Thermodynamics, MECH2010 Fall 2018, Test 3a 2018/12/11

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Name Chinese________________ Name, Pinyin _________________ Student number soln key

Name, English________________

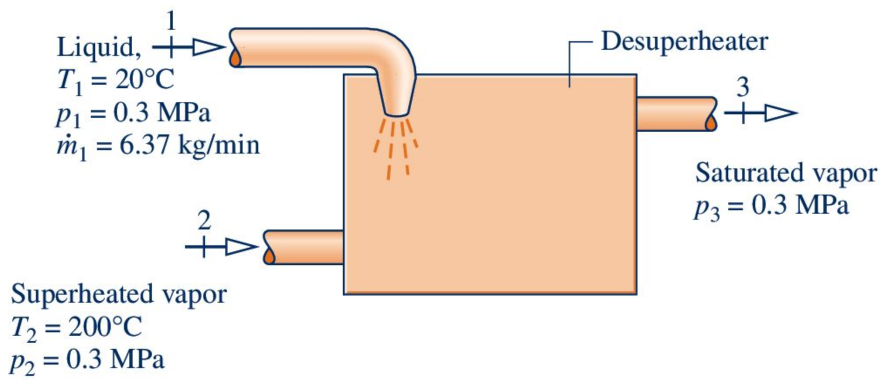
1	2	3	4	5	6	Total
2	13	15	25	25	20	100

Problem 1 (2 pts)

Carnot Cycle is a theoretical thermodynamics cycle that provides the maximum limit on the efficiency that any classical thermodynamic engine can achieve during the conversion of heat into work, or conversely, the maximum performance of a refrigeration system in creating a temperature difference by the application of work to the system.

Hi Bella, this problem can be on the front page, left hand side, underneath of all the writing since is just fill in the blank (the half sheet).

Problem 2 (13 pts)
For the desuperheater shown, liquid water at state 1 is injected into a stream of superheated vapor entering at state 2. As a result, saturated vapor exits at state 3. Data for steady state operation are shown on the figure. Ignoring stray heat transfer and kinetic and potential energy effects, determine the mass flow rate of the incoming superheated vapor, in kg/min. 4.8



mass balance : $\dot{m}_3 = \dot{m}_1 + \dot{m}_2 \qquad (1)$

Hi Bella, this problem can be on the right-hand-side of the front page (the half sheet). Rest of the problems will need full sheet of paper

Energy balance :

$$0 = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}_1\left[h_1 + \cancel{\frac{V_1^2}{2}} + \cancel{g z_1}\right] + \dot{m}_2\left[h_2 + \cancel{\frac{V_2^2}{2}} + \cancel{g z_2}\right] - \dot{m}_3\left[h_3 + \cancel{\frac{V_3^2}{2}} + \cancel{g z_3}\right]$$

$$0 = \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3 \qquad (2)$$

combine (1) & (2)

$$0 = \dot{m}_1 h_1 + \dot{m}_2 h_2 - (\dot{m}_1 + \dot{m}_2) h_3 \Rightarrow \dot{m}_2 = \dot{m}_1 \left[\frac{h_3 - h_1}{h_2 - h_3}\right]$$

A-2: $h_1 \sim 84$ kJ/kg A-3: $h_3 \sim 2725$ kJ/kg

A-4: $h_2 \sim 2866$ kJ/kg

$$\dot{m}_2 = 6.37 \frac{kg}{min}\left[\frac{2725-84}{2866-2725}\right] = \boxed{120.0 \frac{kg}{min}}$$

