

NATIONAL EXAMINATIONS MAY 2009

98-Phys-B6 Applied Thermodynamics and Heat Transfer

3 Hours Duration

Notes

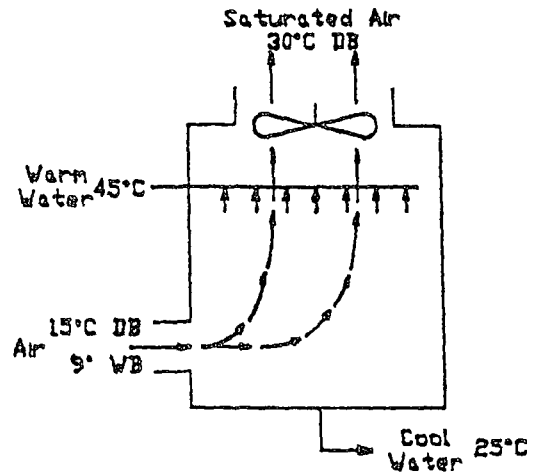
- 1 If doubt exists concerning the interpretation of any question, the candidate is urged to make assumptions and clearly explain what has been assumed along with the answer to the question
- 2 The examination is open book. As a consequence, candidates are permitted to make use of any textbooks, references or notes
- 3 Any non-communicating calculator is permitted. However, candidates must indicate the type of calculator(s) that they have used by writing the name and model designation of the calculator(s) on the inside of the cover of the first examination book
- 4 It is expected that each candidate will have copies of both a thermodynamics text and a heat transfer text in order to make use of the information presented in the tables and graphs contained
- 5 The answers to five questions, either three questions from Part A and two questions from Part B or two questions from Part A and three questions from Part B, comprise a complete examination
- 6 Candidates must indicate the answers that they wish to have graded on the cover of the first examination book. Otherwise the answers will be graded in the order in which they appear in the examination book(s) up to a maximum of three answers per section
- 7 The answer to any question carries the same value in the grading

## PART A - THERMODYNAMICS

1 A cooling tower utilizes the evaporative cooling phenomenon to remove heat from water. The diagram at the right is a schematic representation of the cooling tower. Determine

- the mass flowrate of atmospheric air required to cool 100,000 kg of water per hour
- the rate at which the water is evaporated

Use the psychrometric chart which can be found appended to the end of the examination paper



2 A single stage single acting reciprocating air compressor is driven at 400 rev/min. The bore is 150 mm diameter and the stroke is 225 mm. On the induction stroke, the pressure is 96.5 kPa and the temperature is 30°C. The air is compressed to a delivery pressure of 965 kPa according to  $pV^{1.28} = \text{Constant}$ .

Calculate (a) the mass of the air delivered per minute (b) the volume of the air delivered per minute measured at standard temperature and pressure 101.325 kPa and 20°C (c) the temperature of the air at the end of the compression process and (d) the power required to drive the compressor if the combined mechanical and drive efficiency is 85%. Neglect the effects of clearance.  $R = 0.2870 \text{ kJ/kgK}$ .

3 The air standard dual cycle comprised of an isentropic compression process, constant volume and constant pressure heat addition processes, an isentropic expansion process and a constant volume heat rejection process is a better representation of the cycle that occurs in an internal combustion engine than either the Otto cycle or the Diesel cycle. At the beginning of the compression process of an dual cycle with a compression ratio of 18, the temperature is 300 K and the pressure is 0.1 MPa. The pressure ratio for the constant volume part of the heating process is 1.5:1. The volume ratio for the constant pressure part of the heating process is 1.2:1. Sketch the pressure / volume and temperature / entropy diagrams for the dual process described above and determine (a) the thermal efficiency and (b) the mean effective pressure associated with it.

