

$$\text{Carnot COP} = \frac{273\text{K} + (-86^\circ\text{C})}{30^\circ\text{C} - (-86^\circ\text{C})} = 1.61$$

$$H_5 = 0.365(381 \frac{\text{kJ}}{\text{kg}}) + (1-0.365)(162 \frac{\text{kJ}}{\text{kg}}) = 484 \frac{\text{kJ}}{\text{kg}}$$

$$S_5 = 0.365(0.853 \frac{\text{kJ}}{\text{kg}}) + (1-0.365)(1.171 \frac{\text{kJ}}{\text{kg}}) = 1.42 \frac{\text{kJ}}{\text{kg}}$$

$$Q_{C, \text{Ethanol}} = H_2 - H_1 = 336 \frac{\text{kJ}}{\text{kg}}$$

$$5 \text{ ton} \cdot 12,600 \frac{\text{kJ}}{\text{h}} = 63,000 \frac{\text{kJ}}{\text{h}}$$

$$\dot{m}_{\text{Ethanol}} = \frac{63,000 \frac{\text{kJ}}{\text{h}}}{336 \frac{\text{kJ}}{\text{kg}}} = 188 \frac{\text{kg}}{\text{h}}$$

$$\dot{m}_{\text{Ethanol}} Q_{H, \text{Ethanol}} = -\dot{m}_{R134a} Q_{C, R134a}$$

$$Q_{H, \text{Ethanol}} = H_4 - H_3 = -505 \frac{\text{kJ}}{\text{kg}}$$

$$Q_{C, R134a} = H_6 - H_5 = 138 \frac{\text{kJ}}{\text{kg}}$$

$$\dot{m}_{R134a} = \frac{-(188 \frac{\text{kJ}}{\text{h}})(-505 \frac{\text{kJ}}{\text{kg}})}{138 \frac{\text{kJ}}{\text{kg}}}$$

$$\dot{m}_{R134a} = 688 \frac{\text{kg}}{\text{h}}$$

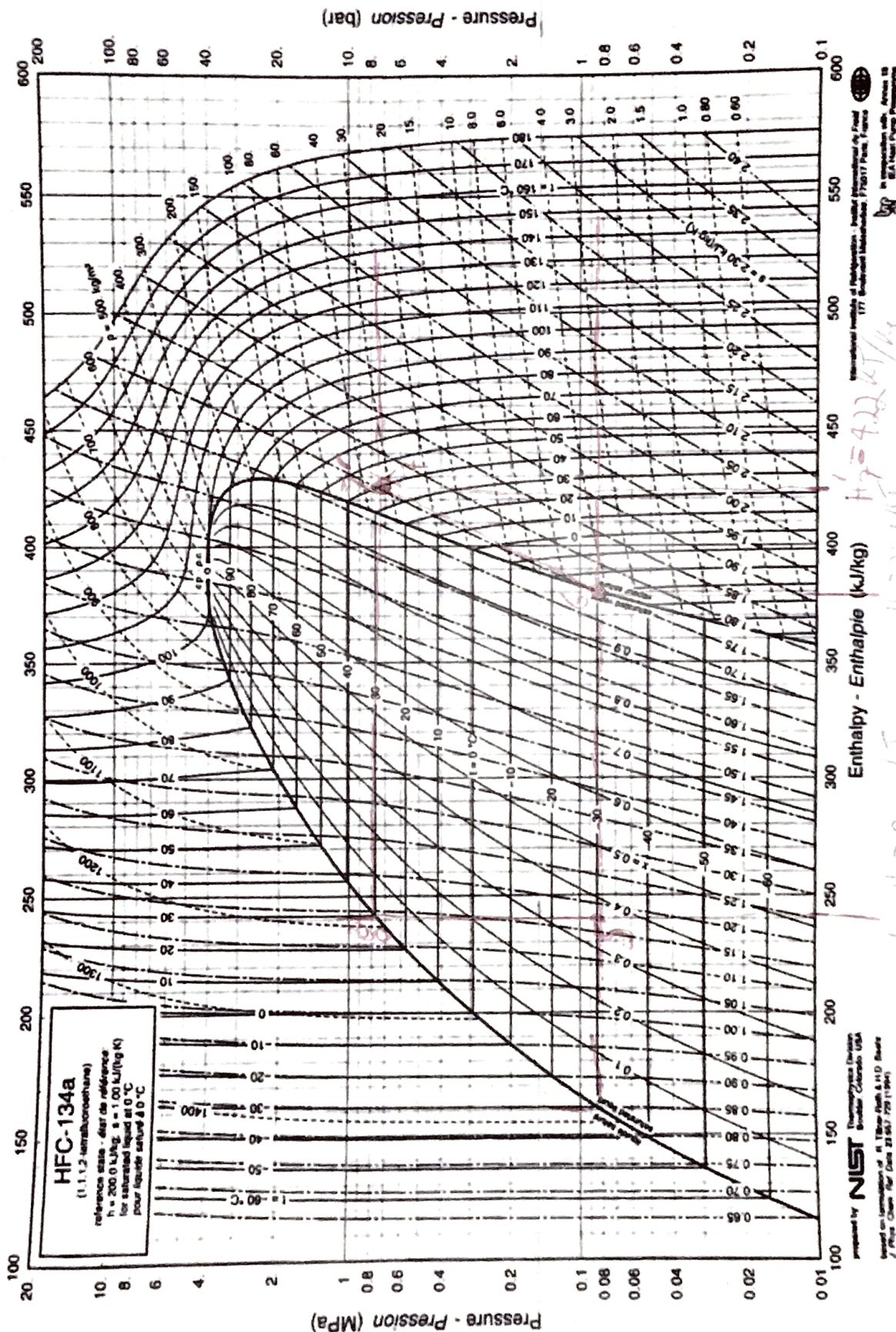
$$\text{COP} = \frac{Q_{C-1}}{H_{7-6} + H_{3-2}} = \frac{63,200 \frac{\text{kJ}}{\text{h}}}{33,200 \frac{\text{kJ}}{\text{h}} + 31,800 \frac{\text{kJ}}{\text{h}}} = 0.972$$