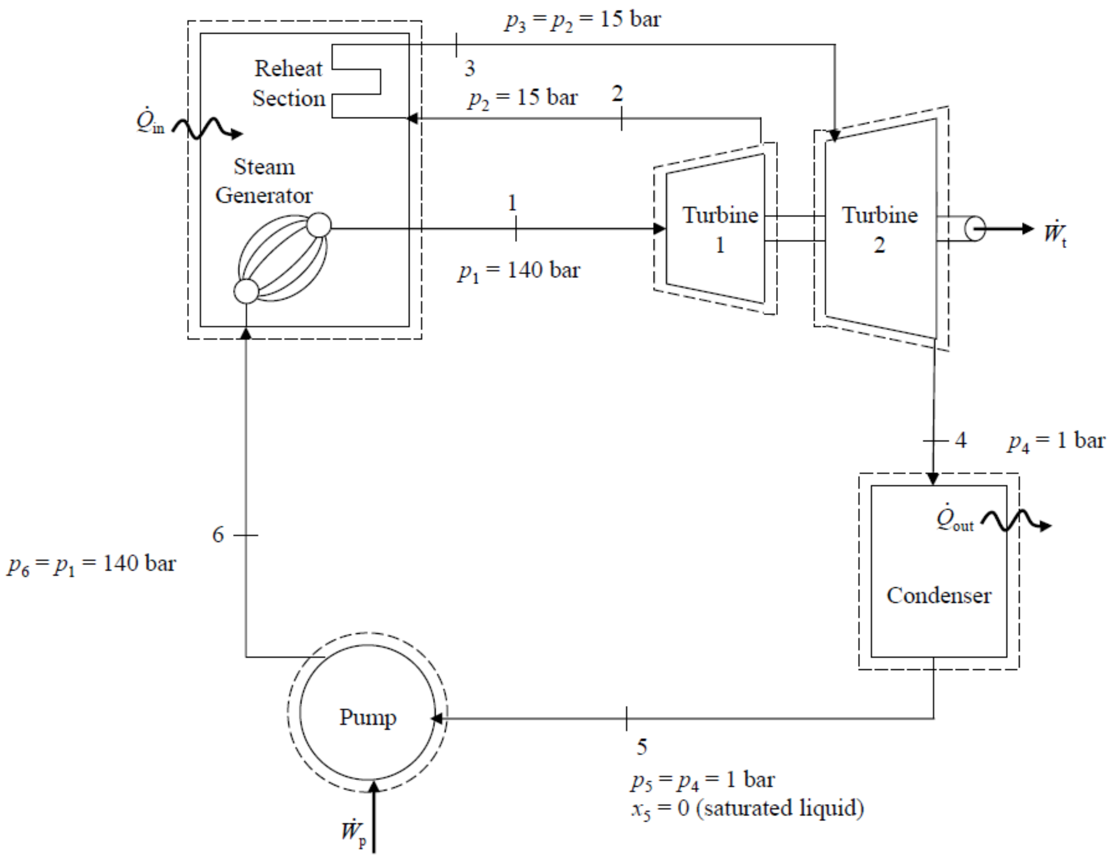
Problem 3 (15 pts)

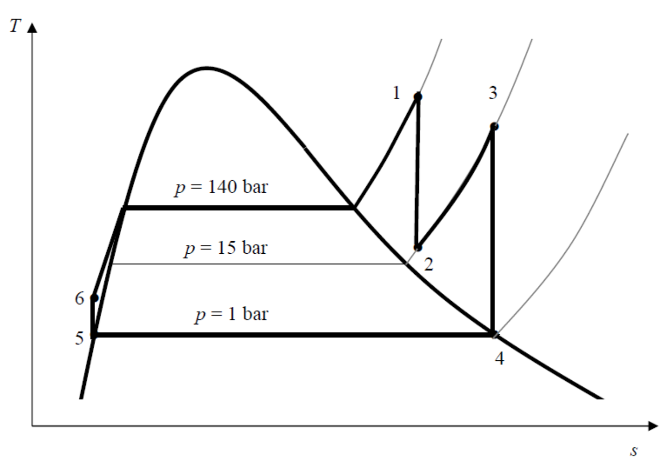
Steam is the working fluid in the ideal reheat cycle shown in the figure together with operational data. If the mass flow rate is 1.3 kg/s, determine

a) the power developed by the cycle, in kW

b) the cycle thermal efficiency.

8.27





State	p (bar)	T (°C)	h (kJ/kg)
1	140	520.0	3377.8
2	15	201.2	2800.0
3	15	428.9	3318.5
4	1	99.63	2675.5
5	1	99.63	417.46
6	140		431.96

(3)

a) $\dot{W}_{cycle} = \dot{W}_{t_1} + \dot{W}_{t_2} - \dot{W}_p$

$\dot{W}_{t_1} = \dot{m}(h_1 - h_2) = \dot{m}(3377.8 - 2800)\frac{kJ}{kg}$

$\dot{W}_{t_2} = \dot{m}(h_3 - h_4) = \dot{m}(3318.5 - 2675.5)\frac{kJ}{kg}$

$\dot{W}_p = \dot{m}(h_6 - h_5) = \dot{m}(431.96 - 417.46)\frac{kJ}{kg}$

$\dot{m} = 1.3\ kg/s$

$$\boxed{\dot{W}_{cycle} = 1568.2\ kW}$$

b) $\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_{in}}$

$\dot{Q}_{in} = \dot{m}[(h_1 - h_6) + (h_3 - h_2)]$

$= 1.3\frac{kg}{s}[(337.8 - 431.96) + (3318.5 - 2800.0)]\frac{kJ}{kg}\frac{kW}{kJ/s}$

