Tables 3 and 4 show properties of water for temperatures above 212 F. These tables were abstracted from the steam tables of Keenan and Keyes.[4]

DEGREE OF SATURATION AND ITS USE IN CALCULATIONS

At given values of temperature and pressure, the humidity ratio W of moist air may have any value between zero (dry air) and W_s (moist air at saturation). For convenience, a parameter μ called *degree of saturation* is introduced through the use of Equation 1.

$$W = \mu W_s \tag{1}$$

To a degree of approximation within the estimated uncertainty of data in Table 1, at temperatures below about 150 F, the volume v of moist air per pound of dry air may be computed by Equation 2.

$$v = v_a + \mu v_{as} \tag{2}$$

To obtain comparable accuracy at temperatures above about 150 F, it is necessary to add a correction term $\bar{v}$ as follows:

$$\bar{v} = \frac{\mu(1-\mu)A}{1 + 1.6078\,\mu W_s} \tag{3}$$

At temperatures below 150 F, the enthalpy h of moist air per pound of dry air may be computed by Equation 4.

$$h = h_a + \mu h_{as} \tag{4}$$

To obtain comparable accuracy at temperatures above about 150 F, it is necessary to add a correction term $\bar{h}$ as follows:

$$\bar{h} = \frac{\mu(1-\mu)B}{1 + 1.6078\,\mu W_s} \tag{5}$$

Unfortunately, values of entropy s of moist air per pound of dry air computed by the relation

$$s = s_a + \mu s_{as} \tag{6}$$

do not approximate the true values as closely as might be desired except at temperatures considerably below 150 F. Only a small portion of the error is compensated for by the correction term

$$\bar{s} = \frac{\mu(1-\mu)C}{1 + 1.6078\,\mu W_s} \tag{7}$$

The larger portion of the deviation arises from the *mixing entropy*. It can be expressed as an additional correction term as follows:

$$\bar{\bar{s}} = 0.1579\,[(1 + 1.6078\,\mu W_s)\log_{10}(1 + 1.6078\,\mu W_s - 1.6078\,\mu W_s \log_{10}\mu) - \mu(1 + 1.6078\,W_s)\log_{10}(1 + 1.6078\,W_s)] \tag{8}$$

Table 5 shows values of the coefficients A, B, and C in Equations 3, 5, and 7 respectively and maximum values of the correction terms $\bar{v}$, $\bar{h}$, $\bar{s}$, and $\bar{\bar{s}}$.

THERMODYNAMIC WET-BULB TEMPERATURE

For any state of moist air, there exists a temperature t^* at which liquid (or solid) water may be evaporated into the air to bring it to saturation at exactly this same temperature. Fig. 8 may be used as a schematic representation of the adiabatic saturation process where the leaving air is saturated and is at a temperature equal to that of the injected water. In the process, the humidity ratio is increased from a given initial value W to the value W_s^* corresponding to saturation at the temperature t^*; the enthalpy is increased from a given initial value h to the value h_s^* corresponding to saturation at the temperature t^*; the weight of water added per pound of dry air is $(W_s^* - W)$ which adds energy to the moist air of amount $(W_s^* - W)h_w^*$, where h_w^* denotes the specific enthalpy of the water added at the temperature t^*. Therefore, if the process is strictly adiabatic, conservation of energy requires that:

$$h + (W_s^* - W)h_w^* = h_s^* \tag{9}$$

The properties W_s^*, h_w^*, and h_s^* are functions only of the temperature t^* for a fixed value of pressure. The value of t^* which satisfies Equation 9 for given values of h and W is called *thermodynamic wet-bulb temperature*.

The psychrometer is a device consisting of two thermometers, one of which has its bulb covered with a suitable wick that has been thoroughly wetted with water. When the wet-bulb is placed in an air stream, water may evaporate from the wick. The equilibrium temperature eventually reached by the water is called the *wet-bulb temperature*. This process is not the same as one of adiabatic saturation which defines the thermodynamic wet-bulb temperature, but rather is one of simultaneous heat and mass transfer from the wet-bulb. The fundamental mechanism of this process is described in Chapter 5, Mass Transfer. Fortunately, and indeed fortuitously, the corrections to be applied to readings of a wet-bulb thermometer to obtain the thermodynamic wet-bulb temperature are usually quite small. Arnold[5] has presented a procedure which allows calculation of these corrections.

Example 1: Find the degree of saturation, humidity ratio, enthalpy, and volume of moist air at 90 F dry-bulb temperature, 63 F thermodynamic wet-bulb temperature, and 29.921 in. Hg pressure.