4 A vapour compression refrigeration system using refrigerant 134a as the working fluid yielded the following measurements during a commissioning test:

Condenser pressure 700 kPa

Evaporator pressure 140 kPa

Compressor inlet temperature 0°C

Compressor outlet temperature 65°C

Condenser inlet temperature 55°C

Condenser outlet temperature 20°C

Expansion valve inlet temperature 25°C

Evaporator outlet temperature -12°C

Plot the state points defined by these measurements on a properly drawn and labelled temperature / entropy diagram. The refrigerant flowrate was found to be 4.5 kg/min and 0.266 kW was transferred from the compressor according to the measurements made during the commissioning test. Determine the coefficient of performance and the power produced by the motor driving the compressor.

## PART B - HEAT TRANSFER

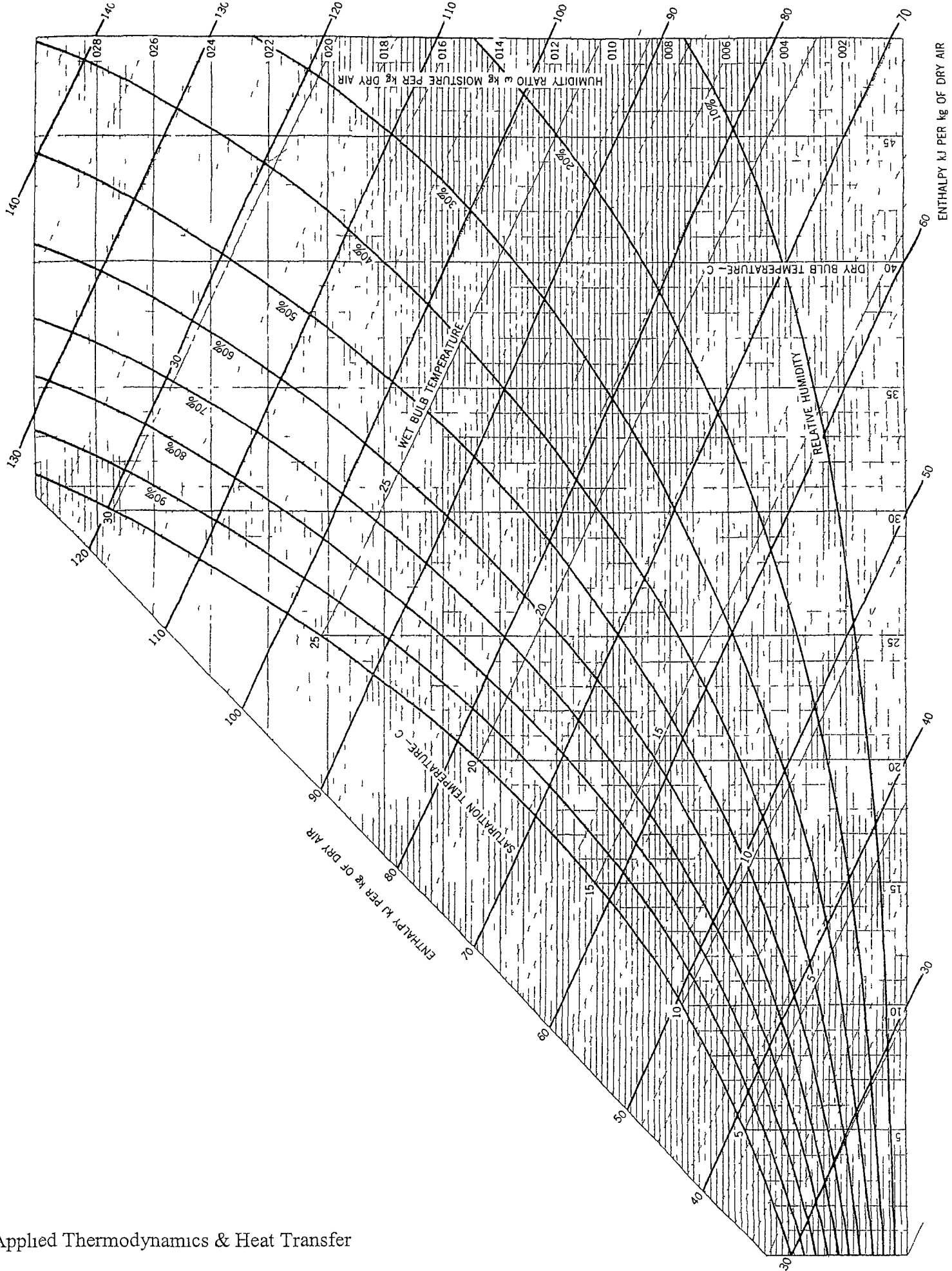
5 An ice chest 50 cm long by 40 cm wide by 30 cm high comprised of 3 cm thick Styrofoam having thermal conductivity  $k = 0.033 \text{ W/m}^\circ\text{C}$  is filled with an ice / water mixture containing 45 kg of ice. The ice / water mixture is separated from the lid by 1 cm of air. The temperature of the surrounding air and the surface on which the ice chest is resting is  $30^\circ\text{C}$ . The temperature of the inner surface of the ice chest in contact with the ice / water mixture may be assumed to be  $0^\circ\text{C}$ . The heat transfer coefficient at the surface of the ice chest exposed to the air is  $20 \text{ W/m}^\circ\text{C}$ . The thermal contact resistance between the ice chest and the surface on which it is resting is  $0.15 \text{ m}^\circ\text{C/W}$ . Given that the heat of fusion of ice is  $333.7 \text{ kJ/kg}$ , how long it would take for the ice to melt completely.