$= 4503.6\ kW$

$$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_{cycle}} = \frac{1568.2}{4503.6} = \boxed{0.35\ (35\%)}$$

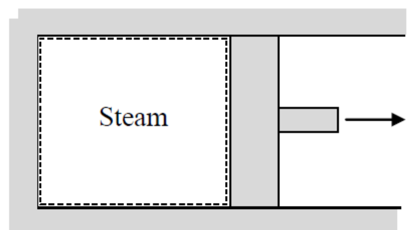
Problem 4 (25 pts)

Steam undergoes an adiabatic expansion in a piston-cylinder assembly from 100 bar, 360 °C to 1 bar, 160 °C. 6.45

a) (5) What is work ~~per~~ $\dot{m}$ kJ per kg of steam for the process?
b) (5) Calculate the amount of entropy produced, in kJ/K per kg of steam.
c) (10) What is the maximum theoretical work that could be obtained from the given initial state to the final pressure?
d) (5) Sketch both processes on a T-s diagram with temp and pressure of state 1 and 2 labeled

a) $\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = \cancel{Q} - W$

$\frac{W}{m} = u_1 - u_2$



$p_1 = 100$ bar
$T_1 = 360$°C

p_2 1 bar
$T_2 = 160$°C

A3: $u_1 \sim 2729$ kJ/kg $s_1 = 6.006$ kJ/kg-K
$u_2 \sim 2598$ kJ/kg, $s_2 = 7.6567$ kJ/kg-K

$W/m = 2729 - 2598 = \boxed{131 \text{ kJ/kg}}$ +, work out

b) $\Delta S = \int_1^2 \cancel{\left(\frac{\delta Q}{T}\right)_b} + \sigma \rightarrow \frac{\sigma}{m} = s_2 - s_1 = (7.6567 - 6.006)$

$= \boxed{1.6537 \frac{\text{kJ}}{\text{kg-K}}}$

c) maximum work $\underline{s_2|_{max} = s_{2s} = s_1}$

$s_{2s} = s_1 = 6.006$ kJ/kg-s

For P_2, T_2, This is $< s_v \Rightarrow$ 2 phase
at $P_2 = 1$ bar

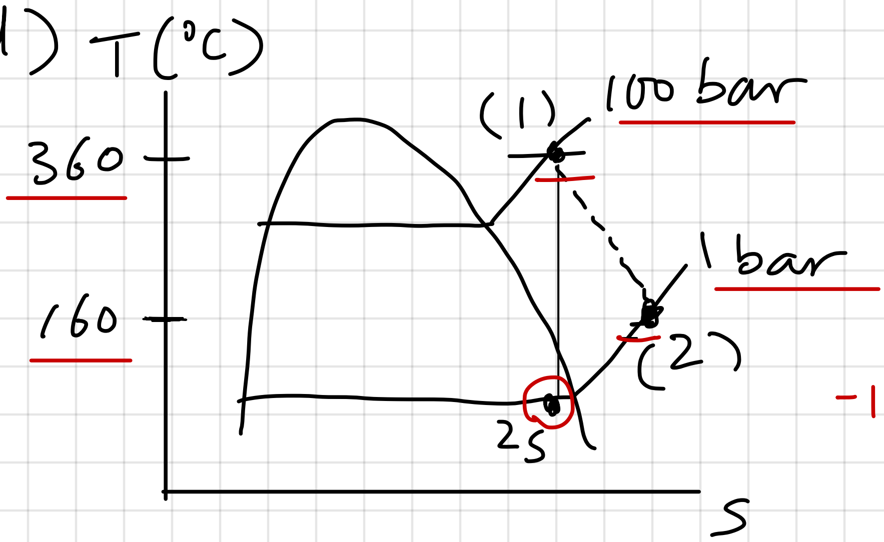
$$\underline{x_{2s} = \frac{s_{2s} - s_f}{s_g - s_f} = \frac{6.006 - 1.3026}{7.3594 - 1.3026} = 0.7765}$$

