$$\boxed{du = C_v dT \Leftrightarrow \Delta u = C_v \Delta T} \longrightarrow$$

Consider now the enthalpy. By definition  $h = u + P v$ , thus differentiating we obtain:

$$dh = d(u + P v) = du + P dv + v dP$$

$$\text{Thus from (1)} \Rightarrow \delta q = du + P dv = dh - v dP \quad (5)$$

Again for a simple system, enthalpy ( $h$ ) is a function of two independent variables, thus we assume it to be a function of temperature  $T$  and pressure  $P$ , hence:

$$h = h(T, P) \Rightarrow dh = \left[ \frac{\partial h}{\partial T} \right]_P dT + \left[ \frac{\partial h}{\partial P} \right]_T dP \quad (6)$$

Substituting equation (6) in the energy equation (5), and simplifying:

$$\delta q = \left[ \frac{\partial h}{\partial T} \right]_P dT + \left( \left[ \frac{\partial h}{\partial P} \right]_T - v \right) dP \quad (7)$$

Hence for a constant pressure process, since  $dP = 0$ :

$$\delta q = \left[ \frac{\partial h}{\partial T} \right]_P dT = C_P dT \Leftrightarrow C_P = \left[ \frac{\partial h}{\partial T} \right]_P \quad (8)$$

where  $C_P$  is the specific constant pressure heat capacity

That is, the specific constant pressure heat capacity of a system is a function only of its enthalpy and temperature. Now by definition

$$h = u + P v = u + R T \quad (\text{since } P v = R T \text{ for ideal gas})$$

Now since for an ideal gas Joule showed that internal energy is a function of temperature only, it follows from the above equation that enthalpy is a function of temperature only. Thus for an ideal gas the partial derivatives can be replaced by ordinary derivatives, and the differential changes in enthalpy can be expressed as

$$\boxed{dh = C_P dT \Leftrightarrow \Delta h = C_P \Delta T} \longrightarrow$$

Finally, from the definition of enthalpy for an ideal gas we have:

$$\begin{aligned} dh &= du + d(Pv) = du + R dT \\ C_P dT &= C_V dT + R dT \Rightarrow \boxed{C_P = C_V + R} \longrightarrow \\ \text{Define: } k &= \left( \frac{C_P}{C_V} \right) \quad (\text{ratio of specific heat capacities}) \longrightarrow \end{aligned}$$

Values of  $R$ ,  $C_P$ ,  $C_V$  and  $k$  for ideal gases are presented (at 300K) in the table on **Properties of Various Ideal Gases**. Note that the values of  $C_P$ ,  $C_V$  and  $k$  are constant with temperature only for mon-atomic gases such as helium and argon. For all other gases their temperature dependence can be considerable and needs to be considered. We find it convenient to express this dependence in tabular form and have provided a table of **Specific Heat Capacities of Air**.

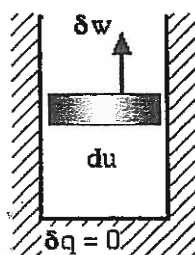


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## The Adiabatic Process of an Ideal Gas

It is unusual to develop the equations of the Adiabatic Process directly from the energy equations, since they are usually introduced after the discussion of entropy as the Isentropic Process. This approach was introduced to us by Potter and Somerton in their Schaum's Outline of Thermodynamics for Engineers, and enables early meaningful analysis of the adiabatic processes in Diesel and Otto cycle engines.

Consider a stationary closed adiabatic system in which the only energy interaction is boundary work, that is, all other work and heat interactions are excluded. The differential form of the energy is thus:



$$\begin{aligned} \text{Energy} &\Rightarrow \delta q - \delta w = du \\ \text{Adiabatic} &\Rightarrow \delta q = 0 = du + \delta w \\ &0 = du + P dv \\ \text{Ideal gas} &\Rightarrow P \cdot v = R \cdot T, \quad du = C_v \cdot dT \\ C_v dT + \left(\frac{R \cdot T}{v}\right) dv &= 0 \Rightarrow \frac{dT}{T} = -\left(\frac{R}{C_v}\right) \frac{dv}{v} \end{aligned}$$

$$\text{Integrating} \Rightarrow \ln\left(\frac{T_2}{T_1}\right) = \left(\frac{R}{C_v}\right) \ln\left(\frac{v_1}{v_2}\right) \Rightarrow \left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{R/C_v}$$

