

# ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2013 SESSION

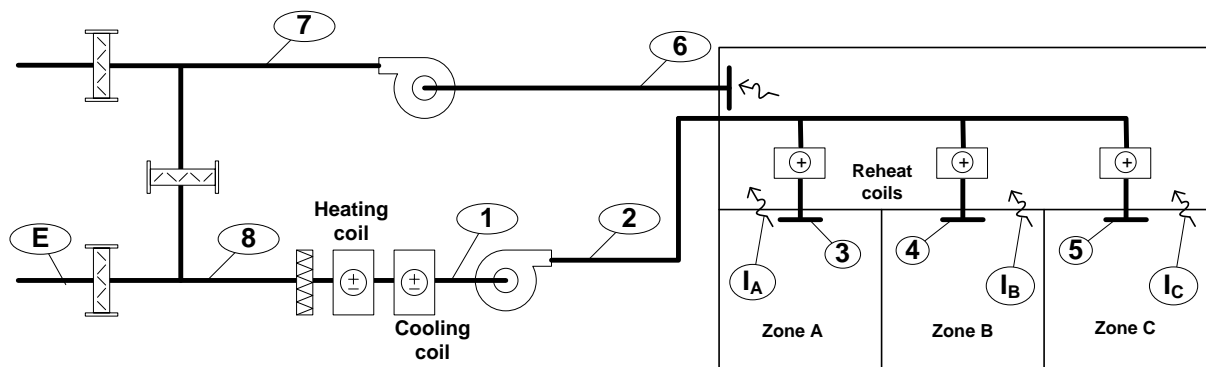
Open-book examination  
Calculators : only authorized models  
Duration : 3 hours

## 07-Méc-B2 Environmental control in buildings

### Problem # 1 (25%)

The diagram shows a multizone constant volume air conditioning system with zonal reheat coils. For the design conditions (the peak of building and the peaks of zone load), the specifications are as follows:

Zone	A		B		C	
Load (kW)	sensible	latent	sensible	latent	sensible	latent
<i>Peak of zone</i>	<i>15 July</i>		<i>15 June</i>		<i>2 July</i>	
	34.5	4.4	23.46	7.32	20.7	4.4
<i>Peak of building</i>	<i>15 July</i>					
	34.5	4.4	20.4	7.32	14.4	0.0
Temperature	24 °C					
Relative humidity	40 à 60 %					



Plenum heat gains

13.68 kW

Temperature rise across the return fan

$\Delta t = 1\text{ }^{\circ}\text{C}$

Temperature rise across the supply fan

$\Delta t = 1\text{ }^{\circ}\text{C}$

Exterior air conditions: dry bulb temperature  
relative humidity

$t = 35\text{ }^{\circ}\text{C}$

$\phi = 50\%$

Exterior air flow rate

$0.855\text{ m}^3/\text{s}$

The state of air leaving the cooling coil (**point 1 on the schema**), used for the peak of building and to determine the supply air flow rate in the zones, is the following

Dry bulb temperature	11.5 °C
Relative humidity	$w = 8.0 \text{ g/kg dry air}$

Locate the key air states (*points 1 to 8,  $I_A$ ,  $I_B$ ,  $I_C$  and E*) on the psychrometric chart (7%) for the peak of building and shown in the table the dry bulb temperature and relative humidity of each point (3%).

Determine:

- Supply air flow rate in each zone (3%);
- Fan air flow rate (4%);
- Cooling coil power (4%);
- Heating capacities of the reheat coils for the zones A, B and C (4%).

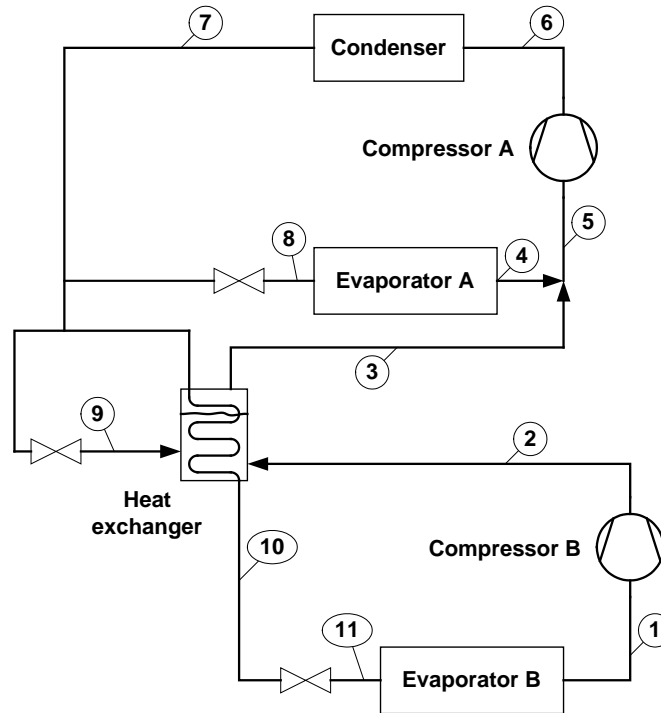
## Problem # 2 (25 %)

Figure shows the schematic diagram of a vapor-compression refrigeration system with two evaporators, two compressors using R-134a as the working fluid. A heat exchanger is used to achieve the subcooling of R-134a (state 10). The specifications are as follows:

- condensing pressure 1600 kPa;
- evaporating pressure (evaporator A) 280 kPa;
- evaporating pressure (evaporator B) 140 kPa;
- temperature at state 10  $T_{10} = 40 \text{ °C}$ ;
- at states 1, 3, 4, et 7, R-134a is a saturated liquid or saturated vapor.
- refrigerating capacity of evaporator B 200 kW;
- power input of compressor A ( $\dot{W}_{C,A}$ ) 90 kW.

Compressions are isentropic and there are no significant pressure drops in the flows through the condenser and the two evaporators. Show the refrigeration cycle on the attached  $p-h$  diagram (7%) and determine:

- mass flow rate of refrigerant R-134a through evaporator A ( $\dot{m}_A$ ), evaporator B ( $\dot{m}_B$ ) and mass flow rate  $\dot{m}_9$  (11%);
- refrigerating capacity of evaporator A in kW (3%);
- coefficient of performance COP (4%).