6 Air passing through an equilateral triangular cross section duct 1 cm to a side by 30 cm in length at a mass flowrate of  $5.0 \times 10^{-5} \text{ kg/s}$  is to be heated from  $27^\circ\text{C}$  to  $77^\circ\text{C}$ . Assuming that the temperature of the surfaces comprising the duct is invariant, determine the temperature required to effect the transfer of heat.

7 (a) Calculate the rate of heat loss per unit length  $q/L$  from a bare horizontal pipe  $D = 50 \text{ mm}$  outside diameter having a constant surface temperature  $T_s = 140^\circ\text{C}$  located in still quiescent air at  $T_\infty = 15^\circ\text{C}$  cooled by natural convection. Depending upon whether the natural convection is laminar or turbulent, use the relationship  $h_c = 1.31 [(T_s - T_\infty)/D]^{1/4}$  or  $h = 1.25 (T_s - T_\infty)^{1/3}$  respectively where  $T_s$  is the temperature of the surface being cooled in  $^\circ\text{C}$ ,  $T_\infty$  is the temperature of the quiescent air in  $^\circ\text{C}$  and  $D$  is the diameter of the surface being cooled in m.

(b) If the pipe were covered with an insulating material having thermal conductivity  $k = 0.037 \text{ W/m}^\circ\text{C}$ , determine the thickness of insulation  $\delta$  required to reduce the heat loss of the bare pipe  $q/L$  by a factor of two. Note that the laminar natural convection heat transfer coefficient depends upon the diameter of the outer surface of the insulation and would change as insulation is added.

8 It is required to design a heat exchanger that will be capable of transferring  $205 \text{ kW}$  to a chemical solution with a specific heat of  $3.26 \text{ kJ/kg}^\circ\text{C}$  in order to increase its temperature from  $65^\circ\text{C}$  to  $93^\circ\text{C}$ . The energy required to heat the chemical solution will be obtained by condensing steam at a pressure of  $250 \text{ kPa}$  on the surface of the seven  $4.0 \text{ cm O.D.}$  by  $3.0 \text{ cm I.D.}$  tubes through which the chemical solution will be flowing. The thermal conductivity of the material from which the tubes are to be made is  $111 \text{ W/m}^\circ\text{C}$  and the inside heat transfer coefficient is to be  $3400 \text{ W/m}^\circ\text{C}$ . The outside heat transfer coefficient will have to be determined. What will the length of the tubes have to be?