From the web page on Specific Heat Capacity of an Ideal Gas we have:

$$C_p - C_v = R, \quad k = \frac{C_p}{C_v} \Rightarrow \left(\frac{R}{C_v}\right) = \left(\frac{C_p - C_v}{C_v}\right) = k - 1$$

$$\text{thus: } \left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{k-1} \Rightarrow \boxed{T \cdot v^{k-1} = \text{const}} \Leftrightarrow \boxed{T_2 = T_1 \cdot \left(\frac{v_1}{v_2}\right)^{k-1}}$$

$$P \cdot v = R \cdot T \Rightarrow T = \frac{P \cdot v}{R} \Rightarrow \left(\frac{P \cdot v}{R}\right) \cdot v^{k-1} = \text{const} \Rightarrow P \cdot v^k = \text{const}$$

$$\boxed{P \cdot v^k = \text{const}} \Leftrightarrow \boxed{P_2 = P_1 \cdot \left(\frac{v_1}{v_2}\right)^k}$$

$$P \cdot v = R \cdot T \Rightarrow v = \frac{R \cdot T}{P} \Rightarrow P \left(\frac{R \cdot T}{P}\right)^k = \text{const} \Rightarrow P^{1-k} \cdot T^k = \text{const}$$

$$\Rightarrow \boxed{T \cdot P^{(1-k)/k} = \text{const}} \Leftrightarrow \boxed{T_2 = T_1 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}}$$

**Digression:** The adiabatic process is fundamental to the analysis of water rockets. Refer: Water Rockets - the transportation system of the future (tounge-in-cheek)

### Properties of Various Ideal Gases (at 300 K)

Gas	Formula	Molar Mass	Gas constant	Specific Heat at Const. Press.	Specific Heat at Const. Vol.	Specific Heat Ratio
		M[kg/kmol]	R[kJ/kg.K]	Cp[kJ/kg.K]	Cv[kJ/kg.K]	k = Cp/Cv
Air	--	28.97	0.287	1.005	0.718	1.4
Argon	Ar	39.948	0.2081	0.5203	0.3122	1.667
Butane	C4H10	58.124	0.1433	1.7164	1.5734	1.091
Carbon Dioxide	CO2	44.01	0.1889	0.846	0.657	1.289
Carbon Monoxide	CO	28.011	0.2968	1.04	0.744	1.4
Ethane	C2H6	30.07	0.2765	1.7662	1.4897	1.186
Ethylene	C2H4	28.054	0.2964	1.5482	1.2518	1.237
Helium	He	4.003	2.0769	5.1926	3.1156	1.667
Hydrogen	H2	2.016	4.124	14.307	10.183	1.405
Methane	CH4	16.043	0.5182	2.2537	1.7354	1.299
Neon	Ne	20.183	0.4119	1.0299	0.6179	1.667
Nitrogen	N2	28.013	0.2968	1.039	0.743	1.4
Octane	C8H18	114.231	0.0729	1.7113	1.6385	1.044
Oxygen	O2	31.999	0.2598	0.918	0.658	1.395
Propane	C3H8	44.097	0.1885	1.6794	1.4909	1.126
Steam	H2O	18.015	0.4615	1.8723	1.4108	1.327

Adapted from TEST (The Expert System for Thermodynamics) <[www.thermofluids.net](http://www.thermofluids.net)>  
by S.Bhattacharjee, San Diego State University

## Specific Heat Capacities of Air

The nominal values used for air at 300 K are  $C_p = 1.00$  kJ/kg.K,  $C_v = 0.718$  kJ/kg.K, and  $k = 1.4$ . However they are all functions of temperature, and with the extremely high temperature range experienced in internal combustion and gas turbine engines one can obtain significant errors. The table following gives the values of specific heat capacities as a function of temperature. We find that choosing values of specific heat capacities at the average temperature of each process gives results with reasonable accuracy (within around 1%).