### Problem # 3 (15%)

Consider a building with five (5) zones (four external zones E, N, O, S and one internal zone I) having the following cooling loads:

#### *Zones cooling peak*

	Zone E	Zone N	Zone O	Zone S	Zone I
$q_{\text{sensible}}$ kW	20	12	45	50	18
$q_{\text{latent}}$ kW	1.5	1.5	5	3	3
	16 June	9 July	6 September	23 June	14 July

#### *Building cooling peak (21 June)*

	Zone E	Zone N	Zone O	Zone S	Zone I
$q_{\text{sensible}}$ kW	15	10	45	40	18
$q_{\text{latent}}$ kW	1.5	1.5	5	3	3

Answer the questions considering two following cases:

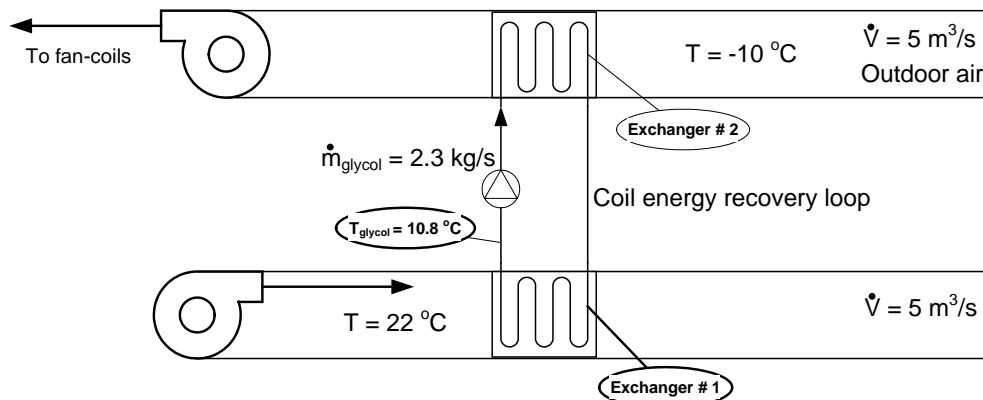
- 1 A **VAV system** with the perimeter heating system in each zone (E, N, O and S) serves the entire building. The temperature of each zone is  $24^{\circ}\text{C}$  and the supply air temperature is  $12^{\circ}\text{C}$ . Determine:
  - a) The maximum supply air flow rate for each zone using to design zone duct dimensions (4%);
  - b) The maximum fan air flow rate (5%).

- 2 A **multizone constant air volume system with zonal reheat coils** serves the entire building. The temperature of each zone is  $24^{\circ}\text{C}$  and the supply air temperature for design conditions is  $12^{\circ}\text{C}$ . Determine:

- c) The supply air flow rate for each zone (3%);
- d) The fan air flow rate (3%).

**Problem #4 (20 %)**

The fan-coil conditioner system serves an entire building. Primary air made up of outdoor air, required to maintain air quality, is supplied to fan-coils by a constant volume air system as illustrated in figure below. The coil energy recovery loop with two glycol-air coils is used to preheat the outdoor air. At a given moment, the data acquisition system shows the results illustrated in figure. Assume that the effectiveness of heat exchanger #1 is  $\epsilon = 64\%$ . Determine:



- a) The heat recovery serving to preheat the outdoor air (in kW) (5 %);
- b) Air temperature leaving the heat exchanger #2 (5 %);
- c) Effectiveness of heat exchanger #2 (5 %);
- d) Effectiveness of the coil energy recovery loop with two glycol-air coils (5 %).

Assume that:

Specific heat of glycol	$c_p = 3.2 \text{ kJ/kg}^{\circ}\text{C}$
Air density	$\rho = 1.2 \text{ kg/m}^3$
Specific heat of air	$c_p = 1.0 \text{ kJ/kg}^{\circ}\text{C}$

**Problem # 5 (15 %)**

The fan shown in the Figure was selected for a VAV system requiring the design conditions as follows:

Fan air flow rate	26000 cfm
Static pressure	3.9 inWG (inches of $\text{H}_2\text{O}$ )
Fan speed	936 rpm
Fan power ( $\dot{W}$ )	23.5 BHP (17.53 kW)

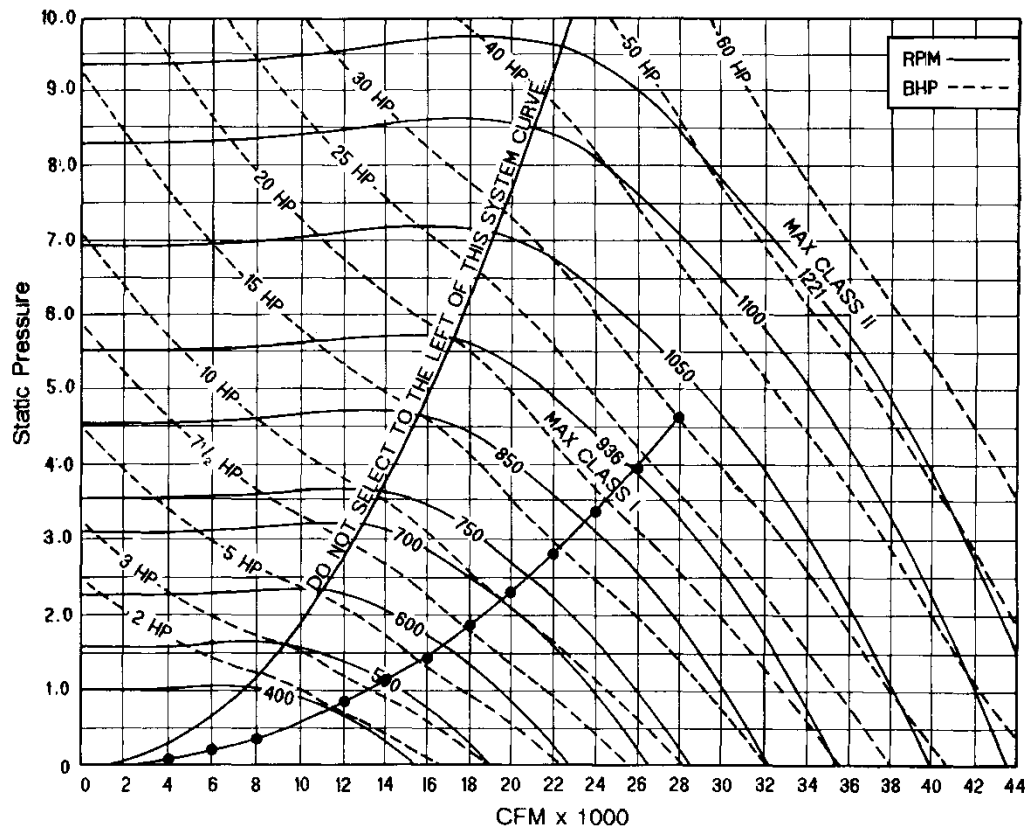
Assume that the fan, to provide variable airflow, could operate in two cases as follows:

Case # 1 fan air flow rate control is realized by outlet dampers;

Case # 2 fan air flow rate control is realized by variable-speed drive.