&

$$\underline{u_{2s} = u_f + x_{2s}(u_g - u_f)}$$
$$= 417.36 + 0.7765(2506.1 - 417.36) = 2039.3 \text{ kJ/kg}$$

$$W/m|_{max} = u_1 - u_{2s} = (2729.1 - 2039.3) = \boxed{689.8 \text{ kJ/kg}}$$

d)



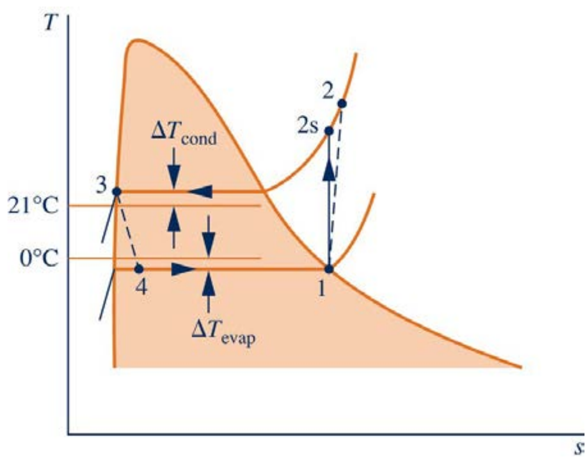
-1 for each item Not correctly labeled

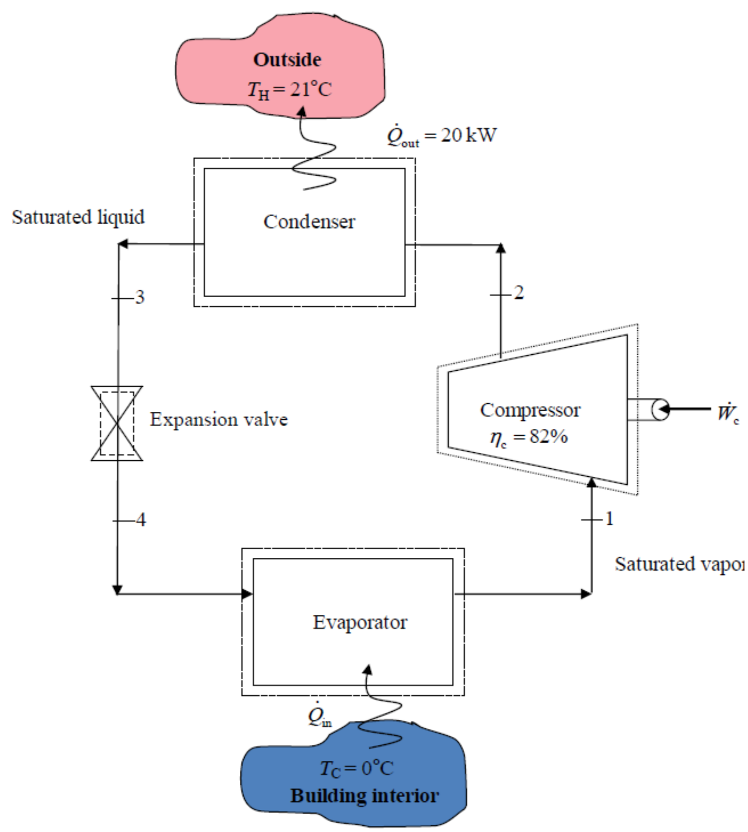
2s must be 2 phase

Problem 5 (25 pts) 10.37

An office building requires a heat transfer rate of 20 kW to maintain the inside temperature at 21° C when the outside temperature is 0° C. A vapor-compression heat pump with Refrigerant 134a as the working fluid is to be used to provide the necessary heating. Assume the compressor's isentropic efficiency is 82%. Specify appropriate evaporator and condenser pressures of a cycle for this purpose assuming the temperature at ΔTcond = ΔTevap = 10° C as shown in the figure. The refrigerant exits the evaporator as saturated vapor and exits the condenser as saturated liquid at the respective pressures. Determine the

(a) mass flow rate of the refrigerant, in kg/s.
(b) compressor power, in kW.
(c) coefficient of performance and compare with the coefficient of performance for a Carnot heat pump cycle operating between the reservoir temperatures.





