UNIVERSITY OF JOHANNESBURG

PROGRAM	:	NATIONAL DIPLOMA) *ENGINEERING: MECHANICAL*
SUBJECT	:	**STEAM PLANT**
CODE	:	**SMP 301**
DATE	:	SUMMER EXAMINATION 2015 16 NOVEMBER 2015
DURATION	:	(SESSION 1) 08:30 - 11:30
WEIGHT	:	
TOTAL MARKS	:	114 = 100%
MAXIMUM MARKS	:	
ASSESSOR	:	ASSESSOR: Mr. E. BAKAYA-KYAHURWA
MODERATOR	:	MODERATOR: Mr. Kobus Van Tonder
NUMBER OF PAGES	:	PAGES: 3 excluding the cover page.
INSTRUCTIONS	:	ONLY ONE POCKET CALCULATOR PER CANDIDATE MAY BE USED.

1. This paper contains **5** questions
2. PLEASE ANSWER **ALL** QUESTIONS
3. Make sure that you understand what the question requires before attempting it.
4. Any additional examination material is to be placed in the answer book and must indicate clearly the question number, and Student number.
5. Draw proper sketches where required with all relevant information
   Answers without calculations will not be considered.
   Answers without units will not be considered.
   All answers to be to the 4th decimal point.
   Number all answer according to the numbering in question paper.

REQUIREMENTS : h-s Chart for steam, Thermodynamic Property Tables

QUESTION 1

1.1 The basic Rankine thermodynamic cycle does not convert heat into work at the optimum level and its performance can be improved by certain enhancements, either to the cycle itself or to the output from the cycle, which ultimately result in better fuel economy. For each of the following explain in detail the fundamental principles which enhance the performance of the cycle.

Where appropriate cycle diagrams or flow diagrams should be included to illustrate the enhancement.

1.1.1 Feedwater heating in a steam cycle as used in a large scale electric power generating plant. (2)

1.1.2 Reheating of the steam after expansion in HP turbine (2)

1.1.3 Lowering the condenser pressure. (2)

1.2 An ideal Rankine Cycle operates at a pressure of 6 MPa with superheating to 400°C. Steam is extracted from the turbine at 0.6 MPa for feed water heating in a direct contact heat exchanger which operates at this pressure. Complete mixing of the steam and water occurs. A condensate extraction pump is required to pump from the condenser pressure of 0.004MPa to 0.6 MPa. Isentropic conditions prevail in the pumps and turbine.

1.2.1 Sketch the process on the Ts diagram labelling all the key points by the number corresponding to the plant diagram (10)

1.2.2 Determine the fractional mass flow of steam required for feed water heating (2)

1.2.3 Calculate the cycle efficiency with feed water heater in operation (5)

[23]

v_f @4 kPa = 0.0010041 m^3/kg

QUESTION 2

2.1 The walls of a furnace consist of parallel layers in contact of cement, brick and wood of thickness 20 mm, 300 mm and 10 mm respectively. Find the quantity of heat that passes through each m^2 of wall per minute, if the temperature of air in contact with the wall is 5° C and 300°C inside. The values of k for cement, brick and wood are 0.294, 0.252 and 0.168 W/mK respectively. [10]

2.2 A steam pipe 20 m long, 100 mm internal diameter and 40 mm thick is covered by a layer of lagging of 25 mm thick. The coefficient of thermal conductivities for the pipe material and lagging are 0.07 W/m K and 0.1 W/mK respectively. If the steam is conveyed at a pressure of 1.7 MPa with 30°C superheat and the outside temperature of the lagging is 24°C, determine:

2.2.1 the heat lost per hour (9)

2.2.2 the interface temperature. (1)

Neglect the pressure drop across the steam pipe.

[20]

QUESTION 3

3.1 Two airstreams A and B are mixed steadily and adiabatically in a ratio of 2 parts of A to 3 parts of B. Stream A enters the mixing chamber at 40°C with a relative humidity of 35%, while stream B enters with a dry bulb and wet bulb temperature of 15°C and 12°C. Assuming that the mixing process occurs at a pressure of 101.325 kPa, determine for the mixture the:

3.1.1 dry-bulb temperature, (3)

3.1.2 moisture content, (3)

3.1.3 percentage saturation, (3)

3.1.4 specific enthalpy, (3)

3.1.5 dew point temperature. (3)

3.1.6 partial pressure of water vapour in the mixture (3)

3.2 A cooling tower must cool 340 kg of water per minute. The water is supplied at 42°C and it sprayed down into the column of air which enters the bottom of the tower at a rate of 540 m^3/min with a temperature of 18°C and relative humidity of 60%. The moist air leaves the top of the tower saturated at 27°C. The whole process occurs at a constant pressure of 1.013 bar. Determine the temperature of the cooled water in the pool and the rate at which make up water must be supplied to replace that evaporated. (16)

[34]

QUESTION 4

One stage of a steam turbine receives steam at a mass flow rate of 30 kg/s. The fixed blade outlet angle is 20°. The moving blade is symmetrical such that the moving blade outlet angle is equal to the moving blade inlet angle.
The initial absolute velocity of steam leaving the fixed blades is 450 m/s. the blade velocity is 250 m/s. Due to friction in the moving blades the outlet relative steam velocity from the moving blades is equal to 0.95 of the inlet relative steam velocity to these blades.