Solution: From Equations 1, 4, and 9

$$(h_a + \mu h_{as}) + (W_s^* - \mu W_s)h_w^* = h_s^*$$

Inserting numerical data from Table 1 gives:

$$(21.625 + 34.31\mu) + (0.01235 - 0.03118\mu)(31.12) = 28.57$$

and

$$\mu = 0.1967$$

From Equation 1

$$W = (0.1967)(0.03118) = 0.006133 \text{ lb water/lb dry air}$$

From Equation 4

$$h = 21.625 + (0.1967)(34.31) = 28.37 \text{ Btu/lb dry air}$$

From Equation 2

$$v = 13.853 + (0.1967)(0.692) = 13.989 \text{ cu ft/lb dry air}$$

PERFECT GAS RELATIONS

Tables 1 and 5, with Equations 1 to 9, allow accurate calculations of moist air properties where sea-level pressure may be assumed. The equations of Goff and Gratch may be used to calculate tables similar to Table 1 for any pressure, but as yet such tables are not available. Fortunately, only slight errors occur when Dalton's Rule and perfect-gas relations are applied where normal barometric pressures exist.

According to Dalton's Rule, if dry air and water vapor are mixed, each occupies the whole volume of the container at the temperature of the mixture, and the pressure of the mixture is the sum of the individual pressures. Assuming that both dry air and water vapor behave like perfect gases, the volume v_T occupied by n_a mols of dry air at temperature T and pressure p_a is:

$$v_T = \frac{n_a RT}{p_a} \tag{10}$$

Table 1 ..... Thermodynamic Properties of MOIST AIR[a] (Standard Atmospheric Pressure, 29.921 in. Hg)

