Seat Number

King Mongkut's University of Technology Thonburi

1st semester midterm-examination, academic year 2013

ChE 241 Thermodynamics 1 — Sophomore, Dept. of Chem. Eng.

Date September 30, 2013 — Time 9.00 am. - 12.00 pm.

Instruction

1. This examination paper has 15 pages and 4 problems.
2. Answer the questions in the space provided. If you run out of space for an answer, continue on the back of the page.
3. Lecture notes and textbooks are not permitted.
4. A calculator must be complied with the university regulation.
5. Do not take the examination out of the examination room.
6. Ask for permission to leave the examination room when finish.
7. Turn in neat, step-by-step solutions with enough explanation for someone else to follow what you have done.

Highest punishment for dishonesty is the expulsion from the university

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Problem No.	1	2	3	4	Total
Student's score					
Full score	25	20	25	30	100

The examination is written by

Assoc. Prof. Dr.Anawat Sungpet
(Tel. 9222 ext. 217)

This examination has been evaluated by the department committee.

Anawat Sungpet

(Assoc. Prof. Dr.Anawat Sungpet)
(Head of the department)

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<u>Mass balance</u>

$$\frac{dm}{dt} = \sum_{j=1}^{J} \dot{m}_j$$

<u>First law of thermodynamics</u>

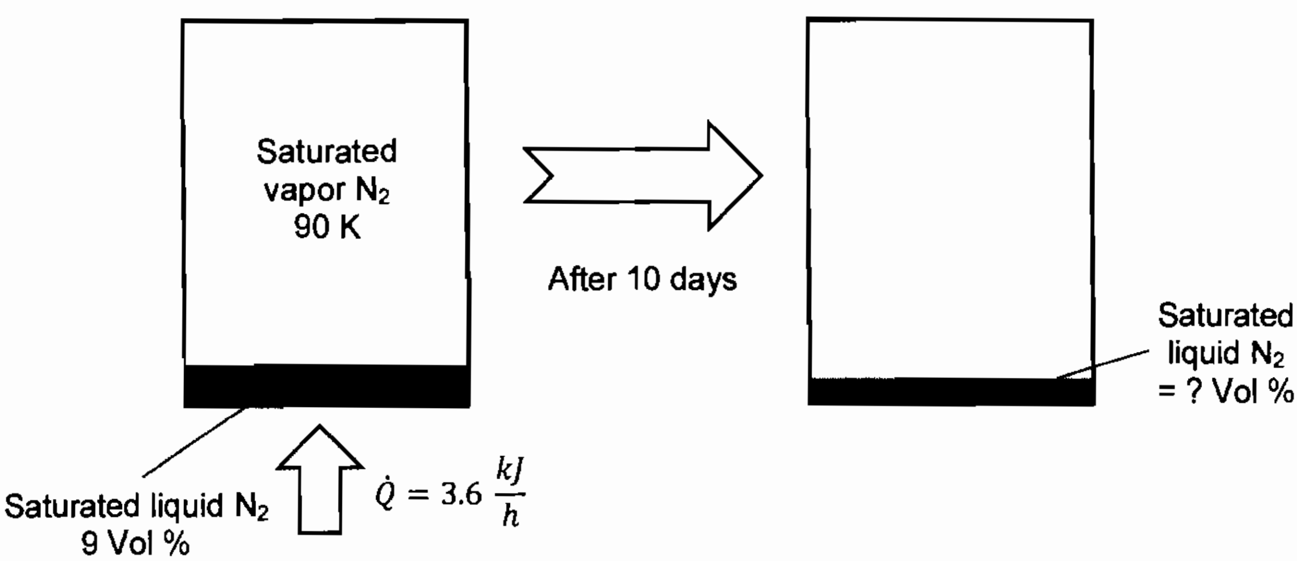
$$\frac{d\,(U + E_k + E_p)}{dt} = \sum_{j=1}^{J} \dot{m}_j\left(\hat{H} + \frac{v^2}{2} + gy\right) + \dot{Q} - \dot{W} \; : where \; \hat{H} = \hat{U} + P\hat{V}$$