Draw to scale a velocity diagram for this turbine stage, find all the velocities and angles not stated and determine the following. (6)

4.1 Final absolute steam velocity leaving the moving blades and its direction (4)
4.2 Power developed in this stage due to change in momentum of the steam (2)
4.3 Blade diagram efficiency related to the energy and flow of the initial steam jet (2)

[14]

QUESTION 5

A convergent divergent nozzle is required to pass 1.8 kg of steam per sec. At inlet the steam pressure and actual temperature are 0.7 MPa and 186.2°C respectively and the speed is 75 m/sec. Expansion is stable throughout to the exit pressure of 110 kPa. There is no loss by friction in the converging section of the nozzle but loss by friction between throat and outlet is equivalent to 70 kJ/kg of steam. Calculate, assuming throat pressure of 4 bar:

5.1 the required area of throat in mm^2. (11)

5.2 the required area of outlet in mm^2. (5)

5.3 the overall efficiency of the nozzle, based on the heat drop between the actual inlet pressure and temperature and the outlet pressure. (7)

[23]

TOTAL = 114

Properties of Water and Saturated Steam

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
1,0	7,0	129,20	29	2 485	2 514	0,106	8,977
1,5	13,0	87,98	55	2 471	2 526	0,196	8,829
2,0	17,5	67,01	74	2 460	2 534	0,261	8,725
2,5	21,1	54,26	89	2 452	2 541	0,312	8,644
3,0	24,1	45,67	101	2 445	2 546	0,354	8,579
3,5	26,7	39,48	112	2 439	2 551	0,391	8,523
4,0	29,0	34,80	121	2 433	2 554	0,423	8,476
4,5	31,0	31,14	130	2 428	2 558	0,451	8,434
5,0	32,9	28,19	138	2 424	2 562	0,476	8,396
5,5	34,6	25,77	145	2 420	2 565	0,500	8,362
6,0	36,2	23,74	152	2 416	2 568	0,521	8,331
6,5	37,7	22,02	158	2 413	2 571	0,541	8,303
7,0	39,0	20,53	163	2 410	2 573	0,559	8,277
7,5	40,3	19,24	169	2 406	2 575	0,576	8,252
8,0	41,6	18,10	174	2 403	2 577	0,593	8,230
8,5	42,7	17,10	179	2 401	2 580	0,608	8,208
9,0	43,8	16,20	183	2 398	2 581	0,622	8,188
9,5	44,8	15,40	188	2 395	2 583	0,636	8,169
10	45,8	14,67	192	2 393	2 585	0,649	8,151
11	47,7	13,42	200	2 388	2 588	0,674	8,118
12	49,5	12,36	207	2 384	2 591	0,696	8,087
13	51,1	11,47	214	2 380	2 594	0,717	8,059
14	52,6	10,69	220	2 377	2 597	0,737	8,033
15	54,0	10,02	226	2 373	2 599	0,755	8,009
16	55,3	9,433	232	2 370	2 602	0,772	7,987
17	56,6	8,911	237	2 367	2 604	0,788	7,966
18	57,8	8,445	242	2 364	2 606	0,804	7,946
19	59,0	8,027	247	2 361	2 608	0,818	7,927
20	60,1	7,650	252	2 358	2 610	0,832	7,909
21	61,1	7,307	256	2 356	2 612	0,845	7,893
22	62,2	6,995	260	2 353	2 613	0,858	7,876
23	63,1	6,709	264	2 351	2 615	0,870	7,861
24	64,1	6,447	268	2 349	2 617	0,882	7,846
25	65,0	6,204	272	2 346	2 618	0,893	7,832
26	65,9	5,980	276	2 344	2 620	0,904	7,819
27	66,7	5,772	279	2 342	2 621	0,915	7,806
28	67,6	5,579	283	2 340	2 623	0,925	7,793
29	68,3	5,398	286	2 338	2 624	0,935	7,781
30	69,1	5,229	289	2 336	2 625	0,944	7,770

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
32	70,6	4,922	296	2 332	2 628	0,962	7,747
34	72,0	4,650	302	2 329	2 631	0,980	7,727
36	73,4	4,408	307	2 326	2 633	0,996	7,707
38	74,7	4,190	313	2 322	2 635	1,011	7,688
40	75,9	3,993	318	2 319	2 637	1,026	7,671
45	78,7	3,576	330	2 312	2 642	1,060	7,631
50	81,4	3,240	341	2 305	2 646	1,091	7,595
55	83,7	2,964	351	2 299	2 650	1,119	7,562
60	86,0	2,732	360	2 294	2 654	1,145	7,533
65	88,0	2,535	369	2 288	2 657	1,170	7,506
70	90,0	2,365	377	2 283	2 660	1,192	7,480
75	91,8	2,217	385	2 279	2 664	1,213	7,457
80	93,5	2,087	392	2 274	2 666	1,233	7,435
85	95,2	1,972	399	2 270	2 669	1,252	7,415
90	96,7	1,869	405	2 266	2 671	1,270	7,395
95	98,2	1,777	412	2 262	2 674	1,287	7,377
100	99,6	1,694	418	2 258	2 676	1,303	7,360
110	102,3	1,549	429	2 251	2 680	1,333	7,328
120	104,8	1,428	439	2 244	2 683	1,361	7,300
130	107,1	1,325	449	2 238	2 687	1,387	7,272
140	109,3	1,236	458	2 232	2 690	1,411	7,247
150	111,4	1,159	467	2 226	2 693	1,434	7,223
160	113,3	1,091	475	2 221	2 696	1,455	7,202
170	115,2	1,031	483	2 216	2 699	1,475	7,181
180	116,9	0,977 2	491	2 211	2 702	1,494	7,162
190	118,6	0,929 0	498	2 206	2 704	1,513	7,144
200	120,2	0,885 4	505	2 202	2 707	1,530	7,127
210	121,8	0,845 9	511	2 197	2 708	1,547	7,111
220	123,3	0,809 8	518	2 193	2 711	1,563	7,095
230	124,7	0,776 8	524	2 189	2 713	1,578	7,080
240	126,1	0,746 5	530	2 185	2 715	1,593	7,066
250	127,4	0,718 4	535	2 181	2 716	1,607	7,052
260	128,7	0,692 5	541	2 177	2 718	1,621	7,039
270	130,0	0,668 4	546	2 174	2 720	1,634	7,026
280	131,2	0,646 0	551	2 170	2 721	1,647	7,014
290	132,4	0,625 1	557	2 167	2 724	1,660	7,002
300	133,5	0,605 6	561	2 163	2 724	1,672	6,991
310	134,7	0,587 2	566	2 160	2 726	1,683	6,980
320	135,8	0,570 0	571	2 157	2 728	1,695	6,969
330	136,8	0,553 8	576	2 154	2 730	1,706	6,959
340	137,9	0,538 5	580	2 150	2 730	1,717	6,949
350	138,9	0,524 0	584	2 147	2 731	1,727	6,939
360	139,9	0,510 3	589	2 144	2 733	1,738	6,930
370	140,8	0,497 4	593	2 141	2 734	1,748	6,921

