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ภาคผนวก

ภาคผนวก ก

Microstructure Analysis

A. Volume fraction of pores by systematic point count

Make a grid (squares) on a sheet of clear plastic. The grid should be large enough so that there will not be more than one point per pore. A grid with 9 or 16 points works best. Place the grid on the micrograph, and count the number of points that fall on pores. Lift the grid and place it somewhere else on the photograph. You may turn it when you do this. Keep repeating this, measuring as many fresh areas as needed until 400 points have been sampled. For example, with a 16-point grid, you would have to sample 25 regions (25×16=400). However, I do have limited micrographs for you so make the regions as much as you can.

Calculation : The number of point that fall on the pore phase = P_a ; the total number of points sampled = P; the volume fraction of pore phase is

$$V_v = P_p = P_a/P$$

Note : Although you will be doing this for the volume fraction of pores in your specimen, this method works for any second phase, as long as it occurs as discrete regions randomly distributed in the volume of the material. This implies that the volume fraction is small.

B. Grain size by mean intercept length

The grain size by mean linear intercept length is the average value of the distance between grain boundaries as given by randomly positioned lines drawn across an image of the structure, such as a photomicrograph. Prepare photomicrographs of at least three different areas of the specimen. There should be no more than 20 grains along any line which is 75 mm long drawn on the picture. Select the magnification to meet this criterion. Draw at least five thin straight lines across each photomicrograph. These lines should have random positions and orientations, and

each should be at least 75 mm long. The total length of all lines on each micrograph should exceed 375 mm, and at least 100 grains should be intersected.

Measure each line to the nearest millimeter, and calculate the total length (l_t). Count the number of intersections (n_i) of the lines with grain boundaries. Each intersection of a line with triple points is counted as 1.5 intersections. If a line intersects a large pore, count this as one intersection. Measure the total length of line that crosses large pores (l_p). If a line runs along a grain boundary, count this as one intersection.

The grain size is then calculated as follows :

$$G = \left(\frac{\ell_t - \ell_p}{n_i m} \right) \left(10^3 \right)$$

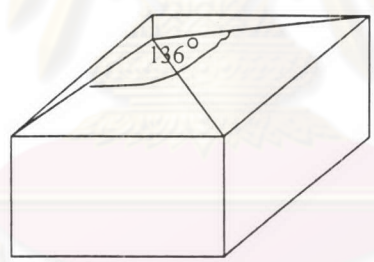
Where G is in micrometers, line lengths are in millimeters, m is the calibrated magnification of the micrograph.

ภาคผนวก ข

Hardness Measurement

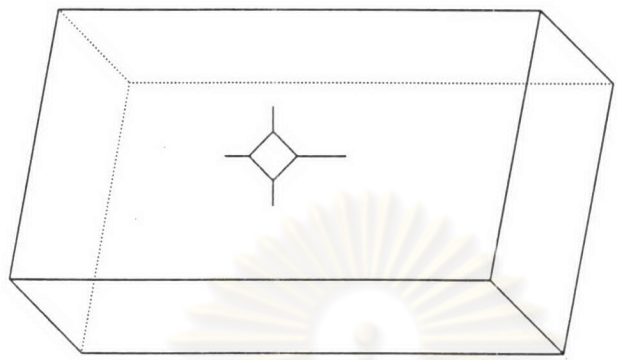
ความแข็ง(hardness) คือความต้านทานต่อการผิดรูปแบบพลาสติก ซึ่งมีผลต่อการสึกกร่อน และขัดสี ทำให้ลักษณะทางกายภาพเสียหาย เช่น การขูดขีด(abrasion) การกระแทก(scratching) การกด (indentation)

อินเดนเทชัน(indentation) เป็นการทำให้เกิดรอยบนผิวชิ้นงานด้วยการกด ซึ่งในการทดสอบนี้ทดสอบด้วยเครื่องทดสอบความแข็ง(Zwick I) โดยใช้หัวกดวิกเกอร์ส (vickers indenter) ดังรูปที่ 1

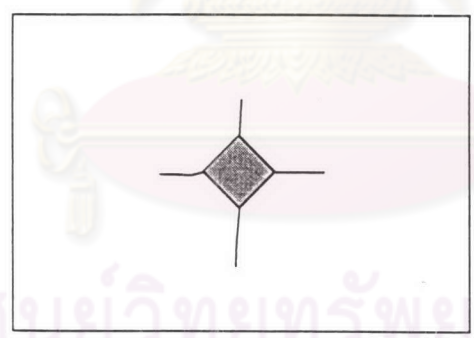


รูปที่ 1 หัวกดวิเกอร์ส

เมื่อกดหัวกดวิกเกอร์สลงบนผิวชิ้นงาน ความเค้นที่เกิดขึ้นในชิ้นงานบริเวณที่สัมผัสปลายแหลมหัวกด จะมีค่าสูงมาก จะทำให้เกิดรอยสัมผัสแบบพลาสติก (plastic contact) คือ เมื่อนำหัวกดออกจากชิ้นงาน รอยสัมผัสระหว่างผิววัตถุกับหัวกด จะมีสภาพไม่เหมือนก่อนถูกกด เกิดเป็นริ้วรอยถาวร (impression) ตรงบริเวณที่สัมผัส ดังแสดงไว้ในบริเวณที่แรเงา ในรูปที่ 2 จากนั้นวัดขนาดของรอยกด(a) ดังรูปที่ 3 เพื่อนำมาคำนวณ