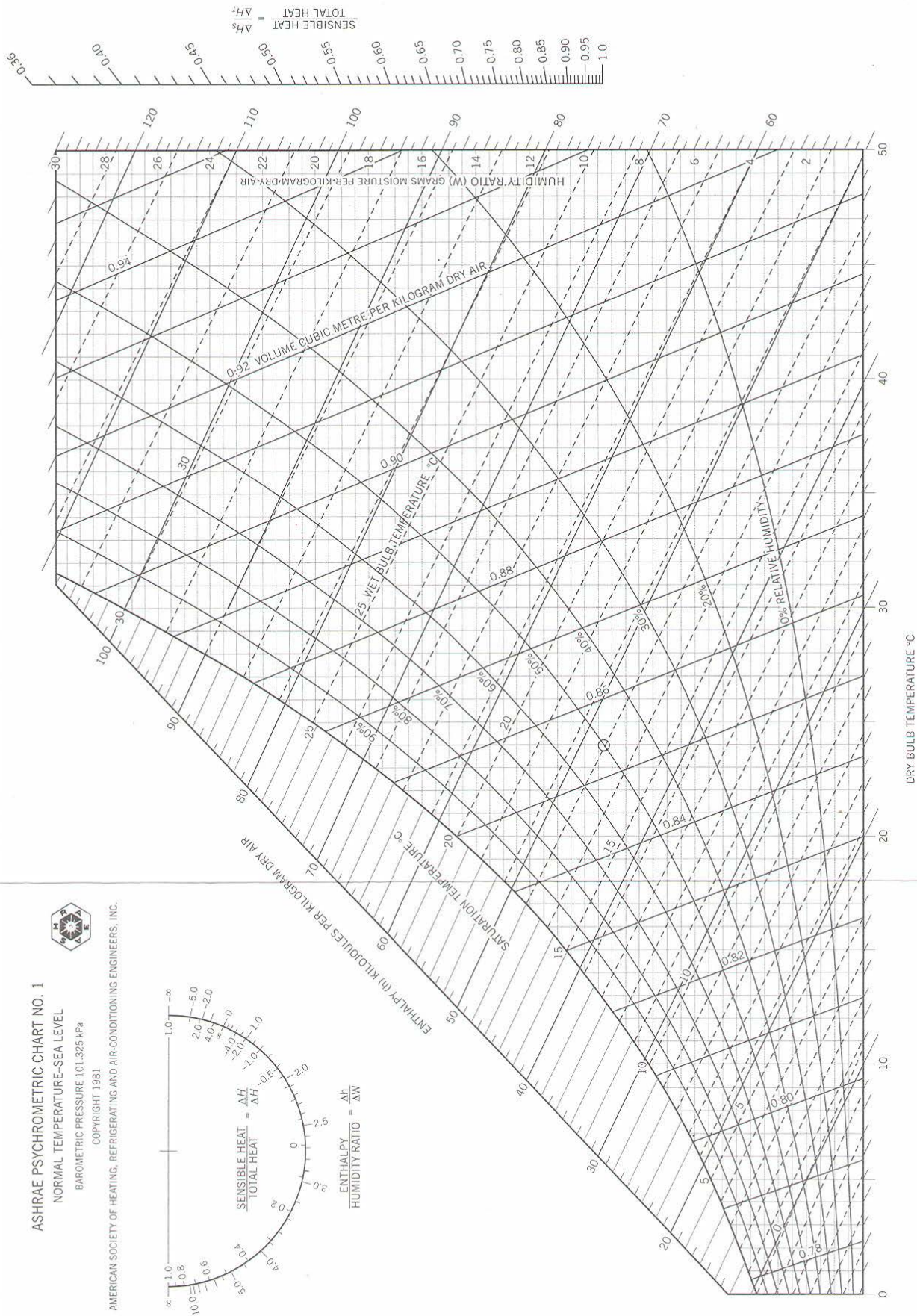
If the fan air flow rate decreases to 22000 cfm, determine for two cases:

- a) Fan power ( $\dot{W}$ ) in BHP (or in kW), (7.5%);
- b) Fan static pressure in inWG (inches of H<sub>2</sub>O), (7.5%).



**Chart 1b** ASHRAE Psychrometric Chart No. 1 (SI) (Reprinted by permission of ASHRAE.)

ASHRAE PSYCHROMETRIC CHART NO. 1  
 NORMAL TEMPERATURE-SEA LEVEL  
 BAROMETRIC PRESSURE 101.325 kPa  
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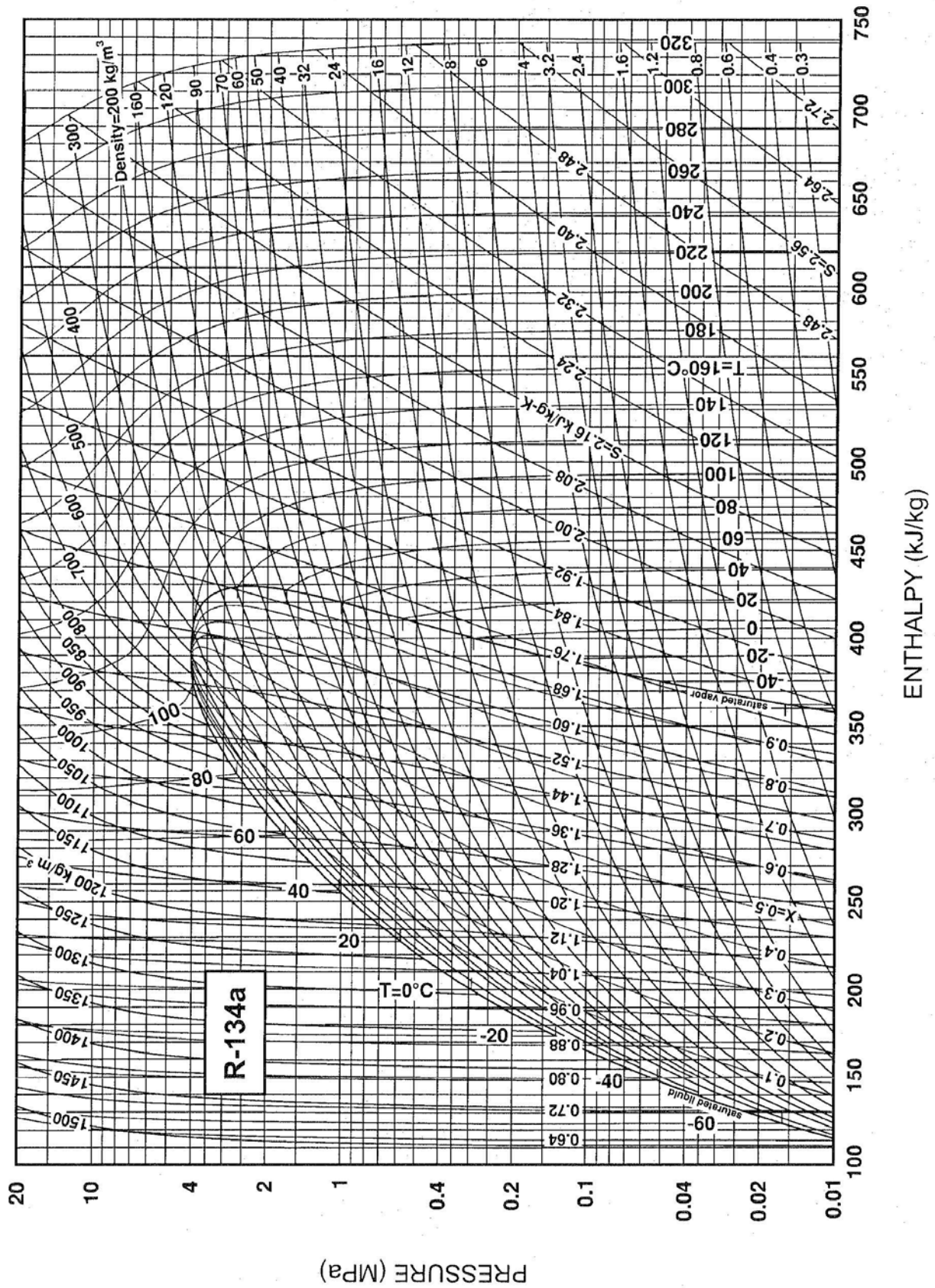