Thermodynamic Properties of R134A

Saturated R134A

Temp °C	Press bars	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg K		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 $s_g$	
-40	0.5164	0.7055	0.3569	-0.04	204.45	0.00	222.88	222.88	0.0000	0.9560	-40
-36	0.6332	0.7113	0.2947	4.68	206.73	4.73	220.67	225.40	0.0201	0.9506	-36
-32	0.7704	0.7172	0.2451	9.47	209.01	9.52	218.37	227.90	0.0401	0.9456	-32
-28	0.9305	0.7233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411	-28
-26	1.0199	0.7265	0.1882	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390	-26
-24	1.1160	0.7296	0.1728	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370	-24
-22	1.2192	0.7328	0.1590	21.68	214.70	21.77	212.32	234.08	0.0897	0.9351	-22
-20	1.3299	0.7361	0.1464	24.17	215.84	24.26	211.05	235.31	0.0996	0.9332	-20
-18	1.4483	0.7395	0.1350	26.67	216.97	26.77	209.76	236.53	0.1094	0.9315	-18
-16	1.5748	0.7428	0.1247	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298	-16
-12	1.8540	0.7498	0.1068	34.25	220.36	34.39	205.77	240.15	0.1388	0.9267	-12
-8	2.1704	0.7569	0.0919	39.38	222.60	39.54	203.00	242.54	0.1583	0.9239	-8
-4	2.5274	0.7644	0.0794	44.56	224.84	44.75	200.15	244.90	0.1777	0.9213	-4
0	2.9282	0.7721	0.0689	49.79	227.06	50.02	197.21	247.23	0.1970	0.9190	0
4	3.3765	0.7801	0.0600	55.08	229.27	55.35	194.19	249.53	0.2162	0.9169	4
8	3.8756	0.7884	0.0525	60.43	231.46	60.73	191.07	251.80	0.2354	0.9150	8
12	4.4294	0.7971	0.0460	65.83	233.63	66.18	187.85	254.03	0.2545	0.9132	12
16	5.0416	0.8062	0.0405	71.29	235.78	71.69	184.52	256.22	0.2735	0.9116	16
20	5.7160	0.8157	0.0358	76.80	237.91	77.26	181.09	258.36	0.2924	0.9102	20
24	6.4566	0.8257	0.0317	82.37	240.01	82.90	177.55	260.45	0.3113	0.9089	24
26	6.8530	0.8309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082	26
28	7.2675	0.8362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076	28
30	7.7006	0.8417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070	30
32	8.1528	0.8473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064	32
34	8.6247	0.8530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058	34
36	9.1168	0.8590	0.0223	99.47	246.11	100.25	166.15	266.40	0.3678	0.9053	36
38	9.6298	0.8651	0.0210	102.38	247.09	103.21	164.12	267.33	0.3772	0.9047	38
40	10.164	0.8714	0.0199	105.30	248.06	106.19	162.05	268.24	0.3866	0.9041	40
42	10.720	0.8780	0.0188	108.25	249.02	109.19	159.94	269.14	0.3960	0.9035	42
44	11.299	0.8847	0.0177	111.22	249.96	112.22	157.79	270.01	0.4054	0.9030	44
48	12.526	0.8989	0.0159	117.22	251.79	118.35	153.33	271.68	0.4243	0.9017	48
52	13.851	0.9142	0.0142	123.31	253.55	124.58	148.66	273.24	0.4432	0.9004	52
56	15.278	0.9308	0.0127	129.51	255.23	130.93	143.75	274.68	0.4622	0.8990	56
60	16.813	0.9488	0.0114	135.82	256.81	137.42	138.57	275.99	0.4814	0.8973	60
70	21.162	1.0027	0.0086	152.22	260.15	154.34	124.08	278.43	0.5302	0.8918	70
80	26.324	1.0766	0.0064	169.88	262.14	172.71	106.41	279.12	0.5814	0.8827	80
90	32.435	1.1949	0.0046	189.82	261.34	193.69	82.63	276.32	0.6380	0.8655	90
100	39.742	1.5443	0.0027	218.60	248.49	224.74	34.40	259.13	0.7196	0.8117	100

## Thermodynamic Properties of R131A

## Superheated R134A

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K
$p = 0.6 \text{ bars} = 0.06 \text{ MPa}$ ( $T_{\text{sat}} = -37.07^\circ\text{C}$ )					$p = 1.0 \text{ bars} = 0.10 \text{ MPa}$ ( $T_{\text{sat}} = -26.43^\circ\text{C}$ )			
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