<u>Entropy balance equation</u>

$$\frac{dS}{dt} = \sum_{j=1}^{J} \dot{m}_j \hat{S}_j + \frac{\dot{Q}}{T} + \dot{S}_P$$

<u>Problem 1</u> (25 points)

A 0.5 m^3-tank containing saturated nitrogen at 90 K is placed in a very cold storage room. Although the tank is insulated, there is still some heat transfer from the surroundings into the tank at the rate of 3.6 kJ/h. Initially, liquid nitrogen in the tank occupies 9 % of the tank volume. After 10 days, the pressure of nitrogen in the tank increases to 541.1 kPa. What is the liquid volume percent in the tank?



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Properties of saturated nitrogen

Temp. (K)	Press. (kPa)	SPECIFIC VOLUME, m³/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	INTERNAL ENERGY, kJ/kg Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapor u_g
85	229.1	0.001299	0.10018	0.10148	−106.55	165.20	58.65
90	360.8	0.001343	0.06477	0.06611	−96.06	156.76	60.70
95	541.1	0.001393	0.04337	0.04476	−85.35	147.60	62.25

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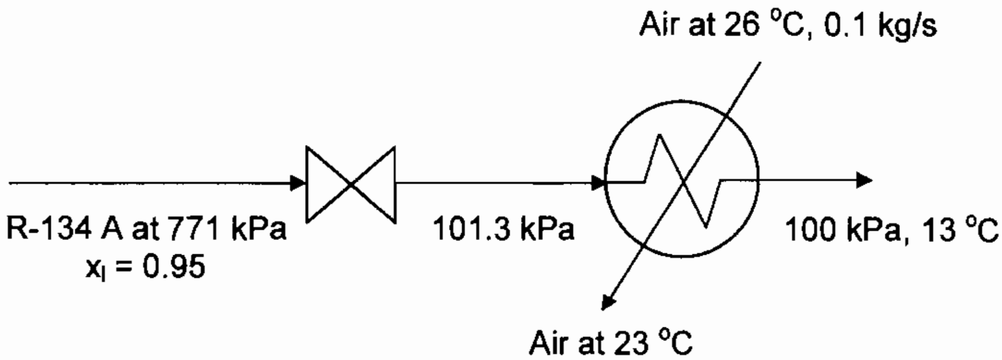
Problem 2 (20 points) R-134 A, a refrigerant, is expanded through a throttling valve from 771 kPa to 101.3 kPa. Before the expansion, the refrigerant is saturated with the liquid mass fraction (x_l) of 0.95. After the expansion, it flows into an evaporator and exchanges heat with air. The pressure and temperature of R-134 A when leaves the evaporator are 100 kPa and 13 °C. Air at 26 °C flows into the evaporator at the flow rate of 0.1 kg/s and leaves at the temperature of 23 °C. The specific heat capacity of air is approximately 1.005 kJ/(kg.K). Determine the mass flow rate of R-134 A.



Properties of saturated R-134 A

Temp. (°C)	Press. (kPa)	ENTHALPY, kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	ENTROPY, kJ/kg-K Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
30	771.0	241.79	173.29	415.08	[illegible]	0.5716	1.7153
35	887.6	249.10	168.42	[illegible]	[illegible]	[illegible]	[illegible]
40	1017.0	256.54	163.28	419.82	[illegible]	0.5214	[illegible]

Properties of superheated R-134 A

Temp. (°C)	v (m³/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)	v (m³/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
	50 kPa (−40.67)				100 kPa (−26.54)			
Sat.	0.36889	354.61	373.06	1.7629	0.19257	362.73	381.98	1.7456
−20	0.40507	368.57	388.82	1.8279	0.19860	367.36	387.22	1.7665
−10	0.42222	375.53	396.64	1.8582	0.20765	374.51	395.27	1.7978
0	0.43921	382.63	404.59	1.8878	0.21652	381.76	403.41	1.8281
10	0.45608	389.90	412.70	1.9170	0.22527	389.14	411.67	1.8578
20	0.47287	397.32	420.96	1.9456	0.23392	396.66	420.05	1.8869