Fig. 8 Pressure-Enthalpy Diagram for Refrigerant 134a



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

Temp.,* °C	Pres- sure, MPa	Density, kg/m <sup>3</sup> Liquid	Volume, m <sup>3</sup> /kg Vapor	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c <sub>p</sub> , kJ/(kg·K)		c <sub>p</sub> /c <sub>v</sub>	Velocity of Sound, m/s		Viscosity, μPa·s		Thermal Cond., mW/(m·K)		Surface Tension, mN/m		Temp., °C
				Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	
-103.30a	0.00039	1591.1	35.496	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164	1120.	126.8	2175.	6.46	145.2	3.08	28.07	-103.30	
-100.00	0.00056	1582.4	25.193	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162	1103.	127.9	1893.	6.60	143.2	3.34	27.50	-100.00	
-90.00	0.00152	1555.8	9.7698	87.23	342.76	0.5020	1.8972	1.189	0.617	1.156	1052.	131.0	1339.	7.03	137.3	4.15	25.79	-90.00	
-80.00	0.00367	1529.0	4.2682	99.16	348.83	0.5654	1.8580	1.198	0.642	1.151	1002.	134.0	1018.	7.46	131.5	4.95	24.10	-80.00	
-70.00	0.00798	1501.9	2.0590	111.20	355.02	0.6262	1.8264	1.210	0.667	1.148	952.	136.8	809.2	7.89	126.0	5.75	22.44	-70.00	
-60.00	0.01591	1474.3	1.0790	123.36	361.31	0.6846	1.8010	1.223	0.692	1.146	903.	139.4	663.1	8.30	120.7	6.56	20.80	-60.00	
-50.00	0.02945	1446.3	0.60620	135.67	367.65	0.7410	1.7806	1.238	0.720	1.146	855.	141.7	555.1	8.72	115.6	7.36	19.18	-50.00	
-40.00	0.05121	1417.7	0.36108	148.14	374.00	0.7956	1.7643	1.255	0.749	1.148	807.	143.6	472.2	9.12	110.6	8.17	17.60	-40.00	
-30.00	0.08438	1388.4	0.22594	160.79	380.32	0.8486	1.7515	1.273	0.781	1.152	760.	145.2	406.4	9.52	105.8	8.99	16.04	-30.00	
-28.00	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.788	1.153	751.	145.4	394.9	9.60	104.8	9.15	15.73	-28.00	
-26.07b	0.10133	1376.7	0.19018	165.81	382.78	0.8690	1.7472	1.281	0.794	1.154	742.	145.7	384.2	9.68	103.9	9.31	15.44	-26.07	
-26.00	0.10167	1376.5	0.18958	165.90	382.82	0.8694	1.7471	1.281	0.794	1.154	742.	145.7	383.8	9.68	103.9	9.32	15.43	-26.00	
-24.00	0.11130	1370.4	0.17407	168.47	384.07	0.8798	1.7451	1.285	0.801	1.155	732.	145.9	373.1	9.77	102.9	9.48	15.12	-24.00	
-22.00	0.12165	1364.4	0.16006	171.05	385.32	0.8900	1.7432	1.289	0.809	1.156	723.	146.1	362.9	9.85	102.0	9.65	14.82	-22.00	
-20.00	0.13273	1358.3	0.14739	173.64	386.55	0.9002	1.7413	1.293	0.816	1.158	714.	146.3	353.0	9.92	101.1	9.82	14.51	-20.00	
-18.00	0.14460	1352.1	0.13592	176.23	387.79	0.9104	1.7396	1.297	0.823	1.159	705.	146.4	343.5	10.01	100.1	9.98	14.21	-18.00	
-16.00	0.15728	1345.9	0.12551	178.83	389.02	0.9205	1.7379	1.302	0.831	1.161	695.	146.6	334.3	10.09	99.2	10.15	13.91	-16.00	
-14.00	0.17082	1339.7	0.11605	181.44	390.24	0.9306	1.7363	1.306	0.838	1.163	686.	146.7	325.4	10.17	98.3	10.32	13.61	-14.00	
-12.00	0.18524	1333.4	0.10744	184.07	391.46	0.9407	1.7348	1.311	0.846	1.165	677.	146.8	316.9	10.25	97.4	10.49	13.32	-12.00	
-10.00	0.20060	1327.1	0.09959	186.70	392.66	0.9506	1.7334	1.316	0.854	1.167	668.	146.9	308.6	10.33	96.5	10.66	13.02	-10.00	
-8.00	0.21693	1320.8	0.09242	189.34	393.87	0.9606	1.7320	1.320	0.863	1.169	658.	146.9	300.6	10.41	95.6	10.83	12.72	-8.00	
-6.00	0.23428	1314.3	0.08587	191.99	395.06	0.9705	1.7307	1.325	0.871	1.171	649.	147.0	292.9	10.49	94.7	11.00	12.43	-6.00	
-4.00	0.25268	1307.9	0.07987	194.65	396.25	0.9804	1.7294	1.330	0.880	1.174	640.	147.0	285.4	10.57	93.8	11.17	12.14	-4.00	
-2.00	0.27217	1301.4	0.07436	197.32	397.43	0.9902	1.7282	1.336	0.888	1.176	631.	147.0	278.1	10.65	92.9	11.34	11.85	-2.00	
