ORDRE DES INGÉNIEURS DU QUÉBEC

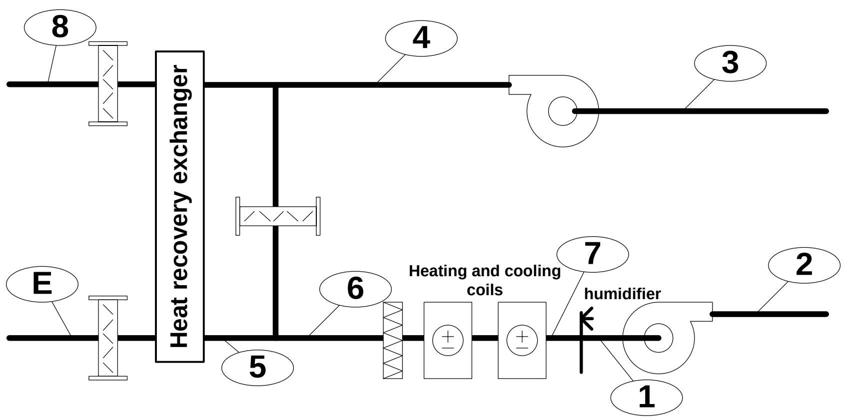
NOVEMBER 2015 SESSION

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

14-BA-A4 BUILDING ENVIRONMENTAL CONTROL

Problem # 1 (25%)

The figure shows an air conditioning system with heat recovery exchanger. At a given moment (out of design operation), the data are as follows:



- Air temperature and humidity at state 3 — $t_3 = 23°C$ $\phi = 30$ %
- Air temperature and humidity ratio at state 2 (supply) — $t_2 = 30°C$ $w_2 = w_3$
- Exterior air — $t_{db} = t_E = 0°C$ $w_E = 0.75$ g/kg$_{dry\ air}$
- Fan air flow rate — $Q = 10$ m^3/s
- Exterior air flow rate — 20% of fan air flow rate
- Temperature rise across the supply fan — $\Delta t_{Va} = 2°C$
- Temperature rise across the return fan — negligible

Consider two cases presented below:

A. Heat recovery exchange is a rotary **sensible** wheel with effectiveness $\varepsilon = 0.7$
B. Heat recovery exchange is a rotary **enthalpy** wheel with effectiveness $\varepsilon = 0.85$

Shown the air states on the psychrometric chart and determine for cases A and B *(12%)*:

- Heating coil power *(6%)*;
- Steam rate injected by humidifier *(7%)*.

Problem # 2 (15%)

A multizones constant air volume system with zonal reheat coils serves the building with the air flow rates as follows:

Fan air flow rate	25 m^3/s
Exterior air flow rate	5 m^3/s

Winter design conditions are as follows:

Zones air temperature	22 °F
Zones relative humidity	30%
Exterior air temperature	-27 °F
Humidity ratio of exterior air	0.0004 $kg/kg_{dry\ air}$
Zones and system latent load	negligible

Use the psychrometric chart and determine for these design conditions:

Steam rate injected by humidifier in : *kg_{steam}/h (15 %)*

Problème # 3 (15%)

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

Fan air flow rate	20 000 cfm (9.0 m^3/s)
Fan speed	1800 rpm

The electric heating coil heats this supply air (100% exterior air) up to 18 ^oC (64.4 ^oF). It is provided to corridors of an apartment building 24/24 daily.

It is proposed to the building manager to reduce the airflow rate up to 50% of current flow during nights (23 h to 6h00). Two scenarios are considered:

A. using a discharge damper that the installation cost is \$ 2, 000.
B. using a variable speed drive that the installation cost is \$ 3,000.

Determine for two scenarios above, the energy savings due to:

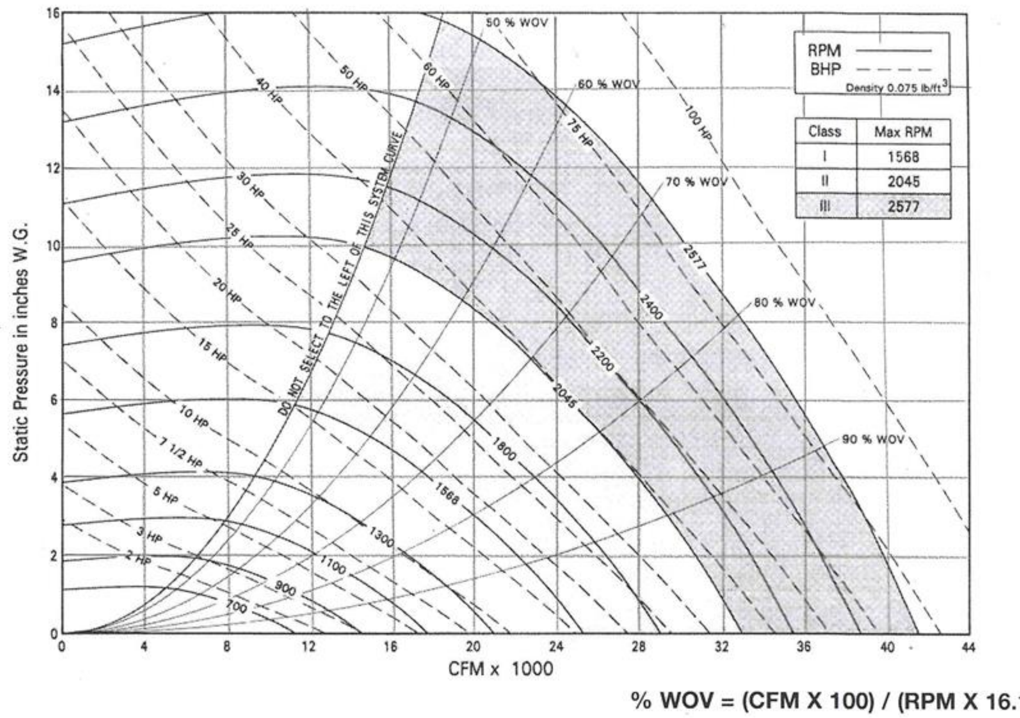
a) the fan air flow rate change (*2x4.5%*);
b) the outside air heating decrease (*2x3%*).

The data to be applied are the following:

- Heating degree-days (base 18 °C (64.4 F)) for 23 h to 6h00 period — 2060 (3708 ^oF)
- Air density — 1.2 kg/m^3

- Specific heat of air 1.0 kJ/kg^{o}C
- Average price of kWh ¢ 6.5

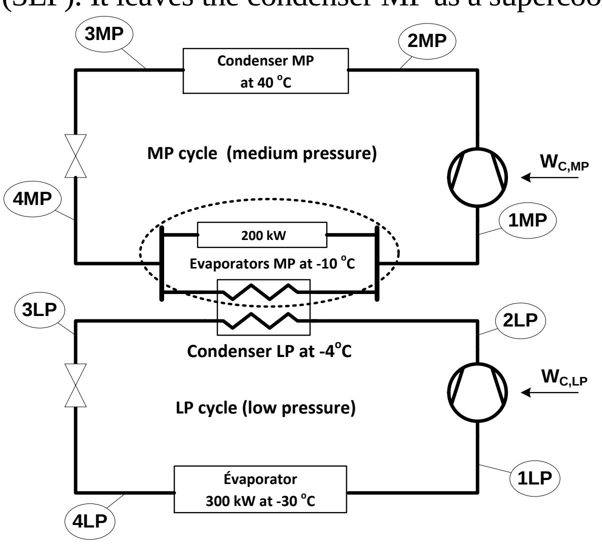
1 m^3/s = 2119 cfm 1 HP = 0.746 kW



Problem # 4 (25%)

The figure shows a cascade refrigeration system with R-507 as refrigerant. The cooling capacity of evaporators and evaporation temperatures are indicated on the attached figure. The compressors used in the cycle are isentropic.

The evaporation and condensation temperatures of R-507 are also indicated on the figure. The R-507 leaves the evaporators as a saturated vapor (1LP and 1MP) and the condenser LP as a saturated liquid (3LP). It leaves the condenser MP as a supercooled liquid at 34^{o}C (3MP).



Show the cycles on the attached R-507 diagram (*5%*) and determine:

a) Heat rejected by the LP condenser (*4%*);
b) The R-507 flow rates of MP and LP cycles (*7%*);
c) COPs (coefficients of performance) of LP and MP cycles and COP of cascade refrigeration cycle (*9%*).

Problem # 5 (20%)

The building cooling load ($\dot{Q}_{actuel}$) varies with the exterior air temperature as follow :

- It is of 875 tons (3080 kW) at 95 ^{o}F (35 ^{o}C)
- It is of 0 ton (0 kW) at 55 ^{o}F (13 ^{o}C)

Two scenarios are proposed to provide the air conditioning of the building.