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K
$p = 1.4 \text{ bars} = 0.14 \text{ MPa}$ ( $T_{\text{sat}} = -18.80^\circ\text{C}$ )					$p = 1.8 \text{ bars} = 0.18 \text{ MPa}$ ( $T_{\text{sat}} = -12.73^\circ\text{C}$ )			
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	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K
$p = 2.0 \text{ bars} = 0.20 \text{ MPa}$ ( $T_{\text{sat}} = -10.09^\circ\text{C}$ )					$p = 2.4 \text{ bars} = 0.24 \text{ MPa}$ ( $T_{\text{sat}} = -5.37^\circ\text{C}$ )			
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	0.08574	228.31	248.89	0.9399
0	0.10438	229.23	250.10	0.9582	0.08993	236.26	257.84	0.9721
10	0.10922	237.05	258.89	0.9898	0.09399	244.30	266.85	1.0034
20	0.11394	244.99	267.78	1.0206	0.09794	252.45	275.95	1.0339
30	0.11856	253.06	276.77	1.0508	0.10181	260.72	285.16	1.0637
40	0.12311	261.26	285.88	1.0804	0.10562	269.12	294.47	1.0930
50	0.12758	269.61	295.12	1.1094	0.10937	277.67	303.91	1.1218
60	0.13201	278.10	304.50	1.1380	0.11307	286.35	313.49	1.1501
70	0.13639	286.74	314.02	1.1661	0.11674	295.18	323.19	1.1780
80	0.14073	295.53	323.68	1.1939	0.12037	304.15	333.04	1.2055
90	0.14504	304.47	333.48	1.2212	0.12398	313.27	343.03	1.2326
100	0.14932	313.57	343.43	1.2483				

Thermodynamic Properties of R134A

Superheated R134A

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K
$p = 6.0 \text{ bars} = 0.60 \text{ MPa}$ ( $T_{\text{sat}} = 21.58^\circ\text{C}$ )					$p = 7.0 \text{ bars} = 0.70 \text{ MPa}$ ( $T_{\text{sat}} = 26.72^\circ\text{C}$ )			
Sat	0.03408	238.74	259.19	0.9097	0.02918	241.42	261.85	0.9080
30	0.03581	246.41	267.89	0.9388	0.02979	244.51	265.37	0.9197
40	0.03774	255.45	278.09	0.9719	0.03157	253.83	275.93	0.9539
50	0.03958	264.48	288.23	1.0037	0.03324	263.08	286.35	0.9867
60	0.04134	273.54	298.35	1.0346	0.03482	272.31	296.69	1.0182
70	0.04304	282.66	308.48	1.0645	0.03634	281.57	307.01	1.0487
80	0.04469	291.86	318.67	1.0938	0.03781	290.88	317.35	1.0784
90	0.04631	301.14	328.93	1.1225	0.03924	300.27	327.74	1.1074
100	0.04790	310.53	339.27	1.1505	0.04064	309.74	338.19	1.1358
110	0.04946	320.03	349.70	1.1781	0.04201	319.31	348.71	1.1637
120	0.05099	329.64	360.24	1.2053	0.04335	328.98	359.33	1.1910
130	0.05251	339.38	370.88	1.2320	0.04468	338.76	370.04	1.2179
140	0.05402	349.23	381.64	1.2584	0.04599	348.66	380.86	1.2444
150	0.05550	359.21	392.52	1.2844	0.04729	358.68	391.79	1.2706
160	0.05698	369.32	403.51	1.3100	0.04857	368.82	402.82	1.2963

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg K
$p = 8.0 \text{ bars} = 0.80 \text{ MPa}$ ( $T_{\text{sat}} = 31.33^\circ\text{C}$ )					$p = 9.0 \text{ bars} = 0.90 \text{ MPa}$ ( $T_{\text{sat}} = 35.53^\circ\text{C}$ )			
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