	T	P	ρ^L	ρ^V	H^L	H^V	S^L	S^V
	K	MPa	kg/m ³	kg/m ³	kJ/kg	kJ/kg	kJ/kg-K	kJ/kg-K
-86°C (187K)	240	0.07248	1397.7	3.8367	156.78	378.33	0.8320	1.7552
	244	0.08784	1385.8	4.5965	161.87	380.85	0.8530	1.7505
	248	0.10568	1373.8	5.4707	166.99	383.35	0.8738	1.7462
	252	0.12627	1361.7	6.4715	172.14	385.84	0.8943	1.7423
	256	0.14989	1349.5	7.6117	177.33	388.31	0.9147	1.7388
	260	0.17684	1337.0	8.9051	182.55	390.75	0.9348	1.7356
-30°C (243K)	264	0.20742	1324.4	10.3660	187.81	393.17	0.9548	1.7327
	268	0.24197	1311.6	12.0110	193.11	395.56	0.9747	1.7301
	272	0.28080	1298.5	13.8570	198.45	397.93	0.9943	1.7277
	276	0.32426	1285.3	15.9230	203.84	400.25	1.0139	1.7255
30°C (303K)	280	0.37271	1271.7	18.2270	209.26	402.54	1.0332	1.7235
	284	0.42651	1258.0	20.7940	214.74	404.79	1.0525	1.7217
	288	0.48603	1243.9	23.6450	220.27	406.99	1.0717	1.7200
	292	0.55165	1229.5	26.8080	225.85	409.14	1.0907	1.7184
	296	0.62378	1214.7	30.3130	231.49	411.23	1.1097	1.7169
	300	0.70282	1199.6	34.1920	237.18	413.26	1.1286	1.7155
30°C	304	0.78918	1184.1	38.4830	242.95	415.22	1.1475	1.7142
	308	0.88330	1168.1	43.2280	248.78	417.11	1.1663	1.7128
	312	0.98560	1151.5	48.4750	254.69	418.92	1.1850	1.7114
	316	1.09650	1134.5	54.2820	260.68	420.63	1.2038	1.7100
	320	1.21660	1116.7	60.7140	266.76	422.25	1.2226	1.7085
	324	1.34620	1098.3	67.8510	272.94	423.74	1.2414	1.7068
	328	1.48600	1079.0	75.7890	279.23	425.10	1.2603	1.7050
	332	1.63640	1058.8	84.6440	285.63	426.31	1.2793	1.7030
	336	1.79810	1037.5	94.5630	292.18	427.34	1.2984	1.7007
	340	1.97150	1015.0	105.7300	298.88	428.17	1.3177	1.6980