Scenario A – the centrifugal chiller used has a cooling nominal capacity ($\dot{Q}_{nom}$) of 925 tons (3250 kW) ;

Scenario B – three (3) centrifugal chillers are used to provide air conditioning of the building. Each chiller has a cooling nominal capacity ($\dot{Q}_{nom}$) of 300 tons (1055 kW). The chiller operation strategy prioritizes the operation at full chiller load.

The chiller power input ($\dot{W}_{in}$) is expressed in terms of PLR as follows:

$$\dot{W}_{in} = \dot{W}_{in,nom} * \dot{Q}_{nom} * [A + B*(PLR) + C*(PLR)^2]$$

where PLR is a Part Load Ratio and the chiller-specific part-load coefficients A, B, C, are given in the table below.

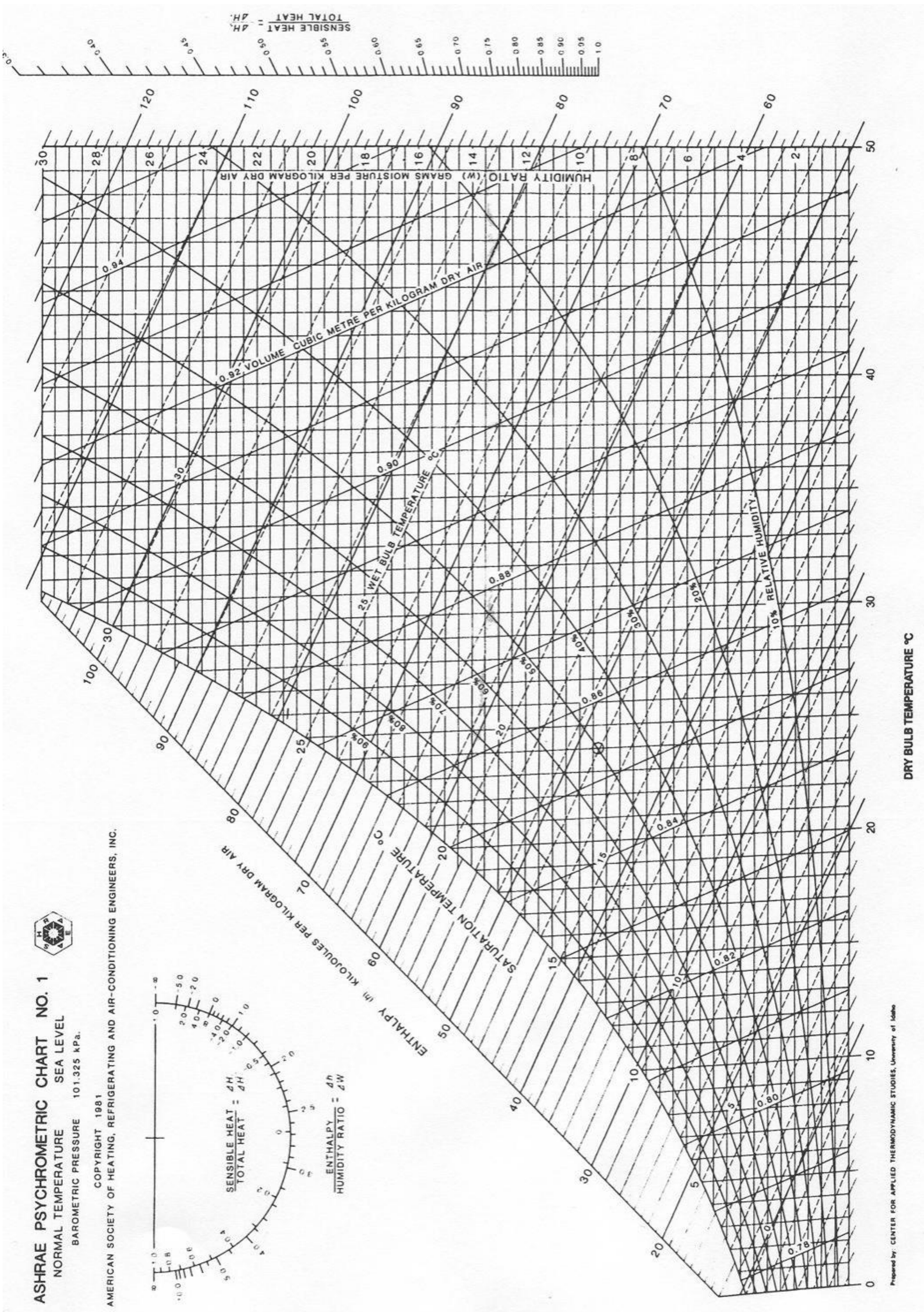
	The chiller nominal power input ($\dot{W}_{in,nom}$)	A	B	C
Scenario A	0.692 kW/ton	0.201	0.555	0.221
Scenario B	0.673 kW/ton	0.201	0.602	0.185