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
380	141,8	0,485 1	597	2 139	2 736	1,757	6,912
390	142,7	0,473 4	601	2 136	2 737	1,767	6,903
400	143,6	0,462 2	605	2 133	2 738	1,776	6,894
410	144,5	0,451 6	609	2 130	2 739	1,786	6,886
420	145,4	0,441 5	612	2 128	2 740	1,795	6,878
430	146,3	0,431 8	616	2 125	2 741	1,803	6,870
440	147,1	0,422 6	620	2 122	2 742	1,812	6,862
450	147,9	0,413 8	624	2 120	2 744	1,820	6,855
460	148,7	0,405 3	627	2 117	2 744	1,829	6,847
470	149,5	0,397 2	630	2 115	2 745	1,837	6,840
480	150,3	0,389 4	634	2 112	2 746	1,845	6,833
490	151,1	0,381 9	637	2 110	2 747	1,853	6,826
500	151,8	0,374 7	640	2 107	2 747	1,860	6,819
520	153,3	0,361 1	647	2 103	2 750	1,875	6,806
540	154,8	0,348 5	653	2 098	2 751	1,890	6,793
560	156,2	0,336 7	659	2 094	2 753	1,904	6,781
580	157,5	0,325 7	665	2 089	2 754	1,918	6,769
600	158,8	0,315 5	670	2 085	2 755	1,931	6,758
620	160,1	0,305 9	676	2 081	2 757	1,944	6,746
640	161,4	0,296 8	682	2 077	2 759	1,956	6,736
660	162,6	0,288 3	687	2 073	2 760	1,968	6,725
680	163,8	0,280 3	692	2 069	2 761	1,980	6,715
700	165,0	0,272 7	697	2 065	2 762	1,992	6,705
720	166,1	0,265 5	702	2 061	2 763	2,003	6,696
740	167,2	0,258 7	707	2 057	2 764	2,014	6,686
760	168,3	0,252 2	712	2 054	2 766	2,025	6,677
780	169,4	0,246 1	717	2 050	2 767	2,035	6,668
800	170,4	0,240 3	721	2 047	2 768	2,046	6,660
820	171,4	0,234 7	725	2 043	2 768	2,056	6,651
840	172,5	0,229 4	730	2 040	2 770	2,066	6,643
860	173,4	0,224 3	734	2 036	2 770	2,075	6,635
880	174,4	0,219 5	739	2 033	2 772	2,085	6,627
900	175,4	0,214 8	743	2 030	2 773	2,094	6,619
920	176,3	0,210 4	747	2 026	2 773	2,103	6,612
940	177,2	0,206 1	751	2 023	2 774	2,112	6,604
960	178,1	0,202 0	755	2 020	2 775	2,121	6,597
980	179,0	0,198 1	759	2 017	2 776	2,130	6,590
1 000	179,9	0,194 3	763	2 014	2 777	2,138	6,583
1 050	182,0	0,185 5	772	2 006	2 778	2,159	6,566
1 100	184,1	0,177 4	781	1 999	2 780	2,179	6,550
1 150	186,1	0,170 0	790	1 991	2 781	2,198	6,534
1 200	188,0	0,163 2	798	1 984	2 782	2,216	6,519
1 250	189,8	0,156 9	807	1 977	2 784	2,234	6,505
1 300	191,6	0,151 1	815	1 971	2 786	2,251	6,491

