Applying psychrometric tables

Where to find data for compressed air, evaporative cooling and more

Psychrometric charts and tables provide moisture content, vapor pressure (saturation pressure), relative humidity, density and enthalpy data for different temperatures. Psychrometric data are required for work on heating, ventilation and air conditioning (HVAC); air pollution; evaporative cooling; drying; vacuum systems; and compressed air.

By its nature, compressed air and cooling to ambient conditions cause moisture to condense. For plant air and especially instrument air, dry air with a dewpoint of –40°F (-40°C) is required.

Though the charts and tables were developed for standard atmospheric pressure, they can be applied to processes where the pressure deviates.

Usually, calculations are made for dry air at standard conditions (60°F, 1 atmosphere or 14.7 psia) It is often more convenient to perform the calculations at actual conditions.

Though the charts and tables were developed for standard atmospheric pressures, they can be applied to processes in which the pressures vary from atmospheric. The following steps are used to calculate a psychrometric chart and table at any pressure.

Step 1

The total absolute pressure exerted is the sum of the (partial) pressures exerted by each gas in the system. So, for air, the partial pressures of its major components, nitrogen, oxygen and water vapor, are added as in Equation 1:

$$P_t = P_o + P_n + P_v \qquad (1)$$

where:

P_t = total pressure, psia;
P_o = pressure exerted by oxygen, psia;
P_n = pressure exerted by nitrogen, psia;
P_v = pressure exerted by water vapor, psia.

Step 2

Because dry air is primarily nitrogen and oxygen, Equation 2 represents this relationship:

$$P_a = P_n + P_o \qquad (2)$$

where:
P_a = pressure exerted by the dry air, psia.

Hence, the total pressure is:

$$P_t = P_v + P_a \qquad (3)$$

Psychrometric tables give volumetric values for saturated vapor (cu ft/lb) of dry gas at various temperatures at atmospheric pressure, as well as vapor pressures at those conditions.

Step 3

At conditions other than saturated and with a certain relative humidity, the vapor-holding capacity is a function of the relative humidity. Table 1 provides such useful data as saturation humidity (100% relative humidity), saturation pressure (vapor pressure of the moisture), volumes and enthalpies.

At 65°F the vapor pressure at saturation is 0.305 psi and the vapor carrying ability is 0.01326 lb of water vapor per lb of dry gas.

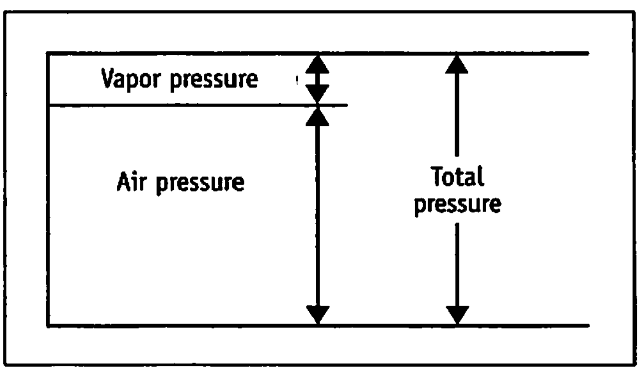


Fig. 1. Partial pressures

Step 4

For example, one might want to find the vapor holding capacity at a relative humidity of 50% at 65°F from Table 1. At 50% relative humidity, the vapor pressure is 0.305 psi divided by 2 or 0.152 psi. The vapor carried in the gas is now 0.01326 times 50% or 0.00663 lbs of vapor per lbs of dry gas.

$$P_{v@RH} = RH \times P_v \qquad (4)$$

$$M_{@RH} = RH \times M \qquad (5)$$

where:
M = water content (moisture), lb/lb dry air;
RH = relative humidity, fraction.

