UNIVERSITY OF ABERDEEN SESSION 2012–2013

Degree Examination in EG3539 Thermodynamics

29$^{\text{th}}$ May 2013 14.00–17.00

Notes: *(i) Candidates ARE permitted to use an approved calculator.*

(ii) Candidates ARE permitted to use steam tables, which will be provided.

PLEASE NOTE THE FOLLOWING

(i) You **must not** have in your possession any material other than that expressly permitted in the rules appropriate to this examination. Where this is permitted, such material **must not** be amended, annotated or modified in any way.

(ii) You **must not** have in your possession any material that could be determined as giving you an advantage in the examination.

(iii) You **must not** attempt to communicate with any candidate during the exam, either orally or by passing written material, or by showing material to another candidate, nor must you attempt to view another candidate's work.

Failure to comply with the above will be regarded as cheating and may lead to disciplinary action as indicated in the Academic Quality Handbook (`www.abdn.ac.uk/registry/quality/appendix7x1.pdf`**) Section 4.14 and 5.**

Candidates must attempt *all* questions.

Question 1

In the secondary cooling circuit of a nuclear power plant, the steam generator (boiler / reheater) is connected to two turbines operating as a reheat Rankine cycle (Fig. 1). Primary superheated steam is at 40 bar and 370°C, with reheat to 7 bar and 370°C. The isentropic efficiencies of the first (η_{T1}) and second (η_{T2}) turbines and boiler feed pump (η_P) are 84%, 80% and 61% respectively.

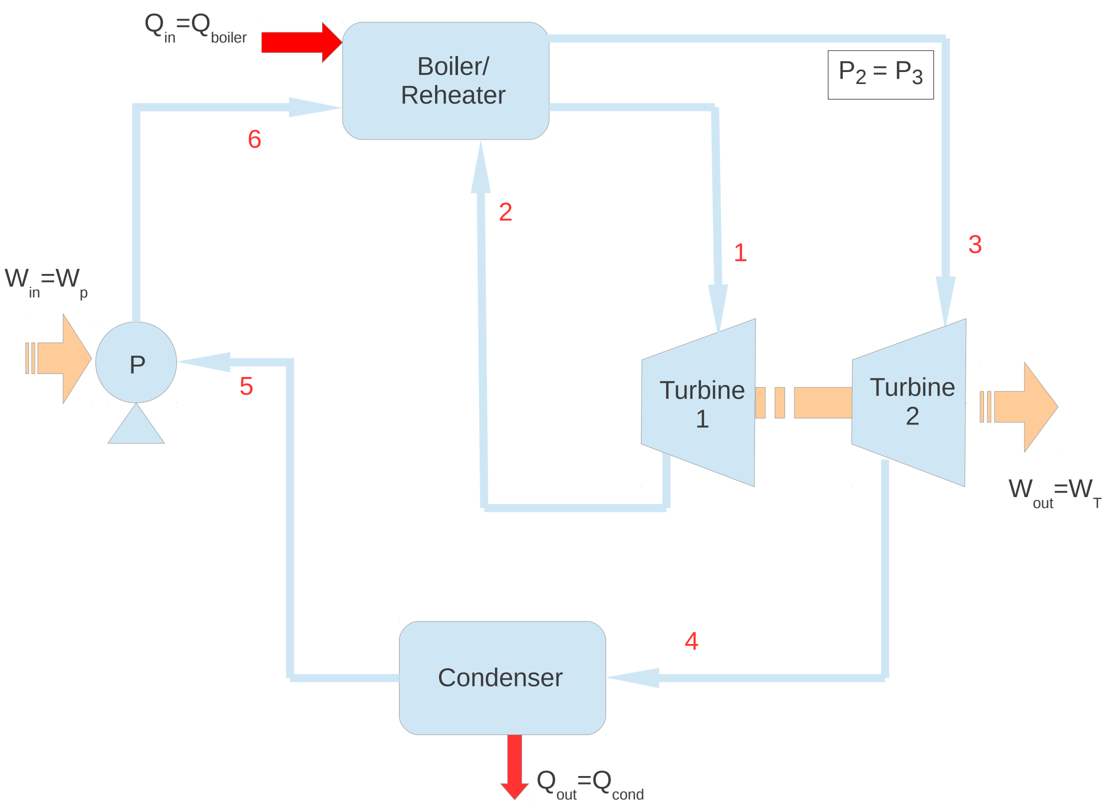

Figure 1: *Reheat Rankine cycle with 2 turbines.*

(a) In the Table below, determine *(a)-(j)*. [**10 Marks**]

Stage	**P (bar)**	**T (°C)**	**State**	**H (kJ.kg^{-1})**	**S (kJ.(kg.K)$^{-1}$)**
1	40	370	superheated steam	**(a)**	**(b)**
2	–	–	**(c)**	–	–
3	7	370	superheated steam	**(d)**	**(e)**
4	0.10	–	–	–	–
5	0.10	–	**(f)**	**(g)**	**(h)**
6	40	–	**(i)**	**(j)**	–

(b) Calculate the thermal efficiency (η_{Thermal}) of the reheat Rankine cycle with 2 turbines. η_{Thermal} is expressed as,

$$\eta_{\text{Thermal}} = \frac{(H_1 - H_{2s})\,\eta_{\text{T1}} + (H_3 - H_{4s})\,\eta_{\text{T2}} - V_5\,(P_6 - P_5)\,\eta_{\text{P}}^{-1}}{(H_1 - H_6) + (H_3 - H_2)}$$

where the subscript s indicates the ideal state. **[5 Marks]**

(c) Sketch the T-S diagram for this cycle. **[5 Marks]**

Question 2

(a) In France, 421 billion kWh of electricity were made from nuclear fuels in 2011. If an equivalent amount had been raised from natural gas, what would have been the carbon footprint? [**8 Marks**]
Heat of combustion of methane = 889 kJ.mol^{-1}
Atomic weights/gmol^{-1}*: C: 12   H: 1*

(b) Give an example, in qualitative terms, of how a chemical and nuclear explosion can have equivalent blasts if quantities in the former are much larger than in the latter. [**2 Marks**]

(c) Coke, of calorific value is 25 MJ.kg^{-1}, is used to make heat at 300 MW. It is desired to reduce the carbon footprint by 10% by blending the coke with citrus peel of calorific value 7 MJ.kg^{-1} whilst maintaining a heat production rate of 300 MW. At what ratios by weight will coke and citrus peel have to be blended? [**8 Marks**]

(d) Explain how in the supply of biomass for fuel use forest sustainability is ensured. [**2 Marks**]

Question 3

(a) A horizontally mounted turbine is housed between circular inlet and outlet pipes of circumference 1 m and 0.6 m, respectively. Assume gas satisfying the steady flow energy conservation

$$\frac{\dot{Q} - \dot{W}_s}{\dot{m}} = \left(h_2 + \frac{u_2^2}{2}\right) - \left(h_1 + \frac{u_1^2}{2}\right),$$

flows through the turbine at a steady rate of 4 kg/s. At the inlet (labelled 1), the fluid has a specific enthalpy h of 70 kJ/kg and a velocity u of 30 m/s, while at the outlet (labelled 2), the fluid has a specific enthalpy of 40 kJ/kg. If the gas does work on the turbine at a rate of 30 kW and transfers heat to the surroundings at a rate of 15 kW, then find the change in gas density between the inlet and the outlet. [**4 Marks**]

(b) For gas flow along a duct whose length is parameterized by x and has slowly-varying cross-sectional area $A(x)$, use equations corresponding to mass and energy conservation to show that

$$\frac{dV}{V} + \frac{dh}{u^2} - \frac{dA}{A} = 0,$$

where the specific volume is denoted V, the specific enthalpy h, and fluid velocity u. [**2 Marks**]

(c) Define the speed of sound c and the Mach number Ma in a gas. State equations that are appropriate for calculating these quantities in an isentropic gas and define the variables used. [**4 Marks**]

(d) For an isentropic process show that changes in specific volume are related to changes in pressure (p) through

$$dV = -\frac{V^2}{c^2}dp,$$

and explain how changes in specific enthalpy are related to changes in pressure. [**3 Marks**]

(e) Hence, for isentropic flow along a duct, show that

$$\frac{1}{A\,(1 - Ma^2)}\frac{dA}{dx} = \frac{1}{\rho\, Ma^2}\frac{d\rho}{dx},$$

where the gas density is denoted ρ. [**5 Marks**]

(f) Explain with reasoning how the gas density changes for flow along a supersonic diffuser. [**2 Marks**]

Question 4

A refrigerator operating with Freon-12 as a refrigerant fluid produces a cooling effect of 20 kJ/s (Fig. 2). The engine operates on a vapour-compression refrigeration cycle with pressure limits of 1.509 bar and 9.607 bar. The vapour leaves the evaporator dry saturated and there is no undercooling. Assume that the compressor operaters at 300 rpm and has a clearance volume of 3% of stroke volume. For the compressor assume that the expansion is described by $PV^{1.13}$ = constant.