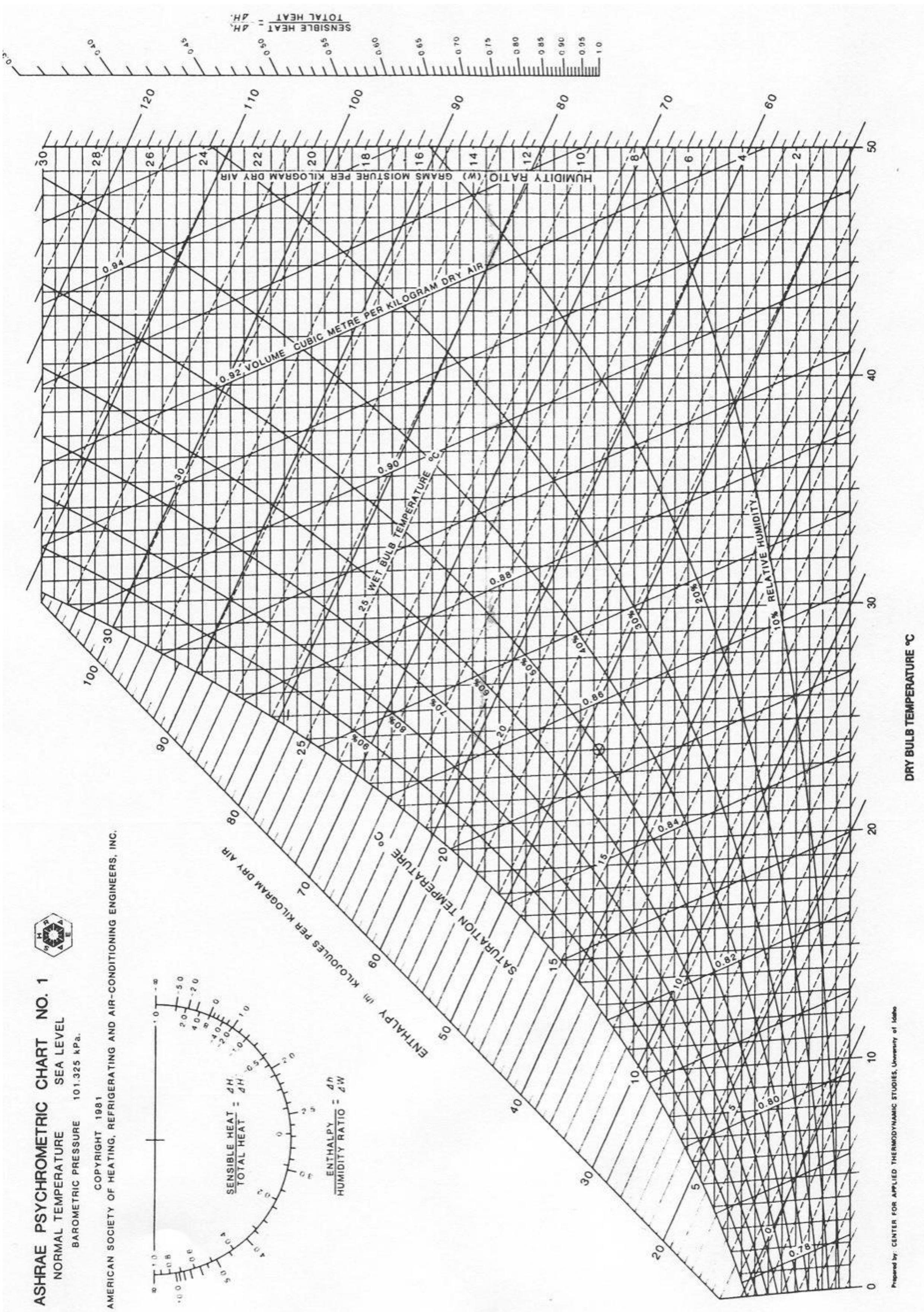
For the **both scenarios (A and B)**, determine:

a) The chiller electric energy consumption for the exterior (BIN) temperature of **75 and 90 ^{o}F** if the numbers of hours (N_{BIN}) for these temperatures are respectively of **500 and 20** *(15%);*

Determine, for the **scenario A** :

b) The chiller COP coefficient for each BIN temperature *(5%)*.


ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa.
COPYRIGHT 1981
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho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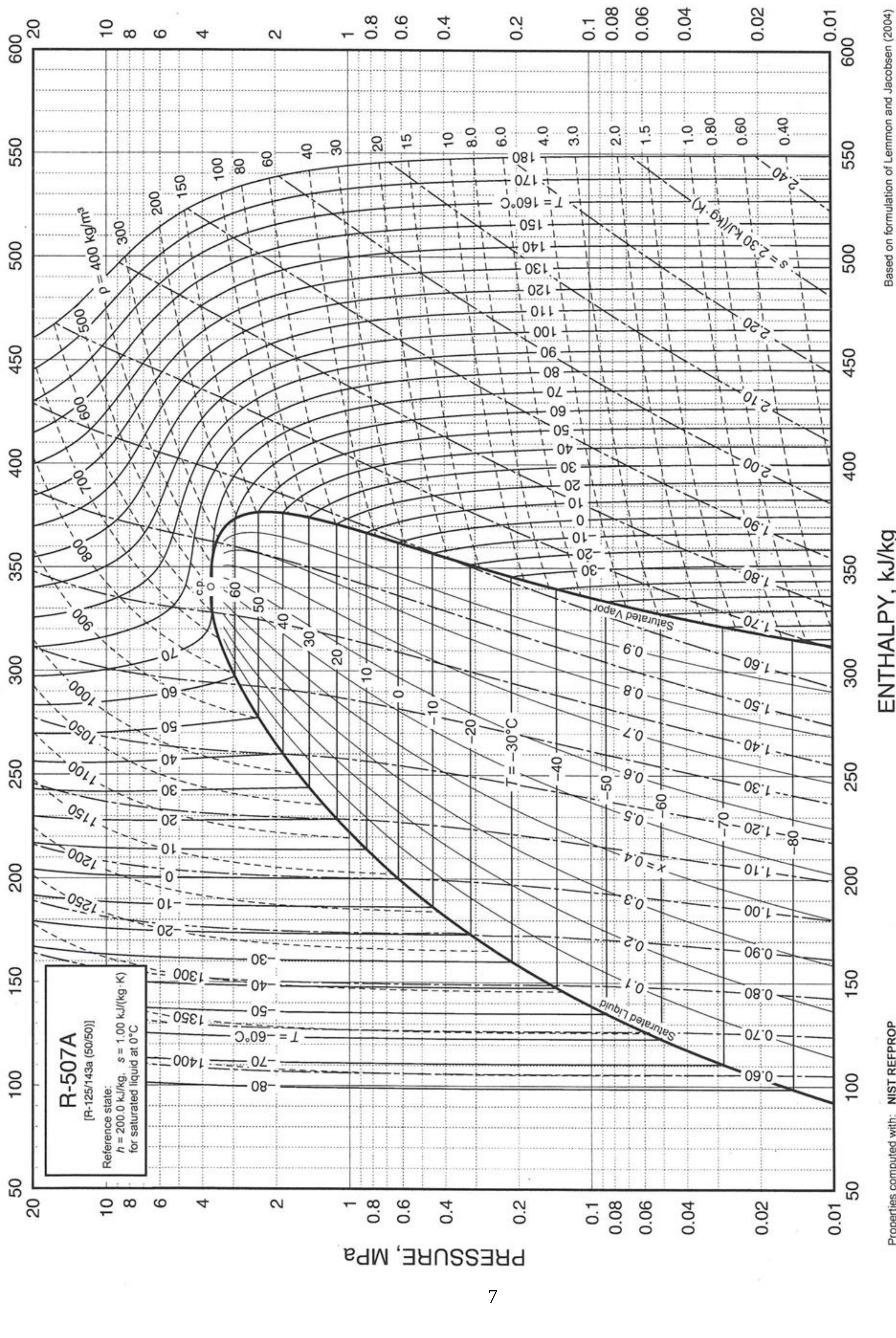

Fig. 15 Pressure-Enthalpy Diagram for Refrigerant 507A

Refrigerant 507A [R-125/143[a] (50/50)] Properties of Saturated Liquid and Saturated Vapor