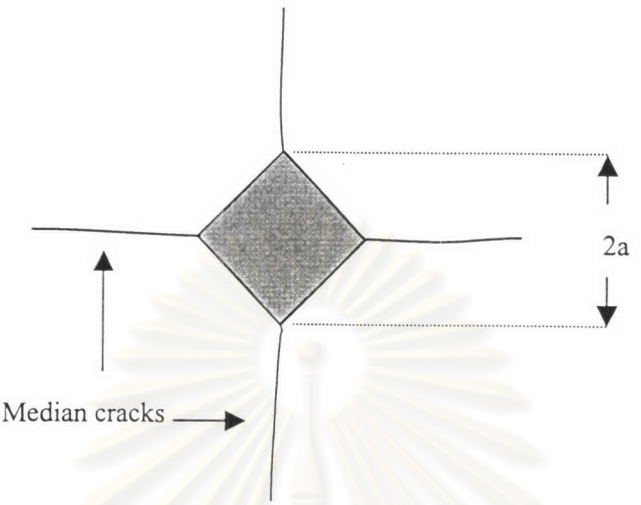


(ก)



(ข)

รูปที่ 2 ลักษณะรอยกด โดยใช้หัวกดวิกเกอร์ส (ก) แสดงใน 3 มิติ (ข) รอยกดที่เกิดบนผิว



รูปที่ 3 การวัดขนาดของรอยกด (a)

คำนวณความแข็งด้วยสมการ

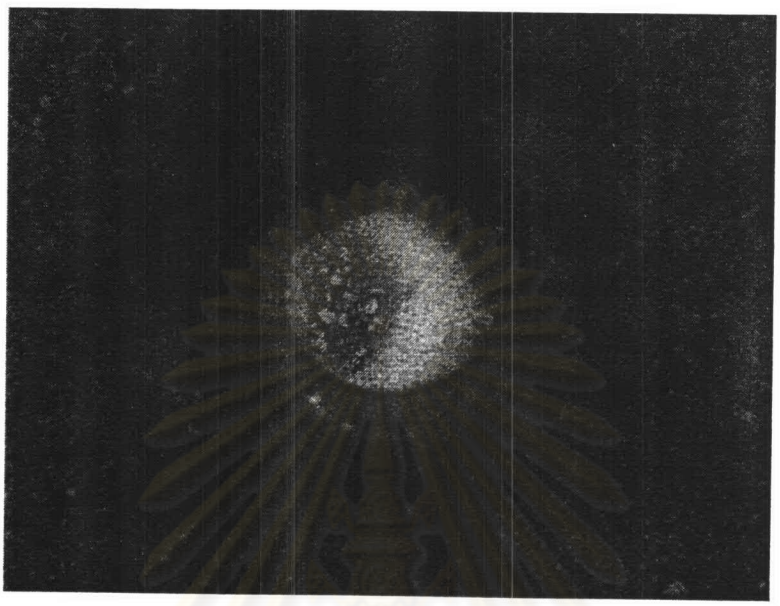
$$H = P/\alpha_0 a^2$$

H = Vickers hardness (GPa)

P = แรงที่ให้กับชิ้นงาน (N)

a = ครึ่งหนึ่งของเส้นทะแยงมุม (m)

α_0 = ค่าคงที่ของการกด = 2



รูปที่ 4 ภาพถ่ายรอยแตกจากการทดสอบความแข็ง

ภาคผนวก ค

Supplementary Tables and Figures (SI UNITS)

Table A-12 Properties of saturated water: Temperature table

(*v*, m³/kg; *u*, kJ/kg; *h*, kJ/kg; *s*, kJ/(kg·K); 1 bar = 0.1 MPa)