(a) Determine the power required by the compressor (in W). **[10 Marks]**

(b) Calculate the piston displacement of the compressor (in m^3). **[10 Marks]**

Given the saturation table of Freon-12:

T (°C)	P_s (bar)	V_g (m^3/kg)	H_f (kJ/kg)	H_g (kJ/kg)	S_f (kJ/(kg.K))	S_g (kJ/(kg.K))	*Specific Heat* (kJ/(kg.K))
-20	1.509	0.1088	17.8	178.61	0.073	0.7082	–
40	9.607	–	74.53	203.05	0.2716	0.682	0.747

where T and P are temperature and saturated pressure, respectively; V, H and S are the specific volume, enthalpy and entropy. Subscripts f and g represents fluid and gas/vapour phases. Swept volume rate $\left(\dot{V}_{\text{swept}}\right)$ and volumetric efficiency (η_{vol}) are expressed as,

$$\dot{V}_{\text{swept}} = \frac{\dot{V}_R}{\eta_{\text{vol}}}$$

$$\eta_{\text{vol}} = 1 + \mathcal{C} - \mathcal{C}\left(\frac{P_d}{P_s}\right)^{1/n}$$

where $\dot{V}_R$ is the volumetric flow rate of the refrigerant at intake conditions, $\mathcal{C}$ is the clearance ratio, P_d and P_s are the discharge and suction pressures, respectively. n is the polytropic index.

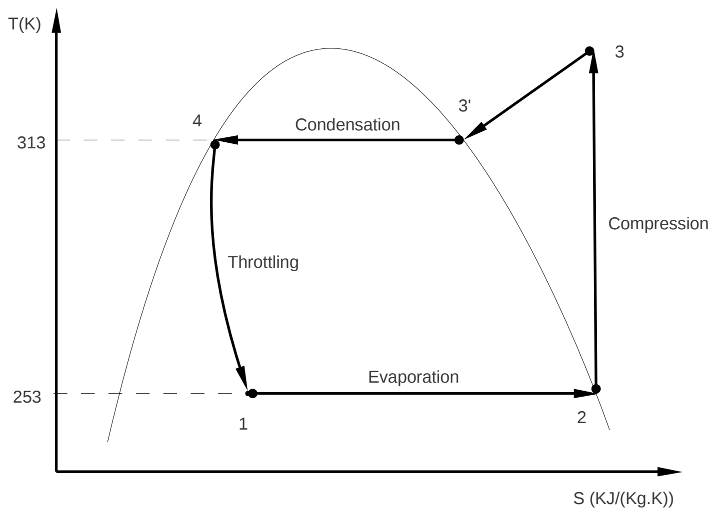

Figure 2: *Refrigeration cycle, Ts diagram – Question 4*

Question 5

(a) Define the specific humidity ω. Assuming both dry air and water vapour behave like ideal gases with specific gas constants $R_a = 0.2871$ kJ/(kg.K) and $R_v = 0.4615$ kJ/(kg.K), respectively, show that

$$\omega = \frac{0.622 p_v}{p - p_v}$$

where p is the absolute pressure and p_v is the partial pressure of water vapour. [**4 Marks**]

(b) If the saturation pressure of water is denoted p_g, and relative humidity φ, then show that [**2 Marks**]

$$\omega = \frac{0.622 \varphi p_g}{p - \varphi p_g}$$

(c) An air-conditioning system takes in outdoor air at 12°C and 25 percent relative humidity at a steady rate of 40 m^3/min and then conditions it to 24°C and 55 percent relative humidity. This heating and humidification takes place in two distinct steady processes. Firstly the outdoor air is heated to 20°C in a heating section, and secondly the air is humidified by the injection of hot steam in a humidifying section. Assuming both stages take place at a constant pressure of 100 kPa, determine:

(i) the partial pressures of water vapour and dry air, and the specific humidity at the inlet; [**3 Marks**]

(ii) the rate heat is supplied in the heating section; [**6 Marks**]

(iii) the mass flow rate of the steam required in the humidifying section. [**5 Marks**]

You may assume that the specific heat of dry air is independent of temperature and has the value $C_p = 1.005$ kJ/(kg.K). The saturation pressure of water is 1.4028 kPa at 12°C, and 2.9858 kPa at 24°C. The enthalpy of saturated water vapour is 2523 kJ/kg at 12°C, and 2537 kJ/kg at 20°C.

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TABLE II

Saturated Water and Steam (Pressure) Tables

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0.006113	0.01	0.01	2 501.3	2 501.4	0.000	9.156	9.156	0.0010002	206.14
0.010	7.0	29.3	2 484.9	2 514.2	0.106	8.870	8.976	0.0010000	129.21
0.015	13.0	54.7	2 470.6	2 525.3	0.196	8.632	8.828	0.0010007	87.98
0.020	17.0	73.5	2 460.0	2 533.5	0.261	8.463	8.724	0.001001	67.00
0.025	21.1	88.5	2 451.6	2 540.1	0.312	8.331	8.643	0.001002	54.25
0.030	24.1	101.0	2 444.5	2 545.5	0.355	8.223	8.578	0.001003	45.67
0.035	26.7	111.9	2 438.4	2 550.3	0.391	8.132	8.523	0.001003	39.50
0.040	29.0	121.5	2 432.9	2 554.4	0.423	8.052	8.475	0.001004	34.80
0.045	31.0	130.0	2 428.2	2 558.2	0.451	7.982	8.433	0.001005	31.13
0.050	32.9	137.8	2 423.7	2 561.5	0.476	7.919	8.395	0.001005	28.19
0.055	34.6	144.9	2 419.6	2 565.5	0.500	7.861	8.361	0.001006	25.77
0.060	36.2	151.5	2 415.9	2 567.4	0.521	7.809	8.330	0.001006	23.74
0.065	37.6	157.7	2 412.4	2 570.1	0.541	7.761	8.302	0.001007	22.01
0.070	39.0	163.4	2 409.1	2 572.5	0.559	7.717	8.276	0.001007	20.53
0.075	40.3	168.8	2 406.0	2 574.8	0.576	7.675	8.251	0.001008	19.24
0.080	41.5	173.9	2 403.1	2 577.0	0.593	7.636	8.229	0.001008	18.10
0.085	42.7	178.7	2 400.3	2 579.0	0.608	7.599	8.207	0.001009	17.10
0.090	43.8	183.3	2 397.7	2 581.0	0.622	7.565	8.187	0.001009	16.20
0.095	44.8	187.7	2 395.2	2 582.9	0.636	7.532	8.168	0.001010	15.40
0.10	45.8	191.8	2 392.8	2 584.7	0.649	7.501	8.150	0.001010	14.67
0.11	47.7	199.7	2 388.3	2 588.0	0.674	7.453	8.117	0.001011	13.42
0.12	49.4	206.9	2 384.2	2 591.1	0.696	7.390	8.086	0.001012	12.36
0.13	51.0	213.7	2 380.2	2 593.9	0.717	7.341	8.058	0.001013	11.47
0.14	52.6	220.0	2 376.6	2 596.6	0.737	7.296	8.033	0.001013	10.69
0.15	54.0	226.0	2 373.2	2 599.2	0.754 9	7.254 4	8.009 3	0.001014	10.022
0.16	55.3	231.6	2 370.0	2 601.6	0.772 1	7.214 8	7.986 9	0.001015	9.433
0.17	56.6	236.9	2 366.9	2 603.8	0.788 3	7.177 5	7.965 8	0.001015	8.911
0.18	57.8	242.0	2 363.9	2 605.9	0.803 6	7.142 4	7.945 9	0.001016	8.445
0.19	59.0	246.8	2 361.1	2 607.9	0.818 2	7.109 0	7.927 2	0.001017	8.027
0.20	60.1	251.5	2 358.4	2 609.9	0.832 1	7.077 3	7.909 4	0.001017	7.650
0.21	61.1	255.9	2 355.8	2 611.7	0.845 3	7.047 2	7.892 5	0.001018	7.307
0.22	62.2	260.1	2 353.3	2 613.5	0.858 1	7.018 4	7.876 4	0.001018	6.995
0.23	63.1	264.2	2 350.9	2 615.2	0.870 2	6.990 8	7.861 1	0.001019	6.709
0.24	64.1	268.2	2 348.6	2 616.8	0.882 0	6.964 4	7.846 4	0.001019	6.447