0.00	0.29280	1294.8	0.06931	200.00	398.60	1.0000	1.7271	1.341	0.897	1.179	622.	146.9	271.1	10.73	92.0	11.51	11.56	0.00	
2.00	0.31462	1288.1	0.06466	202.69	399.77	1.0098	1.7260	1.347	0.906	1.182	612.	146.9	264.3	10.81	91.1	11.69	11.27	2.00	
4.00	0.33766	1281.4	0.06039	205.40	400.92	1.0195	1.7250	1.352	0.916	1.185	603.	146.8	257.6	10.90	90.2	11.86	10.99	4.00	
6.00	0.36198	1274.7	0.05644	208.11	402.06	1.0292	1.7240	1.358	0.925	1.189	594.	146.7	251.2	10.98	89.4	12.04	10.70	6.00	
8.00	0.38761	1267.9	0.05280	210.84	403.20	1.0388	1.7230	1.364	0.935	1.192	585.	146.5	244.9	11.06	88.5	12.22	10.42	8.00	
10.00	0.41461	1261.0	0.04944	213.58	404.32	1.0485	1.7221	1.370	0.945	1.196	576.	146.4	238.8	11.15	87.6	12.40	10.14	10.00	
12.00	0.44301	1254.0	0.04633	216.33	405.43	1.0581	1.7212	1.377	0.956	1.200	566.	146.2	232.9	11.23	86.7	12.58	9.86	12.00	
14.00	0.47288	1246.9	0.04345	219.09	406.53	1.0677	1.7204	1.383	0.967	1.204	557.	146.0	227.1	11.32	85.9	12.77	9.58	14.00	
16.00	0.50425	1239.8	0.04078	221.87	407.61	1.0772	1.7196	1.390	0.978	1.209	548.	145.7	221.5	11.40	85.0	12.95	9.30	16.00	
18.00	0.53718	1232.6	0.03830	224.66	408.69	1.0867	1.7188	1.397	0.989	1.214	539.	145.5	216.0	11.49	84.1	13.14	9.03	18.00	
20.00	0.57171	1225.3	0.03600	227.47	409.75	1.0962	1.7180	1.405	1.001	1.219	530.	145.1	210.7	11.58	83.3	13.33	8.76	20.00	
22.00	0.60789	1218.0	0.03385	230.29	410.79	1.1057	1.7173	1.413	1.013	1.224	520.	144.8	205.5	11.67	82.4	13.53	8.48	22.00	
24.00	0.64578	1210.5	0.03186	233.12	411.82	1.1152	1.7166	1.421	1.025	1.230	511.	144.5	200.4	11.76	81.6	13.72	8.21	24.00	
26.00	0.68543	1202.9	0.03000	235.97	412.84	1.1246	1.7159	1.429	1.038	1.236	502.	144.1	195.4	11.85	80.7	13.92	7.95	26.00	
28.00	0.72688	1195.2	0.02826	238.84	413.84	1.1341	1.7152	1.437	1.052	1.243	493.	143.6	190.5	11.95	79.8	14.13	7.68	28.00	
30.00	0.77020	1187.5	0.02664	241.72	414.82	1.1435	1.7145	1.446	1.065	1.249	483.	143.2	185.8	12.04	79.0	14.33	7.42	30.00	
32.00	0.81543	1179.6	0.02513	244.62	415.78	1.1529	1.7138	1.456	1.080	1.257	474.	142.7	181.1	12.14	78.1	14.54	7.15	32.00	
34.00	0.86263	1171.6	0.02371	247.54	416.72	1.1623	1.7131	1.466	1.095	1.265	465.	142.1	176.6	12.24	77.3	14.76	6.89	34.00	
36.00	0.91185	1163.4	0.02238	250.48	417.65	1.1717	1.7124	1.476	1.111	1.273	455.	141.6	172.1	12.34	76.4	14.98	6.64	36.00	
38.00	0.96315	1155.1	0.02113	253.43	418.55	1.1811	1.7118	1.487	1.127	1.282	446.	141.0	167.7	12.44	75.6	15.21	6.38	38.00	
40.00	1.0166	1146.7	0.01997	256.41	419.43	1.1905	1.7111	1.498	1.145	1.292	436.	140.3	163.4	12.55	74.7	15.44	6.13	40.00	
42.00	1.0722	1138.2	0.01887	259.41	420.28	1.1999	1.7103	1.510	1.163	1.303	427.	139.7	159.2	12.65	73.9	15.68	5.88	42.00	
44.00	1.1301	1129.5	0.01784	262.43	421.11	1.2092	1.7096	1.523	1.182	1.314	418.	138.9	155.1	12.76	73.0	15.93	5.63	44.00	
46.00	1.1903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202	1.326	408.	138.2	151.0	12.88	72.1	16.18	5.38	46.00	
48.00	1.2529	1111.5	0.01595	268.53	422.69	1.2280	1.7081	1.551	1.223	1.339	399.	137.4	147.0	13.00	71.3	16.45	5.13	48.00	
50.00	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.354	389.	136.6	143.1	13.12	70.4	16.72	4.89	50.00	
52.00	1.3854	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.369	379.	135.7	139.2	13.24	69.6	17.01	4.65	52.00	
54.00	1.4555	1083.2	0.01351	277.89	424.83	1.2563	1.7055	1.600	1.296	1.386	370.	134.7	135.4	13.37					