Temp., °C *T*	Press., bars *P*	Specific Volume		Internal Energy		Enthalpy			Entropy	
		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
0	0.006 11	1.0002	206.278	0.03	2375.4	−0.02	2501.4	2501.3	0.0001	9.1565
4	0.008 13	1.0001	157.232	16.77	2380.9	16.78	2491.9	2508.7	0.0610	9.0514
8	0.010 72	1.0003	147.120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257
12	0.014 03	1.0001	106.379	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003
16	0.018 17	1.0002	77.926	29.39	2384.9	29.41	2484.9	2514.3	0.1063	8.9753
20	0.023 38	1.0018	57.762	33.59	2386.2	33.60	2482.5	2516.1	0.1212	8.9501
24	0.029 85	1.0030	43.340	37.80	2387.5	37.81	2480.1	2517.9	0.1360	8.9248
28	0.037 84	1.0041	32.894	42.00	2388.8	42.01	2477.7	2519.8	0.1510	8.9008
32	0.047 60	1.0056	25.216	46.20	2390.1	46.20	2475.4	2521.6	0.1658	8.8765
36	0.059 40	1.0067	19.515	50.41	2391.4	50.42	2473.0	2523.4	0.1806	8.8524
40	0.073 75	1.0079	15.258	54.60	2392.7	54.60	2470.7	2525.3	0.1953	8.8285
44	0.091 03	1.0092	12.032	58.80	2394.0	58.80	2468.3	2527.1	0.2099	8.8048
48	0.111 73	1.0104	9.568	62.99	2395.2	62.99	2465.9	2528.9	0.2245	8.7814
52	0.136 34	1.0118	7.669	67.19	2396.5	67.19	2463.6	2530.8	0.2390	8.7582
56	0.165 43	1.0132	6.204	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351
60	0.199 31	1.0147	5.053	75.58	2400.1	75.58	2458.8	2534.4	0.2679	8.7123
64	0.238 50	1.0161	4.139	79.77	2401.3	79.77	2456.5	2536.2	0.2823	8.6897
68	0.284 56	1.0176	3.409	83.96	2402.6	83.96	2454.1	2538.1	0.2966	8.6672
72	0.338 19	1.0192	2.828	88.14	2403.8	88.14	2451.8	2539.9	0.3109	8.6450
76	0.400 16	1.0208	2.365	92.32	2405.0	92.33	2449.4	2541.7	0.3251	8.6229
80	0.471 34	1.0224	1.987	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011
84	0.552 85	1.0241	1.679	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794
88	0.645 89	1.0259	1.424	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580
92	0.751 96	1.0277	1.213	109.06	2411.1	109.07	2439.9	2549.0	0.3814	8.5367
96	0.872 82	1.0296	1.036	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156
100	1.009 2	1.0316	0.8903	117.43	2413.8	117.43	2435.2	2552.6	0.4093	8.4946
104	1.162 0	1.0337	0.7675	121.60	2415.2	121.61	2432.8	2554.4	0.4231	8.4739
108	1.331 9	1.0358	0.6636	125.78	2416.5	125.79	2430.5	2556.3	0.4369	8.4533
112	1.519 0	1.0380	0.5756	129.96	2418.0	129.97	2428.1	2558.1	0.4507	8.4329
116	1.724 9	1.0403	0.5012	134.14	2419.3	134.15	2425.7	2559.9	0.4644	8.4127
120	1.950 6	1.0426	0.4384	138.32	2420.7	138.33	2423.4	2561.7	0.4781	8.3927
124	2.197 5	1.0450	0.3855	142.50	2422.0	142.50	2421.0	2563.5	0.4917	8.3728
128	2.467 0	1.0474	0.3405	146.67	2423.4	146.68	2418.6	2565.3	0.5053	8.3531
132	2.759 7	1.0500	0.3022	150.85	2424.7	150.86	2416.2	2567.1	0.5188	8.3336
136	3.077 0	1.0526	0.2697	155.03	2425.9	155.04	2413.8	2568.8	0.5323	8.3142
140	3.420 5	1.0553	0.2422	159.21	2427.4	159.21	2411.5	2570.7	0.5458	8.2950
144	3.791 6	1.0580	0.2189	163.39	2428.6	163.40	2409.1	2572.5	0.5593	8.2759
148	4.191 8	1.0609	0.1982	167.57	2429.8	167.57	2406.7	2574.3	0.5725	8.2570
152	4.622 6	1.0639	0.1798	171.75	2431.1	171.76	2404.3	2576.1	0.5859	8.2383
156	5.085 5	1.0670	0.1636	175.94	2432.3	175.94	2401.9	2577.9	0.5993	8.2197
160	5.582 2	1.0702	0.1491	180.12	2433.5	180.12	2399.5	2579.6	0.6127	8.2012
164	6.114 3	1.0735	0.1360	184.31	2434.7	184.31	2397.1	2581.4	0.6261	8.1829
168	6.683 5	1.0770	0.1243	188.49	2435.8	188.45	2394.8	2583.2	0.6387	8.1648

Table A-12 (*Continued*)

Temp., °C T	Press., bars P	Specific Volume		Internal Energy		Enthalpy			Entropy	
		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
50	.1235	1.0121	12.032	209.32	2443.5	209.33	2382.7	2592.1	.7038	8.0763
55	.1576	1.0146	9.568	230.21	2450.1	230.23	2370.7	2600.9	.7679	7.9913
60	.1994	1.0172	7.671	251.11	2456.6	251.13	2358.5	2609.6	.8312	7.9096
65	.2503	1.0199	6.197	272.02	2463.1	272.06	2346.2	2618.3	.8935	7.8310
70	.3119	1.0228	5.042	292.95	2469.6	292.98	2333.8	2626.8	.9549	7.7553
75	.3858	1.0259	4.131	313.90	2475.9	313.93	2321.4	2635.3	1.0155	7.6824
80	.4739	1.0291	3.407	334.86	2482.2	334.91	2308.8	2643.7	1.0753	7.6122
85	.5783	1.0325	2.828	355.84	2488.4	355.90	2296.0	2651.9	1.1343	7.5445
90	.7014	1.0360	2.361	376.85	2494.5	376.92	2283.2	2660.1	1.1925	7.4791
95	.8455	1.0397	1.982	397.88	2500.6	397.96	2270.2	2668.1	1.2500	7.4159
100	1.0133	1.0435	1.673	418.94	2506.5	419.04	2257.0	2676.1	1.3069	7.3549
110	1.433	1.0516	1.210	461.14	2518.1	461.30	2230.2	2691.5	1.4185	7.2387
120	1.985	1.0603	0.8919	503.50	2529.3	503.71	2202.6	2706.3	1.5276	7.1296
130	2.701	1.0697	0.6685	546.02	2539.9	546.31	2174.2	2720.5	1.6344	7.0269
140	3.613	1.0797	0.5089	588.74	2550.0	589.13	2144.7	2733.9	1.7391	6.9299
150	4.758	1.0905	0.3928	631.68	2559.5	632.20	2114.3	2746.5	1.8418	6.8379
160	6.178	1.1020	0.3071	674.86	2568.4	675.55	2082.6	2758.1	1.9427	6.7502
170	7.917	1.1143	0.2428	718.33	2576.5	719.21	2049.5	2768.7	2.0419	6.6663
180	10.02	1.1274	0.1941	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857
190	12.54	1.1414	0.1565	806.19	2590.0	807.62	1978.8	2786.4	2.2359	6.5079
200	15.54	1.1565	0.1274	850.65	2595.3	852.45	1940.7	2793.2	2.3309	6.4323
210	19.06	1.1726	0.1044	895.53	2599.5	897.76	1900.7	2798.5	2.4248	6.3585
220	23.18	1.1900	0.08619	940.87	2602.4	943.62	1858.5	2802.1	2.5178	6.2861
230	27.95	1.2088	0.07158	986.74	2603.9	990.12	1813.8	2804.0	2.6099	6.2146
240	33.44	1.2291	0.05976	1033.2	2604.0	1037.3	1766.5	2803.8	2.7015	6.1437
250	39.73	1.2512	0.05013	1080.4	2602.4	1085.4	1716.2	2801.5	2.7927	6.0730
260	46.88	1.2755	0.04221	1128.4	2599.0	1134.4	1662.5	2796.6	2.8838	6.0019
270	54.99	1.3023	0.03564	1177.4	2593.7	1184.5	1605.2	2789.7	2.9751	5.9301
280	64.12	1.3321	0.03017	1227.5	2586.1	1236.0	1543.6	2779.6	3.0668	5.8571
290	74.36	1.3656	0.02557	1278.9	2576.0	1289.1	1477.1	2766.2	3.1594	5.7821
300	85.81	1.4036	0.02167	1332.0	2563.0	1344.0	1404.9	2749.0	3.2534	5.7045
320	112.7	1.4988	0.01549	1444.6	2525.5	1461.5	1238.6	2700.1	3.4480	5.5362
340	145.9	1.6379	0.01080	1570.3	2464.6	1594.2	1027.9	2622.0	3.6594	5.3357
360	186.5	1.8925	0.006945	1725.2	2351.5	1760.5	720.5	2481.0	3.9147	5.0526
374.14	220.9	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298