Fahr. Temp. t(F)	Humidity Ratio $W_s \times 10^5$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu per(°F) (lb dry air) s_a	s_{as}	s_s	Condensed Water: Enthalpy Btu/Lb h_w	Entropy Btu per (°F)(Lb) s_w	Vap. Press In. Hg $p_s \times 10^5$	Fahr. Temp. t(F)
−160	0.0002120	7.520	0.000	7.520	−38.504	0.000	−38.504	−0.10300	0.00000	−0.10300	−229.00	−0.4967	0.0001009	−160
−155	0.0003289	7.647	0.000	7.647	−37.396	0.000	−37.396	−0.09901	0.00000	−0.09901	−220.40	−0.4833	0.0001842	−155
−150	0.0006937	7.775	0.000	7.775	−36.088	0.000	−36.088	−0.09509	0.00000	−0.09509	−218.77	−0.4800	0.0003301	−150
−145	0.001319	7.902	0.000	7.902	−34.881	0.000	−34.881	−0.09121	0.00000	−0.09121	−217.12	−0.4747	0.0005807	−145
−140	0.002109	8.029	0.000	8.029	−33.674	0.000	−33.674	−0.08740	0.00000	−0.08740	−215.44	−0.4695	0.001004	−140
−135	0.003585	8.156	0.000	8.156	−32.468	0.000	−32.468	−0.08365	0.00000	−0.08365	−213.75	−0.4643	0.001707	−135
−130	0.005000	8.283	0.000	8.283	−31.262	0.000	−31.262	−0.07997	0.00000	−0.07997	−212.02	−0.4590	0.002858	−130
−125	0.009857	8.411	0.000	8.411	−30.057	0.000	−30.057	−0.07634	0.00000	−0.07634	−210.28	−0.4538	0.004710	−125
−120	0.01606	8.537	0.000	8.537	−28.853	0.000	−28.853	−0.07277	0.00000	−0.07277	−208.53	−0.4485	0.007653	−120
−115	0.02571	8.664	0.000	8.664	−27.648	0.000	−27.648	−0.06924	0.00000	−0.06924	−206.73	−0.4433	0.01226	−115
−110	0.04063	8.792	0.000	8.792	−26.444	0.000	−26.444	−0.06577	0.00000	−0.06577	−204.92	−0.4381	0.01939	−110
−105	0.06340	8.919	0.000	8.919	−25.240	0.001	−25.239	−0.06234	0.00000	−0.06234	−203.09	−0.4329	0.03026	−105
−100	0.09773	9.046	0.000	9.046	−24.037	0.001	−24.036	−0.05897	0.00000	−0.05897	−201.23	−0.4277	0.04668	−100
−95	0.1489	9.173	0.000	9.173	−22.833	0.002	−22.833	−0.05565	0.00000	−0.05565	−199.35	−0.4225	0.07111	−95
−90	0.2242	9.300	0.000	9.300	−21.631	0.002	−21.629	−0.05237	0.00001	−0.05236	−197.44	−0.4173	0.1071	−90
−85	0.3343	9.428	0.000	9.428	−20.428	0.003	−20.425	−0.04913	0.00001	−0.04912	−195.51	−0.4121	0.1597	−85
−80	0.4930	9.553	0.000	9.553	−19.225	0.005	−19.220	−0.04595	0.00001	−0.04594	−193.55	−0.4069	0.2356	−80
−75	0.7198	9.680	0.000	9.680	−18.021	0.007	−18.015	−0.04280	0.00002	−0.04278	−191.57	−0.4017	0.3441	−75
−70	1.040	9.806	0.000	9.806	−16.820	0.011	−16.809	−0.03969	0.00003	−0.03966	−189.56	−0.3965	0.4976	−70
−65	1.491	9.932	0.000	9.932	−15.617	0.016	−15.602	−0.03662	0.00005	−0.03658	−187.53	−0.3913	0.7130	−65
−60	2.118	10.059	0.000	10.059	−14.416	0.022	−14.394	−0.03360	0.00006	−0.03354	−185.47	−0.3861	1.0127	−60
−55	2.983	10.186	0.000	10.186	−13.214	0.031	−13.183	−0.03061	0.00009	−0.03052	−183.39	−0.3810	1.4258	−55
−50	4.163	10.313	0.001	10.314	−12.012	0.043	−11.969	−0.02766	0.00013	−0.02754	−181.29	−0.3758	1.9910	−50
−45	4.747	10.364	0.001	10.365	−11.533	0.049	−11.483	−0.02649	0.00013	−0.02636	−180.44	−0.3733	2.3702	−45
−45	5.406	10.414	0.001	10.415	−11.051	0.056	−10.995	−0.02532	0.00014	−0.02518	−179.59	−0.3717	2.5854	−45
−44	6.149	10.465	0.001	10.466	−10.571	0.064	−10.507	−0.02418	0.00016	−0.02402	−178.73	−0.3695	2.8403	−44
−43	6.985	10.516	0.001	10.517	−10.090	0.073	−10.017	−0.02301	0.00019	−0.02282	−177.87	−0.3676	3.1406	−43
−40	7.925	10.566	0.001	10.567	−9.609	0.083	−9.526	−0.02185	0.00021	−0.02165	−177.01	−0.3655	3.7906	−40
−35	8.980	10.617	0.002	10.619	−9.129	0.094	−9.035	−0.02073	0.00024	−0.02048	−176.14	−0.3634	4.2958	−35
−38	10.16	10.668	0.002	10.670	−8.648	0.106	−8.542	−0.01958	0.00028	−0.01932	−175.27	−0.3614	4.8626	−38
−34	11.49	10.718	0.002	10.720	−8.168	0.121	−8.047	−0.01845	0.00030	−0.01815	−174.40	−0.3593	5.4980	−34
−33	12.98	10.769	0.002	10.771	−7.687	0.136	−7.551	−0.01733	0.00034	−0.01699	−173.53	−0.3573	6.2093	−33

