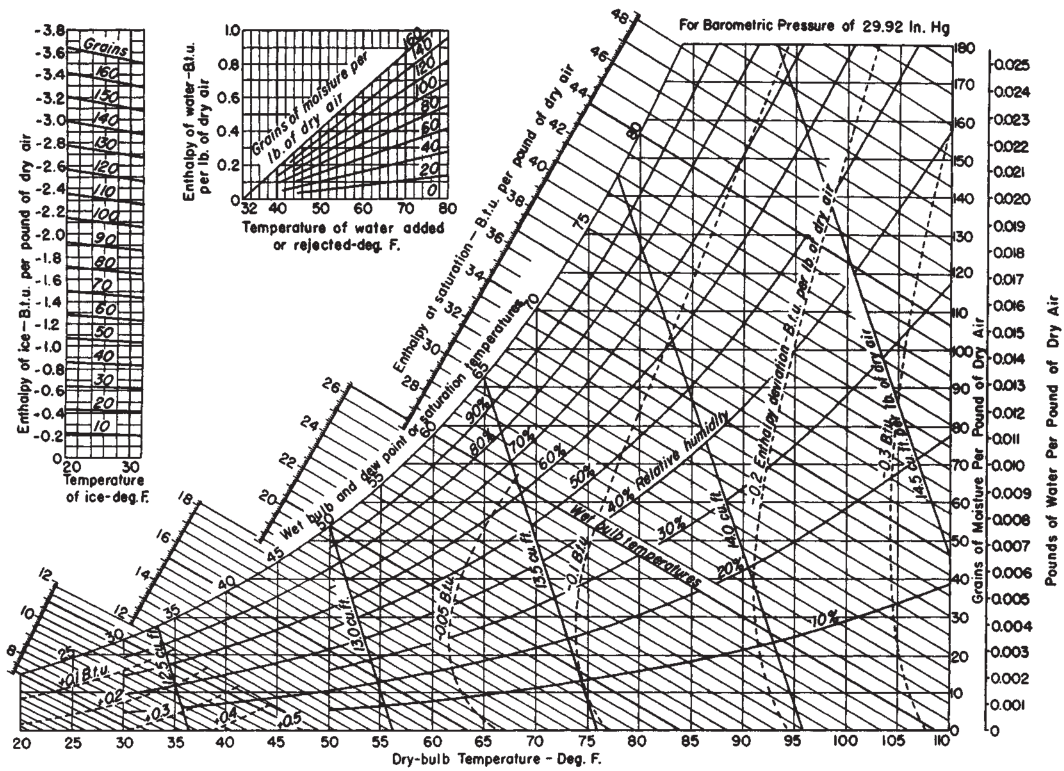

FIG. 12-2 Psychrometric chart—medium temperatures. Barometric pressure, 29.92 inHg. To convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

Relative humidity = 15 percent

Wet-bulb temperature = 51.5°F

Dew point = 25.2°F

The enthalpy of the inlet air is obtained from Fig. 12-2 as $h_1 = h_1' + D_1 = 10.1 + 0.06 = 10.16$ Btu/lb dry air; at the exit, $h_2 = h_2' + D_2 = 21.1 - 0.1 = 21$ Btu/lb dry air. The heat added equals the enthalpy difference, or

$$q_a = \Delta h = h_2 - h_1 = 21 - 10.16 = 10.84 \text{ Btu/lb dry air}$$

If the enthalpy deviation is ignored, the heat added q_a is $\Delta h = 21.1 - 10.1 = 11$ Btu/lb dry air, or the result is 1.5 percent high. Figure 12-7 shows the heating path on the psychrometric chart.

Example 4: Evaporative Cooling Air at 95°F dry-bulb temperature and 70°F wet-bulb temperature contacts a water spray, where its relative humidity is increased to 90 percent. The spray water is recirculated; makeup water enters at 70°F. Determine exit dry-bulb temperature, wet-bulb temperature, change in enthalpy of the air, and quantity of moisture added per pound of dry air.