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
1 350	193,4	0,145 7	823	1 964	2 787	2,268	6,478
1 400	195,0	0,140 7	830	1 958	2 788	2,284	6,465
1 450	196,7	0,136 0	838	1 951	2 789	2,299	6,453
1 500	198,3	0,131 7	845	1 945	2 790	2,315	6,441
1 550	199,9	0,127 5	852	1 939	2 791	2,330	6,429
1 600	201,4	0,123 7	859	1 933	2 792	2,344	6,418
1 650	202,9	0,120 1	865	1 927	2 792	2,358	6,407
1 700	204,3	0,116 6	872	1 922	2 794	2,371	6,396
1 750	205,7	0,113 4	878	1 916	2 794	2,385	6,385
1 800	207,1	0,110 3	885	1 910	2 795	2,398	6,375
1 850	208,5	0,107 4	891	1 905	2 796	2,410	6,365
1 900	209,8	0,104 7	897	1 899	2 796	2,423	6,355
1 950	211,1	0,102 0	903	1 894	2 797	2,435	6,346
2 000	212,4	0,099 54	908	1 889	2 797	2,447	6,337
2 050	213,6	0,097 16	914	1 883	2 797	2,459	6,328
2 100	214,9	0,094 89	920	1 878	2 798	2,470	6,319
2 150	216,1	0,092 72	926	1 873	2 799	2,481	6,310
2 200	217,2	0,090 65	931	1 868	2 799	2,492	6,302
2 250	218,4	0,088 67	936	1 863	2 799	2,503	6,293
2 300	219,6	0,086 77	942	1 858	2 800	2,514	6,285
2 350	220,7	0,084 95	947	1 853	2 800	2,524	6,277
2 400	221,8	0,083 20	952	1 849	2 801	2,534	6,269
2 450	222,9	0,081 52	957	1 844	2 801	2,544	6,261
2 500	223,9	0,079 91	962	1 839	2 801	2,554	6,254
2 550	225,0	0,078 35	967	1 834	2 801	2,564	6,246
2 600	226,0	0,076 86	972	1 830	2 802	2,574	6,239
2 650	227,1	0,075 41	977	1 825	2 802	2,583	6,232
2 700	228,1	0,074 02	981	1 821	2 802	2,592	6,224
2 750	229,1	0,072 68	986	1 816	2 802	2,602	6,217
2 800	230,1	0,071 39	991	1 811	2 802	2,611	6,210
2 850	231,0	0,070 14	995	1 807	2 802	2,620	6,204
2 900	232,0	0,068 93	1 000	1 802	2 802	2,628	6,197
2 950	232,9	0,067 76	1 004	1 798	2 802	2,637	6,190
3 000	233,8	0,066 63	1 008	1 794	2 802	2,646	6,184
3 100	235,7	0,064 47	1 017	1 785	2 802	2,662	6,171
3 200	237,5	0,062 44	1 025	1 777	2 802	2,679	6,159
3 300	239,2	0,060 53	1 034	1 768	2 802	2,695	6,146
3 400	240,9	0,058 73	1 042	1 760	2 802	2,710	6,134
3 500	242,5	0,057 03	1 050	1 752	2 802	2,725	6,123
3 600	244,2	0,055 41	1 058	1 744	2 802	2,740	6,112
3 700	245,8	0,053 89	1 065	1 736	2 801	2,755	6,100
3 800	247,3	0,052 44	1 073	1 728	2 801	2,769	6,090
3 900	248,8	0,051 06	1 080	1 721	2 801	2,783	6,079
4 000	250,3	0,049 75	1 087	1 713	2 800	2,797	6,069

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
4 100	251,8	0,048 50	1 095	1 705	2 800	2,810	6,058
4 200	253,2	0,047 31	1 102	1 698	2 800	2,823	6,048
4 300	254,7	0,046 17	1 109	1 690	2 799	2,836	6,038
4 400	256,1	0,045 08	1 115	1 683	2 798	2,849	6,029
4 500	257,4	0,044 04	1 122	1 676	2 798	2,861	6,019
4 600	258,8	0,043 04	1 129	1 668	2 797	2,874	6,010
4 700	260,1	0,042 08	1 135	1 661	2 796	2,886	6,000
4 800	261,4	0,041 16	1 142	1 654	2 796	2,897	5,991
4 900	262,7	0,040 28	1 148	1 647	2 795	2,909	5,982
5 000	263,9	0,039 43	1 155	1 640	2 795	2,921	5,974
5 100	265,2	0,038 61	1 161	1 633	2 794	2,932	5,965
5 200	266,4	0,037 82	1 167	1 626	2 793	2,943	5,956
5 300	267,6	0,037 07	1 173	1 619	2 792	2,954	5,948
5 400	268,8	0,036 33	1 179	1 612	2 791	2,965	5,939
5 500	269,9	0,035 63	1 185	1 605	2 790	2,976	5,931
5 600	271,1	0,034 95	1 191	1 598	2 789	2,986	5,923
5 700	272,2	0,034 29	1 197	1 591	2 788	2,997	5,915
5 800	273,4	0,033 65	1 202	1 585	2 787	3,007	5,907
5 900	274,5	0,033 03	1 208	1 578	2 786	3,017	5,899
6 000	275,6	0,032 44	1 214	1 571	2 785	3,027	5,891
6 200	277,7	0,031 30	1 225	1 558	2 783	3,047	5,875
6 400	279,8	0,030 23	1 236	1 545	2 781	3,066	5,860
6 600	281,8	0,029 22	1 247	1 532	2 779	3,085	5,845
6 800	283,8	0,028 27	1 257	1 519	2 776	3,104	5,831
7 000	285,8	0,027 37	1 267	1 506	2 773	3,122	5,816
7 200	287,7	0,026 52	1 278	1 493	2 771	3,140	5,802
7 400	289,6	0,025 72	1 288	1 481	2 769	3,157	5,788
7 600	291,4	0,024 95	1 298	1 468	2 766	3,174	5,774
7 800	293,2	0,024 22	1 307	1 455	2 762	3,191	5,761
8 000	295,0	0,023 53	1 317	1 443	2 760	3,208	5,747
8 200	296,7	0,022 86	1 327	1 430	2 757	3,224	5,734
8 400	298,4	0,022 23	1 336	1 418	2 754	3,240	5,721
8 600	300,1	0,021 63	1 345	1 406	2 751	3,256	5,708
8 800	301,7	0,021 05	1 355	1 393	2 748	3,271	5,695
9 000	303,3	0,020 50	1 364	1 381	2 745	3,287	5,682
9 200	304,9	0,019 96	1 373	1 369	2 742	3,302	5,669
9 400	306,4	0,019 45	1 382	1 356	2 738	3,317	5,657
9 600	308,0	0,018 97	1 391	1 344	2 735	3,332	5,644
9 800	309,5	0,018 49	1 399	1 332	2 731	3,346	5,632
10 000	311,0	0,018 04	1 408	1 320	2 728	3,361	5,620
10 400	313,4	0,017 18	1 425	1 295	2 720	3,389	5,596
10 800	316,7	0,016 39	1 442	1 271	2 713	3,417	5,572
11 200	319,4	0,015 64	1 459	1 247	2 706	3,444	5,548
11 600	322,1	0,014 94	1 475	1 222	2 697	3,471	5,524