Absolute pressure (bar) p	Temp. (°C) t_s	Specific enthalpy (kJ/kg) h_f	h_{fg}	h_g	Specific entropy (kJ/kg K) s_f	s_{fg}	s_g	Specific volume (m^3/kg) v_f	v_g
0.25	65.0	272.0	2 346.4	2 618.3	0.893 2	6.939 1	7.832 3	0.001020	6.205
0.26	65.9	275.7	2 344.2	2 619.9	0.904 1	6.914 7	7.818 8	0.001020	5.980
0.27	66.7	279.2	2 342.1	2 621.3	0.914 6	6.891 2	7.805 8	0.001021	5.772
0.28	67.5	282.7	2 340.0	2 622.7	0.924 8	6.868 5	7.793 3	0.001021	5.579
0.29	68.3	286.0	2 338.1	2 624.1	0.934 6	6.846 6	7.781 2	0.001022	5.398
0.30	69.1	289.3	2 336.1	2 625.4	0.944 1	6.825 4	7.769 5	0.001022	5.229
0.32	70.6	295.5	2 332.4	2 628.0	0.962 3	6.785 0	7.747 4	0.001023	4.922
0.34	72.0	301.5	2 328.9	2 630.4	0.979 5	6.747 0	7.726 5	0.001024	4.650
0.36	73.4	307.1	2 325.5	2 632.6	0.995 8	6.711 1	7.707 0	0.001025	4.408
0.38	74.7	312.5	2 322.3	2 634.8	1.011 3	6.677 1	7.688 4	0.001026	4.190
0.40	75.9	317.7	2 319.2	2 636.9	1.026 1	6.644 8	7.670 9	0.001026	3.993
0.42	77.1	322.6	2 316.3	2 638.9	1.040 2	6.614 0	7.654 2	0.001027	3.815
0.44	78.2	327.3	2 313.4	2 640.7	1.053 7	6.584 6	7.638 3	0.001028	3.652
0.46	79.3	331.9	2 310.7	2 642.6	1.066 7	6.556 4	7.623 1	0.001029	3.503
0.48	80.3	336.3	2 308.0	2 644.3	1.079 2	6.529 4	7.608 6	0.001029	3.367
0.50	81.3	340.6	2 305.4	2 646.0	1.091 2	6.503 5	7.594 7	0.001030	3.240
0.55	83.7	350.6	2 299.3	2 649.9	1.119 4	6.442 8	7.562 3	0.001032	2.964
0.60	86.0	359.9	2 293.6	2 653.6	1.145 4	6.387 3	7.532 7	0.001033	2.732
0.65	88.0	368.6	2 288.3	2 656.9	1.169 6	6.336 0	7.505 5	0.001035	2.535
0.70	90.0	376.8	2 283.3	2 660.1	1.192 1	6.288 3	7.480 4	0.001036	2.369
0.75	92.0	384.5	2 278.6	2 663.0	1.213 1	6.243 9	7.457 0	0.001037	2.217
0.80	93.5	391.7	2 274.0	2 665.8	1.233 0	6.202 2	7.435 2	0.001039	2.087
0.85	95.1	398.6	2 269.8	2 668.4	1.251 8	3.162 9	7.414 7	0.001040	1.972
0.90	96.7	405.2	2 265.6	2 670.9	1.269 6	6.125 8	7.395 4	0.001041	1.869
0.95	98.2	411.5	2 261.7	2 673.2	1.286 5	6.090 6	7.377 1	0.001042	1.777
1.0	99.6	417.5	2 257.9	2 675.4	1.302 7	6.057 1	7.359 8	0.001043	1.694
1.1	102.3	428.8	2 250.8	2 679.6	1.333 0	5.994 7	7.327 7	0.001046	1.549
1.2	104.8	439.4	2 244.1	2 683.4	1.360 9	5.937 5	7.298 4	0.001048	1.428
1.3	107.1	449.2	2 237.8	2 687.0	1.386 8	5.884 7	7.271 5	0.001050	1.325
1.4	109.3	458.4	2 231.9	2 690.3	1.410 9	5.835 6	7.246 5	0.001051	1.236
1.5	111.3	467.1	2 226.2	2 693.4	1.433 6	5.789 8	7.233 4	0.001053	1.159
1.6	113.3	475.4	2 220.9	2 696.2	1.455 0	5.746 7	7.201 7	0.001055	1.091
1.7	115.2	483.2	2 215.7	2 699.0	1.475 2	5.706 1	7.181 3	0.001056	1.031
1.8	116.9	490.7	2 210.8	2 701.5	1.494 4	5.667 8	7.162 2	0.001058	0.977
1.9	118.6	497.8	2 206.1	2 704.0	1.512 7	5.631 4	7.144 0	0.001060	0.929

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
2.0	120.2	504.7	2 201.6	2 706.3	1.530 1	5.596 7	7.126 8	0.001061	0.885
2.1	121.8	511.3	2 197.2	2 708.5	1.546 8	5.563 7	7.110 5	0.001062	0.846
2.2	123.3	517.6	2 193.0	2 710.6	1.562 7	5.532 1	7.094 9	0.001064	0.810
2.3	124.7	523.7	2 188.9	2 712.6	1.578 1	5.501 9	7.080 0	0.001065	0.777
2.4	126.1	529.6	2 184.9	2 714.5	1.592 9	5.472 8	7.065 7	0.001066	0.746
2.5	127.4	535.3	2 181.0	2 716.4	1.607 1	5.444 9	7.052 0	0.001068	0.718
2.6	128.7	540.9	2 177.3	2 718.2	1.620 9	5.418 0	7.038 9	0.001069	0.693
2.7	129.9	546.2	2 173.6	2 719.9	1.634 2	5.392 0	7.026 2	0.001070	0.668
2.8	131.2	551.4	2 170.1	2 721.5	1.647 1	5.367 0	7.014 0	0.001071	0.646
2.9	132.4	556.5	2 166.6	2 723.1	1.659 5	5.342 7	7.002 3	0.001072	0.625
3.0	133.5	561.4	2 163.2	2 724.7	1.671 6	5.319 3	6.990 9	0.001074	0.606
3.1	134.6	566.2	2 159.9	2 726.1	1.683 4	5.296 5	6.979 9	0.001075	0.587
3.2	135.7	570.9	2 156.7	2 727.6	1.694 8	5.274 4	6.969 2	0.001076	0.570
3.3	136.8	575.5	2 153.5	2 729.0	1.705 9	5.253 0	6.958 9	0.001077	0.554
3.4	137.8	579.9	2 150.4	2 730.3	1.716 8	5.232 2	6.948 9	0.001078	0.538
3.5	138.8	584.3	2 147.4	2 731.6	1.727 3	5.211 9	6.939 2	0.001079	0.524
3.6	139.8	588.5	2 144.4	2 732.9	1.737 6	5.192 1	6.929 7	0.001080	0.510
3.7	140.8	592.7	2 141.4	2 734.1	1.747 6	5.172 9	6.920 5	0.001081	0.497
3.8	141.8	596.8	2 138.6	2 735.3	1.757 4	5.154 1	6.911 6	0.001082	0.486
3.9	142.7	600.8	2 135.7	2 736.5	1.767 0	5.135 8	6.902 8	0.001083	0.473
4.0	143.6	604.7	2 133.0	2 737.6	1.776 4	5.117 9	6.894 3	0.001084	0.462
4.2	145.4	612.3	2 127.5	2 739.8	1.794 5	5.083 4	6.877 9	0.001086	0.441
4.4	147.1	619.6	2 122.3	2 741.9	1.812 0	5.050 3	6.862 3	0.001088	0.423
4.6	148.7	626.7	2 117.2	2 743.9	1.828 7	5.018 6	6.847 3	0.001089	0.405
4.8	150.3	633.5	2 112.2	2 745.7	1.844 8	4.988 1	6.832 9	0.001091	0.390
5.0	151.8	640.1	2 107.4	2 747.5	1.860 4	4.958 8	6.819 2	0.001093	0.375
5.2	153.3	646.5	2 102.7	2 749.3	1.875 4	4.930 6	6.805 9	0.001094	0.361
5.4	154.7	652.8	2 098.1	2 750.9	1.889 9	4.903 3	6.793 2	0.001096	0.348
5.6	156.2	658.8	2 093.7	2 752.5	1.904 0	4.876 9	6.780 9	0.001098	0.337
5.8	157.5	664.7	2 089.3	2 754.0	1.917 6	4.851 4	6.769 0	0.001099	0.326
6.0	158.8	670.4	2 085.0	2 755.5	1.930 8	4.826 7	6.757 5	0.001101	0.315
6.2	160.1	676.0	2 080.9	2 756.9	1.943 7	4.802 7	6.746 4	0.001102	0.306
6.4	161.4	681.5	2 076.8	2 758.2	1.956 2	4.779 4	6.735 6	0.001104	0.297
6.6	162.6	686.8	2 072.7	2 759.5	1.968 4	4.756 8	6.725 2	0.001105	0.288
6.8	163.8	692.0	2 068.8	2 760.8	1.980 2	4.734 8	6.715 0	0.001107	0.280