SOURCE: J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, "Steam Tables," Wiley, New York, 1969.

Table A-13 Properties of saturated water: Pressure Table

(v, m³/kg; u,kJ/kg; h, kJ/kg; s, KJ/(kg·K); 1 bar = 0.1 MPa)

Press., bars P	Temp., °C T	Specific Volume: Sat. Liquid $v_f \times 10^3$	Specific Volume: Sat. Vapor v_g	Internal Energy: Sat. Liquid u_f	Internal Energy: Sat. Vapor u_g	Enthalpy: Sat. Liquid h_f	Enthalpy: Evap. h_{fg}	Enthalpy: Sat. Vapor h_g	Entropy: Sat. Liquid s_f	Entropy: Sat. Vapor s_g
.040	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	.4226	8.474
.060	36.16	1.0064	23.739	151.53	2425.0	151.33	2415.9	2567.4	.5210	8.3304
.080	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	.5926	8.2287
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	.6493	8.1502
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	.8320	7.9085
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	.9439	7.7686
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.025	7.6700
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.191	7.4797
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226

Table A-13 *(Continued)*

Press., bars P	Temp., °C T	Specific Volume		Internal Energy		Enthalpy			Entropy	
		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
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2853	5.6772
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527
120.	324.8	1.5267	0.01426	1473.0	2513.7	1491.3	1193.6	2684.9	3.4962	5.4924
130.	330.9	1.5671	0.01278	1511.1	2496.1	1531.5	1130.7	2662.2	3.5606	5.4323
140.	336.8	1.6107	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6232	5.3717
150.	342.2	1.6581	0.01034	1585.6	2455.5	1610.5	1000.0	2610.5	3.6848	5.3098
160.	347.4	1.7107	0.009306	1622.7	2431.7	1650.1	930.6	2580.6	3.7461	5.2455
170.	352.4	1.7702	0.008364	1660.2	2405.0	1690.3	856.9	2547.2	3.8079	5.1777
180.	357.1	1.8397	0.007489	1698.9	2374.3	1732.0	777.1	2509.1	3.8715	5.1044
190.	361.5	1.9243	0.006657	1739.9	2338.1	1776.5	688.0	2464.5	3.9388	5.0228
200.	365.8	2.036	0.005834	1785.6	2293.0	1826.3	583.4	2409.7	4.0139	4.9269
220.9	374.1	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298

[1] CC-4 CL. J. H. Keenan, F. G. Keyes, P. G. Hill, J. G. Moore, "Steam Tables," Wiley, New York, 1969.

Table A-14 Properties of water: Superheated-vapor table

(v, m³/kg; u, kJ/kg; h, kJ/kg; s, kJ/kg K)