p	t_s	v_g	h_f	h_{fg}	h_g	s_f	s_g
kPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
12 000	324,7	0,014 28	1 492	1 197	2 689	3,497	5,500
12 400	327,2	0,013 66	1 508	1 173	2 681	3,523	5,477
12 800	329,6	0,013 08	1 524	1 148	2 672	3,549	5,453
13 200	332,0	0,012 52	1 540	1 122	2 662	3,574	5,429
13 600	334,4	0,012 00	1 556	1 097	2 653	3,599	5,405
14 000	336,6	0,011 50	1 572	1 071	2 643	3,624	5,380
14 400	338,9	0,011 02	1 587	1 044	2 631	3,649	5,356
14 800	341,1	0,010 56	1 603	1 018	2 621	3,674	5,331
15 200	343,2	0,010 12	1 619	990	2 609	3,698	5,305
15 600	345,3	0,009 707	1 635	963	2 598	3,723	5,279
16 000	347,3	0,009 308	1 651	934	2 585	3,747	5,253
16 400	349,3	0,008 925	1 667	906	2 573	3,772	5,227
16 800	351,3	0,008 553	1 683	876	2 559	3,797	5,199
17 200	353,2	0,008 191	1 700	844	2 544	3,824	5,171
17 600	355,1	0,007 839	1 718	812	2 530	3,850	5,143
18 000	357,0	0,007 498	1 735	779	2 514	3,877	5,113
18 400	358,8	0,007 165	1 752	745	2 497	3,903	5,082
18 800	360,6	0,006 839	1 770	710	2 480	3,929	5,050
19 200	362,3	0,006 517	1 788	673	2 461	3,957	5,016
19 600	364,0	0,006 198	1 807	634	2 441	3,985	4,980
20 000	365,7	0,005 877	1 827	592	2 419	4,015	4,941

Properties of Superheated Steam

p kPa		t_{sup}							
		50°	100°	150°	200°	250°	300°	400°	500°
1	v_{sup}	149,1	172,2	195,3	218,4	241,4	264,5	310,7	356,8
	h_{sup}	2 595	2 689	2 784	2 880	2 978	3 077	3 280	3 489
	s_{sup}	9,241	9,512	9,751	9,966	10,163	10,344	10,670	10,960
5	v_{sup}	29,78	34,42	39,04	43,66	48,28	52,90	62,13	71,36
	h_{sup}	2 594	2 688	2 784	2 880	2 978	3 077	3 280	3 489
	s_{sup}	8,496	8,768	9,008	9,223	9,420	9,601	9,927	10,217
10	v_{sup}	14,87	17,20	19,51	21,83	24,14	26,45	31,06	35,68
	h_{sup}	2 592	2 688	2 783	2 880	2 977	3 077	3 280	3 489
	s_{sup}	8,173	8,447	8,688	8,903	9,100	9,281	9,607	9,897
50	v_{sup}		3,420	3,890	4,356	4,821	5,284	6,209	7,134
	h_{sup}		2 683	2 780	2 878	2 976	3 076	3 279	3 489
	s_{sup}		7,694	7,940	8,158	8,355	8,537	8,864	9,154
75	v_{sup}		2,271	2,588	2,901	3,211	3,521	4,138	4,755
	h_{sup}		2 680	2 779	2 877	2 975	3 075	3 279	3 489
	s_{sup}		7,500	7,750	7,969	8,167	8,349	8,676	8,967
100	v_{sup}		1,696	1,937	2,173	2,406	2,639	3,103	3,565
	h_{sup}		2 676	2 777	2 876	2 975	3 075	3 278	3 488
	s_{sup}		7,36	7,614	7,834	8,033	8,215	8,543	8,834
150	v_{sup}			1,286	1,445	1,601	1,757	2,067	2,376
	h_{sup}			2 773	2 873	2 973	3 073	3 277	3 488
	s_{sup}			7,420	7,643	7,843	8,027	8,355	8,646
200	v_{sup}			0,960 2	1,081	1,199	1,316	1,549	1,781
	h_{sup}			2 770	2 871	2 971	3 072	3 277	3 487
	s_{sup}			7,280	7,507	7,708	7,892	8,221	8,513
300	v_{sup}			0,634 2	0,716 6	0,796 5	0,875 4	1,031	1,187
	h_{sup}			2 762	2 866	2 968	3 070	3 275	3 486
	s_{sup}			7,078	7,312	7,517	7,702	8,032	8,324
400	v_{sup}			0,471	0,534 5	0,595 3	0,654 9	0,772 5	0,889 3
	h_{sup}			2 753	2 862	2 965	3 067	3 274	3,485
	s_{sup}			6,929	7,172	7,379	7,566	7,898	8,191