## Refrigerant 134a Properties of Superheated Vapor

Pressure = 0.101325 MPa Saturation temperature = -26.07°C						Pressure = 0.200 MPa Saturation temperature = -10.07°C						Pressure = 0.400 MPa Saturation temperature = 8.94°C					
Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	
Saturated						Saturated						Saturated					
Liquid	1374.34	166.07	0.8701	747.1		Liquid	1325.78	186.69	0.9506	672.8		Liquid	1263.84	212.08	1.0432	583.8	
Vapor	5.26	382.90	1.7476	145.7		Vapor	10.01	392.71	1.7337	146.9		Vapor	19.52	403.80	1.7229	146.6	
-20.00	5.11	387.68	1.7667	147.8		-10.00	10.01	392.77	1.7339	147.0							
-10.00	4.89	395.65	1.7976	151.0		0.00	9.54	401.21	1.7654	150.6							
0.00	4.69	403.74	1.8278	154.2		10.00	9.13	409.73	1.7961	154.0		10.00	19.41	404.78	1.7263	147.0	
10.00	4.50	411.97	1.8574	157.2		20.00	8.76	418.35	1.8260	157.3		20.00	18.45	414.00	1.7583	151.2	
20.00	4.34	420.34	1.8864	160.1		30.00	8.42	427.07	1.8552	160.4		30.00	17.61	423.21	1.7892	155.0	
30.00	4.18	428.85	1.9150	162.9		40.00	8.12	435.90	1.8839	163.4		40.00	16.87	432.46	1.8192	158.6	
40.00	4.04	437.52	1.9431	165.7		50.00	7.83	444.87	1.9121	166.3		50.00	16.20	441.76	1.8485	162.0	
50.00	3.91	446.33	1.9708	168.4		60.00	7.57	453.97	1.9398	169.2		60.00	15.60	451.15	1.8771	165.3	
60.00	3.78	455.30	1.9981	171.0		70.00	7.33	463.20	1.9671	171.9		70.00	15.05	460.63	1.9051	168.4	
70.00	3.67	464.43	2.0251	173.6		80.00	7.11	472.57	1.9940	174.6		80.00	14.54	470.21	1.9326	171.4	
80.00	3.56	473.70	2.0518	176.1		90.00	6.89	482.08	2.0206	177.2		90.00	14.08	479.91	1.9597	174.3	
90.00	3.46	483.13	2.0781	178.6		100.00	6.70	491.74	2.0468	179.7		100.00	13.65	489.72	1.9864	177.1	
100.00	3.36	492.71	2.1041	181.0		110.00	6.51	501.53	2.0727	182.2		110.00	13.24	499.65	2.0126	179.8	
110.00	3.27	502.44	2.1298	183.4		120.00	6.34	511.47	2.0983	184.7		120.00	12.87	509.71	2.0386	182.4	
120.00	3.19	512.32	2.1553	185.7		130.00	6.17	521.55	2.1236	187.1		130.00	12.51	519.90	2.0641	185.0	
130.00	3.11	522.35	2.1805	188.1		140.00	6.01	531.76	2.1486	189.4		140.00	12.18	530.21	2.0894	187.5	
140.00	3.03	532.52	2.2054	190.3		150.00	5.87	542.12	2.1734	191.7		150.00	11.87	540.66	2.1144	190.0	
150.00	2.96	542.83	2.2301	192.6													
Pressure = 0.600 MPa Saturation temperature = 21.58°C						Pressure = 0.800 MPa Saturation temperature = 31.33°C						Pressure = 1.000 MPa Saturation temperature = 39.39°C					
Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	
Saturated						Saturated						Saturated					
Liquid	1219.08	229.62	1.1035	524.0		Liquid	1181.92	243.58	1.1495	477.4		Liquid	1149.06	255.44	1.1874	438.6	
Vapor	29.13	410.67	1.7178	145.0		Vapor	38.99	415.58	1.7144	142.9		Vapor	49.16	419.31	1.7117	140.6	
30.00	27.79	418.97	1.7455	149.0		40.00	36.98	424.61	1.7437	147.6		40.00	48.95	419.99	1.7139	141.0	
40.00	26.41	428.72	1.7772	153.4		50.00	35.03	434.85	1.7758	152.4		50.00	45.86	430.91	1.7482	146.9	
50.00	25.21	438.44	1.8077	157.4		60.00	33.36	444.98	1.8067	156.8		60.00	43.34	441.56	1.7807	152.0	
60.00	24.16	448.16	1.8374	161.2		70.00	31.90	455.08	1.8366	160.8		70.00	41.21	452.05	1.8117	156.7	
70.00	23.22	457.93	1.8662	164.7		80.00	30.62	465.17	1.8656	164.6		80.00	39.36	462.47	1.8416	160.9	
80.00	22.37	467.75	1.8944	168.0		90.00	29.46	475.30	1.8939	168.1		90.00	37.74	472.86	1.8706	164.9	
90.00	21.59	477.65	1.9221	171.2		100.00	28.41	485.49	1.9215	171.5		100.00	36.29	483.26	1.8989	168.6	
100.00	20.88	487.64	1.9492	174.3		110.00	27.46	495.74	1.9486	174.7		110.00	34.99	493.69	1.9265	172.1	
110.00	20.22	497.72	1.9759	177.3		120.00	26.58	506.07	1.9753	177.8		120.00	33.80	504.19	1.9535	175.4	
120.00	19.61	507.92	2.0022	180.1		130.00	25.77	516.50	2.0015	180.8		130.00	32.71	514.75	1.9800	178.6	
130.00	19.04	518.22	2.0280	182.9		140.00	25.01	527.03	2.0272	183.7		140.00	31.70	525.39	2.0061	181.7	
140.00	18.51	528.63	2.0536	185.6		150.00	24.31	537.66	2.0527	186.4		150.00	30.76	536.12	2.0318	184.6	
150.00	18.01	539.17	2.0787	188.2		160.00	23.65	548.40	2.0777	189.2		160.00	29.90	546.95	2.0571	187.5	
160.00	17.54	549.82	2.1036	190.8		170.00	23.03	559.24	2.1025	191.8		170.00	29.08	557.88	2.0820	190.3	
170.00	17.10	560.59	2.1282	193.3		180.00	22.45	570.20	2.1270	194.4		180.00	28.32	568.91	2.1066	193.0	
180.00	16.68	571.48	2.1525	195.8		190.00	21.89	581.28	2.1511	196.9		190.00	27.60	580.05	2.1309	195.6	
190.00	16.29	582.50	2.1766	198.2		200.00	21.37	592.46	2.1750	199.4		200.00	26.92	591.29	2.1550	198.2	
200.00	15.91	593.63	2.2003	200.6													
Pressure = 1.200 MPa Saturation temperature = 46.32°C						Pressure = 1.400 MPa Saturation temperature = 52.43°C						Pressure = 1.600 MPa Saturation temperature = 57.91°C					
Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s		Temp., °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	
Saturated						Saturated						Saturated					
Liquid	1118.89	265.91	1.2200	405.0		Liquid	1090.50	275.38	1.2488	375.1		Liquid	1063.28	284.11	1.2748	348.1	
Vapor	59.73	422.22	1.7092	138.2		Vapor	70.76	424.50	1.7068	135.6		Vapor	82.34	426.27	1.7042	132.9	
50.00	58.09	426.51	1.7226	140.7		60.00	66.61	433.69	1.7347	141.2		60.00	80.74	428.99	1.7124	134.7	
60.00	54.32	437.83	1.7571	146.9		70.00	62.25	445.31	1.7691	147.5		70.00	74.43	441.47	1.7493	142.3	
70.00	51.26	448.81	1.7896	152.3		80.00	58.74	456.56	1.8014	153.0		80.00	69.61	453.30	1.7833	148.7	
80.00	48.69	459.61	1.8206	157.1		90.00	55.79	467.60	1.8322	158.0		90.00	65.71	464.76	1.8153	154.2	
90.00	46.49	470.30	1.8504	161.5		100.00	53.24	478.53	1.8619	162.5		100.00	62.43	476.01	1.8458	159.2	
100.00	44.55	480.94	1.8794	165.6		110.00	51.03	489.39	1.8906	166.6		110.00	59.62	487.13	1.8753	163.8	
110.00	42.83	491.58	1.9075	169.4		120.00	49.05	500.25	1.9186	170.5		120.00	57.14	498.19	1.9038	168.0	
120.00	41.28	502.25	1.9350	173.0		130.00	47.28	511.11	1.9459	174.2		130.00	54.95	509.23	1.9315	171.9	
130.00	39.87	512.95	1.9619	176.4		140.00	45.67	522.02	1.9726	177.7		140.00	52.98	520.28	1.9586	175.6	
140.00	38.58	523.72	1.9882	179.7		150.00	44.19	532.97	1.9988	181.0		150.00	51.18	531.36	1.9851	179.1	
150.00	37.39	534.56	2.0142	182.8		160.00	42.83	544.00	2.0246	184.2		160.00	49.54	542.49	2.0111	182.5	
160.00	36.29	545.48	2.0397	185.8		170.00	41.57	555.10	2.0499	187.2		170.00	48.03	553.68	2.0366	185.7	
170.00	35.26	556.50	2.0648	188.8		180.00	40.41	566.28	2.0748	190.2		180.00	46.63	564.94	2.0617	188.8	
180.00	34.31	567.60	2.0896	191.6		190.00	39.31	577.55	2.0994	193.1		190.00	45.32	576.29	2.0865	191.8	
190.00	33.40	578.80	2.1141	194.4		200.00	38.28	588.92	2.1237	195.9		200.00	44.10	587.71	2.1109	194.7	
200.00	32.56	590.11															