Solution. Figure 12-8 shows the path on a psychrometric chart. The leaving dry-bulb temperature is obtained directly from Fig. 12-2 as 72.2°F. Since the spray water enters at the wet-bulb temperature of 70°F and there is no heat added to or removed from it, this is by definition an adiabatic process and there will be no change in wet-bulb temperature. The only change in enthalpy is that from the heat content of the makeup water. This can be demonstrated as follows:

Inlet moisture $H_1 = 70$ gr/lb dry air

Exit moisture $H_2 = 107$ gr/lb dry air

$\Delta H = 37$ gr/lb dry air

Inlet enthalpy $h_1 = h_1' + D_1 = 34.1 - 0.22$
$= 33.88$ Btu/lb dry air

Exit enthalpy $h_2 = h_2' + D_2 = 34.1 - 0.02$
$= 34.08$ Btu/lb dry air

Enthalpy of added water $h_w = 0.2$ Btu/lb dry air (from small diagram, 37 gr at 70°F)

Then $q_a = h_2 - h_1 + h_w$
$= 34.08 - 33.88 + 0.2 = 0$

Example 5: Cooling and Dehumidification Find the cooling load per pound of dry air resulting from infiltration of room air at 80°F dry-bulb temperature and 67°F wet-bulb temperature into a cooler maintained at 30°F dry-bulb and 28°F wet-bulb temperature, where moisture freezes on the coil, which is maintained at 20°F.

Solution. The path followed on a psychrometric chart is shown in Fig. 12-9.

Inlet enthalpy $h_1 = h_1' + D_1 = 31.62 - 0.1$
$= 31.52$ Btu/lb dry air

Exit enthalpy $h_2 = h_2' + D_2 = 10.1 + 0.06$
$= 10.16$ Btu/lb dry air

Inlet moisture $H_1 = 78$ gr/lb dry air

Exit moisture $H_2 = 19$ gr/lb dry air

Moisture rejected $\Delta H = 59$ gr/lb dry air

Enthalpy of rejected moisture $= -1.26$ Btu/lb dry air (from small diagram of Fig. 12-2)

Cooling load $q_r = 31.52 - 10.16 + 1.26$
$= 22.62$ Btu/lb dry air

Note that if the enthalpy deviations were ignored, the calculated cooling load would be about 5 percent low.

Example 6: Cooling Tower Determine water consumption and amount of heat dissipated per 1000 ft^3/min of entering air at 90°F dry-bulb temperature and 70°F wet-bulb temperature when the air leaves saturated at 110°F and the makeup water is at 75°F.

Solution. The path followed is shown in Fig. 12-10.