**Ideal gas specific heat capacities of air**

Temperature K	$C_p$ kJ/kg.K	$C_v$ kJ/kg.K	$k$
250	1.003	0.716	1.401
300	1.005	0.718	1.400
350	1.008	0.721	1.398
400	1.013	0.726	1.395
450	1.020	0.733	1.391
500	1.029	0.742	1.387
550	1.040	0.753	1.381
600	1.051	0.764	1.376
650	1.063	0.776	1.370
700	1.075	0.788	1.364
750	1.087	0.800	1.359
800	1.099	0.812	1.354
900	1.121	0.834	1.344
1000	1.142	0.855	1.336
1100	1.155	0.868	1.331
1200	1.173	0.886	1.324
1300	1.190	0.903	1.318
1400	1.204	0.917	1.313
1500	1.216	0.929	1.309

The values up to 1000 K were originally published in "Tables of Thermal Properties of Gases", NBS Circular 564, 1955. The last five rows were calculated from a formula by B G Kyle "Chemical and Process Thermodynamics", Englewood Cliffs / Prentice Hall, 1984, and have <1% error.



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## Critical Properties of Phase-Change Fluids

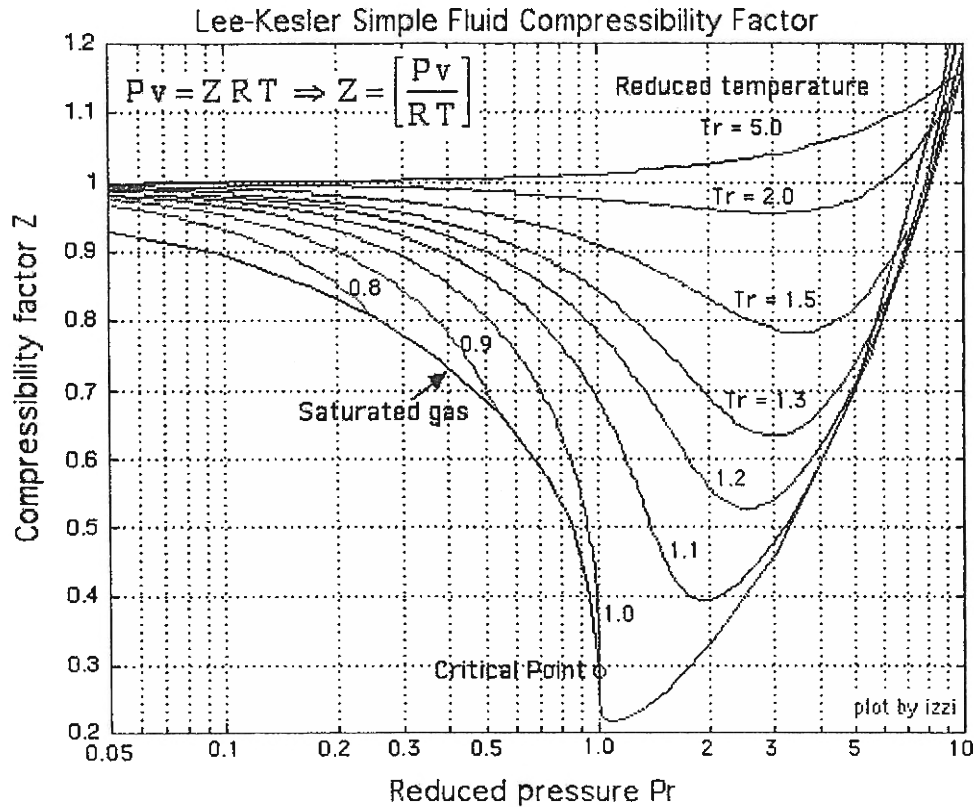
Material Properties Useful for the Real Gas Model			Critical-Point Properties		
Substance	Formula	Molar Mass	Temperature	Pressure	Volume
		M	T <sub>cr</sub>	P <sub>cr</sub>	v <sub>cr</sub>
		kg/kmol	K	MPa	m <sup>3</sup> /kmol
Air	--	28.97	132.5	3.77	0.0883
Ammonia	NH <sub>3</sub>	17.03	405.5	11.28	0.0724
Argon	Ar	39.948	151	4.86	0.0749
Benzene	C <sub>6</sub> H <sub>6</sub>	78.115	562	4.92	0.2603
n-Butane	C <sub>4</sub> H <sub>10</sub>	58.124	425.2	3.8	0.2547
Carbon Dioxide	CO <sub>2</sub>	44.01	304.2	7.39	0.0943
Carbon Monoxide	CO	28.011	133	3.5	0.093
Carbon Tetrachloride	CCl <sub>4</sub>	153.82	556.4	4.56	0.2759
Chlorine	Cl <sub>2</sub>	70.906	417	7.71	0.1242
Ethane	C <sub>2</sub> H <sub>6</sub>	30.07	305.5	4.48	0.148
Ethylene	C <sub>2</sub> H <sub>4</sub>	28.054	282.4	5.12	0.1242
Helium	He	4.003	5.3	0.23	0.0578
Hydrogen (normal)	H <sub>2</sub>	2.016	33.3	1.3	0.0649
Methane	CH <sub>4</sub>	16.043	191.1	4.64	0.0993
Neon	Ne	20.183	44.5	2.68	0.0419
Nitrogen	N <sub>2</sub>	28.013	126.2	3.39	0.0899
Oxygen	O <sub>2</sub>	31.999	154.8	5.08	0.078
Propane	C <sub>3</sub> H <sub>8</sub>	44.097	370	4.26	0.1998
Propylene	C <sub>3</sub> H <sub>6</sub>	42.081	365	4.62	0.181
Sulfur dioxide	SO <sub>2</sub>	64.063	430.7	7.88	0.1217
Tetrafluoroethane (R-134a)	CF <sub>3</sub> CH <sub>2</sub> F	102.03	374.3	4.067	0.1847
Water	H <sub>2</sub> O	18.015	647.1	22.064	0.0564