$\Delta T_{cond} = \Delta T_{evap}$

$\Delta T_{cond} = 10°C \approx T_3 - 21°C \rightarrow \underline{T_3 \sim 31°C}$

T A11 : $T_3 = T_{sat}$, $P_{cond} = \underline{P_3 = 8 \text{ bar}}$

$\underline{T_1 \sim -10°C}$, $P_{evap} = P_1 = \underline{2 \text{ bar}}$

	P (bar)	h kJ/kg	s kJ/kg-K		
state 1	2	241.3	0.9253	S.V.	A11
2s	8	269.9	0.9253		A12
2	8	276.2		$\eta = 82\%$	

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} \Rightarrow h_2 = \frac{h_{2s} - h_1}{\eta_c} + h_1 = 276.2 \ \frac{kJ}{kg}$$

3	8	93.42	S.L.	A11
4		93.42	Throttling	$h_4 = h_3$

a) Mass balance of condenser

$$\dot{Q}_{out} = \dot{m}(h_2 - h_3) \Rightarrow \dot{m} = \frac{\dot{Q}_{out}}{h_2 - h_3}$$

$$= \frac{20 \text{ kW}}{(276.2 - 93.42)\frac{kJ}{kg}} \ \frac{kJ/s}{kW} = \boxed{0.1094 \text{ kg/s}}$$

b) $\dot{W}_c = \dot{m}(h_2 - h_1) = 0.1094(276.2 - 241.3)$

$$= \boxed{3.82 \text{ kW}}$$

c) $\gamma = \dfrac{\dot{Q}_{out}}{W_c} = \dfrac{20}{3.82} = \boxed{5.24}$

$$\gamma_{carnot} = \frac{T_H}{T_H - T_C} = \frac{294 \text{K}}{(294 - 273)\text{ K}} = \boxed{14}$$

Problem 6 (20 pts)

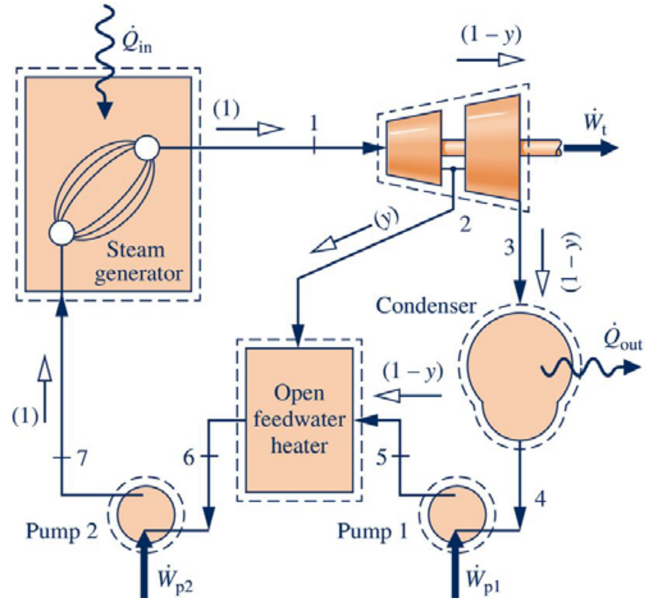
A regenerative vapor power cycle with one open feedwater heater is shown.
The mass flow rate $\dot{m}$ = [y + (1-y)] $\dot{m}$. (the mass flow rate through each circuit is denoted inside the parenthesis "( )")
For this cycle

e8.4

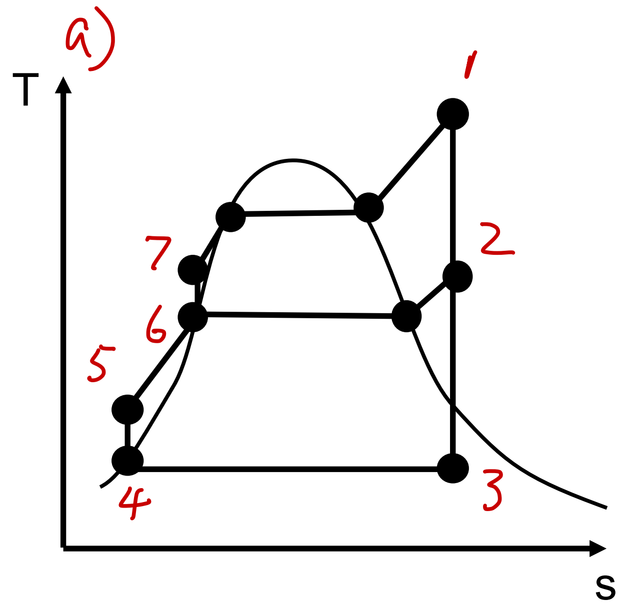
a) Label the states, 1 – 7, on the T-s diagram shown on the bottom