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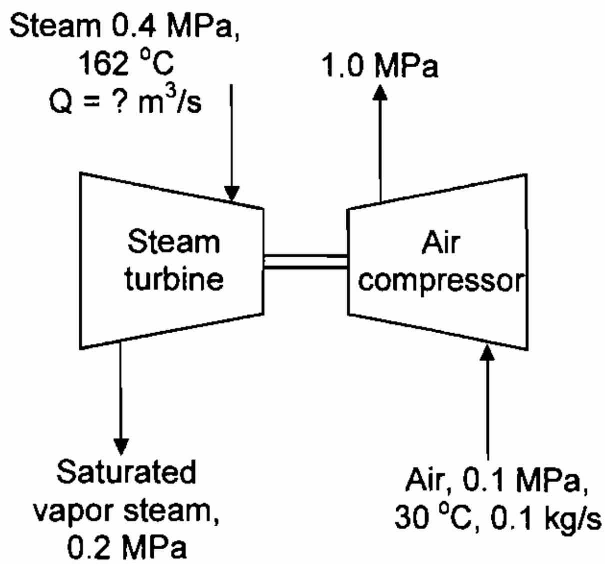
Problem 3 (25 points)

Steam at the pressure of 0.4 MPa and 162 °C is expanded through an adiabatic turbine to supply saturated vapor steam at 0.2 MPa to an industrial process. The power obtained from the turbine is used to drive an adiabatic air compressor. Air at ambient conditions, 0.1 MPa and 30 °C, is supplied to the compressor at the rate of 0.1 kg/s. It is compressed to 1.0 MPa. The efficiency of the compressor is 75 %. By using the enthalpy-entropy diagram for dry air and steam tables, determine the *volumetric flow rate of the inlet steam*.



Saturated steam table (Pressure table)

		Density, kg/m³		Enthalpy, kJ/kg			Entropy, kJ/(kg·K)			Volume, cm³/g	
p, MPa	t, °C	ρ_L	ρ_V	h_L	h_V	Δh	s_L	s_V	Δs	v_L	v_V
0.15	111.349	949.92	0.862 60	467.13	2693.1	2226.0	1.4337	7.2230	5.7893	1.052 73	1159.3
0.16	113.297	948.41	0.916 29	475.38	2696.0	2220.7	1.4551	7.2014	5.7463	1.054 40	1091.4
0.17	115.148	946.97	0.969 76	483.22	2698.8	2215.6	1.4753	7.1812	5.7059	1.056 00	1031.2
0.18	116.911	945.57	1.0230	490.70	2701.4	2210.7	1.4945	7.1621	5.6676	1.057 56	977.47
0.19	118.596	944.23	1.0761	497.85	2703.9	2206.0	1.5127	7.1440	5.6313	1.059 06	929.24
0.20	120.210	942.94	1.1291	504.70	2706.2	2201.5	1.5302	7.1269	5.5967	1.060 52	885.68
0.21	121.759	941.68	1.1818	511.29	2708.5	2197.2	1.5469	7.1106	5.5638	1.061 93	846.14
0.22	123.250	940.47	1.2345	517.63	2710.6	2193.0	1.5628	7.0951	5.5323	1.063 30	810.07
0.23	124.686	939.28	1.2869	523.74	2712.7	2188.9	1.5782	7.0803	5.5021	1.064 64	777.04
0.24	126.072	938.13	1.3393	529.64	2714.6	2185.0	1.5930	7.0661	5.4731	1.065 94	746.68