Absolute pressure (bar)	Temp. (°C)	Specific enthalpy (kJ/kg)			Specific entropy (kJ/kg K)			Specific volume (m^3/kg)	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
7.0	165.0	697.1	2 064.9	2 762.0	1.991 8	4.713 4	6.705 2	0.001108	0.273
7.2	166.1	702.0	2 061.1	2 763.2	2.003 1	4.692 5	6.695 6	0.001110	0.265
7.4	167.2	706.9	2 057.4	2 764.3	2.014 1	4.672 1	6.686 2	0.001111	0.258
7.6	168.3	711.7	2 053.7	2 765.4	2.024 9	4.652 2	6.677 1	0.001112	0.252
7.8	169.4	716.3	2 050.1	2 766.4	2.035 4	4.632 8	6.668 3	0.001114	0.246
8.0	170.4	720.9	2 046.5	2 767.5	2.045 7	4.613 9	6.659 6	0.001115	0.240
8.2	171.4	725.4	2 043.0	2 768.5	2.055 8	4.595 3	6.651 1	0.001116	0.235
8.4	172.4	729.9	2 039.6	2 769.4	2.065 7	4.577 2	6.642 9	0.001118	0.229
8.6	173.4	734.2	2 036.2	2 770.4	2.075 3	4.559 4	6.634 8	0.001119	0.224
8.8	174.4	738.5	2 032.8	2 771.3	2.084 8	4.542 1	6.626 9	0.001120	0.219
9.0	175.4	742.6	2 029.5	2 772.1	2.094 1	4.525 0	6.619 2	0.001121	0.215
9.2	176.3	746.8	2 026.2	2 773.0	2.103 3	4.508 3	6.611 6	0.001123	0.210
9.4	177.2	750.8	2 023.0	2 773.8	2.112 2	4.492 0	6.604 2	0.001124	0.206
9.6	178.1	754.8	2 019.8	2 774.6	2.121 0	4.475 9	6.596 9	0.001125	0.202
9.8	179.0	758.7	2 016.7	2 775.4	2.129 7	4.460 1	6.589 8	0.001126	0.198
10.0	179.9	762.6	2 013.6	2 776.2	2.138 2	4.444 6	6.582 8	0.001127	0.194
10.5	182.0	772.0	2 005.9	2 778.0	2.158 8	4.407 1	6.565 9	0.001130	0.185
11.0	184.1	781.1	1 998.5	2 779.7	2.178 6	4.371 1	6.549 7	0.001133	0.177
11.5	186.0	789.9	1 991.3	2 781.3	2.197 7	4.336 6	6.534 2	0.001136	0.170
12.0	188.0	798.4	1 984.3	2 782.7	2.216 1	4.303 3	6.519 4	0.001139	0.163
12.5	189.8	806.7	1 977.4	2 784.1	2.233 8	4.271 2	6.505 0	0.001141	0.157
13.0	191.6	814.7	1 970.7	2 785.4	2.251 0	4.240 3	6.491 3	0.001144	0.151
13.5	193.3	822.5	1 964.2	2 786.6	2.267 6	4.210 4	6.477 9	0.001146	0.146
14.0	195.0	830.1	1 957.7	2 787.8	2.283 7	4.181 4	6.465 1	0.001149	0.141
14.5	196.7	837.5	1 951.4	2 788.9	2.299 3	4.153 3	6.452 6	0.001151	0.136
15.0	198.3	844.7	1 945.2	2 789.9	2.314 5	4.126 1	6.440 6	0.001154	0.132
15.5	199.8	851.7	1 939.2	2 790.8	2.329 2	4.099 6	6.428 9	0.001156	0.128
16.0	201.4	858.6	1 933.2	2 791.7	2.343 6	4.073 9	6.417 5	0.001159	0.124
16.5	202.8	865.3	1 927.3	2 792.6	2.357 6	4.048 9	6.406 5	0.001161	0.120
17.0	204.3	871.8	1 921.5	2 793.4	2.371 3	4.024 5	6.395 7	0.001163	0.117
17.5	205.7	878.3	1 915.9	2 794.1	2.384 6	4.000 7	6.385 3	0.001166	0.113
18.0	207.1	884.6	1 910.3	2 794.8	2.397 6	3.977 5	6.375 1	0.001168	0.110
18.5	208.4	890.7	1 904.7	2 795.5	2.410 3	3.954 8	6.365 1	0.001170	0.107
19.0	209.8	896.8	1 899.3	2 796.1	2.422 8	3.932 6	6.355 4	0.001172	0.105
19.5	211.1	902.8	1 893.9	2 796.7	2.434 9	3.911 0	6.345 9	0.001174	0.102

Absolute pressure (bar)	Temp. (°C)	Specific enthalpy (kJ/kg)			Specific entropy (kJ/kg K)			Specific volume (m^3/kg)	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
20.0	212.4	908.6	1 888.6	2 797.2	2.446 9	3.889 8	6.336 6	0.001177	0.0995
20.5	213.6	914.3	1 883.4	2 797.7	2.458 5	3.869 0	6.327 6	0.001179	0.0971
21.0	214.8	920.0	1 878.2	2 798.2	2.470 0	3.848 7	6.318 7	0.001181	0.0949
21.5	216.1	925.5	1 873.1	2 798.6	2.481 2	3.828 8	6.310 0	0.001183	0.0927
22.0	217.2	931.0	1 868.1	2 799.1	2.492 2	3.809 3	6.301 5	0.001185	0.0907
22.5	218.4	936.3	1 863.1	2 799.4	2.503 0	3.790 1	6.293 1	0.001187	0.0887
23.0	219.5	941.6	1 858.2	2 799.8	2.513 6	3.771 3	6.284 9	0.001189	0.0868
23.5	220.7	946.8	1 853.3	2 800.1	2.524 1	3.752 8	6.276 9	0.001191	0.0849
24.0	221.8	951.9	1 848.5	2 800.4	2.534 3	3.734 7	6.269 0	0.001193	0.0832
24.5	222.9	957.0	1 843.7	2 800.7	2.544 4	3.716 8	6.261 2	0.001195	0.0815
25.0	223.9	962.0	1 839.0	2 800.9	2.554 3	3.699 3	6.253 6	0.001197	0.0799
25.5	225.0	966.9	1 834.3	2 801.2	2.564 0	3.682 1	6.246 1	0.001199	0.0783
26.0	226.0	971.7	1 829.6	2 801.4	2.573 6	3.665 1	6.238 7	0.001201	0.0769
26.5	227.1	976.5	1 825.1	2 801.6	2.583 1	3.648 4	6.231 5	0.001203	0.0754
27.0	228.1	981.2	1 820.5	2 801.7	2.592 4	3.632 0	6.224 4	0.001205	0.0740
27.5	229.1	985.9	1 816.0	2 801.9	2.601 6	3.615 8	6.217 3	0.001207	0.0727
28.0	230.0	990.5	1 811.5	2 802.0	2.610 6	3.599 8	6.210 4	0.001209	0.0714
28.5	231.0	995.0	1 807.1	2 802.1	2.619 5	3.584 1	6.203 6	0.001211	0.0701
29.0	232.0	999.5	1 802.6	2 802.2	2.628 3	3.568 6	6.196 9	0.001213	0.0689
29.5	233.0	1 004.0	1 798.3	2 802.2	2.637 0	3.553 3	6.190 2	0.001214	0.0677
30.0	233.8	1 008.4	1 793.9	2 802.3	2.645 5	3.538 2	6.183 7	0.001216	0.0666
30.5	234.7	1 012.7	1 789.6	2 802.3	2.653 9	3.523 3	6.177 2	0.001218	0.0655
31.0	235.6	1 017.0	1 785.4	2 802.3	2.662 3	3.508 7	6.170 9	0.001220	0.0645
31.5	236.5	1 021.2	1 781.1	2 802.3	2.670 5	3.494 2	6.164 7	0.001222	0.0634
32.0	237.4	1 025.4	1 776.9	2 802.3	2.678 6	3.479 9	6.158 5	0.001224	0.0624
32.5	238.3	1 029.6	1 772.7	2 802.3	2.686 6	3.465 7	6.152 3	0.001225	0.0615
33.0	239.2	1 033.7	1 768.6	2 802.3	2.694 5	3.451 8	6.146 3	0.001227	0.0605
33.5	240.0	1 037.8	1 764.4	2 802.2	2.702 3	3.438 0	6.140 3	0.001229	0.0596
34.0	240.9	1 041.8	1 760.3	2 802.1	2.710 1	3.424 4	6.134 4	0.001231	0.0587
34.5	241.7	1 045.8	1 756.3	2 802.1	2.717 7	3.410 9	6.128 6	0.001233	0.0579
35.0	242.5	1 049.8	1 752.2	2 802.0	2.725 3	3.397 6	6.122 8	0.001234	0.0570
35.5	243.3	1 053.7	1 748.2	2 801.8	2.732 7	3.384 4	6.117 1	0.001236	0.0562
36.0	244.2	1 057.6	1 744.2	2 801.7	2.740 1	3.371 4	6.111 5	0.001238	0.0554
36.5	245.0	1 061.4	1 740.2	2 801.6	2.747 4	3.358 5	6.105 9	0.001239	0.0546
37.0	245.7	1 065.2	1 736.2	2 801.4	2.754 7	3.345 8	6.100 4	0.001242	0.0539