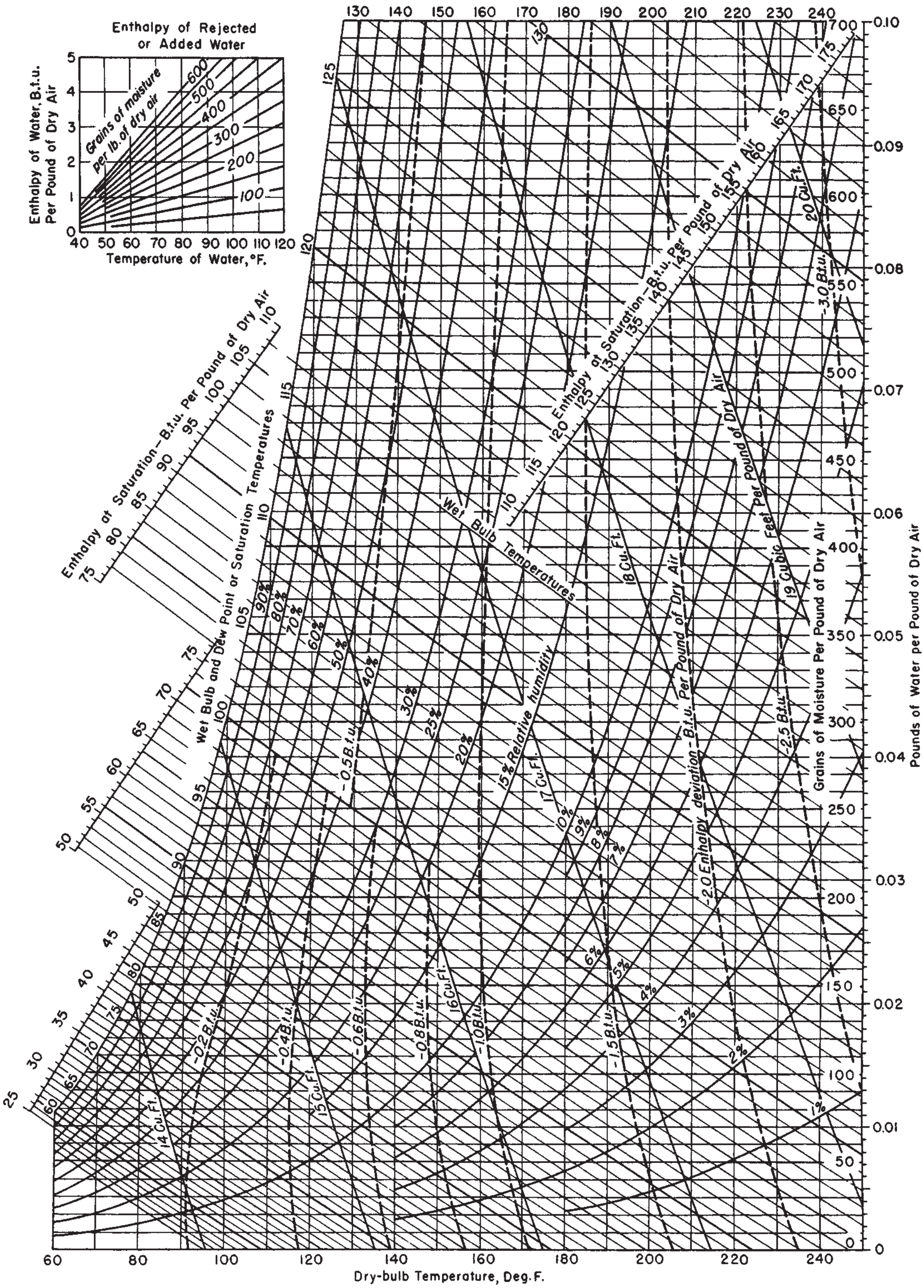

FIG. 12-3 Psychrometric chart—high temperatures. Barometric pressure, 29.92 inHg. To convert British thermal units per pound to joules per kilogram, multiply by 2326; to convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

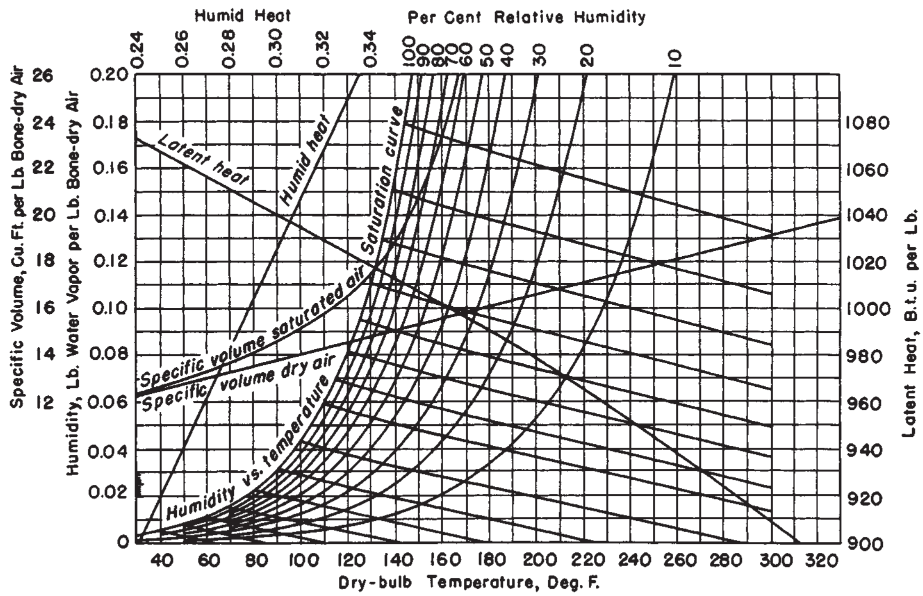

FIG. 12-4 Humidity chart for air-water vapor mixtures. To convert British thermal units per pound to joules per kilogram, multiply by 2326; to convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