Temp.,* °C	Pressure,** MPa	Density, kg/m³ Liquid	Volume, m³/kg Vapor	Enthalpy, kJ/kg Liquid	Enthalpy, kJ/kg Vapor	Entropy, kJ/(kg·K) Liquid	Entropy, kJ/(kg·K) Vapor	Specific Heat c_p, kJ/(kg·K) Liquid	Specific Heat c_p, kJ/(kg·K) Vapor	c_p/c_v Vapor	Velocity of Sound, m/s Liquid	Velocity of Sound, m/s Vapor	Viscosity, µPa·s Liquid	Viscosity, µPa·s Vapor	Thermal Cond., mW/(m·K) Liquid	Thermal Cond., mW/(m·K) Vapor	Surface Tension, mN/m	Temp.,* °C
−100	0.00295	1476.9	4.92920	74.41	303.90	0.4323	1.7579	1.219	0.618	1.164	1046	129.6	—	—	124.6	5.77	18.35	−100
−95	0.00458	1461.7	3.25360	80.48	306.85	0.4669	1.7377	1.210	0.631	1.162	1000	131.2	784.2	7.29	121.7	6.06	17.88	−95
−90	0.00693	1446.8	2.20850	86.51	309.83	0.5003	1.7197	1.205	0.644	1.161	960	132.6	701.5	7.49	118.8	6.36	17.41	−90
−85	0.01019	1431.9	1.53750	92.53	312.83	0.5327	1.7036	1.203	0.658	1.159	925	134.0	631.9	7.68	116.1	6.67	16.92	−85
−80	0.01464	1417.1	1.09510	98.54	315.85	0.5642	1.6893	1.203	0.672	1.159	892	135.4	572.7	7.88	113.4	6.99	16.43	−80
−75	0.02058	1402.3	0.79638	104.57	318.88	0.5950	1.6766	1.205	0.686	1.158	862	136.6	521.7	8.07	110.8	7.31	15.92	−75
−70	0.02836	1387.4	0.59012	110.60	321.92	0.6250	1.6652	1.208	0.701	1.158	833	137.8	477.4	8.27	108.2	7.63	15.40	−70
−65	0.03837	1372.5	0.44482	116.66	324.96	0.6545	1.6552	1.213	0.716	1.159	806	138.9	438.5	8.46	105.7	7.96	14.88	−65
−60	0.05105	1357.4	0.34056	122.74	328.00	0.6833	1.6463	1.220	0.732	1.160	779	139.8	404.3	8.65	103.2	8.30	14.34	−60
−55	0.06688	1342.3	0.26444	128.87	331.03	0.7116	1.6384	1.227	0.749	1.161	754	140.7	373.8	8.84	100.8	8.65	13.80	−55
−50	0.08638	1326.9	0.20801	135.03	334.05	0.7395	1.6314	1.235	0.766	1.164	729	141.4	346.5	9.02	98.4	9.00	13.24	−50
−48	0.09533	1320.7	0.18960	137.51	335.25	0.7505	1.6288	1.239	0.773	1.165	719	141.6	336.4	9.10	97.4	9.14	13.02	−48
−46.74[b]	0.10132	1316.8	0.17902	139.07	336.01	0.7574	1.6273	1.241	0.777	1.166	713	141.8	330.2	9.15	96.8	9.23	12.88	−46.74
−46	0.10499	1314.5	0.17313	139.99	336.45	0.7615	1.6264	1.243	0.780	1.166	709	141.9	326.7	9.17	96.5	9.28	12.80	−46
−44	0.11541	1308.2	0.15836	142.48	337.65	0.7724	1.6241	1.247	0.787	1.167	699	142.1	317.4	9.25	95.5	9.42	12.57	−44
−42	0.12662	1301.9	0.14510	144.99	338.84	0.7832	1.6219	1.251	0.795	1.169	690	142.3	308.4	9.32	94.6	9.57	12.34	−42
−40	0.13867	1295.6	0.13317	147.49	340.03	0.7940	1.6198	1.255	0.803	1.170	680	142.5	299.8	9.40	93.7	9.71	12.12	−40
−38	0.15159	1289.2	0.12240	150.01	341.21	0.8047	1.6178	1.259	0.810	1.172	670	142.6	291.4	9.47	92.7	9.86	11.89	−38
−36	0.16542	1282.8	0.11268	152.54	342.38	0.8153	1.6159	1.264	0.818	1.174	661	142.7	283.4	9.55	91.8	10.01	11.66	−36
−34	0.18022	1276.3	0.10388	155.08	343.55	0.8260	1.6141	1.269	0.826	1.176	651	142.8	275.7	9.62	90.9	10.16	11.42	−34