p kPa		t_{sup}							
		200°	250°	300°	350°	400°	450°	500°	600°
500	v_{sup} h_{sup} s_{sup}	0,425 2 2 857 7,060	0,474 5 2 962 7,271	0,522 6 3 065 7,460	0,570 1 3 168 7,633	0,617 2 3 272 7,793	0,664 1 3 377 7,944	0,710 8 3 484 8,087	0,804 3 702 8,351
600	v_{sup} h_{sup} s_{sup}	0,352 2 2 851 6,968	0,394 2 958 7,182	0,434 4 3 062 7,373	0,474 3 3 166 7,546	0,513 6 3 270 7,707	0,552 8 3 376 7,858	0,591 9 3 483 8,001	0,669 7 3 701 8,267
700	v_{sup} h_{sup} s_{sup}	0,300 1 2 846 6,888	0,336 4 2 955 7,106	0,371 4 3 060 7,298	0,405 8 3 164 7,473	0,439 7 3 269 7,634	0,473 4 3 374 7,786	0,506 9 3 482 7,929	0,573 7 3 700 8,195
800	v_{sup} h_{sup} s_{sup}	0,261 2 840 6,817	0,293 3 2 951 7,040	0,324 2 3 057 7,233	0,354 4 3 162 7,409	0,384 2 3 267 7,571	0,413 8 3 373 7,723	0,443 2 3 401 7,866	0,501 8 3 699 8,132
900	v_{sup} h_{sup} s_{sup}	0,230 5 2 835 6,753	0,259 7 2 948 6,980	0,287 4 3 055 7,176	0,314 4 3 160 7,352	0,341 3 268 7,515	0,367 4 3 372 7,667	0,393 7 3 480 7,811	0,445 8 3 699 8,077
1 000	v_{sup} h_{sup} s_{sup}	0,206 1 2 829 6,695	0,232 8 2 944 6,926	0,258 3 052 7,124	0,282 5 3 158 7,301	0,306 5 3 264 7,464	0,330 3 3 370 7,617	0,354 3 478 7,761	0,401 3 698 8,028
1 500	v_{sup} h_{sup} s_{sup}	0,132 4 2 796 6,452	0,152 2 925 6,711	0,169 7 3 039 6,919	0,186 5 3 148 7,102	0,202 9 3 256 7,268	0,219 1 3 364 7,423	0,235 1 3 473 7,569	0,266 7 3 694 7,838
2 000	v_{sup} h_{sup} s_{sup}		0,111 5 2 904 6,547	0,125 5 3 025 6,768	0,138 6 3 138 6,957	0,151 1 3 248 7,126	0,163 4 3 357 7,283	0,175 6 3 467 7,431	0,199 5 3 690 7,701
3 000	v_{sup} h_{sup} s_{sup}		0,070 6 2 858 6,289	0,081 2 2 995 6,541	0,090 5 3 117 6,744	0,099 3 3 231 6,921	0,107 8 3 343 7,082	0,116 1 3 456 7,233	0,132 4 3 682 7,507
4 000	v_{sup} h_{sup} s_{sup}			0,058 8 2 963 6,364	0,066 4 3 094 6,584	0,077 3 3 214 6,769	0,080 3 330 6,935	0,086 4 3 445 7,089	0,098 8 3 674 7,368
5 000	v_{sup} h_{sup} s_{sup}			0,045 3 2 927 6,212	0,051 9 3 070 6,451	0,057 8 3 196 6,646	0,063 2 3 316 6,818	0,068 5 3 433 6,975	0,078 6 3 666 7,258
6 000	v_{sup} h_{sup} s_{sup}			0,036 2 2 887 6,071	0,042 2 3 045 6,336	0,047 3 3 177 6,541	0,052 1 3 301 6,719	0,056 6 3 421 6,879	0,065 2 3 657 7,166
7 000	v_{sup} h_{sup} s_{sup}			0,029 5 2 841 5,934	0,035 2 3 018 6,231	0,039 9 3 158 6,448	0,044 1 3 287 6,632	0,048 1 3 410 6,796	0,055 6 3 649 7,088

p kPa		t_{sup}							
		350°	375°	400°	425°	450°	500°	600°	700°
8 000	v_{sup} h_{sup} s_{sup}	0,029 94 2 990 6,133	0,032 2 3 067 6,255	0,034 28 3 139 6,364	0,036 25 3 207 6,463	0,038 12 3 272 6,555	0,041 7 3 398 6,723	0,048 39 3 641 7,109	0,054 76 3 881 7,279
9 000	v_{sup} h_{sup} s_{sup}	0,025 78 2 959 6,039	0,027 94 3 042 6,171	0,029 91 3 118 6,286	0,031 73 3 189 6,390	0,033 46 3 256 6,484	0,036 73 3 385 6,657	0,042 79 3 633 6,958	0,048 52 3 874 7,220
10 000	v_{sup} h_{sup} s_{sup}	0,022 41 2 926 5,947	0,024 53 3 017 6,091	0,026 39 3 097 6,213	0,028 12 3 172 6,321	0,029 72 3 241 6,419	0,032 75 3 373 6,596	0,038 31 3 624 6,902	0,043 53 3 868 7,166
11 000	v_{sup} h_{sup} s_{sup}	0,019 6 2 889 5,856	0,021 69 2 989 6,014	0,023 5 3 075 6,143	0,025 14 3 153 6,257	0,026 66 3 225 6,358	0,029 49 3 360 6,539	0,034 65 3 616 6,850	0,039 45 3 862 7,117
12 000	v_{sup} h_{sup} s_{sup}	0,017 19 2 849 5,762	0,019 31 2 980 5,937	0,021 07 3 052 6,076	0,022 65 3 134 6,195	0,024 1 3 209 6,301	0,026 77 3 348 6,487	0,031 59 3 607 6,802	0,036 05 3 856 7,072
13 000	v_{sup} h_{sup} s_{sup}	0,015 09 2 804 5,664	0,017 26 2 929 5,862	0,019 01 3 028 6,011	0,020 53 3 114 6,136	0,021 93 3 192 6,246	0,024 47 3 335 6,437	0,029 01 3 599 6,758	0,033 18 3 850 7,030
14 000	v_{sup} h_{sup} s_{sup}	0,013 21 2 753 5,559	0,015 48 2 896 5,784	0,017 22 3 003 5,946	0,018 72 3 093 6,079	0,020 06 3 175 6,193	0,022 5 3 322 6,390	0,026 79 3 590 6,716	0,030 71 3 843 6,991
15 000	v_{sup} h_{sup} s_{sup}	0,011 46 2 693 5,443	0,013 91 2 861 5,707	0,015 66 2 977 5,883	0,017 14 3 073 6,023	0,018 44 3 157 6,142	0,020 78 3 309 6,345	0,024 87 3 581 6,677	0,028 57 3 837 6,954
16 000	v_{sup} h_{sup} s_{sup}	0,009 76 2 617 5,304	0,012 48 2 821 5,626	0,014 27 2 949 5,820	0,015 73 3 051 5,968	0,017 02 3 139 6,093	0,019 28 3 295 6,301	0,023 19 3 573 6,639	0,026 7 3 831 6,919
17 000	v_{sup} h_{sup} s_{sup}		0,011 17 2 778 5,541	0,013 03 2 920 5,756	0,014 49 3 028 5,914	0,015 76 3 121 6,044	0,017 96 3 281 6,260	0,021 71 3 564 6,603	0,025 06 3 825 6,886
18 000	v_{sup} h_{sup} s_{sup}		0,009 97 2 729 5,449	0,011 91 2 888 5,691	0,013 38 3 004 5,861	0,014 63 3 102 5,997	0,016 78 3 268 6,219	0,020 39 3 555 6,569	0,023 59 3 818 6,855
19 000	v_{sup} h_{sup} s_{sup}		0,008 82 2 674 5,348	0,010 89 2 855 5,625	0,012 38 2 980 5,807	0,013 62 3 082 5,950	0,015 72 3 254 6,180	0,019 21 3 546 6,536	0,022 28 3 812 6,825
20 000	v_{sup} h_{sup} s_{sup}		0,007 60 2 605 5,228	0,009 95 2 819 5,556	0,011 47 2 955 5,753	0,012 7 3 062 5,904	0,014 77 3 239 6,142	0,018 15 3 537 6,505	0,021 1 3 806 6,796