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
37.5	246.5	1 069.0	1 732.3	2 801.3	2.761 8	3.333 2	6.095 0	0.001243	0.0531
38.0	247.3	1 072.7	1 728.4	2 801.1	2.768 9	3.320 7	6.089 6	0.001245	0.0524
38.5	248.1	1 076.4	1 724.5	2 800.9	2.775 9	3.308 3	6.084 2	0.001247	0.0517
39.0	248.8	1 080.1	1 720.6	2 800.8	2.782 9	3.296 1	6.078 9	0.001249	0.0511
39.5	249.6	1 083.8	1 716.8	2 800.5	2.789 7	3.284 0	6.073 7	0.001250	0.0504
40.0	250.3	1 087.4	1 712.9	2 800.3	2.796 5	3.272 0	6.068 5	0.001252	0.0497
41.0	251.8	1 094.6	1 705.3	2 799.9	2.809 9	3.248 3	6.058 2	0.001255	0.0485
42.0	253.2	1 101.6	1 697.8	2 799.4	2.823 1	3.225 1	6.048 2	0.001259	0.0473
43.0	254.6	1 108.5	1 690.3	2 798.8	2.836 0	3.202 3	6.038 3	0.001262	0.0461
44.0	256.0	1 115.4	1 682.9	2 798.3	2.848 7	3.179 9	6.028 6	0.001266	0.0451
45.0	257.4	1 122.1	1 675.6	2 797.7	2.861 2	3.157 9	6.019 1	0.001269	0.0440
46.0	258.7	1 128.8	1 668.3	2 797.0	2.873 5	3.136 2	6.009 7	0.001272	0.0430
47.0	260.1	1 135.3	1 661.1	2 796.4	2.885 5	3.114 9	6.000 4	0.001276	0.0421
48.0	261.4	1 141.8	1 653.9	2 795.7	2.897 4	3.093 9	5.991 3	0.001279	0.0412
49.0	262.6	1 148.2	1 646.8	2 794.9	2.909 1	3.073 3	5.982 3	0.001282	0.0403
50.0	263.9	1 154.5	1 639.7	2 794.2	2.920 6	3.052 9	5.973 5	0.001286	0.0394
51.0	265.1	1 160.7	1 632.7	2 793.4	2.931 9	3.032 8	5.964 8	0.001289	0.0386
52.0	266.4	1 166.8	1 625.7	2 792.6	2.943 1	3.013 0	5.956 1	0.001292	0.0378
53.0	267.6	1 172.9	1 618.8	2 791.7	2.954 1	2.993 5	5.947 6	0.001296	0.0371
54.0	268.7	1 178.9	1 611.9	2 790.8	2.965 0	2.974 2	5.939 2	0.001299	0.0363
55.0	269.9	1 184.9	1 605.0	2 789.9	2.975 7	2.955 2	5.930 9	0.001302	0.0356
56.0	271.1	1 190.8	1 598.2	2 789.0	2.986 3	2.936 4	5.922 7	0.001306	0.0349
57.0	272.2	1 196.6	1 591.4	2 788.0	2.996 7	2.917 9	5.914 6	0.001309	0.0343
58.0	273.3	1 202.3	1 584.7	2 787.0	3.007 1	2.899 5	5.906 6	0.001312	0.0336
59.0	274.4	1 208.0	1 578.0	2 786.0	3.017 2	2.881 4	5.898 6	0.001315	0.0330
60.0	275.5	1 213.7	1 571.3	2 785.0	3.027 3	2.863 5	5.890 8	0.001318	0.0324
61.0	276.6	1 219.3	1 564.7	2 784.0	3.037 2	2.845 8	5.883 0	0.001322	0.0319
62.0	277.7	1 224.8	1 558.0	2 782.9	3.047 1	2.828 3	5.875 3	0.001325	0.0313
63.0	278.7	1 230.3	1 551.5	2 781.8	3.056 8	2.810 9	5.867 7	0.001328	0.0308
64.0	279.8	1 235.7	1 544.9	2 780.6	3.066 4	2.793 8	5.860 1	0.001332	0.0302
65.0	280.8	1 241.1	1 538.4	2 779.5	3.075 9	2.776 8	5.852 7	0.001335	0.0297
66.0	281.8	1 246.5	1 531.9	2 778.3	3.085 3	2.760 0	5.845 2	0.001338	0.0292
67.0	282.8	1 251.8	1 525.4	2 777.1	3.094 6	2.743 3	5.837 9	0.001341	0.0287
68.0	283.8	1 257.0	1 518.9	2 775.9	3.103 8	2.726 8	5.830 6	0.001345	0.0283
69.0	284.8	1 262.2	1 512.5	2 774.7	3.112 9	2.710 5	5.823 3	0.001348	0.0278

Absolute pressure (bar) p	Temp. (°C) t_s	Specific enthalpy (kJ/kg) h_f	h_{fg}	h_g	Specific entropy (kJ/kg K) s_f	s_{fg}	s_g	Specific volume (m^3/kg) v_f	v_g
70.0	285.8	1 267.4	1 506.0	2 773.5	3.121 9	2.694 3	5.816 2	0.001351	0.0274
71.0	286.7	1 272.5	1 499.6	2 772.2	3.130 8	2.678 2	5.809 0	0.001355	0.0269
72.0	287.7	1 277.6	1 493.3	2 770.9	3.139 7	2.662 3	5.802 0	0.001358	0.0265
73.0	288.6	1 282.7	1 486.9	2 769.6	3.148 4	2.646 5	5.794 9	0.001361	0.0261
74.0	289.6	1 287.7	1 480.5	2 768.3	3.157 1	2.630 9	5.788 0	0.001364	0.0257
75.0	290.5	1 292.7	1 474.2	2 766.9	3.165 7	2.615 3	5.781 0	0.001368	0.0253
76.0	291.4	1 297.6	1 467.9	2 765.5	3.174 2	2.599 9	5.774 2	0.001371	0.0249
77.0	292.3	1 302.5	1 461.6	2 764.2	3.182 7	2.584 6	5.767 3	0.001374	0.0246
78.0	293.2	1 307.4	1 455.3	2 762.8	3.191 1	2.569 5	5.760 5	0.001378	0.0242
79.0	294.1	1 312.3	1 449.1	2 761.3	3.199 4	2.554 4	5.753 8	0.001381	0.0239
80.0	294.9	1 317.1	1 442.8	2 759.9	3.207 6	2.539 5	5.747 1	0.001384	0.0235
81.0	295.8	1 321.9	1 436.6	2 758.4	3.215 8	2.524 6	5.740 4	0.001387	0.0232
82.0	296.7	1 326.6	1 430.3	2 757.0	3.223 9	2.509 9	5.733 8	0.001391	0.0229
83.0	297.5	1 331.4	1 424.1	2 755.5	3.232 0	2.495 2	5.727 2	0.001394	0.0225
84.0	298.4	1 336.1	1 417.9	2 754.0	3.239 9	2.480 7	5.720 6	0.001397	0.0222
85.0	299.2	1 340.7	1 411.7	2 752.5	3.247 9	2.466 3	5.714 1	0.001401	0.0219
86.0	300.1	1 345.4	1 405.5	2 750.9	3.255 7	2.451 9	5.707 6	0.001404	0.0216
87.0	300.9	1 350.0	1 399.3	2 749.4	3.263 6	2.437 6	5.701 2	0.001408	0.0213
88.0	301.7	1 354.6	1 393.2	2 747.8	3.271 3	2.423 5	5.694 8	0.001411	0.0211
89.0	302.5	1 359.2	1 387.0	2 746.2	3.279 0	2.409 4	5.688 4	0.001414	0.0208
90.0	303.3	1 363.7	1 380.9	2 744.6	3.286 7	2.395 3	5.682 0	0.001418	0.0205
91.0	304.1	1 368.3	1 374.7	2 743.0	3.294 3	2.381 4	5.675 7	0.001421	0.0202
92.0	304.9	1 372.8	1 368.6	2 741.4	3.301 8	2.367 6	5.669 4	0.001425	0.0199
93.0	305.7	1 377.2	1 362.5	2 739.7	3.309 3	2.353 8	5.663 1	0.001428	0.0197
94.0	306.4	1 381.7	1 356.3	2 738.0	3.316 8	2.340 1	5.656 8	0.001432	0.0194
95.0	307.2	1 386.1	1 350.2	2 736.4	3.324 2	2.326 4	5.650 6	0.001435	0.0192
96.0	308.0	1 390.6	1 344.1	2 734.7	3.331 5	2.312 9	5.644 4	0.001438	0.0189
97.0	308.7	1 395.0	1 338.0	2 733.0	3.338 8	2.299 4	5.638 2	0.001442	0.0187
98.0	309.4	1 399.3	1 331.9	2 731.2	3.346 1	2.285 9	5.632 1	0.001445	0.0185
99.0	310.2	1 403.7	1 325.8	2 729.5	3.353 4	2.272 6	5.625 9	0.001449	0.0183
100.0	311.1	1 408.0	1 319.7	2 727.7	3.360 5	2.259 3	5.619 8	0.001452	0.0181
102.0	312.4	1 416.7	1 307.5	2 724.2	3.374 8	2.232 8	5.607 6	0.001459	0.0176
104.0	313.8	1 425.2	1 295.3	2 720.5	3.388 9	2.206 6	5.595 5	0.001467	0.0172
106.0	315.3	1 433.7	1 283.1	2 716.8	3.402 9	2.180 6	5.583 5	0.001474	0.0168
108.0	316.6	1 442.2	1 270.9	2 713.1	3.416 7	2.154 8	5.571 5	0.001481	0.0164