Note: The gas constant R can be calculated from  $R = R_u/M$ , where:

$R_u$  is the Universal Gas Constant = 8.314 [kJ/kmol.K]

M is the Molar Mass [kg/kmol]

Adapted from TEST (The Expert System for Thermodynamics) <[www.thermofluids.net](http://www.thermofluids.net)>  
by S.Bhattacharjee, San Diego State University



Both pressure and temperature are normalized by their respective critical values as follows:

$$\text{Reduced temp: } T_r = \left[ \frac{T}{T_{\text{critical}}} \right]$$

$$\text{Reduced press: } P_r = \left[ \frac{P}{P_{\text{critical}}} \right]$$

---

Ref: "A Generalized Thermodynamic Correlation based on Three-Parameter Corresponding States", B.I.Lee & M.G.Kesler, *AIChE Journal*, Volume 21, Issue 3, 1975, pp. 510-527



## Water Vapor Saturation Data (Tsat, Pg) and the Psychrometric Chart

The following Water Vapor Saturation Data is required in order to plot the Saturation Curve (Relative Humidity  $\phi=100\%$ ) of the Psychrometric Chart.

Temp	Pressure	Temp	Pressure
Tsat (°C)	Pg (kPa)	Tsat (°C)	Pg (kPa)
0.01	0.6117	25	3.1699
1	0.6571	26	3.3639
2	0.7060	27	3.5681
3	0.7581	28	3.7831
4	0.8136	29	4.0092
5	0.8726	30	4.2470
6	0.9354	31	4.4969
7	1.0021	32	4.7596
8	1.0730	33	5.0354
9	1.1483	34	5.3251
10	1.2282	35	5.6290
11	1.3130	36	5.9479
12	1.4028	37	6.2823
13	1.4981	38	6.6328
14	1.5990	39	7.0002
15	1.7058	40	7.3849
16	1.8188	41	7.7878
17	1.9384	42	8.2096
18	2.0647	43	8.6508
19	2.1983	44	9.1124
20	2.3393	45	9.5950
21	2.4882	46	10.099
22	2.6453	47	10.627
23	2.8111	48	11.177
24	2.9858	49	11.752
25	3.1699	50	12.352

The basic information used to construct a psychrometric chart is the water vapor saturation data (Tsat, Pg) which is obtained from steam tables over the range from Tsat = 0.01°C through 50°C. The specific humidity  $\omega$  is then evaluated using the relative humidity  $\phi$  as a parameter to produce the various relative humidity curves (blue lines) as follows:

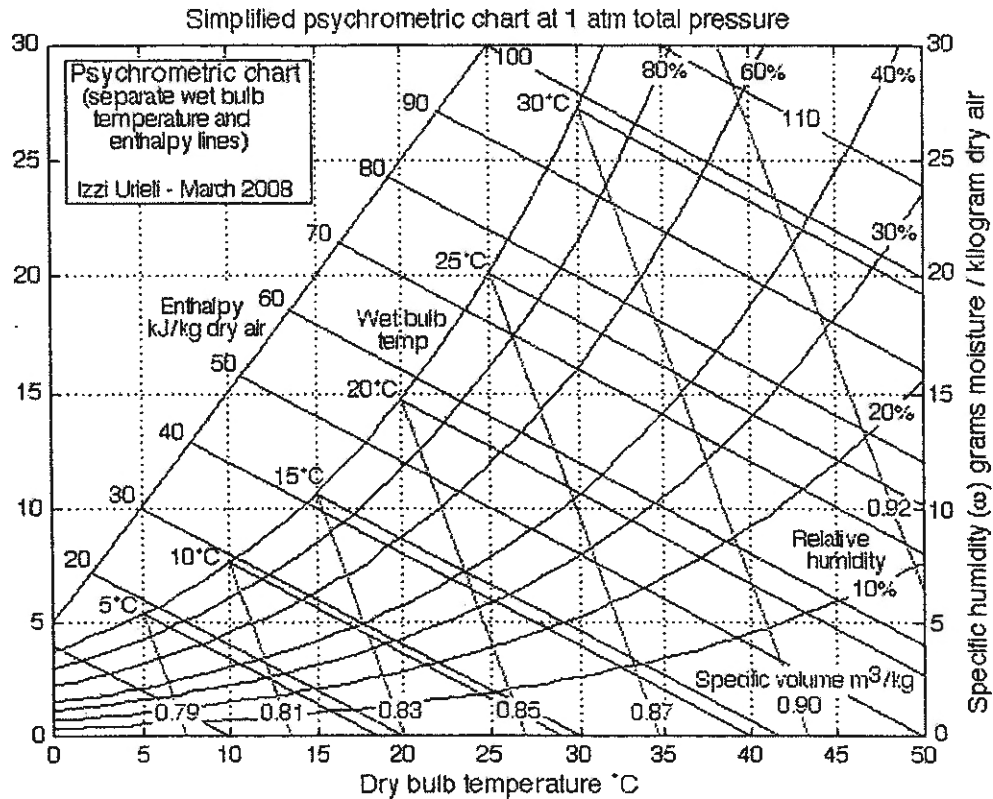
$$\omega \left[ \frac{\text{grams vap.}}{\text{kg dry air}} \right] = 622 \left( \frac{\phi P_g}{P - \phi P_g} \right) \text{ specific humidity}$$

where P is the standard atmospheric pressure 101.325 [kPa].

The saturation curve (100% relative humidity) is also known as the dew point curve is drawn as a red line. Notice that on the saturation curve the wet and dry bulb temperatures have the same values.

For more information refer to Chapter 10b on the Psychrometric Chart

Source of the (Tsat, Pg) data: NIST Chemistry WebBook - accessed Feb 2008



The major simplifying assumption in the construction of the chart is that the enthalpy of the mixture is assumed to be constant throughout the adiabatic saturation process (described in **Chapter 10a**). This implies that the evaporating liquid added does not significantly affect the enthalpy of the air-vapor mixture, leading to the constant slope wet bulb temperature / enthalpy lines defined by:

$$h_{\text{air+vap}} \left[ \frac{\text{kJ}}{\text{kg dry air}} \right] = T [^{\circ}\text{C}] + 2.5 \omega \quad \text{enthalpy}$$

Note:  $\omega$  has units of grams

Note that this simplified linear equation results in an error of less than 1% over the temperature range 0.01°C to 50°C.

Finally the specific volume curves which complete the chart are given by:

$$v \left[ \frac{\text{m}^3}{\text{kg dry air}} \right] = \left( \frac{R_{\text{air}} (T_{\text{sat}} + 273)}{P - P_g} \right) \quad \text{specific volume at saturation}$$

and at  $\omega = 0$ ,  $T [^{\circ}\text{C}] = \left( \frac{P v}{R_{\text{air}}} \right) - 273$

Refer to the complete **MATLAB program for Plotting the Psychrometric Chart** using these equations.