Superheated steam table

0.40 MPa (t_s = 143.608 °C)					0.45 MPa (t_s = 147.903 °C)					0.50 MPa (t_s = 151.831 °C)			
v	ρ	h	s	t, °C	v	ρ	h	s	t, °C	v	ρ	h	s
1.083 55	922.89	604.65	1.7765	t_s(L)	1.088 19	918.96	623.14	1.8205	t_s(L)	1.092 55	915.29	640.09	1.8604
462.38	2.1627	2738.1	6.8955	t_s(V)	413.90	2.4161	2743.4	6.8560	t_s(V)	374.81	2.6680	2748.1	6.8207
470.88	2.1237	2752.8	6.9306	150	416.42	2.4014	2748.3	6.8678	150	1.090 49	917.02	632.19	1.8418
477.44	2.0945	2764.1	6.9571	155	422.37	2.3676	2759.9	6.8950	155	378.27	2.6436	2755.7	6.8384
483.93	2.0664	2775.2	6.9829	160	428.25	2.3351	2771.3	6.9215	160	383.66	2.6064	2767.4	6.8656
490.37	2.0393	2786.2	7.0081	165	434.06	2.3038	2782.6	6.9473	165	388.99	2.5708	2778.9	6.8919
496.76	2.0131	2797.1	7.0329	170	439.83	2.2736	2793.7	6.9725	170	394.26	2.5364	2790.2	6.9176

List of symbols

h = enthalpy (kJ/kg), p = pressure (MPa), s = entropy (kJ/kg.K),
t = temperature (°C), v = specific volume (cm³/g)

Subscripts

L = liquid at saturation, V = vapor at saturation, s = saturation

Greek letters

Δ = property change on vaporization, ρ = density (kg/m³)

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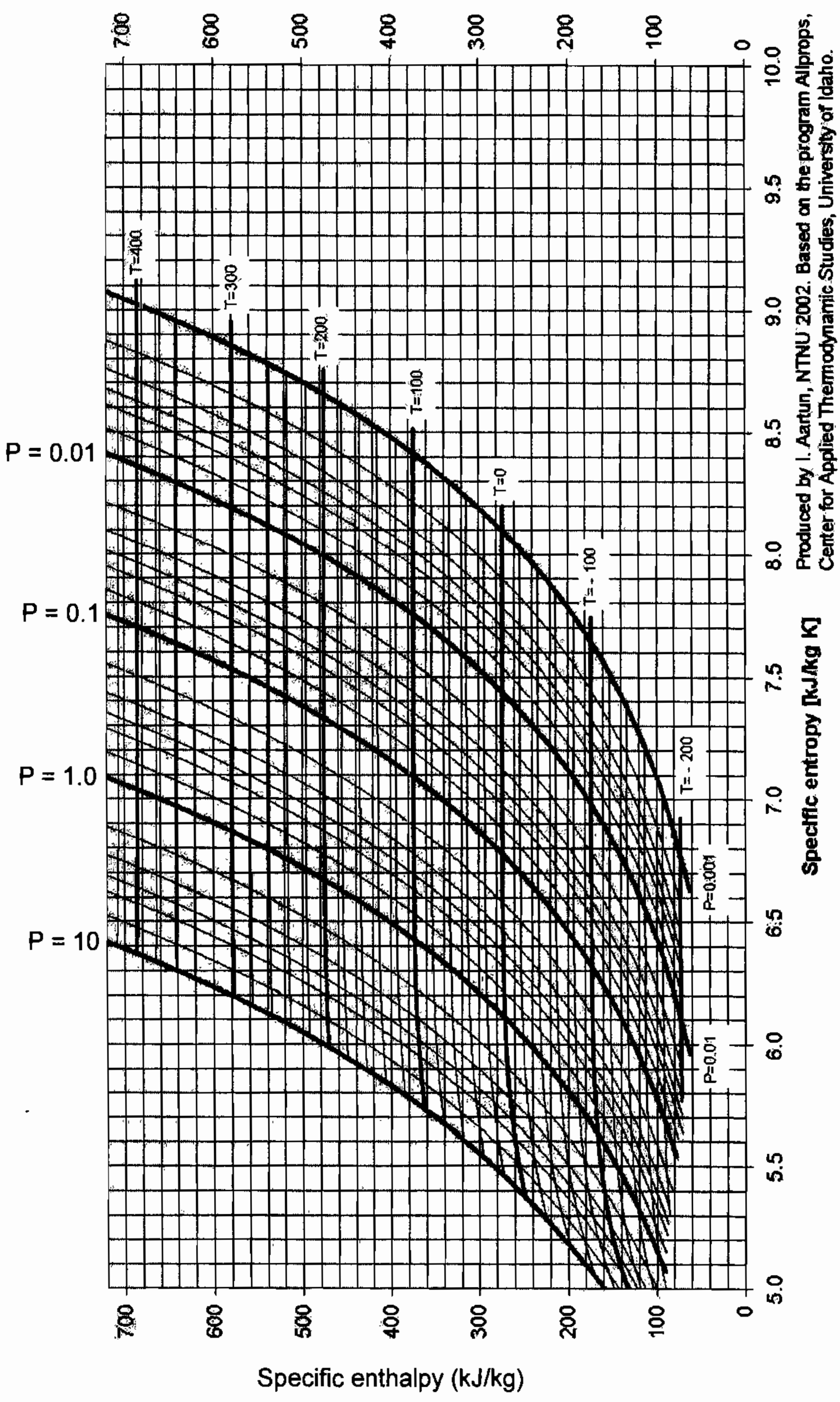