Fahr. Temp. t(F)	Humidity Ratio $W_s \times 10^4$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu per (°F) (lb dry air) s_a	s_{as}	s_s	Condensed Water: Enthalpy Btu/Lb h_w	Entropy Btu per (°F)(Lb) s_w	Vap. Press In. Hg $p_s \times 10^2$	Fahr. Temp. t(F)
−30	1.464	10.820	0.002	10.822	−7.207	0.154	−7.053	−0.01631	0.00038	−0.01593	−172.64	−0.3553	0.70046	−30
−28	1.649	10.870	0.003	10.873	−6.726	0.173	−6.553	−0.01509	0.00043	−0.01466	−171.75	−0.3531	0.78923	−28
−26	1.856	10.921	0.003	10.924	−6.246	0.196	−6.050	−0.01393	0.00048	−0.01350	−170.86	−0.3511	0.88838	−26
−24	2.087	10.973	0.004	10.976	−5.765	0.219	−5.546	−0.01287	0.00054	−0.01233	−169.97	−0.3490	0.99855	−24
−22	2.344	11.022	0.004	11.026	−5.285	0.246	−5.039	−0.01177	0.00061	−0.01116	−169.07	−0.3469	1.1319	−22
−20	2.630	11.073	0.005	11.078	−4.804	0.277	−4.527	−0.01067	0.00068	−0.00999	−168.17	−0.3449	1.2587	−20
−19	2.785	11.098	0.005	11.103	−4.564	0.293	−4.271	−0.01012	0.00073	−0.00939	−167.72	−0.3439	1.3327	−19
−18	2.948	11.124	0.005	11.129	−4.324	0.310	−4.014	−0.00958	0.00076	−0.00883	−167.28	−0.3428	1.4107	−18
−17	3.120	11.149	0.006	11.155	−4.083	0.328	−3.755	−0.00904	0.00080	−0.00824	−166.81	−0.3418	1.4929	−17
−16	3.301	11.174	0.006	11.180	−3.843	0.348	−3.495	−0.00850	0.00084	−0.00766	−166.35	−0.3408	1.5795	−16
−15	3.491	11.200	0.006	11.206	−3.603	0.368	−3.235	−0.00796	0.00089	−0.00707	−165.90	−0.3398	1.6706	−15
−14	3.692	11.225	0.007	11.232	−3.363	0.389	−2.974	−0.00743	0.00094	−0.00649	−165.44	−0.3387	1.7666	−14
−13	3.903	11.250	0.007	11.257	−3.123	0.412	−2.711	−0.00689	0.00099	−0.00590	−164.98	−0.3377	1.8677	−13
−12	4.125	11.275	0.008	11.283	−2.882	0.438	−2.446	−0.00635	0.00104	−0.00532	−164.52	−0.3367	1.9740	−12
−11	4.359	11.301	0.008	11.309	−2.642	0.461	−2.181	−0.00582	0.00109	−0.00473	−164.06	−0.3357	2.0859	−11
−10	4.606	11.326	0.008	11.334	−2.402	0.487	−1.915	−0.00529	0.00115	−0.00414	−163.60	−0.3345	2.2035	−10
−9	4.865	11.351	0.008	11.359	−2.162	0.514	−1.648	−0.00475	0.00121	−0.00354	−163.14	−0.3336	2.3272	−9
−8	5.137	11.376	0.009	11.385	−1.922	0.543	−1.379	−0.00422	0.00123	−0.00294	−162.67	−0.3326	2.4572	−8
−7	5.423	11.401	0.010	11.411	−1.681	0.574	−1.107	−0.00369	0.00135	−0.00234	−162.21	−0.3315	2.5940	−7
−6	5.724	11.427	0.010	11.437	−1.441	0.606	−0.835	−0.00316	0.00142	−0.00174	−161.74	−0.3305	2.7377	−6
−5	6.040	11.452	0.011	11.463	−1.201	0.639	−0.562	−0.00263	0.00149	−0.00114	−161.28	−0.3295	2.8886	−5
−4	6.371	11.477	0.012	11.489	−0.961	0.675	−0.286	−0.00210	0.00157	−0.00053	−160.81	−0.3285	3.0479	−4
−3	6.720	11.502	0.013	11.515	−0.721	0.713	−0.009	−0.00157	0.00165	0.00008	−160.34	−0.3275	3.2157	−3
−2	7.085	11.528	0.013	11.541	−0.480	0.751	0.271	−0.00105	0.00174	0.00069	−159.87	−0.3264	3.3855	−2
−1	7.469	11.553	0.014	11.567	−0.240	0.792	0.552	−0.00053	0.00183	0.00131	−159.40	−0.3254	3.5730	−1
0	7.873	11.578	0.015	11.593	0.000	0.835	0.835	0.00000	0.00192	0.00192	−158.93	−0.3244	3.7645	0
1	8.295	11.604	0.015	11.619	0.240	0.880	1.120	0.00052	0.00202	0.00254	−158.46	−0.3234	3.9686	1
2	8.739	11.629	0.016	11.645	0.480	0.928	1.408	0.00104	0.00212	0.00316	−157.99	−0.3223	4.1785	2
3	9.204	11.654	0.017	11.671	0.721	0.977	1.698	0.00156	0.00223	0.00379	−157.52	−0.3213	4.4007	3
4	9.692	11.679	0.018	11.697	0.961	1.030	1.991	0.00208	0.00234	0.00442	−157.04	−0.3203	4.6337	4
5	10.20	11.705	0.019	11.724	1.201	1.085	2.286	0.00260	0.00246	0.00506	−156.57	−0.3192	4.8779	5
6	10.74	11.730	0.020	11.750	1.441	1.142	2.583	0.00313	0.00258	0.00570	−156.09	−0.3182	5.1339	6

[a] Compiled by John A. Goff and S. Gratch.