## Molar Enthalpy of Formation of Various Substances

Substance	Formula	M [kg/kmol]	hfo [kJ/kmol]
Carbon	C(s)	12.001	0
Hydrogen	H <sub>2</sub> (g)	2.016	0
Nitrogen	N <sub>2</sub> (g)	28.012	0
Oxygen	O <sub>2</sub> (g)	32	0
Carbon monoxide	CO(g)	28.013	-110,530
Carbon dioxide	CO <sub>2</sub> (g)	44.001	-393,520
Water Vapor	H <sub>2</sub> O(g)	18.016	-241,820
Water	H <sub>2</sub> O(l)	18.016	-285,820
Hydrogen peroxide	H <sub>2</sub> O <sub>2</sub> (g)	34.016	-136,310
Ammonia	NH <sub>3</sub> (g)	17.03	-46,190
Methane	CH <sub>4</sub> (g)	16.043	-74,850
Acetylene	C <sub>2</sub> H <sub>2</sub> (g)	26.038	226,730
Ethylene	C <sub>2</sub> H <sub>4</sub> (g)	24.034	52,280
Ethane	C <sub>2</sub> H <sub>6</sub> (g)	30.07	-84,680
Propylene	C <sub>3</sub> H <sub>6</sub> (g)	42.051	20,410
Propane	C <sub>3</sub> H <sub>8</sub> (g)	44.097	-103,850
n-Butane	C <sub>4</sub> H <sub>10</sub> (g)	58.123	-126,150
Benzene	C <sub>6</sub> H <sub>6</sub> (g)	78.114	82,930
n-Octane	C <sub>8</sub> H <sub>18</sub> (g)	114.231	-208,450
n-Octane	C <sub>8</sub> H <sub>18</sub> (l)	114.231	-249,950
n-Dodecane	C <sub>12</sub> H <sub>26</sub> (g)	170.22	-291,010
Methyl alcohol	CH <sub>3</sub> OH(g)	32.043	-200,670
Methyl alcohol	CH <sub>3</sub> OH(l)	32.043	-238,660
Ethyl alcohol	C <sub>2</sub> H <sub>5</sub> OH(g)	46.069	-235,310
Ethyl alcohol	C <sub>2</sub> H <sub>5</sub> OH(l)	46.069	-277,690
Oxygen	O(g)	16	249,190
Hydrogen	H(g)	1.008	218,000
Nitrogen	N(g)	14.006	472,650
Hydroxyl	OH(g)	17.008	39,460

[www.thermofluids.net](http://www.thermofluids.net) by

## Ideal Gas Enthalpy of Carbon Dioxide (CO<sub>2</sub>)

Enthalpy of Formation: -393,522 (kJ/kmol)

Molecular Weight: 44.01 (kg/kmol)

Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]
298	0						
300	67	650	15310	1000	33432	1700	73492
310	443	660	15796	1020	34495	1720	74679
320	822	670	16284	1040	35589	1740	75867
330	1206	680	16774	1060	36687	1760	77056
340	1595	690	17267	1080	37789	1780	78248
350	1987	700	17761	1100	38894	1800	79442
360	2384	710	18258	1120	40005	1820	80636
370	2784	720	18757	1140	41120	1840	81832
380	3188	730	19258	1160	42238	1860	83030
390	3596	740	19760	1180	43060	1880	84229
400	4008	750	20265	1200	44484	1900	85429
410	4423	760	19771	1220	45613	1920	86631
420	4842	770	21280	1240	46744	1940	87833
430	4964	780	21790	1260	47880	1960	89037
440	5690	790	21801	1280	49017	1980	90242
450	6119	800	22815	1300	50158	2000	91440
460	6552	810	23330	1320	51302	2050	94471
470	6987	820	23848	1340	52449	2100	97500
480	7427	830	24366	1360	53599	2150	100534
490	7868	840	24887	1380	54752	2200	103575
500	8314	850	25409	1400	55907	2250	106620
510	8762	860	25932	1420	57063	2300	109671
520	9212	870	26457	1440	58222	2350	112727
530	9665	880	26983	1460	59384	2400	115788
540	10121	890	27512	1480	57547	2450	118855
550	10581	900	28041	1500	61714	2500	121926
560	11043	910	28571	1520	62882	2550	125004
570	11506	920	29103	1540	64053	2600	128085
580	11973	930	29636	1560	65226	2650	131169
590	12443	940	30171	1580	67403	2700	134256
600	12916	950	30706	1600	67580	2750	137349
610	13390	960	31243	1620	68759	2800	140444
620	13867	970	31781	1640	69939	2850	143544
630	14345	980	32321	1660	71122	2900	146645
640	14826	990	32862	1680	72306	3000	152862