Temp., °C	v	u	h	s	v	u	h	s
	0.06 bar (0.006MPa) (T_{sat} = 36.16°C)				**0.35 bar (0.035MPa) (T_{sat} = 72.69°C)**			
Sat.	23.739	2425.0	2567.4	8.3301	4.526	2473.0	2631.4	7.7158
80	27.132	2487.3	2650.1	8.5804	4.625	2483.7	2645.6	7.7564
120	30.219	2544.7	2726.0	8.7840	5.163	2542.4	2723.1	7.9644
160	33.302	2602.7	2802.5	8.9693	5.696	2601.2	2800.6	8.1519
200	36.383	2661.4	2879.7	9.1398	6.228	2660.4	2878.4	8.3237
240	39.462	2721.0	2957.8	9.2982	6.758	2720.3	2956.8	8.4828
280	42.540	2781.5	3036.8	9.4464	7.287	2780.9	3036.0	8.6314
320	45.618	2843.0	3116.7	9.5859	7.815	2842.5	3116.1	8.7712
360	48.696	2905.5	3197.7	9.7180	8.344	2905.1	3197.1	8.9034
400	51.774	2969.0	3279.6	9.8435	8.872	2968.6	3279.2	9.0291
440	54.851	3033.5	3362.6	9.9633	9.400	3033.2	3362.2	9.1490
500	59.467	3132.3	3489.1	10.134	10.192	3132.1	3488.8	9.3194
	0.70 bar (0.07 MPa) (T_{sat} = 89.95°C)				**1.0 bar (0.10 MPa) (T_{sat} = 99.63°C)**			
Sat.	2.365	2494.5	2660.0	7.4797	1.694	2506.1	2675.5	7.3594
100	2.434	2509.7	2680.0	7.5341	1.696	2506.7	2676.2	7.3614
120	2.571	2539.7	2719.6	7.6375	1.793	2537.3	2716.6	7.4668
160	2.841	2599.4	2798.2	7.8279	1.984	2597.8	2796.2	7.6597
200	3.108	2659.1	2876.7	8.0012	2.172	2658.1	2875.3	7.8343
240	3.374	2719.3	2955.5	8.1611	2.359	2718.5	2954.5	7.9949
280	3.640	2780.2	3035.0	8.3162	2.546	2779.6	3034.2	8.1445
320	3.905	2842.0	3115.3	8.4504	2.732	2841.5	3114.6	8.2849
360	4.170	2904.6	3196.5	8.5828	2.917	2904.2	3195.9	8.4175
400	4.434	2968.2	3278.6	8.7086	3.103	2967.9	3278.2	8.5435
440	4.698	3032.9	3361.8	8.8286	3.288	3032.6	3361.4	8.6636
500	5.095	3131.8	3488.5	8.9991	3.565	3131.6	3488.1	8.8342
	1.5 bars (0.15 MPa) (T_{sat} = 111.37°C)				**3.0 bars (0.30 MPa) (T_{sat} = 133.55°C)**			
Sat.	1.159	2519.7	2693.6	7.2233	0.606	2543.6	2725.3	6.9919
120	1.188	2533.3	2711.4	7.2693				
160	1.317	2595.2	2792.8	7.4665	0.651	2587.1	2782.3	7.1276
200	1.444	2656.2	2872.9	7.6433	0.716	2650.7	2865.5	7.3115
240	1.570	2717.2	2952.7	7.8052	0.781	2713.1	2947.3	7.4774
280	1.695	2778.6	3032.8	7.9555	0.844	2775.4	3028.6	7.6299
320	1.819	2840.6	3113.5	8.0964	0.907	2838.1	3110.1	7.7722
360	1.943	2903.5	3195.0	8.2293	0.969	2901.4	3192.2	7.9061
400	2.067	2967.3	3277.4	8.3555	1.032	2965.6	3275.0	8.0330
440	2.191	3032.1	3360.7	8.4757	1.094	3030.6	3358.7	8.1538
500	2.376	3131.2	3487.6	8.6466	1.187	3130.0	3486.0	8.3251
600	2.685	3301.7	3704.3	8.9101	1.341	3300.8	3703.2	8.5892

Table A-14 *(Continued)*

Temp., °C	v	u	h	s	v	u	h	s
	5.0 bars (0.50 MPa) (T_{sat} = 151.86°C)				7.0 bars (0.70 MPa) (T_{sat} = 164.97°C)			
Sat.	0.3749	2561.2	2748.7	6.8213	0.2729	2572.5	2763.5	6.7080
180	0.4045	2609.7	2812.0	6.9656	0.2847	2599.8	2799.1	6.7880
200	0.4249	2642.9	2855.4	7.0592	0.2999	2634.8	2844.8	6.8865
240	0.4646	2707.6	2939.6	7.2307	0.3292	2701.8	2932.2	7.0641
280	0.5034	2771.2	3022.9	7.3865	0.3574	2766.9	3017.1	7.2233
320	0.5416	2834.7	3105.6	7.5308	0.3852	2831.3	3100.9	7.3697
360	0.5796	2898.7	3188.4	7.6660	0.4126	2895.8	3184.7	7.5063
400	0.6173	2963.2	3271.9	7.7938	0.4397	2960.9	3268.7	7.6350
440	0.6548	3028.6	3356.0	7.9152	0.4667	3026.6	3353.3	7.7571
500	0.7109	3128.4	3483.9	8.0873	0.5070	3126.8	3481.7	7.9299
600	0.8041	3299.6	3701.7	8.3522	0.5738	3298.5	3700.2	8.1956
700	0.8969	3477.5	3925.9	8.5952	0.6403	3476.6	3924.8	8.4391
	10.0 bars (1.0 MPa) (T_{sat} = 179.91°C)				15.0 bars (1.5 MPa) (T_{sat} = 198.32°C)			
Sat.	0.1944	2585.6	2778.1	6.5865	0.1318	2594.5	2792.2	6.4448
200	0.2060	2621.9	2827.9	6.6940	0.1325	2598.1	2796.8	6.4546
240	0.2275	2692.9	2920.4	6.8817	0.1483	2676.9	2899.3	6.6628
280	0.2480	2760.2	3008.2	7.0465	0.1627	2748.6	2992.7	6.8381
320	0.2678	2826.1	3093.9	7.1962	0.1765	2817.1	3081.9	6.9938
360	0.2873	2891.6	3178.9	7.3349	0.1899	2884.4	3169.2	7.1363
400	0.3066	2957.3	3263.9	7.4651	0.2030	2951.3	3255.8	7.2690
440	0.3257	3023.6	3349.3	7.5883	0.2160	3018.5	3342.5	7.3940
500	0.3541	3124.4	3478.5	7.7622	0.2352	3120.3	3473.1	7.5698
540	0.3729	3192.6	3565.6	7.8720	0.2478	3189.1	3560.9	7.6805
600	0.4011	3296.8	3697.9	8.0290	0.2668	3293.9	3694.0	7.8385
640	0.4198	3367.4	3787.2	8.1290	0.2793	3364.8	3783.8	7.9391
	20.0 bars (2.0 MPa) (T_{sat} = 212.42°C)				30.0 bars (3.0 MPa) (T_{sat} = 233.90°C)			
Sat.	0.0996	2600.3	2799.5	6.3409	0.0667	2604.1	2804.2	6.1869
240	0.1085	2659.6	2876.5	6.4952	0.0682	2619.7	2824.3	6.2265
280	0.1200	2736.4	2976.4	6.6828	0.0771	2709.6	2941.3	6.4462
320	0.1308	2807.9	3069.5	6.8452	0.0850	2788.4	3043.4	6.6245
360	0.1411	2877.0	3159.3	6.9917	0.0923	2861.7	3138.7	6.7801
400	0.1512	2945.2	3247.6	7.1271	0.0994	2932.8	3230.9	6.9212
440	0.1611	3013.4	3335.5	7.2540	0.1062	3002.9	3321.5	7.0520
500	0.1757	3116.2	3467.6	7.4317	0.1162	3108.0	3456.5	7.2338
540	0.1853	3185.6	3556.1	7.5434	0.1227	3178.4	3546.6	7.3474
600	0.1996	3290.9	3690.1	7.7024	0.1324	3285.0	3682.3	7.5085
640	0.2091	3362.2	3780.4	7.8035	0.1388	3357.0	3773.5	7.6106
700	0.2232	3470.9	3917.4	7.9487	0.1484	3466.5	3911.7	7.7571