b) Write the equation for the total turbine work $\dot{W}_t / \dot{m}_1$ in terms of h, and y (note $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$)

c) Write the equation for the total pump work $\dot{W}_p / \dot{m}_1$



a)



b) $\dot{W}_t = \underline{\dot{m}_1(h_1 - h_2)} + \underline{(1-y)\dot{m}_1(h_2 - h_3)}$

$$\boxed{\frac{\dot{W}_t}{\dot{m}_1} = (h_1 - h_2) + (1-y)(h_2 - h_3)}$$

c) $\dot{W}_p = \underline{(1-y)\dot{m}_1(h_5 - h_4)}$
$+ \underline{\dot{m}_1(h_7 - h_6)}$

$$\boxed{\frac{\dot{W}_p}{\dot{m}_1} = (h_7 - h_6) + (1-y)(h_5 - h_4)}$$

TABLE A-11

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

Properties of Saturated Refrigerant 134a (Liquid–Vapor): Pressure Table

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.6	−37.07	0.7097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520	0.6
0.8	−31.21	0.7184	0.2366	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447	0.8
1.0	−26.43	0.7258	0.1917	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395	1.0
1.2	−22.36	0.7323	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354	1.2
1.4	−18.80	0.7381	0.1395	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322	1.4
1.6	−15.62	0.7435	0.1229	29.66	218.32	29.78	208.19	237.97	0.1211	0.9295	1.6
1.8	−12.73	0.7485	0.1098	33.31	219.94	33.45	206.26	239.71	0.1352	0.9273	1.8
2.0	−10.09	0.7532	0.0993	36.69	221.43	36.84	204.46	241.30	0.1481	0.9253	2.0
2.4	−5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222	2.4
2.8	−1.23	0.7697	0.0719	48.18	226.38	48.39	198.13	246.52	0.1911	0.9197	2.8
3.2	2.48	0.7770	0.0632	53.06	228.43	53.31	195.35	248.66	0.2089	0.9177	3.2
3.6	5.84	0.7839	0.0564	57.54	230.28	57.82	192.76	250.58	0.2251	0.9160	3.6
4.0	8.93	0.7904	0.0509	61.69	231.97	62.00	190.32	252.32	0.2399	0.9145	4.0
5.0	15.74	0.8056	0.0409	70.93	235.64	71.33	184.74	256.07	0.2723	0.9117	5.0
6.0	21.58	0.8196	0.0341	78.99	238.74	79.48	179.71	259.19	0.2999	0.9097	6.0
7.0	26.72	0.8328	0.0292	86.19	241.42	86.78	175.07	261.85	0.3242	0.9080	7.0
8.0	31.33	0.8454	0.0255	92.75	243.78	93.42	170.73	264.15	0.3459	0.9066	8.0
9.0	35.53	0.8576	0.0226	98.79	245.88	99.56	166.62	266.18	0.3656	0.9054	9.0
10.0	39.39	0.8695	0.0202	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043	10.0
12.0	46.32	0.8928	0.0166	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023	12.0
14.0	52.43	0.9159	0.0140	123.98	253.74	125.26	148.14	273.40	0.4453	0.9003	14.0
16.0	57.92	0.9392	0.0121	132.52	256.00	134.02	141.31	275.33	0.4714	0.8982	16.0
18.0	62.91	0.9631	0.0105	140.49	257.88	142.22	134.60	276.83	0.4954	0.8959	18.0
20.0	67.49	0.9878	0.0093	148.02	259.41	149.99	127.95	277.94	0.5178	0.8934	20.0
25.0	77.59	1.0562	0.0069	165.48	261.84	168.12	111.06	279.17	0.5687	0.8854	25.0
30.0	86.22	1.1416	0.0053	181.88	262.16	185.30	92.71	278.01	0.6156	0.8735	30.0