Abstracted from R. Tillner-Roth; H. D. Baehr, 1994. *J. Phys. Chem. Ref. Data*, 23:657.

E.12 PRESSURE-ENTHALPY DIAGRAM FOR R134A (1,1,1,2-TETRAFLUOROETHANE)

(Source: NIST, Thermophysics Division, Boulder, CO, USA, used with permission.)



PROPERTIES OF SATURATED ETHANE

Handwritten notes: -30°C, 1674, 2434

T K	P MPa	volume, m ³ /kg		enthalpy, kJ/kg			entropy, kJ/(kg·K)		
		v _f	v _g	h _f	h _{fg}	h _g	s _f	s _{fg}	s _g
150	0.009591	0.001693	4.299	0.0	539.18	539.18	0.0	3.5945	3.5945
160	0.02153	0.001735	2.031	27.17	523.99	551.16	0.1752	3.2750	3.4502
170	0.04329	0.001779	1.064	53.61	509.29	562.90	0.3353	2.9959	3.3312
180	0.07968	0.001823	0.6053	79.62	494.67	574.29	0.4836	2.7482	3.2318
184.32	0.101325	0.001843	0.4845	90.80	488.28	579.08	0.5448	2.6491	3.1939
190	0.1364	0.001869	0.3676	105.51	479.72	585.23	0.6230	2.5249	3.1479
200	0.2200	0.001918	0.2355	131.50	464.11	595.61	0.7555	2.3206	3.0761
210	0.3376	0.001969	0.1575	157.69	447.64	605.33	0.8822	2.1316	3.0138
220	0.4968	0.002023	0.1091	184.13	430.15	614.28	1.0037	1.9553	2.9590
230	0.7057	0.002082	0.07768	210.90	411.44	622.34	1.1208	1.7889	2.9097
240	0.9730	0.002147	0.05655	238.21	391.10	629.31	1.2346	1.6296	2.8642
250	1.308	0.002221	0.04184	266.47	368.49	634.96	1.3470	1.4739	2.8209
260	1.720	0.002308	0.03130	296.21	342.70	638.91	1.4599	1.3181	2.7780
270	2.221	0.002415	0.02352	327.97	312.59	640.56	1.5753	1.1577	2.7330
280	2.822	0.002555	0.01759	362.34	276.44	638.78	1.6948	0.9873	2.6821
290	3.541	0.002759	0.01286	400.71	230.25	630.96	1.8228	0.7939	2.6167
300	4.409	0.003142	0.008602	450.52	156.97	607.49	1.9828	0.5232	2.5060
305.88	5.010	0.004596	0.004596	532.03	0.0	532.03	2.2441	0.0	2.2441