Table A-14 *(Continued)*

Temp., °C	v	u	h	s	v	u	h	s
	40 bars (4.0 MPa) (T_{sat} = 250.40°C)				60 bars (6.0 MPa) (T_{sat} = 275.64°C)			
Sat.	0.04978	2602.3	2801.4	6.0701	0.03244	2589.7	2784.3	5.8892
280	0.05546	2680.0	2901.8	6.2568	0.03317	2605.2	2804.2	5.9252
320	0.06199	2767.4	3015.4	6.4553	0.03876	2720.0	2952.6	6.1846
360	0.06788	2845.7	3117.2	6.6215	0.04331	2811.2	3071.1	6.3782
400	0.07341	2919.9	3213.6	6.7690	0.04739	2892.9	3177.2	6.5408
440	0.07872	2992.2	3307.1	6.9041	0.05122	2970.0	3277.3	6.6853
500	0.08643	3099.5	3445.3	7.0901	0.05665	3082.2	3422.2	6.8803
540	0.09145	3171.1	3536.9	7.2056	0.06015	3156.1	3517.0	6.9999
600	0.09885	3279.1	3674.4	7.3688	0.06525	3266.9	3658.4	7.1677
640	0.1037	3351.8	3766.6	7.4720	0.06859	3341.0	3752.6	7.2731
700	0.1110	3462.1	3905.9	7.6198	0.07352	3453.1	3894.1	7.4234
740	0.1157	3536.6	3999.6	7.7141	0.07677	3528.3	3989.2	7.5190
	80 bars (8.0 MPa) (T_{sat} = 295.06°C)				100 bars (10.0 MPa) (T_{sat} = 311.06°C)			
Sat.	0.02352	2569.8	2758.0	5.7432	0.01803	2544.4	2724.7	5.6141
320	0.02682	2662.7	2877.2	5.9489	0.01925	2588.8	2781.3	5.7103
360	0.03089	2772.7	3019.8	6.1819	0.02331	2729.1	2962.1	6.0060
400	0.03432	2863.8	3138.3	6.3634	0.02641	2832.4	3096.5	6.2120
440	0.03742	2946.7	3246.1	6.5190	0.02911	2922.1	3213.2	6.3805
480	0.04034	3025.7	3348.4	6.6586	0.03160	3005.4	3321.4	6.5282
520	0.04313	3102.7	3447.7	6.7871	0.03394	3085.6	3425.1	6.6622
560	0.04582	3178.7	3545.3	6.9072	0.03619	3164.1	3526.0	6.7864
600	0.04845	3254.4	3642.0	7.0206	0.03837	3241.7	3625.3	6.9029
640	0.05102	3330.1	3738.3	7.1283	0.04048	3318.9	3723.7	7.0131
700	0.05481	3443.9	3882.4	7.2812	0.04358	3434.7	3870.5	7.1687
740	0.05729	3520.4	3978.7	7.3782	0.04560	3512.1	3968.1	7.2670
	120 bars (12.0 MPa) (T_{sat} = 324.75°C)				140 bars (14.0 MPa) (T_{sat} = 336.75°C)			
Sat.	0.01426	2513.7	2684.9	5.4924	0.01149	2476.8	2637.6	5.3717
360	0.01811	2678.4	2895.7	5.8361	0.01422	2617.4	2816.5	5.6602
400	0.02108	2798.3	3051.3	6.0747	0.01722	2760.9	3001.9	5.9448
440	0.02355	2896.1	3178.7	6.2586	0.01954	2868.6	3142.2	6.1474
480	0.02576	2984.4	3293.5	6.4154	0.02157	2962.5	3264.5	6.3143
520	0.02781	3068.0	3401.8	6.5555	0.02343	3049.8	3377.8	6.4610
560	0.02977	3149.0	3506.2	6.6840	0.02517	3133.6	3486.0	6.5941
600	0.03164	3228.7	3608.3	6.8037	0.02683	3215.4	3591.1	6.7172
640	0.03345	3307.5	3709.0	6.9164	0.02843	3296.0	3694.1	6.8326
700	0.03610	3425.2	3858.4	7.0749	0.03075	3415.7	3846.2	6.9939
740	0.03781	3503.7	3957.4	7.1746	0.03225	3495.2	3946.7	7.0952

Table A-14 (*Continued*)