Absolute pressure (bar) p	*Temp. (°C)* t_s	*Specific enthalpy (kJ/kg)* h_f	h_{fg}	h_g	*Specific entropy (kJ/kg K)* s_f	s_{fg}	s_g	*Specific volume (m^3/kg)* v_f	v_g
110.0	318.0	1 450.6	1 258.7	2 709.3	3.430 4	2.129 1	5.559 5	0.001488	0.0160
112.0	319.4	1 458.9	1 246.5	2 705.4	3.444 0	2.103 6	5.547 6	0.001496	0.0157
114.0	320.7	1 467.2	1 234.3	2 701.5	3.457 4	2.078 3	5.535 7	0.001504	0.0153
116.0	322.1	1 475.4	1 222.0	2 697.4	3.470 8	2.053 1	5.523 9	0.001511	0.0149
118.0	323.4	1 483.6	1 209.7	2 693.3	3.484 0	2.028 0	5.512 1	0.001519	0.0146
120.0	324.6	1 491.8	1 197.4	2 689.2	3.497 2	2.003 0	5.500 2	0.001527	0.0143
122.0	325.9	1 499.9	1 185.0	2 684.9	3.510 2	1.978 2	5.488 4	0.001535	0.0139
124.0	327.1	1 508.0	1 172.6	2 680.6	3.523 2	1.953 3	5.476 5	0.001543	0.0137
126.0	328.4	1 516.0	1 160.1	2 676.1	3.536 0	1.928 6	5.464 6	0.001551	0.0134
128.0	329.6	1 524.0	1 147.6	2 671.6	3.548 8	1.903 9	5.452 7	0.001559	0.0131
130.0	330.8	1 532.0	1 135.0	2 667.0	3.561 6	1.879 2	5.440 8	0.001567	0.0128
132.0	332.0	1 540.0	1 122.3	2 662.3	3.574 2	1.854 6	5.428 8	0.001576	0.0125
134.0	333.2	1 547.9	1 109.5	2 657.4	3.586 8	1.830 0	5.416 8	0.001584	0.0123
136.0	334.3	1 555.8	1 096.7	2 652.5	3.599 3	1.805 3	5.404 7	0.001593	0.0120
138.0	335.5	1 563.7	1 083.8	2 647.5	3.611 8	1.780 7	5.392 5	0.001602	0.0117
140.0	336.6	1 571.6	1 070.7	2 642.4	3.624 2	1.756 0	5.380 3	0.001611	0.0115
142.0	337.7	1 579.5	1 057.6	2 637.1	3.636 6	1.731 3	5.367 9	0.001619	0.0112
144.0	338.8	1 587.4	1 044.4	2 631.8	3.649 0	1.706 6	5.355 5	0.001629	0.0110
146.0	339.9	1 595.3	1 031.0	2 626.3	3.661 3	1.681 8	5.343 1	0.001638	0.0108
148.0	341.1	1 603.1	1 017.6	2 620.7	3.673 6	1.656 9	5.330 5	0.001648	0.0106
150.0	342.1	1 611.0	1 004.0	2 615.0	3.685 9	1.632 0	5.317 9	0.001658	0.0103
152.0	343.2	1 618.9	990.3	2 609.2	3.698 1	1.607 0	5.305 1	0.001668	0.0101
154.0	344.2	1 626.8	976.5	2 603.3	3.710 3	1.581 9	5.292 2	0.001678	0.00991
156.0	345.3	1 634.7	962.6	2 597.3	3.722 6	1.556 7	5.279 3	0.001689	0.00971
158.0	346.3	1 642.6	948.5	2 591.1	3.734 8	1.531 4	5.266 3	0.001699	0.00951
160.0	347.3	1 650.5	934.3	2 584.9	3.747 1	1.506 0	5.253 1	0.001710	0.00931
162.0	348.3	1 658.5	920.0	2 578.5	3.759 4	1.480 6	5.239 9	0.001721	0.00911
164.0	349.3	1 666.5	905.6	2 572.1	3.771 7	1.455 0	5.226 7	0.001733	0.00893
166.0	350.3	1 674.5	891.0	2 565.5	3.784 2	1.429 0	5.213 2	0.001745	0.00874
168.0	351.3	1 683.0	875.6	2 558.6	3.797 4	1.402 1	5.199 4	0.001757	0.00855
170.0	352.3	1 691.7	859.9	2 551.6	3.810 7	1.374 8	5.185 5	0.001769	0.00837
172.0	353.2	1 700.4	844.0	2 544.4	3.824 0	1.347 3	5.171 3	0.001783	0.00819
174.0	354.2	1 709.0	828.1	2 537.1	3.837 2	1.319 8	5.157 0	0.001796	0.00801
176.0	355.1	1 717.6	811.9	2 529.5	3.850 4	1.292 2	5.142 5	0.001810	0.00784
178.0	356.0	1 726.2	795.6	2 521.8	3.863 5	1.264 3	5.127 8	0.001825	0.00767

Absolute pressure (bar) p	*Temp. (°C)* t_s	*Specific enthalpy (kJ/kg)* h_f	h_{fg}	h_g	*Specific entropy (kJ/kg K)* s_f	s_{fg}	s_g	*Specific volume (m^3/kg)* v_f	v_g
180.0	356.9	1 734.8	779.1	2 513.9	3.876 5	1.236 2	5.112 8	0.001840	0.00750
182.0	357.8	1 743.4	762.3	2 505.8	3.889 6	1.207 9	5.097 5	0.001856	0.00733
184.0	358.7	1 752.1	745.3	2 497.4	3.902 8	1.179 2	5.082 0	0.001872	0.00717
186.0	359.6	1 760.9	727.9	2 488.8	3.916 0	1.150 1	5.066 1	0.001889	0.00701
188.0	360.5	1 769.7	710.1	2 479.8	3.929 4	1.120 5	5.049 8	0.001907	0.00684
190.0	361.4	1 778.7	692.0	2 470.6	3.942 9	1.090 3	5.033 2	0.001926	0.00668
192.0	362.3	1 787.8	673.3	2 461.1	3.956 6	1.059 4	5.016 0	0.001946	0.00652
194.0	363.2	1 797.0	654.1	2 451.1	3.970 6	1.027 8	4.998 3	0.001967	0.00636
196.0	364.0	1 806.6	634.2	2 440.7	3.984 9	0.995 1	4.980 0	0.001989	0.00620
198.0	364.8	1 816.3	613.5	2 429.8	3.999 6	0.961 4	4.961 1	0.002012	0.00604
200.0	365.7	1 826.5	591.9	2 418.4	4.014 9	0.926 3	4.941 2	0.002037	0.00588
202.0	366.5	1 837.0	569.2	2 406.2	4.030 8	0.889 7	4.920 4	0.002064	0.00571
204.0	367.3	1 848.1	545.1	2 393.3	4.047 4	0.851 0	4.898 4	0.002093	0.00555
206.0	368.2	1 859.9	519.5	2 379.4	4.065 1	0.809 9	4.875 0	0.002125	0.00538
208.0	368.9	1 872.5	491.7	2 364.2	4.084 1	0.765 7	4.849 8	0.002161	0.00521
210.0	369.8	1 886.3	461.3	2 347.6	4.104 8	0.717 5	4.822 3	0.002201	0.00502
212.0	370.6	1 901.5	427.4	2 328.9	4.127 9	0.663 9	4.791 7	0.002249	0.00483
214.0	371.3	1 919.0	388.4	2 307.4	4.154 3	0.602 6	4.756 9	0.002306	0.00462
216.0	372.1	1 939.9	341.6	2 281.6	4.186 1	0.529 3	4.715 4	0.002379	0.00439
218.0	372.9	1 967.2	280.8	2 248.0	4.227 6	0.434 6	4.662 2	0.002483	0.00412
220.0	373.7	2 011.1	184.5	2 195.6	4.294 7	0.285 2	4.579 9	0.002671	0.00373
221.2	374.1	2 107.4	0.0	2 107.4	4.442 9	0.0	4.442 9	0.003170	0.00317

TABLE III

Superheated Steam at Various Pressures and Temperatures

↓*p* (bar) (t_s)	*t* (°C) →	50	100	150	200	250	300	400	500
0.01 (7.0)	*v*	149.1	172.2	195.3	218.4	241.5	264.5	310.7	356.8
	u	2445.4	2516.4	2588.4	2661.6	2736.9	2812.2	2969.0	3132.4
	h	2594.5	2688.6	2783.6	2880.0	2978.4	3076.8	3279.7	3489.2
	s	9.242	9.513	9.752	9.967	10.163	10.344	10.671	10.960
0.05 (32.9)	*v*	29.78	34.42	39.04	48.66	48.28	52.9	62.13	71.36
	u	2444.8	2516.2	2588.4	2661.9	2736.6	2812.6	2969.6	3133.0
	h	2593.7	2688.1	2783.4	2879.9	2977.6	3076.7	3279.7	3489.2
	s	8.498	8.770	9.009	9.225	9.421	9.602	9.928	10.218
0.1 (45.8)	*v*	14.57	17.19	19.51	21.82	24.14	26.44	31.06	35.68
	u	2443.9	2515.5	2587.9	2661.3	2736.0	2812.1	2968.9	3132.3
	h	2592.6	2687.5	2783.0	2879.5	2977.3	3076.5	3279.6	3489.1
	s	8.175	8.448	8.688	8.904	9.100	9.281	9.608	9.898
0.5 (81.3)	*v*		34.18	3.889	43.56	4.821	5.284	6.209	7.134
	u		2511.6	2585.6	2659.9	2735.0	2811.3	2968.5	3132.0
	h		2682.5	2780.1	2877.7	2976.0	3075.5	3278.9	3488.7
	s		7.695	7.940	8.158	8.356	8.537	8.864	9.155
0.75 (92.0)	*v*		2.27	2.587	2.900	3.211	3.520	4.138	4.755
	u		2509.2	2584.2	2659.0	2734.4	2810.9	2968.2	3131.8
	h		2679.4	2778.2	2876.5	2975.2	3074.9	3278.5	3488.4
	s		7.501	7.749	7.969	8.167	8.349	8.677	8.967
1.0 (99.6)	*v*		1.696	1.936	2.172	2.406	2.639	3.103	3.565
	u		2506.2	2582.8	2658.1	2733.7	2810.4	2967.9	3131.6
	h		2676.2	2776.4	2875.3	2974.3	3074.3	3278.2	3488.1
	s		7.361	7.613	7.834	8.033	8.216	8.544	8.834
1.01325 (100)	*v*			1.912	2.146	2.375	2.603	3.062	3.519
	u			2582.6	2658.0	2733.6	2810.3	2967.8	3131.5
	h			2776.3	2875.2	2974.2	3074.2	3278.1	3488.0
	s			7.828	7.827	8.027	8.209	8.538	8.828
1.5 (111.4)	*v*			1.285	1.143	1.601	1.757	2.067	2.376
	u			2579.8	2656.2	2732.5	2809.5	2967.3	3131.2
	h			2772.6	2872.9	2972.7	3073.1	3277.4	3487.6
	s			7.419	7.643	7.844	8.027	8.356	8.647