v_f = (table value)/1000

R-134a

TABLE A-12

Properties of Superheated Refrigerant 134a Vapor

T °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
	p = 0.6 bar = 0.06 MPa (T_{sat} = −37.07°C)				p = 1.0 bar = 0.10 MPa (T_{sat} = −26.43°C)			
Sat.	0.31003	206.12	224.72	0.9520	0.19170	212.18	231.35	0.9395
−20	0.33536	217.86	237.98	1.0062	0.19770	216.77	236.54	0.9602
−10	0.34992	224.97	245.96	1.0371	0.20686	224.01	244.70	0.9918
0	0.36433	232.24	254.10	1.0675	0.21587	231.41	252.99	1.0227
10	0.37861	239.69	262.41	1.0973	0.22473	238.96	261.43	1.0531
20	0.39279	247.32	270.89	1.1267	0.23349	246.67	270.02	1.0829
30	0.40688	255.12	279.53	1.1557	0.24216	254.54	278.76	1.1122
40	0.42091	263.10	288.35	1.1844	0.25076	262.58	287.66	1.1411
50	0.43487	271.25	297.34	1.2126	0.25930	270.79	296.72	1.1696
60	0.44879	279.58	306.51	1.2405	0.26779	279.16	305.94	1.1977
70	0.46266	288.08	315.84	1.2681	0.27623	287.70	315.32	1.2254
80	0.47650	296.75	325.34	1.2954	0.28464	296.40	324.87	1.2528
90	0.49031	305.58	335.00	1.3224	0.29302	305.27	334.57	1.2799

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

T °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
	p = 1.4 bar = 0.14 MPa (T_{sat} = −18.80°C)				p = 1.8 bar = 0.18 MPa (T_{sat} = −12.73°C)			
Sat.	0.13945	216.52	236.04	0.9322	0.10983	219.94	239.71	0.9273
−10	0.14549	223.03	243.40	0.9606	0.11135	222.02	242.06	0.9362
0	0.15219	230.55	251.86	0.9922	0.11678	229.67	250.69	0.9684
10	0.15875	238.21	260.43	1.0230	0.12207	237.44	259.41	0.9998
20	0.16520	246.01	269.13	1.0532	0.12723	245.33	268.23	1.0304
30	0.17155	253.96	277.97	1.0828	0.13230	253.36	277.17	1.0604
40	0.17783	262.06	286.96	1.1120	0.13730	261.53	286.24	1.0898
50	0.18404	270.32	296.09	1.1407	0.14222	269.85	295.45	1.1187
60	0.19020	278.74	305.37	1.1690	0.14710	278.31	304.79	1.1472
70	0.19633	287.32	314.80	1.1969	0.15193	286.93	314.28	1.1753
80	0.20241	296.06	324.39	1.2244	0.15672	295.71	323.92	1.2030
90	0.20846	304.95	334.14	1.2516	0.16148	304.63	333.70	1.2303
100	0.21449	314.01	344.04	1.2785	0.16622	313.72	343.63	1.2573

T °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
	p = 2.0 bar = 0.20 MPa (T_{sat} = −10.09°C)				p = 2.4 bar = 0.24 MPa (T_{sat} = −5.37°C)			
Sat.	0.09933	221.43	241.30	0.9253	0.08343	224.07	244.09	0.9222
−10	0.09938	221.50	241.38	0.9256				
0	0.10438	229.23	250.10	0.9582	0.08574	228.31	248.89	0.9399
10	0.10922	237.05	258.89	0.9898	0.08993	236.26	257.84	0.9721
20	0.11394	244.99	267.78	1.0206	0.09399	244.30	266.85	1.0034
30	0.11856	253.06	276.77	1.0508	0.09794	252.45	275.95	1.0339
40	0.12311	261.26	285.88	1.0804	0.10181	260.72	285.16	1.0637
50	0.12758	269.61	295.12	1.1094	0.10562	269.12	294.47	1.0930
60	0.13201	278.10	304.50	1.1380	0.10937	277.67	303.91	1.1218
70	0.13639	286.74	314.02	1.1661	0.11307	286.35	313.49	1.1501
80	0.14073	295.53	323.68	1.1939	0.11674	295.18	323.19	1.1780
90	0.14504	304.47	333.48	1.2212	0.12037	304.15	333.04	1.2055
100	0.14932	313.57	343.43	1.2483	0.12398	313.27	343.03	1.2326

TABLE A-12

(Continued)