Temp., °C	v	u	h	s	v	u	h	s
	160 bars (16.0 MPa) ($T_{sat.}$ = 347.44°C)				180 bars (18.0 MPa) (T_{sat} = 357.06°C)			
Sat.	0.00931	2431.7	2580.6	5.2455	0.00749	2374.3	2509.1	5.1043
360	0.01105	2539.0	2715.8	5.4614	0.00809	2418.9	2564.5	5.1922
400	0.01426	2719.4	2947.6	5.8175	0.01190	2672.8	2887.0	5.6887
440	0.01652	2839.4	3103.7	6.0429	0.01414	2808.2	3062.8	5.9428
480	0.01842	2939.7	3234.4	6.2215	0.01596	2915.9	3203.2	6.1345
520	0.02013	3031.1	3353.3	6.3752	0.01757	3011.8	3378.0	6.2960
560	0.02172	3117.8	3465.4	6.5132	0.01904	3101.7	3444.4	6.4392
600	0.02323	3201.8	3573.5	6.6399	0.02042	3188.0	3555.6	6.5696
640	0.02467	3284.2	3678.9	6.7580	0.02174	3272.3	3663.6	6.6905
700	0.02674	3406.0	3833.9	6.9224	0.02362	3396.3	3821.5	6.8580
740	0.02808	3486.7	3935.9	7.0251	0.02483	3478.0	3925.0	6.9623
	200 bars (20.0 MPa) (T_{sat} = 365.81°C)				240 bars (24.0 MPa)			
Sat.	0.00583	2293.0	2409.7	4.9269				
400	0.00994	2619.3	2818.1	5.5540	0.00673	2477.8	2639.4	5.2393
440	0.01222	2774.9	3019.4	5.8450	0.00929	2700.6	2923.4	5.6506
480	0.01399	2891.2	3170.8	6.0518	0.01100	2838.3	3102.3	5.8950
520	0.01551	2992.0	3302.2	6.2218	0.01241	2950.5	3248.5	6.0842
560	0.01689	3085.2	3423.0	6.3705	0.01366	3051.1	3379.0	6.2448
600	0.01818	3174.0	3537.6	6.5048	0.01481	3145.2	3500.7	6.3875
640	0.01940	3260.2	3648.1	6.6286	0.01588	3235.5	3616.7	6.5174
700	0.02113	3386.4	3809.0	6.7993	0.01739	3366.4	3783.8	6.6947
740	0.02224	3469.3	3914.1	6.9052	0.01835	3451.7	3892.1	6.8038
800	0.02385	3592.7	4069.7	7.0544	0.01974	3578.0	4051.6	6.9567
	280 bars (28.0 MPa)				320 bars (32.0 MPa)			
400	0.00383	2223.5	2330.7	4.7494	0.00236	1980.4	2055.9	4.3239
440	0.00712	2613.2	2812.6	5.4494	0.00544	2509.0	2683.0	5.2327
480	0.00885	2780.8	3028.5	5.7446	0.00722	2718.1	2949.2	5.5968
520	0.01020	2906.8	3192.3	5.9566	0.00853	2860.7	3133.7	5.8357
560	0.01136	3015.7	3333.7	6.1307	0.00963	2979.0	3287.2	6.0246
600	0.01241	3115.6	3463.0	6.2823	0.01061	3085.3	3424.6	6.1858
640	0.01338	3210.3	3584.8	6.4187	0.01150	3184.5	3552.5	6.3290
700	0.01473	3346.1	3758.4	6.6029	0.01273	3325.4	3732.8	6.5203
740	0.01558	3433.9	3870.0	6.7153	0.01350	3415.9	3847.8	6.6361
800	0.01680	3563.1	4033.4	6.8720	0.01460	3548.0	4015.1	6.7966
900	0.01873	3774.3	4298.8	7.1084	0.01633	3762.7	4285.1	7.0372

SOURCE: J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, "Steam Tables," Wiley, New York, 1969.

Table A-15 Properties of water: Compressed-liquid table

(v, m³/g; u, kJ/kg; h, kJ/kg; s, kJ/(kg·K))

Temp., °C	$v \times 10^3$	u	h	s	$v \times 10^3$	u	h	s
	25 bars (2.5 MPa) (223.99°C)				50 bars (5.0 MPa) (263.99°C)			
20	1.0006	83.80	86.30	.2961	.9995	83.65	88.65	.2956
40	1.0067	167.25	169.77	.5715	1.0056	166.95	171.97	.5705
80	1.0280	334.29	336.86	1.0737	1.0268	333.72	338.85	1.0720
100	1.0423	418.24	420.85	1.3050	1.0410	417.52	422.72	1.3030
140	1.0784	587.82	590.52	1.7369	1.0768	586.76	592.15	1.7343
180	1.1261	761.16	763.97	2.1375	1.1240	759.63	765.25	2.1341
200	1.1555	849.9	852.8	2.3294	1.1530	848.1	848.1	2.3255
220	1.1898	940.7	943.7	2.5174	1.1866	938.4	944.4	2.5128
Sat.	1.1973	959.1	962.1	2.5546	1.2859	1147.8	1154.2	2.9202
	75 bars (7.5 MPa) (290.59°C)				100 bars (10 MPa) (311.06°C)			
20	.9984	83.50	90.99	.2950	.9972	83.36	93.33	.2945
40	1.0045	166.64	174.18	.5696	1.0034	166.35	176.38	.5686
80	1.0256	333.15	340.84	1.0704	1.0245	332.59	342.83	1.0688
100	1.0397	416.81	424.62	1.3011	1.0385	416.12	426.5	1.2992
140	1.0752	585.72	593.78	1.7317	1.0737	584.68	595.42	1.7292
180	1.1219	758.13	766.55	2.1308	1.1199	756.65	767.84	2.1275
220	1.1835	936.2	945.1	2.5083	1.1805	934.1	945.9	2.5039
260	1.2696	1124.4	1134.0	2.8763	1.2645	1121.1	1133.7	2.8699
Sat.	1.3677	1282.0	1292.2	3.1649	1.4524	1393.0	1407.6	3.3596
	150 bars (15 MPa) (342.24°C)				200 bars (20 MPa) (365.81°C)			
20	.9950	83.06	97.99	.2934	.9928	82.77	102.62	.2923
40	1.0013	165.76	180.78	.5666	.9992	165.17	185.16	.5646
80	1.0222	331.48	346.81	1.0656	1.0199	330.40	350.80	1.0624
100	1.0361	414.74	430.28	1.2955	1.0337	413.39	434.06	1.2917
140	1.0707	582.66	598.72	1.7242	1.0678	580.69	602.04	1.7193
180	1.1159	753.76	770.50	2.1210	1.1120	750.95	773.20	2.1147
220	1.1748	929.9	947.5	2.4953	1.1693	925.9	949.3	2.4870
260	1.2550	1114.6	1133.4	2.8576	1.2462	1108.6	1133.5	2.8459
300	1.3770	1316.6	1337.3	3.2260	1.3596	1306.1	1333.3	3.2071
Sat.	1.6581	1585.6	1610.5	3.6848	2.036	1785.6	1826.3	4.0139
	250 bars (25 MPa)				300 bars (30 MPa)			
20	.9907	82.47	107.24	.2911	.9886	82.17	111.84	.2899
40	.9971	164.60	189.52	.5626	.9951	164.04	193.89	.5607
100	1.0313	412.08	437.85	1.2881	1.0290	410.78	441.66	1.2844
200	1.1344	834.5	862.8	2.2961	1.1302	831.4	865.3	2.2893
300	1.3442	1296.6	1330.2	3.1900	1.3304	1287.9	1327.8	3.1741