## Refrigerant 134a Properties of Superheated Vapor (Concluded)

Pressure = 1.800 MPa Saturation temperature = 62.90°C					Pressure = 2.000 MPa Saturation temperature = 67.49°C					Pressure = 2.200 MPa Saturation temperature = 71.74°C				
Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated					Saturated					Saturated				
Liquid	1036.81	292.26	1.2987	323.2	Liquid	1010.74	299.96	1.3209	300.1	Liquid	984.76	307.32	1.3417	278.4
Vapor	94.53	427.59	1.7014	130.1	Vapor	107.46	428.52	1.6983	127.2	Vapor	121.25	429.08	1.6948	124.3
70.00	88.23	437.17	1.7296	136.5	70.00	104.37	432.22	1.7091	129.9	80.00	110.03	441.49	1.7303	133.3
80.00	81.54	449.76	1.7657	144.0	80.00	94.85	445.86	1.7483	138.9	90.00	100.70	454.98	1.7680	141.8
90.00	76.38	461.74	1.7992	150.3	90.00	87.97	458.49	1.7835	149.9	100.00	93.78	467.61	1.8023	148.7
100.00	72.17	473.36	1.8308	155.9	100.00	82.58	470.57	1.8164	152.4	110.00	88.25	479.75	1.8344	154.7
110.00	68.64	484.78	1.8610	160.8	110.00	78.17	482.32	1.8474	157.8	120.00	83.70	491.59	1.8649	160.0
120.00	65.60	496.06	1.8900	165.4	120.00	74.44	493.86	1.8772	162.7	130.00	79.79	503.25	1.8942	164.9
130.00	62.91	507.29	1.9183	169.6	130.00	71.18	505.30	1.9059	167.2	140.00	76.41	514.81	1.9226	169.3
140.00	60.53	518.50	1.9457	173.5	140.00	68.33	516.68	1.9338	171.4	150.00	73.40	526.32	1.9501	173.5
150.00	58.37	529.71	1.9725	177.3	150.00	65.78	528.03	1.9609	175.4	160.00	70.71	537.81	1.9769	177.4
160.00	56.42	540.95	1.9988	180.8	160.00	63.47	539.39	1.9875	179.1	170.00	68.28	549.31	2.0032	181.1
170.00	54.62	552.24	2.0246	184.2	170.00	61.37	550.79	2.0135	182.6	180.00	66.06	560.84	2.0289	184.6
180.00	52.97	563.59	2.0499	187.4	180.00	59.45	562.23	2.0390	186.0	190.00	64.02	572.42	2.0542	188.0
190.00	51.44	575.01	2.0748	190.6	190.00	57.67	573.72	2.0641	189.3	200.00	62.13	584.06	2.0790	191.3
200.00	50.01	586.50	2.0993	193.6	200.00	56.02	585.28	2.0888	192.4	210.00	60.38	595.76	2.1035	194.4
210.00	48.68	598.08	2.1236	196.5	210.00	54.49	596.92	2.1131	195.5	220.00	58.74	607.53	2.1276	197.5
220.00	47.43	609.74	2.1475	199.4	220.00	53.05	608.64	2.1371	198.4	230.00	57.21	619.38	2.1514	200.4
230.00	46.25	621.50	2.1710	202.1	230.00	51.70	620.44	2.1608	201.3	240.00	55.77	631.31	2.1749	203.3
240.00	45.14	633.34	2.1944	204.9	240.00	50.43	632.33	2.1842	204.1	250.00	54.42	643.33	2.1981	206.1
250.00	44.09	645.28	2.2174	207.5	250.00	49.23	644.30	2.2073	206.8					

