

ASHRAE PSYCHROMETRIC CHART STANDARD ATMOSPHERIC PRESSURE 29.921 IN. HG

DEGREE OF SATURATION = HUMIDITY RATIO
RELATIVE HUMIDITY = MOL FRACTION OF WATER VAPOR IN MOIST AIR
MOL FRACTION AT SATURATION

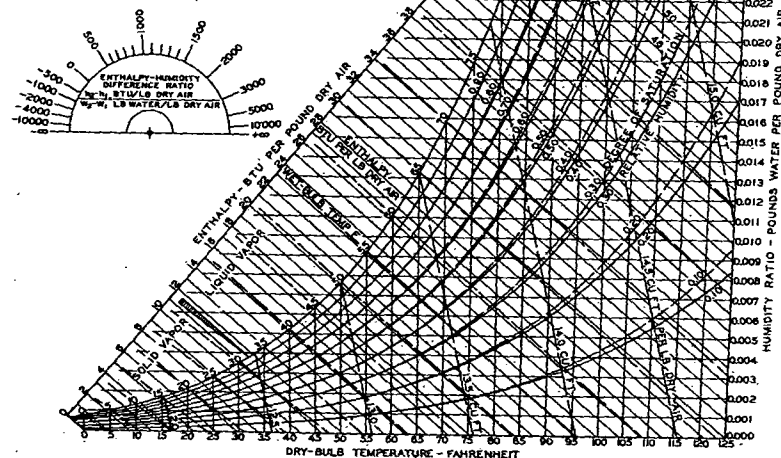


Fig. 6 Abridgment of ASHRAE Psychrometric Chart

for the total (including both phases) mixture and the humidity ratio for saturated air.

The shaded solid-liquid vapor region near the lower left of the chart covers mixtures which contain water in all three phases, solid, liquid, and vapor. The temperature is 32 F throughout this zone. In passing through this region on a line at constant humidity ratio, the change in enthalpy corresponds to the latent heat involved in converting the liquid water to ice, or vice versa. The fraction of the horizontal distance between these boundaries, on a line of constant humidity ratio, for any given state point, represents the corresponding fractional conversion between liquid and solid.

It is possible to obtain two values for the wet-bulb temperature when this temperature is below 32 F. If the bulb of a thermometer is dipped into water at a temperature slightly above 32 F and held in a stream of air whose wet-bulb temperature is below 32 F, the temperature indicated by the thermometer will drop rapidly and may reach a minimum below 32 F. If this happens, ice will not be formed on the bulb of the thermometer. After reaching this minimum temperature, the reading will jump back to 32 F and remain there until the water on the bulb is frozen, after which it will slowly drop again until equilibrium is reached. The final temperature may be higher or lower than the first minimum reading, or it may be the same depending on the amount of moisture present in the mixture. In the absence of reliable data on the wet-bulb temperature over subcooled water, the chart, below 32 F, has been drawn for the equilibrium condition, that

is, the values plotted on the ASHRAE Chart are for the condition where the minimum temperature is reached with ice on the bulb of the thermometer.

USE OF TABLES 2 AND 3 AND THE ASHRAE PSYCHROMETRIC CHART

Engineering analysis of air-conditioning problems requires consistently selected data, procedures, and techniques yielding the desired accuracy, for the application under consideration. The data and principles contained in this chapter offer the advantage of thermodynamic accuracy, with no limitation upon range of validity, for calculations correctly formulated in terms of enthalpy and humidity ratio. With demonstration of principle as the foremost objective here, illustrative examples will be presented to show typical applications of the ASHRAE PSYCHROMETRIC CHART and the tabulated properties.

In each of the following it is to be understood that the processes in question take place at a constant pressure of 29.921 in. Hg, i.e., standard atmospheric pressure.

Example 1: Determine the enthalpy of moist air at 80 F dry-bulb temperature and 0.40 degree of saturation.

Solution a: From the data of Table 2, at 80 F, $h_a = 19.221$ Btu per lb of dry air and $h_{a,s} = 24.47$ Btu per lb of dry air. Then h at the specified conditions is $19.221 + 0.40(24.47) = 29.01$ Btu per lb of dry air. The term h (Equation 32) is negligible for this condition.

Solution b: From the ASHRAE Chart. Follow the 80 F dry-bulb line upward until it intersects the 0.40 degree of saturation

Thermodynamics

line. From this intersection, follow the line of constant enthalpy to the enthalpy scale and read 29.0 Btu per lb of dry air. (The chart is not intended to be read to 0.01 Btu.)

Example 2: Determine the thermodynamic wet-bulb temperature of moist air at the conditions of Example 1.