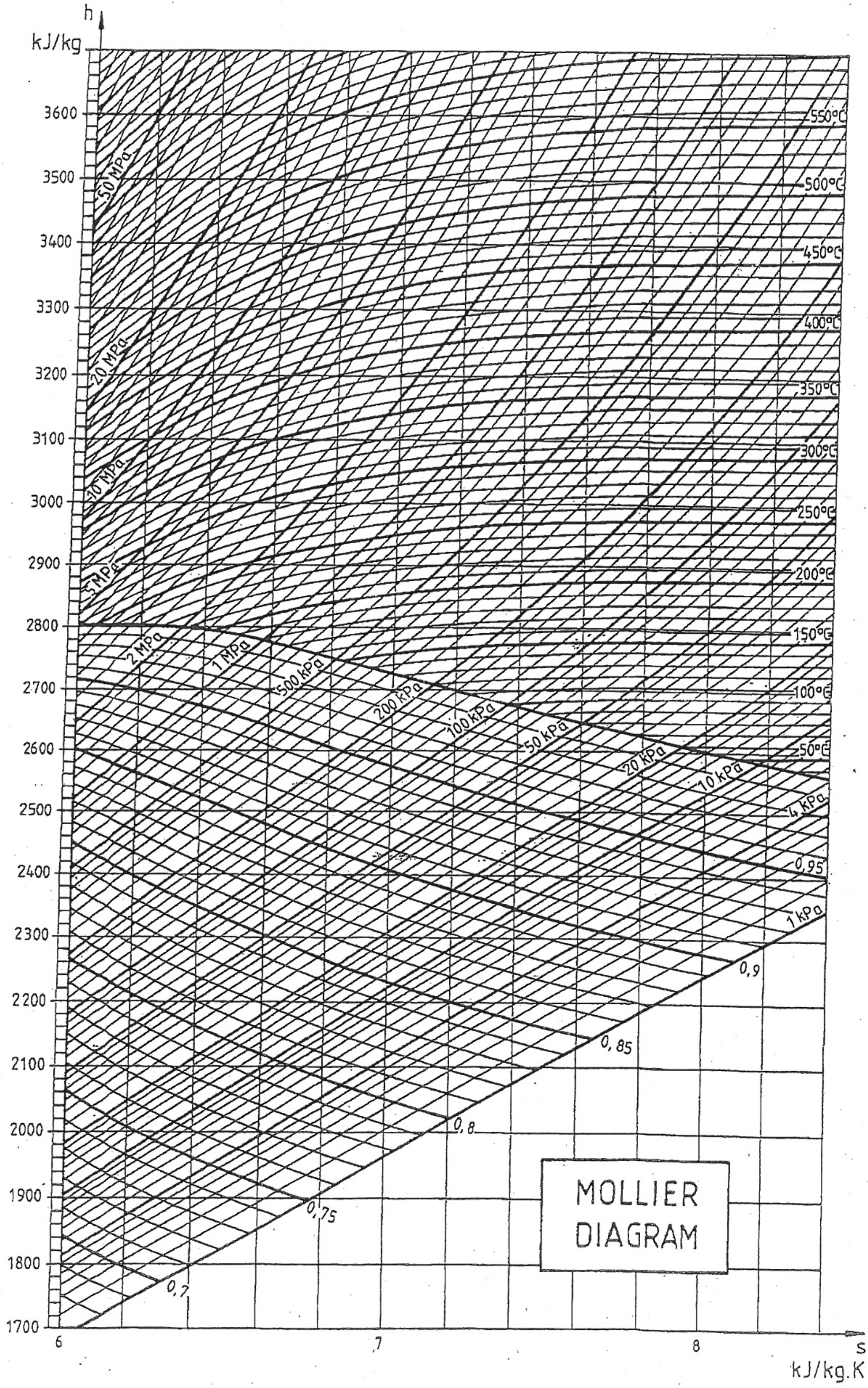
h
kJ/kg
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
6
7
8
s
kJ/kg.K
50 MPa
20 MPa
10 MPa
5 MPa
2 MPa
1 MPa
500 kPa
200 kPa
100 kPa
50 kPa
20 kPa
10 kPa
4 kPa
1 kPa
550°C
500°C
450°C
400°C
350°C
300°C
250°C
200°C
150°C
100°C
50°C
0,95
0,9
0,85
0,8
0,75
0,7
MOLLIER
DIAGRAM