−32	0.19602	1269.7	0.09590	157.63	344.72	0.8365	1.6123	1.274	0.835	1.178	642	142.9	268.3	9.70	90.0	10.31	11.19	−32
−30	0.21287	1263.2	0.08865	160.18	345.88	0.8470	1.6107	1.279	0.843	1.180	632	142.9	261.1	9.77	89.1	10.46	10.96	−30
−28	0.23081	1256.5	0.08205	162.75	347.03	0.8575	1.6092	1.284	0.852	1.183	622	143.0	254.1	9.85	88.2	10.61	10.72	−28
−26	0.24989	1249.8	0.07604	165.33	348.17	0.8679	1.6077	1.289	0.861	1.186	613	143.0	247.4	9.93	87.3	10.77	10.49	−26
−24	0.27016	1243.1	0.07055	167.92	349.30	0.8783	1.6063	1.295	0.870	1.188	603	142.9	240.9	10.00	86.5	10.93	10.25	−24
−22	0.29167	1236.3	0.06553	170.52	350.43	0.8886	1.6049	1.301	0.879	1.191	594	142.9	234.5	10.08	85.6	11.08	10.02	−22
−20	0.31446	1229.4	0.06094	173.13	351.54	0.8989	1.6037	1.307	0.888	1.195	584	142.8	228.4	10.15	84.7	11.24	9.78	−20
−18	0.33858	1222.5	0.05673	175.76	352.65	0.9091	1.6024	1.313	0.898	1.198	575	142.7	222.5	10.23	83.8	11.40	9.54	−18
−16	0.36408	1215.4	0.05286	178.39	353.75	0.9193	1.6013	1.319	0.908	1.202	566	142.5	216.8	10.31	83.0	11.56	9.30	−16
−14	0.39102	1208.4	0.04931	181.04	354.83	0.9295	1.6001	1.326	0.918	1.206	556	142.3	211.2	10.39	82.1	11.73	9.06	−14
−12	0.41945	1201.2	0.04603	183.71	355.91	0.9397	1.5991	1.333	0.929	1.210	547	142.1	205.7	10.47	81.2	11.89	8.82	−12
−10	0.44941	1193.9	0.04301	186.39	356.97	0.9498	1.5980	1.340	0.940	1.214	537	141.9	200.5	10.55	80.4	12.06	8.58	−10
−8	0.48096	1186.6	0.04023	189.08	358.02	0.9599	1.5971	1.348	0.951	1.219	528	141.6	195.3	10.63	79.5	12.23	8.34	−8
−6	0.51416	1179.2	0.03765	191.78	359.06	0.9699	1.5961	1.355	0.962	1.224	518	141.3	190.3	10.71	78.7	12.41	8.10	−6
−4	0.54906	1171.7	0.03527	194.51	360.08	0.9800	1.5952	1.363	0.974	1.230	508	141.0	185.5	10.79	77.8	12.58	7.86	−4
−2	0.58571	1164.0	0.03306	197.25	361.08	0.9900	1.5943	1.372	0.987	1.236	499	140.6	180.7	10.88	77.0	12.76	7.62	−2
0	0.62417	1156.3	0.03101	200.00	362.07	1.0000	1.5934	1.381	0.999	1.242	489	140.2	176.1	10.97	76.2	12.96	7.37	0
2	0.66450	1148.5	0.02910	202.77	363.05	1.0100	1.5925	1.390	1.012	1.249	480	139.8	171.6	11.05	75.3	13.16	7.13	2
4	0.70676	1140.5	0.02733	205.56	364.00	1.0199	1.5917	1.399	1.026	1.256	470	139.3	167.2	11.14	74.5	13.36	6.89	4
6	0.75099	1132.4	0.02568	208.37	364.94	1.0299	1.5908	1.410	1.040	1.264	460	138.8	162.9	11.23	73.7	13.57	6.65	6
8	0.79728	1124.2	0.02415	211.20	365.85	1.0398	1.5900	1.420	1.055	1.272	451	138.2	158.7	11.33	72.8	13.79	6.41	8
10	0.84566	1115.9	0.02271	214.04	366.75	1.0498	1.5891	1.431	1.071	1.282	441	137.6	154.5	11.43	72.0	14.01	6.17	10
12	0.89622	1107.4	0.02138	216.91	367.61	1.0597	1.5883	1.443	1.088	1.291	431	137.0	150.5	11.52	71.2	14.24	5.93	12
14	0.94900	1098.7	0.02012	219.80	368.46	1.0696	1.5874	1.455	1.105	1.302	422	136.3	146.6	11.63	70.4	14.49	5.69	14