# Ideal Gas Enthalpy of Carbon Monoxide (CO)

Unit:  $\text{kJ/kmol}$        $2 \text{ J}$

M      W

Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]
298	0						
300	54	650	10472	1000	21686	1700	45940
310	345	660	10780	1020	22351	1720	46654
320	637	670	11089	1040	23019	1740	47370
330	928	680	11399	1060	23688	1760	48087
340	1220	690	11709	1080	24360	1780	48804
350	1512	700	12021	1100	25033	1800	49522
360	1804	710	12333	1120	25708	1820	50241
370	2096	720	12646	1140	26385	1840	50960
380	2389	730	12959	1160	27064	1860	51682
390	2682	740	13274	1180	27737	1880	52403
400	2975	750	13589	1200	28426	1900	53125
410	3269	760	13904	1220	29111	1920	53847
420	3563	770	14221	1240	29797	1940	54569
430	3857	780	14539	1260	30485	1960	55292
440	4152	790	14857	1280	31175	1980	56015
450	4447	800	15175	1300	31865	2000	56739
460	4743	810	15495	1320	32557	2050	58555
470	5039	820	15814	1340	33250	2100	60375
480	5336	830	16134	1360	33944	2150	62195
490	5633	840	16455	1380	34640	2200	64019
500	5931	850	16777	1400	35358	2250	65847
510	6229	860	17099	1420	36038	2300	67676
520	6528	870	17422	1440	36739	2350	69509
530	6828	880	17746	1460	37441	2400	71346
540	7128	890	18071	1480	38144	2450	73183
550	7428	900	18397	1500	38848	2500	75023
560	7730	910	18723	1520	39553	2550	76868
570	8032	920	19050	1540	40259	2600	78714
580	8334	930	19377	1560	40966	2650	80561
590	8638	940	19706	1580	41675	2700	82408
600	8942	950	20034	1600	42384	2750	84261
610	9246	960	20364	1620	43094	2800	86115
620	9552	970	20693	1640	43803	2850	87970
630	9858	980	21024	1660	44515	2900	89826
640	10164	990	21355	1680	45226	3000	93541

Adapted from TEST (The Expert System for Thermodynamics) <[www.thermofluids.net](http://www.thermofluids.net)> by S.Bhattacharjee, San Diego State University

## Ideal Gas Enthalpy of Water Vapor (H<sub>2</sub>O)

Enthalpy of Formation: -241,826 (kJ/kmol)

Molecular Weight: 18.015 (kg/kmol)

Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]
298	0						
300	62	650	12326	1000	25978	1700	57685
310	398	660	12696	1020	26805	1720	58663
320	735	670	13066	1040	27638	1740	59646
330	1072	680	13438	1060	28476	1760	60631
340	1410	690	13810	1080	29319	1780	61619
350	1748	700	14184	1100	30167	1800	62609
360	2088	710	14560	1120	31019	1820	63603
370	2427	720	14936	1140	31876	1840	64602
380	2768	730	15314	1160	32738	1860	65602
390	3110	740	15693	1180	33605	1880	66607
400	3452	750	16073	1200	34476	1900	67613
410	3795	760	16454	1220	35352	1920	68623
420	4139	770	16837	1240	36233	1940	69636
430	4484	780	17221	1260	37118	1960	70651
440	4830	790	17606	1280	38008	1980	71669
450	5176	800	17992	1300	38903	2000	72689
460	5524	810	18380	1320	39803	2050	75252
470	5873	820	18768	1340	40708	2100	77849
480	6222	830	19158	1360	41617	2150	80426
490	6573	840	19550	1380	42530	2200	83036
500	6924	850	19942	1400	43447	2250	85658
510	7277	860	20336	1420	44369	2300	88295
520	7630	870	20731	1440	45294	2350	90942
530	7985	880	21128	1460	46224	2400	93604
540	8341	890	21525	1480	47158	2450	96279
550	8697	900	21924	1500	48095	2500	98964
560	9055	910	22324	1520	49038	2550	101661
570	9414	920	22725	1540	49984	2600	104379
580	9774	930	23128	1560	50934	2650	107087
590	10135	940	23532	1580	51888	2700	109813
600	10498	950	23937	1600	52844	2750	112549
610	10861	960	24343	1620	53805	2800	115294
620	11226	970	24749	1640	54771	2850	118048
630	11591	980	25157	1660	55739	2900	120813
640	11958	990	25568	1680	56710	3000	126360