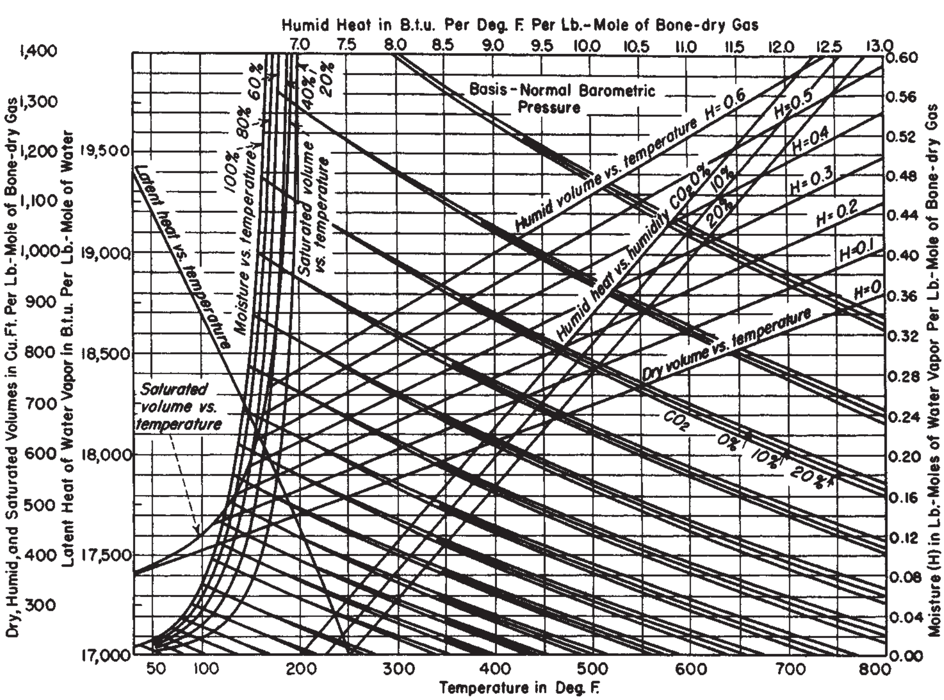

FIG. 12-5 Revised form of high-temperature psychrometric chart for air and combustion products, based on pound-moles of water vapor and dry gases. [*Hatta,* Chem. Metall. Eng., **37,** *64* (*1930*).]