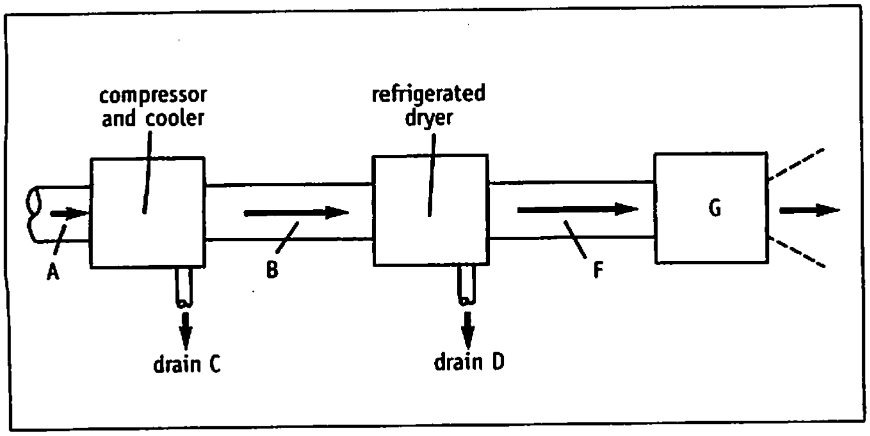
$$P_{v@50\%} = 0.50 \times 0.305 = 0.1525 \text{ psi}$$

$$M_{@50\%} = 0.50 \times 0.01326 = \frac{0.00663 \text{ lb} H_2O}{\text{lb dry air}}$$

Step 5

If the atmospheric psychrometric tables are applied at other pressures, remember that at saturation the water vapor pressure applied to the total is the same, no matter what the total pressure. The only limitation is that the vapor pressure must be lower than

Fig. 2. Typical air compressor process



the total pressure in the system.

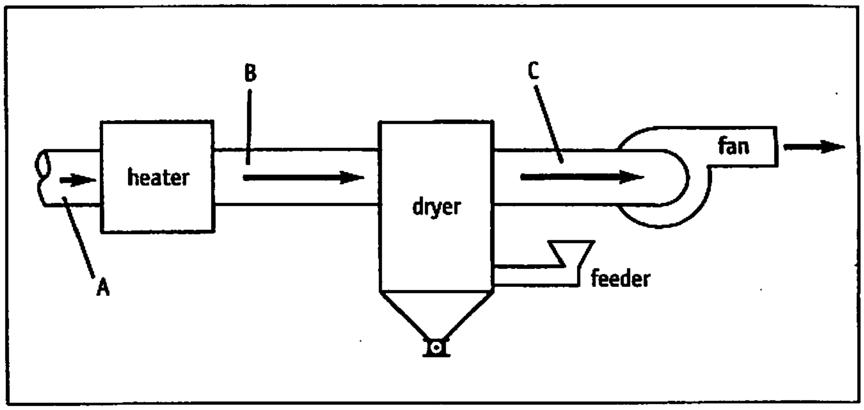
If the total pressure changes and the temperature remains the same, the maximum vapor-carrying ability at any pressure is a function of the ratio of vapor pressure to total pressure, compared to vapor pressure to atmospheric pressure. From this, the ratio of the vapor load per lb of dry air can be determined by the ratio of vapor pressures to new total pressure:

$$M_{new} = M \times \frac{P_v}{P_t} \qquad (6)$$

Table 1. Table of psychrometric data at atmospheric pressure

Temperature (°F)	Saturation pressure, (psia)	Humidity ratio (lbH_2O/lb dry gas)	Volume dry gas (cu ft/lb)	Volume water vapor (cu ft/lb)	Volume saturated gas (cu ft/lb dry gas)	Enthalpy dry gas (Btu/lb dry gas)	Enthalpy saturated vapor (Btu/lb dry gas)	Enthalpy mixture (Btu/lb dry gas)
-20	0.00822	0.0003473	11.07	17.82	11.08	-12.48	1052	-12.12
-10	0.01361	0.0005576	11.33	18.23	11.34	-10.09	1056	-9.48
0	0.02199	0.0009322	11.58	18.63	11.58	-7.68	1061	-6.696
10	0.03478	0.001475	11.82	19.04	11.86	-5.28	1065	-3.712
20	0.05384	0.002637	12.09	19.44	12.13	-2.88	1070	-4.357
32	0.08858	0.003621	12.29	19.92	12.46	0	1075	4.071
35	0.09991	0.001274	12.46	20.04	12.58	0.96	1077	5.751
45	0.14755	0.006329	12.72	20.44	12.85	3.12	1081	9.963
50	0.17818	0.007655	12.84	20.65	13.01	4.32	1083	12.615
55	0.21391	0.009223	12.97	20.85	13.16	5.52	1085	15.536
60	0.2561	0.01108	13.11	21.05	13.33	6.73	1088	18.771
65	0.3055	0.01326	13.22	21.25	13.51	7.93	1090	22.37
70	0.3631	0.01108	13.48	21.45	13.69	9.13	1092	26.39
75	0.4397	0.01881	13.88	21.62	13.88	10.33	1094	30.91
80	0.5069	0.02231	13.61	21.84	14.09	11.53	1096	35.99
85	0.5959	0.02639	13.73	22.04	14.31	12.74	1098	41.72
90	0.6962	0.03115	13.85	22.24	14.55	13.94	1100	48.21
95	0.8154	0.03668	13.98	22.43	14.81	15.14	1103	55.59
100	0.9493	0.04312	14.11	22.63	15.08	16.34	1105	63.98
110	1.2751	0.05983	14.36	23.02	15.73	18.75	1109	84.54
120	1.6927	0.08131	14.61	23.41	16.52	21.15	1113	111.65
130	2.227	0.1113	14.86	23.79	17.51	23.56	1118	147.99
140	2.889	0.1531	15.12	24.18	18.82	25.96	1122	197.51
150	3.719	0.2121	15.37	24.56	20.58	28.38	1126	267.06
160	4.7412	0.2985	15.62	24.93	23.06	30.786	1130	368.3
170	5.9923	0.4321	15.88	25.31	26.81	33.11	1133	523.01
180	7.5109	0.6569	16.13	25.66	32.98	35.61	1138	783.08
190	9.3392	1.097	16.38	26.03	44.09	38.02	1142	1291.11
200	11.526	2.292	16.32	26.38	77.1	40.43	1146	2667
212	14.7			26.81		43.33	1150	

Fig. 3. A vacuum dryer with direct-fired heater



where:

M_{new} = moisture at the new total pressure, lb/lb dry air;
M = moisture at atmospheric pressure from charts or tables, lb/lb dry air;
P_v = vapor pressure at a particular temperature, psi;
p_t = new total pressure, psia.

Step 6

As the new pressure is increased, the vapor-carrying capacity diminishes. Likewise, as the new pressure decreases, the vapor-holding capacity increases. As the example continues, the results at 65°F will be compared when the gases are compressed or expanded. At 14.7 psia, the air can carry 0.01326 lb water vapor/lb of dry gas. At 29.7 psia, Equation 6 says the water vapor capacity will be reduced and condensation will occur. The following provides the way to calculate the resulting condensation.

$$M_{new} = \frac{0.01326 \times 14.7}{29.7} = 0.00656 \text{ lb/lb dry air water vapor}$$

Therefore, if the air was saturated and compressed to 29.7 psia, 0.01326 - 0.00656 = 0.0067 lb/lb dry gas will be condensed.

Step 7

If the gas is expanded to 5 psia, its capacity to carry water vapor is increased, using Equation 6 again.

$$M_{new} = \frac{0.01326 \times 14.7}{5} = 0.0390 \text{ lb/lb dry air}$$

The relative humidity will be reduced from 100% to 0.01326 lb/lb dry air divided by 0.0390 lb/lb dry air or 34% relative humidity.

Air compressor example

An air compressor discharges 200 scfm dry gas at 65°F at a dew point of 60° at A into the aftercooler (Fig. 2). At B the discharge from the aftercooler and inlet to the refrigerated dryer, the temperature is 70°F and the pressure is 99.7 psia. At the discharge of the refrigerated dryer the dry bulb temperature is 55°F. The problem is to find the flowrates at the various points and the apparent dewpoint at G, which is at atmospheric pressure.