## Ideal Gas Enthalpy of Nitrogen (N<sub>2</sub>)

Enthalpy of Formation: 0 (kJ/kmol)

Molecular Weight: 28.013 (kg/kmol)

Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]
298	0						
300	54	650	10406	1000	missing	1700	45430
310	345	660	10711	1020	22115	1720	46138
320	637	670	11016	1040	22773	1740	46847
330	928	680	11322	1060	23432	1760	missing
340	1219	690	11628	1080	24093	1780	48269
350	1511	700	11935	1100	24757	1800	48982
360	1802	710	12243	1120	25423	1820	49694
370	2094	720	12551	1140	26091	1840	50406
380	2386	730	12860	1160	26761	1860	51121
390	2678	740	13170	1180	27435	1880	51835
400	2971	750	13480	1200	28108	1900	52551
410	3263	760	13791	1220	28783	1920	53267
420	3556	770	14103	1240	29460	1940	53985
430	3849	780	14416	1260	30138	1960	54712
440	4142	790	14729	1280	30819	1980	55421
450	4436	800	15045	1300	31501	2000	56141
460	4730	810	15358	1320	32184	2050	57943
470	5024	820	15673	1340	32870	2100	59748
480	5319	830	15989	1360	33558	2150	61557
490	5616	840	16305	1380	34246	2200	63371
500	5912	850	16623	1400	34936	2250	65187
510	6207	860	16941	1420	35626	2300	67007
520	6503	870	17259	1440	36319	2350	68827
530	6800	880	17579	1460	37013	2400	70651
540	7097	890	17899	1480	37708	2450	72480
550	7395	900	18221	1500	38404	2500	74312
560	7694	910	18541	1520	39102	2550	76145
570	7993	920	18863	1540	39801	2600	77981
580	8293	930	19185	1560	40499	2650	79819
590	8593	940	19509	1580	41200	2700	81659
600	missing	950	19832	1600	41902	2750	83502
610	missing	960	20157	1620	42606	2800	85345
620	missing	970	20482	1640	43311	2850	87190
630	9799	980	20807	1660	44017	2900	89036
640	10103	990	21134	1680	44724	3000	92738

## Ideal Gas Enthalpy of Oxygen (O<sub>2</sub>)

Enthalpy of Formation: 0 (kJ/kmol)

Molecular Weight: 32 (kg/kmol)

Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]	Temp. [K]	Enthalpy [kJ/kmol]
298	0						
300	54	650	10862	1000	missing	1700	47970
310	348	660	11188	1020	missing	1720	48712
320	643	670	11515	1040	24107	1740	49454
330	938	680	11842	1060	24808	1760	missing
340	1234	690	12172	1080	25512	1780	missing
350	1531	700	12502	1100	26217	1800	51689
360	1829	710	12832	1120	26924	1820	52436
370	2127	720	13163	1140	27632	1840	53184
380	2427	730	13495	1160	28341	1860	53934
390	2727	740	13828	1180	29052	1880	54683
400	3029	750	14162	1200	29765	1900	55434
410	3330	760	14496	1220	30480	1920	56186
420	3632	770	14831	1240	31195	1940	56938
430	3936	780	15168	1260	31912	1960	57692
440	4241	790	15504	1280	32630	1980	58445
450	4546	800	15841	1300	33351	2000	59199
460	4843	810	16179	1320	34071	2050	61090
470	5160	820	16517	1340	34793	2100	62986
480	5469	830	16855	1360	35516	2150	64891
490	5778	840	17195	1380	36241	2200	66802
500	6088	850	17536	1400	36966	2250	68715
510	6400	860	17877	1420	37692	2300	70634
520	6713	870	18217	1440	38420	2350	72561
530	7026	880	18560	1460	39149	2400	74492
540	7340	890	18902	1480	39879	2450	76430
550	7656	900	19246	1500	40610	2500	78375
560	7972	910	19590	1520	41342	2550	80322
570	8289	920	19934	1540	42074	2600	82274
580	8608	930	20278	1560	42808	2650	84234
590	8927	940	20624	1580	43542	2700	86199
600	9247	950	20970	1600	44279	2750	88170
610	9568	960	21317	1620	45014	2800	90144
620	9890	970	21663	1640	45752	2850	92126
630	10213	980	22010	1660	46490	2900	94111
640	10537	990	22359	1680	47230	3000	98098