TABLE A–5

Saturated water—Pressure table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476	7.3545
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100	7.2841
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894	7.2231
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200	6.9917
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645	6.9650
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0	1.7274	5.2128	6.9402
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9	594.73	2140.4	2735.1	1.7526	5.1645	6.9171
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1	604.66	2133.4	2738.1	1.7765	5.1191	6.8955
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356	6.8561
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603	6.8207
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916	6.7886
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285	6.7593
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322
700	164.95	0.001108	0.27278	696.23	1875.6	2571.8	697.00	2065.8	2762.8	1.9918	4.7153	6.7071
750	167.75	0.001111	0.25552	708.40	1865.6	2574.0	709.24	2056.4	2765.7	2.0195	4.6642	6.6837

Saturated Water and Steam

t [°C]	p_s [bar]	v_g [m³/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.01	0.006112	206.1	0*	2500.8	2500.8	0†	9.155	9.155
1	0.006566	192.6	4.2	2498.3	2502.5	0.015	9.113	9.128
2	0.007054	179.9	8.4	2495.9	2504.3	0.031	9.071	9.102
3	0.007575	168.2	12.6	2493.6	2506.2	0.046	9.030	9.076
4	0.008129	157.3	16.8	2491.3	2508.1	0.061	8.989	9.050
5	0.008719	147.1	21.0	2488.9	2509.9	0.076	8.948	9.024
6	0.009346	137.8	25.2	2486.6	2511.8	0.091	8.908	8.999
7	0.01001	129.1	29.4	2484.3	2513.7	0.106	8.868	8.974
8	0.01072	121.0	33.6	2481.9	2515.5	0.121	8.828	8.949
9	0.01147	113.4	37.8	2479.6	2517.4	0.136	8.788	8.924
10	0.01227	106.4	42.0	2477.2	2519.2	0.151	8.749	8.900
11	0.01312	99.90	46.2	2474.9	2521.1	0.166	8.710	8.876
12	0.01401	93.83	50.4	2472.5	2522.9	0.180	8.671	8.851
13	0.01497	88.17	54.6	2470.2	2524.8	0.195	8.633	8.828
14	0.01597	82.89	58.8	2467.8	2526.6	0.210	8.594	8.804
15	0.01704	77.97	62.9	2465.5	2528.4	0.224	8.556	8.780
16	0.01817	73.38	67.1	2463.1	2530.2	0.239	8.518	8.757
17	0.01936	69.09	71.3	2460.8	2532.1	0.253	8.481	8.734
18	0.02063	65.08	75.5	2458.4	2533.9	0.268	8.444	8.712
19	0.02196	61.34	79.7	2456.0	2535.7	0.282	8.407	8.689
20	0.02337	57.84	83.9	2453.7	2537.6	0.296	8.370	8.666
21	0.02486	54.56	88.0	2451.4	2539.4	0.310	8.334	8.644
22	0.02642	51.49	92.2	2449.0	2541.2	0.325	8.297	8.622
23	0.02808	48.62	96.4	2446.6	2543.0	0.339	8.261	8.600
24	0.02982	45.92	100.6	2444.2	2544.8	0.353	8.226	8.579
25	0.03166	43.40	104.8	2441.8	2546.6	0.367	8.190	8.557
26	0.03360	41.03	108.9	2439.5	2548.4	0.381	8.155	8.536
27	0.03564	38.81	113.1	2437.2	2550.3	0.395	8.120	8.515
28	0.03778	36.73	117.3	2434.8	2552.1	0.409	8.085	8.494
29	0.04004	34.77	121.5	2432.4	2553.9	0.423	8.050	8.473
30	0.04242	32.93	125.7	2430.0	2555.7	0.436	8.016	8.452
32	0.04754	29.57	134.0	2425.3	2559.3	0.464	7.948	8.412
34	0.05318	26.60	142.4	2420.5	2562.9	0.491	7.881	8.372
36	0.05940	23.97	150.7	2415.8	2566.5	0.518	7.814	8.332
38	0.06624	21.63	159.1	2411.0	2570.1	0.545	7.749	8.294
40	0.07375	19.55	167.5	2406.2	2573.7	0.572	7.684	8.256
42	0.08198	17.69	175.8	2401.4	2577.2	0.599	7.620	8.219
44	0.09100	16.03	184.2	2396.6	2580.8	0.625	7.557	8.182
46	0.1009	14.56	192.5	2391.8	2584.3	0.651	7.494	8.145
48	0.1116	13.23	200.9	2387.0	2587.9	0.678	7.433	8.111
50	0.1233	12.04	209.3	2382.1	2591.4	0.704	7.371	8.075
55	0.1574	9.578	230.2	2370.1	2600.3	0.768	7.223	7.991
60	0.1992	7.678	251.1	2357.9	2609.0	0.831	7.078	7.909
65	0.2501	6.201	272.0	2345.7	2617.7	0.893	6.937	7.830
70	0.3116	5.045	293.0	2333.3	2626.3	0.955	6.800	7.755
75	0.3855	4.133	313.9	2320.8	2634.7	1.015	6.666	7.681
80	0.4736	3.408	334.9	2308.3	2643.2	1.075	6.536	7.611
85	0.5780	2.828	355.9	2295.6	2651.5	1.134	6.410	7.544
90	0.7011	2.361	376.9	2282.8	2659.7	1.192	6.286	7.478
95	0.8453	1.982	398.0	2269.8	2667.8	1.250	6.166	7.416
100	1.01325	1.673	419.1	2256.7	2675.8	1.307	6.048	7.355

† u and s are chosen to be zero for saturated liquid at the triple point.

Note: values of v_f can be found on p. 10.

CIBSE PSYCHROMETRIC CHART

BASED ON A BAROMETRIC PRESSURE OF 101·325 kPa