Pressure = 2.400 MPa Saturation temperature = 75.70°C					Pressure = 2.600 MPa Saturation temperature = 79.41°C					Pressure = 2.800 MPa Saturation temperature = 82.90°C				
Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated					Saturated					Saturated				
Liquid	958.58	314.40	1.3616	257.9	Liquid	931.88	321.29	1.3806	238.2	Liquid	904.29	328.05	1.3990	219.1
Vapor	136.07	429.27	1.6908	121.4	Vapor	152.12	429.08	1.6863	118.3	Vapor	169.71	428.50	1.6812	115.3
80.00	127.96	436.42	1.7112	126.9	80.00	150.48	430.22	1.6895	119.3	90.00	150.13	441.84	1.7183	125.9
90.00	114.90	451.12	1.7523	137.0	90.00	131.08	446.81	1.7359	131.7	100.00	133.85	457.32	1.7603	136.4
100.00	105.89	464.44	1.7885	144.8	100.00	119.15	461.03	1.7745	140.8	110.00	122.89	471.16	1.7970	144.6
110.00	99.00	477.04	1.8218	151.5	110.00	110.50	474.19	1.8093	148.1	120.00	114.63	484.17	1.8305	151.5
120.00	93.44	489.22	1.8532	157.2	120.00	103.72	486.75	1.8417	154.4	130.00	108.00	496.70	1.8620	157.5
130.00	88.79	501.14	1.8831	162.4	130.00	98.17	498.96	1.8724	160.0	140.00	102.49	508.93	1.8919	162.9
140.00	84.77	512.90	1.9119	167.2	140.00	93.46	510.94	1.9017	165.0	150.00	97.78	520.97	1.9207	167.8
150.00	81.27	524.57	1.9398	171.6	150.00	89.39	522.79	1.9301	169.7	160.00	93.66	532.90	1.9486	172.3
160.00	78.15	536.20	1.9670	175.7	160.00	85.80	534.57	1.9576	174.0	170.00	90.01	544.77	1.9757	176.5
170.00	75.35	547.82	1.9935	179.6	170.00	82.59	546.30	1.9844	178.1	180.00	86.74	556.61	2.0021	180.5
180.00	72.81	559.45	2.0195	183.3	180.00	79.70	558.04	2.0106	181.9	190.00	83.78	568.45	2.0279	184.3
190.00	70.48	571.11	2.0449	186.8	190.00	77.07	569.79	2.0362	185.5	200.00	81.08	580.31	2.0533	187.9
200.00	68.34	582.82	2.0699	190.2	200.00	74.65	581.57	2.0614	189.0	210.00	78.59	592.21	2.0782	191.4
210.00	66.36	594.58	2.0945	193.4	210.00	72.43	593.40	2.0861	192.4	220.00	76.29	604.16	2.1027	194.7
220.00	64.51	606.41	2.1188	196.6	220.00	70.36	605.29	2.1105	195.6	230.00	74.15	616.17	2.1268	198.0
230.00	62.79	618.31	2.1427	199.6	230.00	68.44	617.24	2.1345	198.8	240.00	72.16	628.25	2.1505	201.1
240.00	61.18	630.29	2.1662	202.5	240.00	66.64	629.27	2.1581	201.8	250.00	70.30	640.39	2.1740	204.1
250.00	59.66	642.35	2.1895	205.4	250.00	64.95	641.37	2.1815	204.8					

Pressure = 3.000 MPa Saturation temperature = 86.20°C					Pressure = 4.000 MPa Saturation temperature = 100.35°C					Pressure = 6.00 MPa Saturation temperature = n/a (supercritical)				
Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s	Temp.,* °C	Density, kg/m <sup>3</sup>	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated					Saturated					Saturated				
Liquid	875.30	334.75	1.4171	200.4	Liquid	626.95	376.48	1.5272	101.3	Liquid				
Vapor	189.25	427.47	1.6752	112.2	Vapor	396.29	404.57	1.6024	93.4	Vapor				
90.00	173.82	435.84	1.6983	119.1										
100.00	150.47	453.20	1.7455	131.8										
110.00	136.36	467.93	1.7845	141.0	110.00	233.68	446.28	1.7131	119.8	110.00	762.66	375.61	1.5174	173.6
120.00	126.23	481.47	1.8194	148.5	120.00	199.79	465.29	1.7621	132.5	120.00	591.77	405.75	1.5950	127.4
130.00	118.34	494.36	1.8518	155.0	130.00	179.83	481.11	1.8018	142.0	130.00	418.90	439.87	1.6807	120.4
140.00	111.89	506.86	1.8824	160.7	140.00	165.73	495.51	1.8371	149.7	140.00	333.91	465.19	1.7428	130.1
150.00	106.45	519.11	1.9117	165.9	150.00	154.89	509.13	1.8697	156.4	150.00	289.37	484.69	1.7894	139.9
160.00	101.75	531.21	1.9399	170.6	160.00	146.10	522.25	1.9004	162.4	160.00	260.70	501.52	1.8288	148.3
170.00	97.62	543.21	1.9673	175.0	170.00	138.74	535.07	1.9296	167.8	170.00	239.96	516.92	1.8639	155.7
180.00	93.94	555.16	1.9940	179.2	180.00	132.41	547.69	1.9578	172.7	180.00	223.87	531.45	1.8963	162.2
190.00	90.62	567.10	2.0201	183.1	190.00	126.88	560.17	1.9850	177.4	190.00	210.82	545.43	1.9269	168.1
200.00	87.61	579.05	2.0456	186.8	200.00	121.97	572.58	2.0115	181.7	200.00	199.88	559.04	1.9559	173.6
210.00	84.84	591.02	2.0706	190.4	210.00	117.53	584.95	2.0374	185.8	210.00	190.50	572.39	1.9839	178.6
220.00	82.30	603.03	2.0952	193.8	220.00	113.56	597.30	2.0627	189.7	220.00	182.31	585.57	2.0109	183.4
230.00	79.94	615.10	2.1195	197.2	230.00	109.90	609.66	2.0875	193.4	230.00	175.06	598.64	2.0371	187.8
240.00	77.74	627.22	2.1433	200.4	240.00	106.55	622.05	2.1119	197.0	240.00	168.56	611.63	2.0626	192.1
250.00	75.69	639.41	2.1668	203.4	250.00	103.44	634.47	2.1359	200.5	250.00	162.68	624.57	2.0876	196.2
260.00	73.77	651.66	2.1900	206.5	260.00	100.56	646.93	2.1595	203.8	260.00	157.33	637.50	2.1121	200.0
270.00	71.96	664.00	2.2130	209.4	270.00	97.87	659.45	2.1827	207.1	270.00	152.41	650.43	2.1361	203.8
280.00	70.25	676.41	2.2356	212.2	280.00	95.35	672.03	2.2057	210.2	280.00	147.88	663.38	2.1598	207.4
290.00	68.63	688.89	2.2580	215.0	290.00	92.98	684.67	2.2283	213.3	290.00	143.67	676.35	2.1830	210.9
300.00	67.10	701.46	2.2801	217.8	300.00	90.75	697.38	2.2507	216.2	300.00	139.75	689.36	2.2059	214.3