↓*p* (bar) (t_s)	*t* (°C) →	50	100	150	200	250	300	400	500
	v			0.960	1.080	1.199	1.316	1.549	1.781
2.0	u			2576.9	2654.4	2731.2	2808.6	2966.7	3130.8
(120.2)	h			2768.8	2870.5	2971.0	3071.8	3276.6	3487.1
	s			7.279	7.507	7.709	7.893	8.222	8.513
	v			0.764	0.862	0.957	1.052	1.238	1.424
2.5	u			2574.7	2655.7	2734.9	2813.8	2973.9	3139.6
(127.4)	h			2764.5	2868.0	2969.6	3070.9	3275.9	3486.5
	s			7.169	7.401	7.604	7.789	8.119	8.410
	v			0.634	0.716	0.796	0.875	1.031	1.187
3.0	u			2570.8	2650.7	2728.7	2806.7	2965.6	3130.0
(133.5)	h			2761.0	2865.6	2967.6	3069.3	3275.0	3486.1
	s			7.078	7.311	7.517	7.702	8.033	8.325
	v			0.471	0.534	0.595	0.655	0.773	0.889
4.0	u			2564.5	2646.8	2726.1	2804.8	2964.4	3129.2
(143.6)	h			2752.8	2860.5	2964.2	3066.8	3273.4	3484.9
	s			6.930	7.171	7.379	7.566	7.899	8.191

↓*p* (bar) (t_s)	*t* (°C) →	200	250	300	350	400	450	500	600
	v	0.425	0.474	0.523	0.570	0.617	0.664	0.711	0.804
5.0	u	2642.9	2723.5	2802.9	2882.6	2963.2	3045.3	3128.4	3299.6
(151.8)	h	2855.4	2960.7	3064.2	3167.7	3271.9	3377.2	3483.9	3701.7
	s	7.059	7.271	7.460	7.633	7.794	7.945	8.087	8.353
	v	0.352	0.394	0.434	0.474	0.514	0.553	0.592	0.670
6.0	u	2638.9	2720.9	2801.0	2881.2	2962.1	3044.2	3127.6	3299.1
(158.8)	h	2850.1	2957.2	3061.6	3165.7	3270.3	3376.0	3482.8	3700.9
	s	6.967	7.182	7.372	7.546	7.708	7.859	8.002	8.267
	v	0.300	0.336	0.371	0.406	0.440	0.473	0.507	0.574
7.0	u	2634.8	2718.2	2799.1	2879.7	2960.9	3043.2	3126.8	3298.5
(165.0)	h	2844.8	2953.6	3059.1	3163.7	3268.7	3374.7	3481.7	3700.2
	s	6.886	7.105	7.298	7.473	7.635	7.787	7.930	8.196
	v	0.261	0.293	0.324	0.354	0.384	0.414	0.443	0.502
8.0	u	2630.6	2715.5	2797.2	2878.2	2959.7	3042.3	3126.0	3297.8
(170.4)	h	2839.3	2950.1	3056.5	3161.7	3267.1	3373.4	3480.6	3699.4
	s	6.816	7.038	7.233	7.409	7.572	7.724	7.867	8.133

↓*p (bar)* (t_s)	*t* (°C) →	200	250	300	350	400	450	500	600
	v	0.230	0.260	0.287	0.314	0.341	0.367	0.394	0.446
9.0	*u*	2626.3	2712.7	2795.2	2876.7	2958.5	3041.3	3125.2	3297.3
(175.4)	*h*	2833.6	2946.3	3053.8	3159.7	3265.5	3372.1	3479.6	3698.6
	s	6.752	6.979	7.175	7.352	7.516	7.668	7.812	8.078
	v	0.206	0.233	0.258	0.282	0.307	0.330	0.354	0.401
10.0	*u*	2621.9	2709.9	2793.2	2875.2	2957.3	3040.3	3124.4	3296.8
(179.9)	*h*	2827.9	2942.6	3051.2	3157.8	3263.9	3370.7	3478.5	3697.9
	s	6.694	6.925	7.123	7.301	7.465	7.618	7.762	8.029
	v	0.132	0.152	0.169	0.187	0.203	0.219	0.235	0.267
15.0	*u*	2598.8	2695.3	2783.1	2867.6	2951.3	3035.3	3120.3	3293.9
(198.3)	*h*	2796.8	2923.3	3037.6	3147.5	3255.8	3364.2	3473.1	3694.0
	s	6.455	6.709	6.918	7.102	7.269	7.424	7.570	7.839
	v		0.111	0.125	0.139	0.151	0.163	0.176	0.200
20.0	*u*		2679.6	2772.6	2859.8	2945.2	3030.5	3116.2	3290.9
(212.4)	*h*		2902.5	3023.5	3137.0	3247.6	3357.5	3467.6	3690.1
	s		6.545	6.766	6.956	7.127	7.285	7.432	7.702
	v		0.0870	0.0989	0.109	0.120	0.130	0.140	0.159
25	*u*		2662.6	2761.6	2851.9	2939.1	3025.5	3112.1	3288.0
(223.9)	*h*		2880.1	3008.8	3126.3	3239.3	3350.8	3462.1	3686.3
	s		6.408	6.644	6.840	7.015	7.175	7.323	7.596
	v		0.0706	0.0811	0.0905	0.0994	0.108	0.116	0.132
30	*u*		2644.0	2750.1	2843.7	2932.8	3020.4	3108.0	3285.0
(233.8)	*h*		2855.8	2993.5	3115.3	3230.9	3344.0	3456.5	3682.3
	s		6.287	6.539	6.743	6.921	7.083	7.234	7.509
	v			0.0588	0.0664	0.0734	0.080	0.0864	0.0989
40	*u*			2725.3	2826.7	2919.9	3010.2	3099.5	3279.1
(250.4)	*h*			2960.7	3092.5	3213.6	3330.3	3445.3	3674.4
	s			6.362	6.582	6.769	6.936	7.090	7.369
	v			0.0453	0.0519	0.0578	0.0633	0.0686	0.0787
50	*u*			2698.0	2808.7	2906.6	2999.7	3091.0	3273.0
(263.9)	*h*			2924.5	3068.4	3195.7	3316.2	3433.8	3666.5
	s			6.208	6.449	6.646	6.819	6.976	7.259

↓p (bar) (t_s)	t (°C) →	200	250	300	350	400	450	500	600
	v			0.0362	0.0422	0.0474	0.0521	0.0567	0.0653
60	u			2667.2	2789.6	2892.9	2988.9	3082.2	3266.9
(275.5)	h			2884.2	3043.0	3177.2	3301.8	3422.2	3658.4
	s			6.067	6.333	6.541	6.719	6.880	7.168
	v			0.0295	0.0352	0.0399	0.0442	0.0481	0.0557
70	u			2632.2	2769.4	2878.6	2978.0	3073.4	3260.7
(285.8)	h			2838.4	3016.0	3158.1	3287.1	3410.3	3650.3
	s			5.931	6.228	6.448	6.633	6.798	7.089

↓p (bar) (t_s)	t (°C) →	350	375	400	450	500	550	600	700
80	v	0.02995	0.03222	0.03432	0.03817	0.04175	0.04516	0.04845	0.05481
(294.9)	h	2987.3	3066.1	3138.3	3272.0	3398.3	3521.0	3642.0	3882.4
	s	6.130	6.254	6.363	6.555	6.724	6.878	7.021	7.281
90	v	0.0258	0.02796	0.02993	0.03350	0.03677	0.03987	0.04285	0.04857
(303.3)	h	2956.6	3041.3	3117.8	3256.6	3386.1	3511.0	3633.7	3876.5
	s	6.036	6.169	6.285	6.484	6.658	6.814	6.959	7.222
100	v	0.02242	0.02453	0.02641	0.02975	0.03279	0.03564	0.03837	0.04358
(311.0)	h	2923.4	3015.4	3096.5	3240.9	3373.7	3500.9	3625.3	3870.5
	s	5.944	6.089	6.212	6.419	6.597	6.756	6.903	7.169
110	v	0.01961	0.02169	0.02351	0.02668	0.02952	0.03217	0.03470	0.03950
(318.0)	h	2887.3	2988.2	3074.3	3224.7	3361.0	3490.7	3616.9	3864.5
	s	5.853	6.011	6.142	6.358	6.540	6.703	6.851	7.120
120	v	0.01721	0.01931	0.02108	0.02412	0.02680	0.02929	0.03164	0.03610
(324.6)	h	2847.7	2958.9	3051.3	3208.2	3348.2	3480.4	3608.3	3858.4
	s	5.760	5.935	6.075	6.300	6.487	6.653	6.804	7.075
130	v	0.01511	0.01725	0.01900	0.02194	0.0245	0.02684	0.02905	0.03322
(330.8)	h	2803.3	2927.9	3027.2	3191.3	3335.2	3469.9	3599.7	3852.3
	s	5.663	5.859	6.009	6.245	6.437	6.606	6.759	7.033
140	v	0.01322	0.01546	0.01722	0.02007	0.02252	0.02474	0.02683	0.03075
(336.6)	h	2752.6	2894.5	3001.9	3174.0	3322.0	3459.3	3591.1	3846.2
	s	5.559	5.782	5.945	6.192	6.390	6.562	6.712	6.994
150	v	0.01145	0.01388	0.01565	0.01845	0.02080	0.02293	0.02491	0.02861
(342.1)	h	2692.4	2858.4	2975.5	3156.2	3308.6	3448.6	3582.3	3840.1
	s	5.442	5.703	5.881	6.140	6.344	6.520	6.679	6.957