16	1.00410	1089.9	0.01895	222.71	369.28	1.0796	1.5865	1.468	1.124	1.314	412	135.6	142.7	11.73	69.6	14.75	5.45	16
18	1.06150	1080.9	0.01785	225.65	370.07	1.0895	1.5856	1.482	1.144	1.327	402	134.9	138.9	11.86	68.8	15.01	5.21	18
20	1.12140	1071.7	0.01683	228.61	370.83	1.0995	1.5846	1.497	1.165	1.341	392	134.1	135.1	11.97	67.9	15.29	4.97	20
22	1.18370	1062.4	0.01586	231.60	371.55	1.1094	1.5836	1.513	1.188	1.356	382	133.2	131.5	12.09	67.1	15.58	4.74	22
24	1.24860	1052.8	0.01495	234.61	372.25	1.1194	1.5826	1.530	1.212	1.372	372	132.3	127.9	12.22	66.3	15.89	4.50	24
26	1.31610	1043.0	0.01410	237.66	372.91	1.1294	1.5815	1.548	1.239	1.391	362	131.4	124.3	12.35	65.5	16.21	4.27	26
28	1.38640	1032.9	0.01329	240.73	373.52	1.1394	1.5804	1.568	1.268	1.411	352	130.4	120.8	12.48	64.7	16.54	4.04	28
30	1.45940	1022.6	0.01253	243.84	374.10	1.1495	1.5792	1.589	1.299	1.433	341	129.3	117.4	12.62	63.9	16.90	3.81	30
32	1.53520	1011.9	0.01182	246.98	374.63	1.1595	1.5779	1.612	1.333	1.458	331	128.2	114.0	12.77	63.1	17.28	3.58	32
34	1.61400	1001.0	0.01114	250.16	375.11	1.1697	1.5765	1.637	1.371	1.485	321	127.1	110.6	12.93	62.2	17.68	3.35	34
36	1.69580	989.7	0.01050	253.39	375.54	1.1799	1.5750	1.664	1.413	1.516	310	125.9	107.3	13.10	61.4	18.12	3.12	36
38	1.78070	978.1	0.00989	256.65	375.91	1.1901	1.5734	1.695	1.459	1.551	300	124.6	104.0	13.28	60.6	18.58	2.90	38
40	1.86880	966.0	0.00932	259.96	376.22	1.2004	1.5717	1.729	1.511	1.591	289	123.2	100.7	13.47	59.8	19.09	2.68	40
42	1.96020	953.5	0.00877	263.33	376.46	1.2108	1.5698	1.767	1.570	1.636	278	121.8	97.5	13.68	59.0	19.63	2.47	42
44	2.05490	940.5	0.00825	266.74	376.61	1.2213	1.5678	1.811	1.638	1.689	267	120.4	94.3	13.90	58.1	20.23	2.25	44
46	2.15310	926.9	0.00776	270.23	376.68	1.2320	1.5655	1.860	1.716	1.750	256	118.8	91.0	14.14	57.3	20.89	2.04	46
48	2.25480	912.7	0.00728	273.78	376.66	1.2427	1.5631	1.918	1.807	1.823	245	117.2	87.8	14.41	56.5	21.62	1.83	48
50	2.36030	897.7	0.00683	277.41	376.52	1.2536	1.5603	1.985	1.915	1.910	233	115.5	84.6	14.70	55.7	22.43	1.63	50
55	2.64090	856.2	0.00578	286.91	375.54	1.2818	1.5519	2.225	2.304	2.228	203	110.8	76.4	15.59	53.6	24.98	1.15	55
60	2.94760	806.1	0.00480	297.28	373.26	1.3120	1.5401	2.677	3.060	2.855	171	105.5	67.7	16.86	51.7	28.77	0.70	60
65	3.28380	739.1	0.00384	309.30	368.44	1.3465	1.5215	3.940	5.190	4.625	135	99.3	57.9	18.93	50.7	35.54	0.31	65
70	3.65570	599.6	0.00260	328.32	353.47	1.4007	1.4740	31.960	44.630	36.780	92	90.7	42.0	25.07	63.2	67.27	0.02	70
70.62[c]	3.70500	490.8	0.00204	340.45	340.45	1.4358	1.4358	∞	∞	∞	0	0.0	—	—	—	—	0.00	70.62

*Temperatures on ITS-90 scale

**Small deviations from azeotropic behavior occur at some conditions; tabulated pressures are average of bubble and dew-point pressures

[b]Normal boiling point

[c]Critical point