Enthalpy-Entropy diagram for dry air, T in °C, P in MPa

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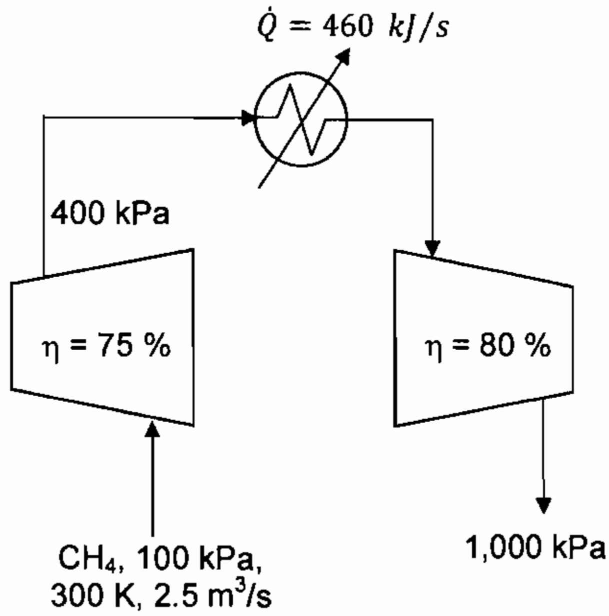
Problem 4 (30 points)

Methane flows into an adiabatic compressor at the rate of 2.5 m^3/s and is compressed from 100 kPa and 300 K to 400 kPa. The efficiency of the compressor is 75 %. Methane is subsequently cooled by an isobaric inter-cooler that removes heat from the methane at the rate of 460 kJ/s. The second adiabatic compressor increases the pressure of methane to 1,000 kPa. Its efficiency is 80 %. Determine

4.1. The total power requirement (the power of the first compressor plus the power of the second compressor)

4.2. The total power requirement if the inter-cooler is not used.



Superheated methane properties

Temp. (K)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
	100 kPa (111.50 K)				200 kPa (120.61 K)			
Sat.	0.55665	167.90	223.56	9.5084	0.29422	179.30	238.14	9.2918
125	0.63126	190.21	253.33	9.7606	0.30695	186.80	248.19	9.3736
150	0.76586	230.18	306.77	10.1504	0.37700	227.91	303.31	9.7759
175	0.89840	269.72	359.56	10.4759	0.44486	268.05	357.02	10.1071
200	1.02994	309.20	412.19	10.7570	0.51165	307.88	410.21	10.3912
225	1.16092	348.90	464.99	11.0058	0.57786	347.81	463.38	10.6417
250	1.29154	389.12	518.27	11.2303	0.64370	388.19	516.93	10.8674
275	1.42193	430.17	572.36	11.4365	0.70931	429.36	571.22	11.0743
300	1.55215	472.36	627.58	11.6286	0.77475	471.65	626.60	11.2670
325	1.68225	516.00	684.23	11.8100	0.84008	515.37	683.38	11.4488
350	1.81226	561.34	742.57	11.9829	0.90530	560.77	741.83	11.6220
375	1.94220	608.58	802.80	12.1491	0.97046	608.07	802.16	11.7885
400	2.07209	657.89	865.10	12.3099	1.03557	657.41	864.53	11.9495
425	2.20193	709.36	929.55	12.4661	1.10062	708.92	929.05	12.1059

