centage saturation may be calculated if the composition, pressure, and temperature are specified. The temperature required to produce a specified degree of saturation may be calculated if the composition at a specified pressure is known.

Illustration 3. Moist air is found to contain 8.1 grains of water vapor per cubic foot at a temperature of 30° C. Calculate the temperature to which it must be heated in order that its relative saturation shall be 15%.

Basis: 1 cu ft of moist air.

$$\text{Water} = \frac{8.1}{7000} = 1.16 \times 10^{-3} \text{ lb or} \qquad 6.42 \times 10^{-5} \text{ lb-mole}$$

$$\text{Pure-component volume of water vapor} = 6.42 \times 10^{-5} \times 359 = 0.0230 \text{ cu ft at S.C.}$$

$$\text{Partial pressure of water vapor} = 760 \times \frac{0.0230}{1.0} \times \frac{303}{273} = 19.4 \text{ mm Hg}$$

$$\text{Vapor pressure of water at temperature corresponding to } 15\% \text{ relative saturation} = \frac{19.4}{0.15} = 130 \text{ mm Hg}$$

From the vapor-pressure data for water it is found that this pressure corresponds to a temperature of 57° C.

Humidity. Because of the widespread occurrence of water vapor in gases of all kinds, special attention has been given to this case and a special terminology has been developed. The humidity H of a gas is generally defined as the weight of water per unit weight of moisture-free gas. The molal humidity H_m is the number of moles of water per mole of moisture-free gas. When the vapor under consideration is water, the percentage saturation is termed the percentage humidity. The relative saturation becomes the relative humidity.

Considerable confusion exists in the literature in the use of these terms, and care must always be exercised to avoid misuse. The terminology recommended above is an extension of that proposed by Grosvenor.[1]

Dew Point. If an unsaturated mixture of vapor and gas is cooled, the relative amounts of the components and the percentage composition by volume will at first remain unchanged. It follows that, if the total pressure is constant, the partial pressure of the vapor will be unchanged by cooling. This will be the case until the temperature is lowered to such a value that the vapor pressure of the pure liquid at this temperature is equal to the existing partial pressure of the vapor in the mixture. The mixture will then be saturated, and any further cooling will result in condensation. The temperature at which the equilibrium vapor pressure of the liquid is equal to the existing partial pressure of the vapor is termed the *dew point* of the mixture.

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[1] W. M. Grosvenor, *Trans. Am. Inst. Chem. Engrs.*, **1**, 184 (1908).

The vapor content of a vapor-gas mixture may be calculated from dew-point data, or, conversely, the dew point may be predicted from the composition of the mixture.

Illustration 4. A mixture of benzene vapor and air contains 10.1% benzene by volume.

(*a*) Calculate the dew point of the mixture when at a temperature of 25° C and a pressure of 750 mm Hg.

(*b*) Calculate the dew point when the mixture is at a temperature of 30° C and a pressure of 750 mm Hg.

(*c*) Calculate the dew point when the mixture is at a temperature of 30° C and a pressure of 700 mm Hg.

Solution

(*a*) Partial pressure of benzene = 0.101 × 750 = 75.7 mm Hg

From the vapor-pressure data for benzene (Fig. 15) it is found that this pressure corresponds to a temperature of 20.0° C, the dew point.

(*b*) Partial pressure of benzene = 75.7 mm
Dew point = 20.0° C

(*c*) Partial pressure of benzene = 0.101 × 700 = 70.7 mm Hg

The temperature corresponding to a vapor pressure of 70.7 mm Hg is found to be 18.7° C. From these results it is seen that the dew point does not depend on the temperature but does vary with the total pressure.

Vaporization Processes

The manufacturing operations of drying, air conditioning, and certain types of evaporation all involve the vaporization of a liquid into a stream of gases. In dealing with such operations it is of interest to calculate the relationships between the quantities and volumes of gases entering and leaving and the quantity of material evaporated. Such problems are of the general class that was discussed on page 60 under the heading of "Volume Changes with Change in Composition." The concentrations of vapor in these problems are generally expressed in terms of the dew points, the relative saturations, or the moles of vapor per mole of vapor-free gas. The first two methods of expression are convenient because they are directly determined from dew point or wet- and dry-bulb temperature measurements. From such data the partial pressures of vapor may be readily calculated and the partial-pressure method of solution might be used as described in Chapter 3.

The vaporization processes all require the introduction of energy in the form of heat. The effective utilization of this heat is frequently the most important factor governing the operation of the process, and

Bubble-Point Equilibria. A liquid at its bubble-point temperature is in equilibrium with the first bubble of vapor that is formed upon heating the liquid at a given pressure.

Let N_i = mole fraction of component i in the original mixture
x_i = mole fraction of component i in the liquid phase
y_i = mole fraction of component i in the vapor phase

Under all conditions, $\sum N_i = 1.0$, $\sum x_i = 1.0$; $\sum y_i = 1.0$, and $y_i = K_i x_i$. At the bubble point, the composition of the liquid is the same as the entire system:

$$x_i = N_i$$

$$y_i = K_i x_i = K_i N_i \tag{10}$$

Hence,

$$\sum K_i N_i = 1.0$$

If the total pressure is fixed, the bubble-point temperature is calculated by a graphical procedure, assuming various values of temperature until the value of $\sum K_i N_i = 1.0$. Since $x_i = N_i$, the composition of the vapor is then obtained from the ratio $y_i = K_i N_i$.

If the temperature is fixed, the bubble-point pressure is calculated by a similar graphical procedure, assuming various values of pressure until the value of $\sum K_i N_i = 1.0$.

Dew-Point Equilibria. A vapor is at its dew-point temperature when the first drop of liquid forms upon cooling the vapor at constant pressure and the composition of the vapor remaining is the same as the initial vapor mixture:

$$y_i = N_i = K_i x_i \quad \text{or} \quad x_i = N_i/K_i \tag{11}$$

$$\sum N_i/K_i = 1.0$$

The dew-point temperature or pressure is obtained by a similar graphical procedure to that used in calculating bubble-point equilibria.