↓*p (bar)* (t_s)	*t* (°C) →	*350*	*375*	*400*	*450*	*500*	*550*	*600*	*700*
160	*v*	0.00975	0.01245	0.01426	0.01701	0.01930	0.02134	0.02323	0.02674
(347.3)	*h*	2615.7	2818.9	2947.6	3138.0	3294.9	3437.8	3573.5	3833.9
	s	5.302	5.622	5.188	6.091	6.301	6.480	6.640	6.922
170	*v*		0.01117	0.01302	0.01575	0.01797	0.01993	0.02174	0.02509
(352.3)	*h*		2776.8	2918.2	3119.3	3281.1	3426.9	3564.6	3827.7
	s		5.539	5.754	6.042	6.259	6.442	6.604	6.889
180	*v*		0.00996	0.01190	0.01462	0.01678	0.01868	0.02042	0.02362
(356.9)	*h*		2727.9	2887.0	3100.1	3267.0	3415.9	3555.6	3821.5
	s		5.448	5.689	5.995	6.218	6.405	6.570	6.858
190	*v*		0.00881	0.01088	0.01361	0.01572	0.01756	0.01924	0.02231
(361.4)	*h*		2671.3	2853.8	3080.4	3252.7	3404.7	3546.6	3815.3
	s		5.346	5.622	5.948	6.179	6.369	6.537	6.828
200	*v*		0.00767	0.00994	0.01269	0.9477	0.01655	0.01818	0.02113
(365.7)	*h*		2602.5	2818.1	3060.1	3238.2	3393.5	3537.6	3809.0
	s		5.227	5.554	5.902	6.140	6.335	6.505	6.799
210	*v*		0.00645	0.00907	0.01186	0.01390	0.01564	0.01722	0.02006
(369.8)	*h*		2511.0	2779.6	3039.3	3223.5	3382.1	3528.4	3802.8
	s		5.075	5.483	5.856	6.103	6.301	6.474	6.772
220	*v*		0.00482	0.00825	0.01110	0.01312	0.01481	0.01634	0.01909
(373.7)	*h*		2345.1	2737.6	3017.9	3208.6	3370.6	3519.2	3796.5
	s		4.810	5.407	5.811	6.066	6.269	6.444	6.745

TABLE IV

Supercritical Steam

p(bar)	t (°C) →	350	375	400	425	450	500	600	700	800
230	v	0.00162	0.00221	0.00748	0.00915	0.01040	0.01239	0.01554	0.01821	0.02063
	h	1632.8	1912.2	2691.2	2869.2	2995.8	3193.4	3510.0	3790.2	4056.2
	s	3.137	4.137	5.327	5.587	5.765	6.030	6.415	6.719	6.980
250	v	0.00160	0.00197	0.00600	0.00788	0.00916	0.01112	0.01414	0.01665	0.01891
	h	1623.5	1848.0	2580.2	2806.3	2949.7	3162.4	3491.4	3775.5	4047.1
	s	3.680	4.032	5.142	5.472	5.674	5.959	6.360	6.671	6.934
300	v	0.00155	0.00179	0.00279	0.00530	0.00673	0.00868	0.01145	0.01366	0.01562
	h	1608.5	1791.5	2151.1	2614.2	2821.4	3081.1	3443.9	3745.6	4024.2
	s	3.643	3.930	4.473	5.150	5.442	5.790	6.233	6.561	6.833
350	v	0.00152	0.00110	0.00210	0.00343	0.00496	0.00693	0.00953	0.01153	0.01328
	h	1597.1	1762.4	1987.6	2373.4	2672.4	2994.4	3395.5	3713.5	4001.5
	s	3.612	3.872	4.213	4.775	5.196	5.628	6.118	6.463	6.745
400	v	0.00149	0.00164	0.00191	0.00253	0.00369	0.00562	0.00809	0.00994	0.01152
	h	1588.3	1742.8	1930.9	2198.1	2512.8	2903.3	3346.4	3681.2	3978.7
	s	3.586	3.829	4.113	4.503	4.946	5.470	6.011	6.375	6.666
500	v	0.00144	0.00156	0.00173	0.00201	0.00249	0.00389	0.00611	0.00773	0.00908
	h	1575.3	1716.6	1874.6	2060.0	2284.0	2720.1	3247.6	3616.8	3933.6
	s	3.542	3.764	4.003	4.273	4.588	5.173	5.818	6.219	6.529
600	v	0.00140	0.00150	0.00163	0.00182	0.00209	0.00296	0.00483	0.00627	0.00746
	h	1566.4	1699.5	1843.4	2001.7	2179.0	2567.9	3151.2	3553.5	3889.1
	s	3.505	3.764	3.932	4.163	4.412	4.932	5.645	6.082	6.411
700	v	0.00137	0.00146	0.00157	0.00171	0.00189	0.00247	0.00398	0.00526	0.00632
	h	1560.4	1687.7	1822.8	1967.2	2122.7	2463.2	3061.7	3492.4	3845.7
	s	3.473	3.673	3.877	4.088	4.307	4.762	5.492	5.961	6.307
800	v	0.00135	0.00142	0.00152	0.00163	0.00177	0.00219	0.00339	0.00452	0.00548
	h	1556.4	1679.4	1808.3	1943.9	2086.9	2394.0	2982.7	3434.6	3803.8
	s	3.444	3.638	3.833	4.031	4.232	4.642	5.360	5.851	6.213
900	v	0.00133	0.00139	0.00147	0.00157	0.00169	0.00201	0.00297	0.00397	0.00484
	h	1553.9	1673.4	1797.7	1927.2	2062.0	2346.7	2915.6	3381.1	3763.8
	s	3.419	3.607	3.795	3.984	4.174	4.554	5.247	5.753	6.128
1000	v	0.01308	0.00137	0.00144	0.00152	0.00163	0.00189	0.00267	0.00355	0.00434
	h	1552.7	1669.4	1790.0	1914.8	2043.8	2312.8	2859.8	3332.3	3726.1
	s	3.396	3.579	3.762	3.944	4.126	4.485	5.151	5.664	6.050

TABLE V

Conversion Factors

Force

1 newton	=	1 kg-m/sec^2
	=	0.012 kgf
1 kgf	=	9.81 N

Pressure

1 bar	=	750.06 mm Hg
	=	0.9869 atm
	=	10^5 N/m^2
	=	10^3 kg/m-sec^2
1 N/m^2	=	1 pascal
	=	10^{-5} bar
	=	10^{-2} kg/m-sec^2
1 atm	=	760 mm Hg
	=	1.03 kgf/cm^2 = 1.01325 bar
	=	1.01325×10^5 N/m^2

Work, Energy or Heat

1 joule	=	1 newton metre
	=	1 watt-sec
	=	2.7778×10^{-7} kWh
	=	0.239 cal
	=	0.239×10^{-3} kcal
1 cal	=	4.184 joule
	=	1.1622×10^{-6} kWh
1 kcal	=	4.184×10^3 joule
	=	427 kgfm
	=	1.1622×10^{-3} kWh
1 kWh	=	8.6×10^5 cal
	=	860 kcal
	=	3.6×10^6 joule
1 kgfm	=	$\left(\frac{1}{427}\right)$ kcal = 9.81 joules

Power

1 watt	=	1 joule/sec = 0.86 kcal/h
1 h.p.	=	75 mkgf/sec = 0.1757 kcal/sec
	=	735.3 watt
1 kW	=	1000 watts
	=	860 kcal/h

Specific heat

1 kcal/kg - °K	=	4.18 kJ/kg-K

Thermal conductivity

1 watt/m-K	=	0.8598 kcal/h-m-°C
1 kcal/h-m-°C	=	1.16123 watt/m-K
	=	1.16123 joules/s-m-K

Heat transfer co-efficient

1 watt/m^2-K	=	0.86 kcal/m^2-h-°C
1 kcal/m^2-h-°C	=	1.163 watt/m^2-K

IMPORTANT ENGINEERING CONSTANTS AND EXPRESSIONS IN SI UNITS

	Engineering constants and expressions	*M.K.S. system*	*S.I. units*
1.	Value of g_0	9.81 kg-m/kgf-sec^2	1 kg-m/N-sec^2
2.	Universal gas constant	848 kgf-m/kg mole-°K	848 × 9.81 = 8314 J/kg-mole-°K ($\because$ 1 kgf-m = 9.81 joules)
3.	Gas constant (R)	29.27 kgf m/kg-°K for air	$\frac{8314}{29}$ = 287 joules/kg-K for air
4.	Specific heats (for air)	c_v = 0.17 kcal/kg-°K c_p = 0.24 kcal/kg-°K	c_v = 0.17 × 4.184 = 0.71128 kJ/kg-K c_p = 0.24 × 4.184 = 1 kJ/kg-K
5.	Flow through nozzle-exit velocity (C_2)	91.5 $\sqrt{U}$ where U is in kcal	44.7 $\sqrt{U}$ where U is in kJ
6.	Refrigeration 1 ton	= 50 kcal/min	= 210 kJ/min
7.	**Heat transfer** The Stefan Boltzman Law is given by :	Q = σT^4 kcal/m^2-h when σ = 4.9 × 10^{-8} kcal/h-m^2-°K^4	Q = σT^4 watts/m^2-h when σ = 5.67 × 10^{-8} W/m^{2}K^4