Solution a: From the data of Table 2. Applying Equation 8, $h_1 = 29.01$ Btu per lb of dry air (Example 1). As a first approximation this is h^* , the enthalpy at saturation at the thermodynamic wet-bulb temperature which is, therefore, approximately 63.5 F. W^* at 63.5 F is 12.57×10^{-3} lb of water vapor per lb of dry air, and W_1 is $0.02233 \times 0.40 = 0.00893$ lb of water vapor per lb of dry air. The enthalpy of liquid water at 63.5 F is 31.62 Btu per lb water; this is read from Table 2, which applies to liquid water in the presence of air at 1 atmosphere pressure. (Use of Table 3 is wrong here, because it gives data for liquid water in equilibrium with saturated steam at the saturation pressure.) As a second approximation, $h^* = 29.01 + (0.01257 - 0.00893)(31.62) = 29.15$ Btu per lb of dry air. Interpolation in Table 2 gives as the final answer $t^* = 63.64$ F.

Solution b: From the ASHRAE Chart. At the intersection of the 80 F dry-bulb temperature line and the 0.40 degree of saturation line, read the thermodynamic wet-bulb temperature.

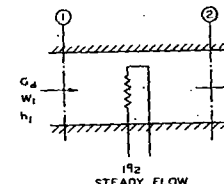


Fig. 7 Illustration of Process of Example 3

Heating of Moist Air at Constant Pressure With-out Addition of Moisture

Example 3: Air initially at 20 F, 0.80 degree of saturation, is heated to 120 F. Find the rate of heat supply required to process 20,000 cfm of heated air.

The process is diagrammatically illustrated in Fig. 7. The energy equation for the process is

$$G_1 h_1 + \dot{q}_1 = G_2 h_2$$

$$\dot{q}_1 = G_2 (h_2 - h_1)$$

Solution a: From the data of Table 2. The initial humidity ratio, which is the same as the final humidity ratio, is $0.80 \times (0.002152) = 0.001722$ lb of water vapor per lb of dry air; the initial enthalpy is $4.804 + 0.80(2.362) = 6.648$ Btu per lb of dry air; the final degree of saturation is $0.001722/0.08149 = 0.02113$; the final enthalpy is $28.841 + 0.02113(90.70) = 30.757$ Btu per lb of dry air; the final volume is $14.611 + 0.02113(1.905) = 14.651$ cu ft per lb of dry air. The terms h and h_s (Equations 31 and 32) have been neglected. Since 20,000 cfm of heated air are to be processed, the total quantity of heat required per minute is

$$\dot{q}_1 = (20,000/14.651) \times 24.111 = 32,914 \text{ Btu per min.}$$

Solution b: From the ASHRAE Chart. The process is represented by the horizontal line 1-2, Fig. 8. The initial enthalpy, at 20 F dry-bulb temperature and 0.80 degree of saturation, is 6.65 Btu per lb of dry air. Since the final humidity ratio is the same as the initial humidity ratio, the ratio $(h_2 - h_1)/(W_2 - W_1) = \infty$. The horizontal line 1-2, Fig. 8, then represents the condition line for the process, and the final state of the moist air must lie on this line. The final state is located at the point at which the 120 F dry-bulb temperature line crosses the condition line, and is labeled Point 2 on the figure. At this condition the final enthalpy is 30.8 Btu per lb of dry air and

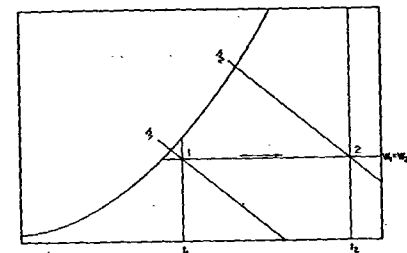


Fig. 8 Solution of Example 3 on ASHRAE Psychrometric Chart

the final specific volume is 14.65 cu ft per lb of dry air. Substituting these values in the energy equation,

$$\dot{q}_1 = (20,000/14.65) \times (30.8 - 6.65) = 32,950 \text{ Btu per min.}$$

Cooling of Moist Air at Constant Pressure with Condensation of Water

This is illustrated in Fig. 9 where moist air cooled from State 1 passes through successive states along the line, $W = W_1$, constant, until the saturation line is intersected. The temperature at this point of intersection is by definition the dew-point temperature for State 1.

Further cooling through successive equilibrium states is accompanied by condensation. The succession of states for the total system, moist air, and liquid water, is represented by a continuation of the $W = W_1$ line into the liquid-vapor region. (Temperatures below 32 F would involve the solid-vapor region.) Consider that the final temperature is t_4 . The final enthalpy is then h_4 ; the liquid water formed is $(W_1 - W_4)$, where Point 3 is at the intersection of the isotherm through 2 and the saturation curve; the final humidity ratio of the moist air is W_3 ; and this final moist air has dew-point, wet-bulb, and dry-bulb temperatures all equal to t_4 .

Example 4: How much heat must be removed from 20,000 cfm of air at 95 F dry-bulb temperature and 0.50 degree of saturation to cool the air to 70 F, saturated?

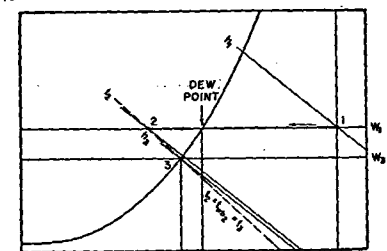


Fig. 9 Cooling of Air at Constant Pressure Shown on ASHRAE Psychrometric Chart