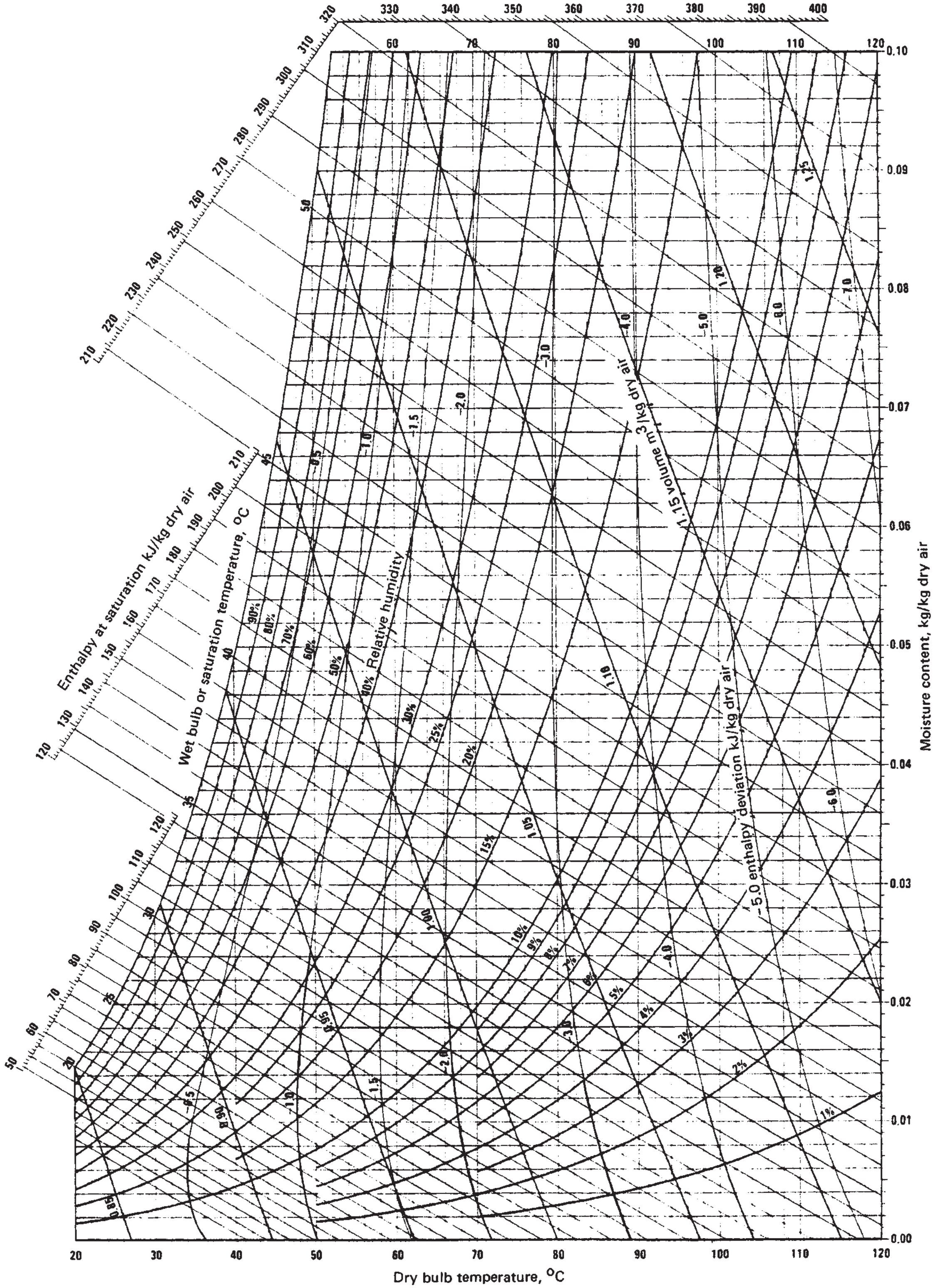

FIG. 12-36 Psychrometric chart: properties of air and water-vapor mixtures from 20 to 120°C. (*Carrier Corp.*)

where h_c = heat-transfer coefficient by convection, J/(m^2·s·K) [Btu/(h·ft^2·°F)]; t = air temperature, K; t_w = wet-bulb temperature of air, K; k'_g = mass-transfer coefficient, kg/(s·m^2) (kg/kg) [lb/(h·ft^2)(lb/lb)]; λ = latent heat of evaporation at t_w, J/kg (Btu/lb); H_w = saturated humidity at t_w = kg/kg of dry air; and H_a = humidity of the surrounding air, kg/kg of dry air.

For air–water-vapor mixtures, it so happens that $h_c/k'_g = C_s$ approximately, although there is no theoretical reason for this. Hence, since the ratio $(H_w - H_a)/(t_w - t)$ equals $h_c/k'_g/\lambda$, which represents the slope of the wet-bulb-temperature lines, it is also equal to C_s/λ, the slope of the adiabatic-saturation lines as shown previously.

A given humidity chart is precise only at the pressure for which it is evaluated. Most air–water-vapor charts are based on a pressure of 1 atm. Humidities read from these charts for given values of wet- and dry-bulb temperature apply only at an atmospheric pressure of 760 mmHg. If the total pressure is different from 760 mmHg, the humidity at a given wet-bulb and dry-bulb temperature must be corrected according to the following relationship.

$$H_a = H_o + 0.622p_w\left(\frac{1}{P - p_w} - \frac{1}{760 - p_w}\right) \qquad (12\text{-}23)$$

where H_a = humidity of air at pressure P, kg/kg of dry air; H_o = humidity of air as read from a humidity chart based on 760-mm pressure at the observed wet- and dry-bulb temperatures, kg/kg dry air, p_w = vapor pressure of water at the observed wet-bulb temperature, mmHg; and P = the pressure at which the wet- and dry-bulb readings were taken. Similar corrections can be derived to correct specific volume, the saturation-humidity curve, and the relative-humidity curves.

HUMIDITY CHARTS FOR SOLVENT VAPORS

Humidity charts for other solvent vapors may be prepared in an analogous manner. There is one important difference involved, however, in that the wet-bulb temperature differs considerably from the adiabatic-saturation temperatures for vapors other than water.