At 60°F dewpoint, the saturation humidity is 0.011087 lb vapor/lb dry gas. At 65°F the dry gas takes up 13.223 cu ft/lb and the saturation humidity is 0.013270 lb vapor/lb dry gas. The difference between the volume of dry air at 65°F and saturated wet air at the same temperature is 0.281 cu ft/lb dry air. The flow or volume/lb dry air, Fa, is found below:

$$Fa = 13.223\text{ cu ft/lb} + \left(\frac{0.011087\text{ lbH}_2\text{O/lb dry air}}{0.013270\text{ lbH}_2\text{O/lb dry air}}\right) \times 0.281\text{ cu ft/lb dry air} = 13.458\text{ cu ft/lb dry air}$$

Total lb of dry air is found by dividing 200 scfm by 13.458 cu ft/lb = 14.861 lb/min.

At B (70°F), the vapor holding capacity at 14.7 psia is 0.015832 lb vapor/lb dry gas. At 99.7 psia, it is 0.015832 lb vapor/lb dry gas times 14.7 psia divided by 99.7 psia or 0.002334 lb vapor/lb dry gas.

At C, the drain will be 14.861 lb/min dry gas times (0.011087 - 0.02334) lb vapor/lb dry gas, which is 0.13007 lb/min or 7.80 lb/hr condensate water.

Need to determine the boiling point of water at various vacuums? Water boils when saturation pressure equals the total pressure.

At the outlet from the refrigerant dryer (55°F), the saturation humidity is 0.009233 lb vapor/lb dry gas. The vapor holding capacity is calculated by multiplying 0.009233 lb vapor/lb dry gas times 14.7 and dividing by 99.7 to arrive at 0.001361 lb vapor/lb dry gas.

To find the vapor that is condensed at drain C, (0.002334-0.001361) lb vapor/lb dry air times 14.861 lb/min dry air equals 0.01446 lb/min or 0.868 lb/hr condensate.

At G, the saturation holding capacity is 0.001361 lb vapor/lb dry air, so the dewpoint at 14.7 psia is approximately 10°F. That would be the rating of the refrigerant dryer at those conditions of flow.

Vacuum dryer example

In a vacuum dryer (Fig. 3), the inlet conditions at A are 200 scfm at 70°F dry bulb and 55°F dewpoint. The conditions at B are 5 psia and 75°F dry bulb. To calculate the amount of water that can be evaporated from the product, the dryer exit conditions are 80% relative humidity at 5 psia.

At 55°F dewpoint, the saturation humidity is 0.009233 lb vapor/lb dry gas. At 70°F the dry gas takes up 13.349 cu ft/lb, and the saturation humidity is 0.015832 lb vapor/lb dry gas. The difference between the volume of dry air at 70°F and saturated wet air at the same temperature is 0.339 cu ft/lb dry air. The flow or volume/lb dry air, F_a, is found below:

$$F_a = (13.349\text{ cu ft/lb dry air}) + \left(\frac{0.009233\text{ lbH}_2\text{O/lb dry air}}{0.015832\text{ lbH}_2\text{O/lb dry air}}\right) \times 0.339\text{ cu ft/lb dry air} = 13.547\text{ cu ft/lb dry air}$$

Total lb dry air is found by dividing 200 scfm by 13.547 cu ft/lb = 14.764 lb/min.

Moisture, M, entering the dryer at B is found by multiplying the lb/min dry air times the lb H_2O/lb dry air.

$$M = 0.009233\text{ lb H}_2\text{O/lb dry air} \times 14.764\text{ lb/min dry air} = 0.1363\text{ lb/min water vapor}$$

The vapor carrying capacity at 75°F and 14.7 psia is 0.018833 lb H_2O/lb dry gas. At 5 psia it will be 0.018833 lb H_2O/lb dry gas x 14.7 psia divided by 5 psia, which equals 0.0554 lb H_2O/lb dry gas.

Assuming that the conditions leaving the dryer are 80% relative humidity and 5 psia, the water vapor leaving the product is 0.0554 lb H_2O/lb dry gas times 80% times 14.764 lb/min dry air, or 0.654 lb/min H_2O or 39.44 lb/hr H_2O.

After converting to lb/min water vapor, the normal calculation procedures that are valid at 14.7 psia for the charts can be used.

The boiling point of water at various vacuums can be easily determined. When the saturation pressure is equal to the total pressure, the boiling point is at that temperature.

Bibliography

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• To receive a free copy of "Psychrometric Table Design Procedures" Technical Information TI-059—Dustex Corp., Charlotte, NC. **CIRCLE 418**

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