PROPERTIES OF GASEOUS ETHANE

P, MPa (T _{sat} , K)	T, K									
	sat	300	340	380	420	460	500	540	580	
0.070 v, m ³ /kg (177.8) h, kJ/kg s, kJ/(kg·K)	0.6824 571.78 3.2525	1.180 764.36 4.0686	1.340 838.62 4.3007	1.499 919.15 4.5245	1.658 1006.11 4.7419	1.816 1099.55 4.9543	1.975 1199.46 5.1625	2.134 1305.74 5.3669	2.292 1418.27 5.5679	
0.101325 v, m ³ /kg (184.3) h, kJ/kg s, kJ/(kg·K)	0.4845 579.08 3.1939	0.8132 763.73 3.9648	0.9240 838.14 4.1974	1.034 918.77 4.4214	1.144 1005.80 4.6390	1.254 1099.29 4.8516	1.364 1199.24 5.0598	1.474 1305.56 5.2643	1.583 1418.11 5.4653	
0.20 v, m ³ /kg (197.9) h, kJ/kg s, kJ/(kg·K)	0.2575 593.49 3.0902	0.4089 761.74 3.7720	0.4658 836.62 4.0061	0.5222 917.58 4.2310	0.5783 1004.83 4.4492	0.6342 1098.49 4.6621	0.6901 1198.56 4.8706	0.7458 1304.98 5.0753	0.8014 1417.61 5.2765	
0.40 v, m ³ /kg (214.3) h, kJ/kg s, kJ/(kg·K)	0.1341 609.25 2.9896	0.2012 757.62 3.5706	0.2305 833.52 3.8079	0.2592 915.14 4.0347	0.2877 1002.86 4.2541	0.3160 1096.86 4.4677	0.3441 1197.19 4.6768	0.3721 1303.80 4.8818	0.4001 1416.60 5.0833	
0.70 v, m ³ /kg (229.8) h, kJ/kg s, kJ/(kg·K)	0.07829 622.15 2.9108	0.1122 751.24 3.4008	0.1296 828.77 3.6433	0.1465 911.44 3.8730	0.1632 999.88 4.0942	0.1796 1094.40 4.3090	0.1958 1195.12 4.5189	0.2120 1302.04 4.7245	0.2281 1415.07 4.9264	
1.0 v, m ³ /kg (240.9) h, kJ/kg s, kJ/(kg·K)	0.05502 629.87 2.8603	0.07648 744.60 3.2865	0.08926 823.91 3.5345	0.1015 907.68 3.7673	0.1133 996.87 3.9904	0.1250 1091.93 4.2064	0.1365 1193.05 4.4171	0.1480 1300.27 4.6234	0.1593 1413.55 4.8257	
2.0 v, m ³ /kg (265.8) h, kJ/kg s, kJ/(kg·K)	0.02651 640.20 2.7523	0.03451 720.03 3.0353	0.04205 806.77 3.3067	0.04882 894.73 3.5512	0.05520 986.63 3.7811	0.06135 1083.58 4.0015	0.06736 1186.08 4.2151	0.07326 1294.36 4.4233	0.07910 1408.47 4.6271	
4.0 v, m ³ /kg (295.5) h, kJ/kg s, kJ/(kg·K)	0.01051 621.42 2.5659	0.01183 644.02 2.6418	0.01813 766.56 3.0271	0.02243 866.58 3.3054	0.02614 965.16 3.5520	0.02957 1066.43 3.7823	0.03283 1171.98 4.0022	0.03597 1282.52 4.2148	0.03904 1398.37 4.4218	
7.0 v, m ³ /kg h, kJ/kg s, kJ/(kg·K)			0.00727 678.32 2.6637	0.01106 817.80 3.0531	0.01374 930.66 3.3357	0.01604 1039.90 3.5841	0.01812 1150.64 3.8149	0.02009 1264.88 4.0347	0.02197 1383.51 4.2466	
10. v, m ³ /kg h, kJ/kg s, kJ/(kg·K)			0.00397 589.90 2.3579	0.00672 764.34 2.8446	0.00892 894.94 3.1719	0.01074 1013.29 3.4411	0.01235 1129.67 3.6837	0.01383 1247.78 3.9109	0.01523 1369.25 4.1279	
20. v, m ³ /kg h, kJ/kg s, kJ/(kg·K)			0.00277 532.36 2.0966	0.00342 668.78 2.4756	0.00429 808.21 2.8246	0.00521 941.97 3.1289	0.00609 1071.47 3.3989	0.00691 1199.79 3.6458	0.00769 1329.20 3.8769	
30. v, m ³ /kg h, kJ/kg s, kJ/(kg·K)			0.00252 526.36 2.0017	0.00287 646.92 2.3367	0.00332 774.99 2.6570	0.00384 905.97 2.9549	0.00438 1037.43 3.2290	0.00492 1169.40 3.4829	0.00544 1302.75 3.7211	

THERMODYNAMIC PROPERTIES OF ETHANE