Figures 12-37 to 12-39 show humidity charts for carbon tetrachloride, benzene, and toluene. The lines on these charts have been calculated in the manner outlined for air–water vapor except for the wet-bulb-temperature lines. The determination of these lines depends on data for the psychrometric ratio h_c/k'_g, as indicated by Eq. (12-22). For the charts shown, the wet-bulb-temperature lines are based on the following equation:

$$H_w - H = (\alpha h_c/\lambda_w k'_g)(t - t_w) \qquad (12\text{-}24)$$

where α = radiation correction factor, a value of 1.06 having been used for these charts. Values of h_c/k'_g, obtained from values of $h_c/k'_g C_s$ as presented by Walker, Lewis, McAdams, and Gilliland (*Principles of Chemical Engineering*, 3d ed., McGraw-Hill, New York, 1937), where C_s = humid heat of air with respect to the vapor involved, are as follows:

Material	Carbon tetrachloride	Benzene	Toluene
$h_c/k'_g C_s$	0.51	0.54	0.47

A discussion of the theory of the relationship between h_c and k'_g may be found in the psychrometry part of this section. Because both theoretical and experimental values of h_c/k'_g apply only to dilute gas mixtures, the wet-bulb lines at high concentrations have been omitted. For a discussion of the precautions to be taken in making psychrometric determinations of solvent vapors at low solvent wet-bulb temperatures in the presence of water vapor, see the paper by Sherwood and Comings [*Trans. Am. Inst. Chem. Eng.*, **28,** 88 (1932)].

GENERAL CONDITIONS FOR DRYING

Solids drying encompasses two fundamental and simultaneous processes: (1) heat is transferred to evaporate liquid, and (2) mass is

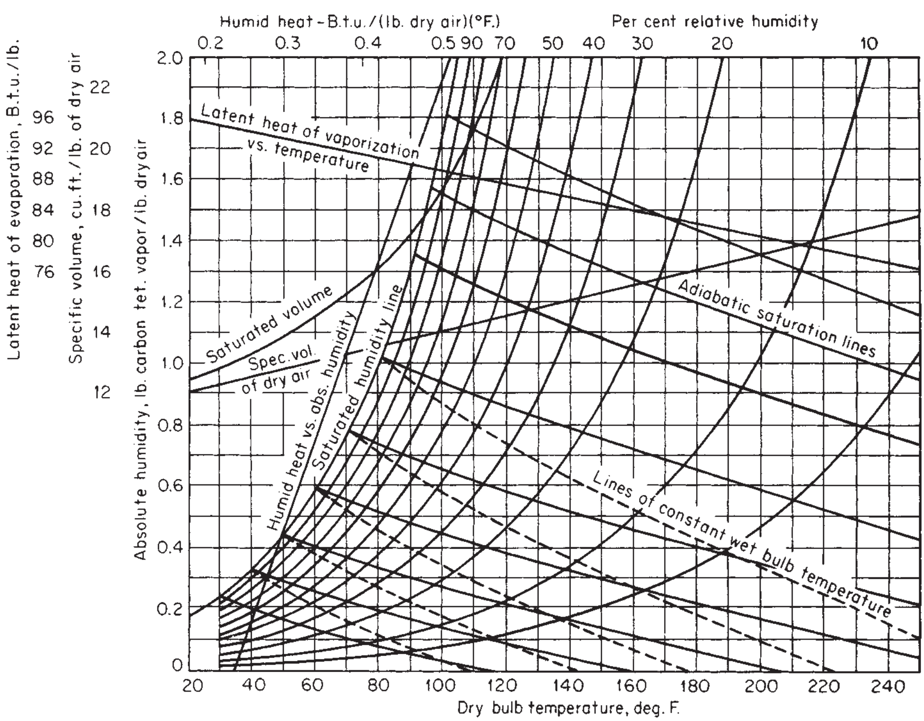

FIG. 12-37 Humidity chart for air-carbon tetrachloride vapor mixture. To convert British thermal units per pound to joules per kilogram, multiply by 2326; to convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