Superheated Refrigerant 134a Vapor

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

T °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
	p = 8.0 bar = 0.80 MPa (T_{sat} = 31.33°C)				p = 9.0 bar = 0.90 MPa (T_{sat} = 35.53°C)			
Sat.	0.02547	243.78	264.15	0.9066	0.02255	245.88	266.18	0.9054
40	0.02691	252.13	273.66	0.9374	0.02325	250.32	271.25	0.9217
50	0.02846	261.62	284.39	0.9711	0.02472	260.09	282.34	0.9566
60	0.02992	271.04	294.98	1.0034	0.02609	269.72	293.21	0.9897
70	0.03131	280.45	305.50	1.0345	0.02738	279.30	303.94	1.0214
80	0.03264	289.89	316.00	1.0647	0.02861	288.87	314.62	1.0521
90	0.03393	299.37	326.52	1.0940	0.02980	298.46	325.28	1.0819
100	0.03519	308.93	337.08	1.1227	0.03095	308.11	335.96	1.1109
110	0.03642	318.57	347.71	1.1508	0.03207	317.82	346.68	1.1392
120	0.03762	328.31	358.40	1.1784	0.03316	327.62	357.47	1.1670
130	0.03881	338.14	369.19	1.2055	0.03423	337.52	368.33	1.1943
140	0.03997	348.09	380.07	1.2321	0.03529	347.51	379.27	1.2211
150	0.04113	358.15	391.05	1.2584	0.03633	357.61	390.31	1.2475
160	0.04227	368.32	402.14	1.2843	0.03736	367.82	401.44	1.2735
170	0.04340	378.61	413.33	1.3098	0.03838	378.14	412.68	1.2992
180	0.04452	389.02	424.63	1.3351	0.03939	388.57	424.02	1.3245
	p = 10.0 bar = 1.00 MPa (T_{sat} = 39.39°C)				p = 12.0 bar = 1.20 MPa (T_{sat} = 46.32°C)			
Sat.	0.02020	247.77	267.97	0.9043	0.01663	251.03	270.99	0.9023
40	0.02029	248.39	268.68	0.9066				
50	0.02171	258.48	280.19	0.9428	0.01712	254.98	275.52	0.9164
60	0.02301	268.35	291.36	0.9768	0.01835	265.42	287.44	0.9527
70	0.02423	278.11	302.34	1.0093	0.01947	275.59	298.96	0.9868
80	0.02538	287.82	313.20	1.0405	0.02051	285.62	310.24	1.0192
90	0.02649	297.53	324.01	1.0707	0.02150	295.59	321.39	1.0503
100	0.02755	307.27	334.82	1.1000	0.02244	305.54	332.47	1.0804
110	0.02858	317.06	345.65	1.1286	0.02335	315.50	343.52	1.1096
120	0.02959	326.93	356.52	1.1567	0.02423	325.51	354.58	1.1381
130	0.03058	336.88	367.46	1.1841	0.02508	335.58	365.68	1.1660
140	0.03154	346.92	378.46	1.2111	0.02592	345.73	376.83	1.1933
150	0.03250	357.06	389.56	1.2376	0.02674	355.95	388.04	1.2201
160	0.03344	367.31	400.74	1.2638	0.02754	366.27	399.33	1.2465
170	0.03436	377.66	412.02	1.2895	0.02834	376.69	410.70	1.2724
180	0.03528	388.12	423.40	1.3149	0.02912	387.21	422.16	1.2980
	p = 14.0 bar = 1.40 MPa (T_{sat} = 52.43°C)				p = 16.0 bar = 1.60 MPa (T_{sat} = 57.92°C)			
Sat.	0.01405	253.74	273.40	0.9003	0.01208	256.00	275.33	0.8982
60	0.01495	262.17	283.10	0.9297	0.01233	258.48	278.20	0.9069
70	0.01603	272.87	295.31	0.9658	0.01340	269.89	291.33	0.9457
80	0.01701	283.29	307.10	0.9997	0.01435	280.78	303.74	0.9813
90	0.01792	293.55	318.63	1.0319	0.01521	291.39	315.72	1.0148
100	0.01878	303.73	330.02	1.0628	0.01601	301.84	327.46	1.0467
110	0.01960	313.88	341.32	1.0927	0.01677	312.20	339.04	1.0773
120	0.02039	324.05	352.59	1.1218	0.01750	322.53	350.53	1.1069
130	0.02115	334.25	363.86	1.1501	0.01820	332.87	361.99	1.1357
140	0.02189	344.50	375.15	1.1777	0.01887	343.24	373.44	1.1638
150	0.02262	354.82	386.49	1.2048	0.01953	353.66	384.91	1.1912
160	0.02333	365.22	397.89	1.2315	0.02017	364.15	396.43	1.2181
170	0.02403	375.71	409.36	1.2576	0.02080	374.71	407.99	1.2445
180	0.02472	386.29	420.90	1.2834	0.02142	385.35	419.62	1.2704
190	0.02541	396.96	432.53	1.3088	0.02203	396.08	431.33	1.2960
200	0.02608	407.73	444.24	1.3338	0.02263	406.90	443.11	1.3212