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Superheated methane properties (Continued)

Temp. (K)	*v* (m³/kg)	*u* (kJ/kg)	*h* (kJ/kg)	*s* (kJ/kg-K)	*v* (m³/kg)	*u* (kJ/kg)	*h* (kJ/kg)	*s* (kJ/kg-K)
	400 kPa (131.42 K)				600 kPa (138.72 K)			
Sat.	0.15427	191.01	252.72	9.0754	0.10496	197.54	260.51	8.9458
150	0.18233	223.16	296.09	9.3843	0.11717	218.08	288.38	9.1390
175	0.21799	264.61	351.81	9.7280	0.14227	261.03	346.39	9.4970
200	0.25246	305.19	406.18	10.0185	0.16603	302.44	402.06	9.7944
225	0.28631	345.61	460.13	10.2726	0.18911	343.37	456.84	10.0525
250	0.31978	386.32	514.23	10.5007	0.21180	384.44	511.52	10.2830
275	0.35301	427.74	568.94	10.7092	0.23424	426.11	566.66	10.4931
300	0.38606	470.23	624.65	10.9031	0.25650	468.80	622.69	10.6882
325	0.41899	514.10	681.69	11.0857	0.27863	512.82	680.00	10.8716
350	0.45183	559.63	740.36	11.2595	0.30067	558.48	738.88	11.0461
375	0.48460	607.03	800.87	11.4265	0.32264	605.99	799.57	11.2136
400	0.51731	656.47	863.39	11.5879	0.34456	655.52	862.25	11.3754
425	0.54997	708.05	928.04	11.7446	0.36643	707.18	927.04	11.5324
450	0.58260	761.85	994.89	11.8974	0.38826	761.05	994.00	11.6855
475	0.61520	817.89	1063.97	12.0468	0.41006	817.15	1063.18	11.8351
500	0.64778	876.18	1135.29	12.1931	0.43184	875.48	1134.59	11.9816
525	0.68033	936.67	1208.81	12.3366	0.45360	936.03	1208.18	12.1252
	800 kPa (144.40 K)				1000 kPa (149.13 K)			
Sat.	0.07941	201.70	265.23	8.8505	0.06367	204.45	268.12	8.7735
150	0.08434	212.53	280.00	8.9509	0.06434	206.28	270.62	8.7902
175	0.10433	257.30	340.76	9.3260	0.08149	253.38	334.87	9.1871
200	0.12278	299.62	397.85	9.6310	0.09681	296.73	393.53	9.5006
225	0.14050	341.10	453.50	9.8932	0.11132	338.79	450.11	9.7672
250	0.15781	382.53	508.78	10.1262	0.12541	380.61	506.01	10.0028
275	0.17485	424.47	564.35	10.3381	0.13922	422.82	562.04	10.2164
300	0.19172	467.36	620.73	10.5343	0.15285	465.91	618.76	10.4138
325	0.20845	511.55	678.31	10.7186	0.16635	510.26	676.61	10.5990
350	0.22510	557.33	737.41	10.8938	0.17976	556.18	735.94	10.7748
375	0.24167	604.95	798.28	11.0617	0.19309	603.91	797.00	10.9433
400	0.25818	654.57	861.12	11.2239	0.20636	653.62	859.98	11.1059
425	0.27465	706.31	926.03	11.3813	0.21959	705.44	925.03	11.2636
450	0.29109	760.24	993.11	11.5346	0.23279	759.44	992.23	11.4172
475	0.30749	816.40	1062.40	11.6845	0.24595	815.66	1061.61	11.5672
500	0.32387	874.79	1133.89	11.8311	0.25909	874.10	1133.19	11.7141
525	0.34023	935.38	1207.56	11.9749	0.27221	934.73	1206.95	11.8580
550	0.35657	998.14	1283.45	12.1161	0.28531	997.53	1282.84	11.9992