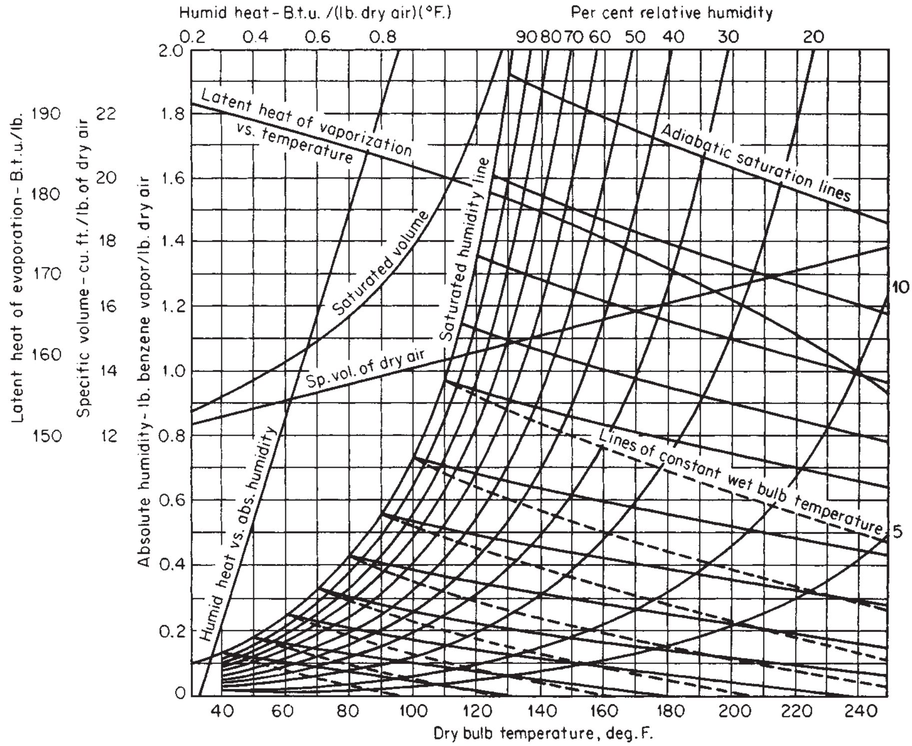

FIG. 12-38 Humidity chart for air-benzene-vapor mixture. To convert British thermal units per pound to joules per kilogram, multiply by 2326; to convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

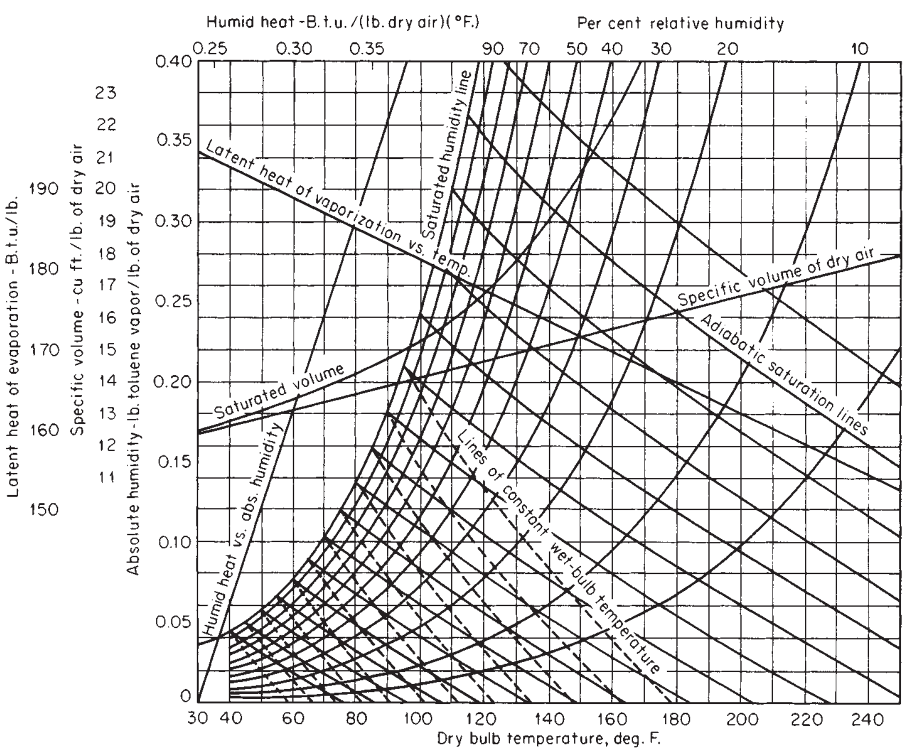

FIG. 12-39 Humidity chart for air-toluene-vapor mixture. To convert British thermal units per pound to joules per kilogram, multiply by 2326; to convert British thermal units per pound dry air-degree Fahrenheit to joules per kilogram-kelvin, multiply by 4186.8; and to convert cubic feet per pound to cubic meters per kilogram, multiply by 0.0624.

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