SOURCE: J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, "Steam Tables," Wiley, New York, 1969.

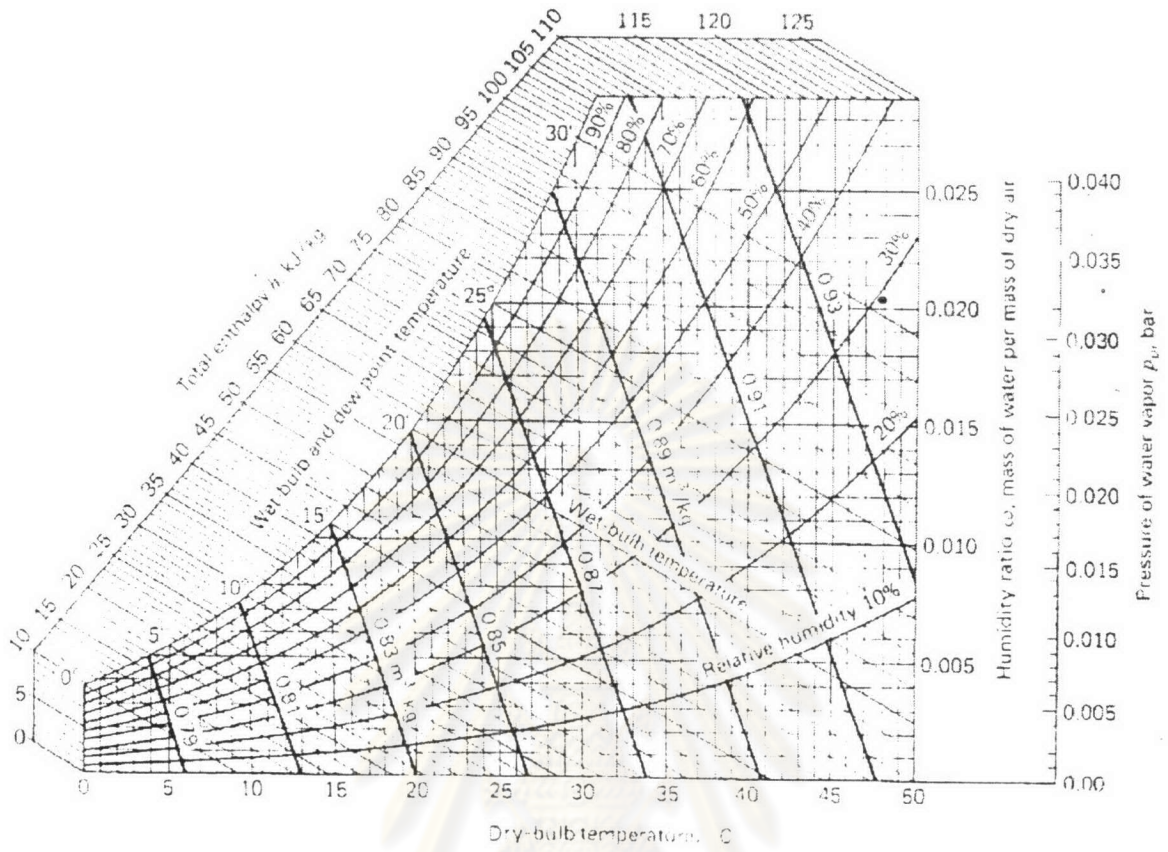


Figure A-25 Psychrometric chart, metric units, barometric pressure 1.01 bars

ประวัติผู้เขียนวิทยานิพนธ์

นายอรุณ โมฮารา เกิดวันที่ 31 กรกฎาคม 2520 จังหวัดนครศรีธรรมราช สำเร็จการศึกษาปริญญาตรีวิทยาศาสตร์บัณฑิต สาขาวัสดุศาสตร์ คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย เมื่อเดือนมีนาคม 2542 และเข้าศึกษาต่อในหลักสูตรวิทยาศาสตร์มหาบัณฑิต สาขาเทคโนโลยีเซรามิก ภาควิชาวัสดุศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย เมื่อเดือนพฤษภาคม 2543 และสำเร็จหลักสูตรในเดือนเมษายน 2547