

below the saturation curve as lines of constant *thermodynamic wet-bulb temperature*. The definition of thermodynamic wet-bulb temperature will be given later.

On the Mollier Diagram provided with THE 1948 GUIDE there has been drawn a *protractor* from which can be determined the direction in which the state point of a mixture of water and dry air will be moved by *simultaneous addition of energy and water without addition of dry air*. A particular direction is specified by the numerical value of the *ratio of energy to water added* which ratio is designated as q and called the *specific enthalpy of water added, Btu per pound*. The protractor is useful in locating the *condition line* of a cooling load or heating load problem.

DERIVED PROPERTIES

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. The humidity ratio of the air is increased from a given initial value W to the value W_s^* corresponding to saturation at the temperature t^* ; the enthalpy of the air 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 $W_s^* - W$ and this adds energy of amount $(W_s^* - W)h_w^*$, where h_w^* denotes the specific enthalpy of the water as added at the temperature t^* ; therefore, if the process is strictly adiabatic,

$$h + (W_s^* - W)h_w^* = h_s^* \quad (7)$$

The solution of Equation 7 for given values of h and W is called *thermodynamic wet-bulb temperature*.

Example 1. Find the thermodynamic wet-bulb temperature of moist air at 80 F, 50 per cent saturation, atmospheric pressure.

Solution. From the data of Table 1, the enthalpy of the air is $h = 19.221 + 0.50 \times 24.47 = 31.46$ Btu/lb_a (Equation 5). To a first approximation this is the enthalpy at saturation at the thermodynamic wet-bulb temperature which is therefore approximately 67 F.

At 67 F the humidity ratio at saturation is 0.01424 lb_w/lb_a and the specific enthalpy of liquid water is 35.11 Btu/lb_w. The humidity ratio of the air is $W = 0.50 \times 0.02233 = 0.01117$ lb_w/lb_a (Equation 3). Therefore, to a second approximation, the enthalpy at saturation at the thermodynamic wet-bulb temperature is $h_s^* = 31.46 + (0.01424 - 0.01117) \times 35.11 = 31.57$ Btu/lb_a, Equation 7. Interpolation in Table 1 gives as final answer,

$$t^* = 66.94 \text{ F}$$

The answer can also be read directly on the Mollier Diagram at the intersection of the 80 F dry-bulb and 50 per cent saturation lines.

The psychrometer is an instrument consisting of two thermometers one of which has the bulb covered with a suitable wick that has been dipped in liquid water and thoroughly wetted by it. On placing the wet-bulb of the instrument in an air stream, the liquid begins to evaporate from the wick and it is usually assumed that such evaporation brings the air immediately adjacent to the wick to saturation. At first this air may reach saturation at a higher or lower temperature than that of the liquid on the wick; but in a relatively short time the temperature of the liquid will have changed to approach equality with that of the air touching the wick, even if this requires the liquid to freeze on the wick. Then the liquid (or solid) will continue for a time to evaporate into the air stream at such temperature as will bring a portion of the air stream to saturation

at this same temperature. This equilibrium temperature is called *wet-bulb temperature*.

It is clear that the readings of an actual wet-bulb thermometer cannot be regarded as values of a thermodynamic property of moist air; for these readings are importantly affected by a number of non-thermodynamic factors including design, construction, installation, and technique of using the instrument. Thus, unless the wet-bulb is effectively shielded against radiation from relatively warm surfaces the process will not be strictly adiabatic as tacitly assumed in writing Equation 7. Also, partial drying of the wick will prevent the air immediately adjacent to it from reaching complete saturation as assumed in Equation 7. A working theory developed by Arnold⁵ enables the calculation of corrections to be applied to the readings of the actual instrument in order to make them agree with the values of temperature calculated from Equation 7. Fortunately, and indeed fortuitously, these corrections can be made small, but to emphasize the necessity of making them in accurate experimentation, the temperature defined by Equation 7 is called *thermodynamic wet-bulb temperature*.

Example 2. Find the degree of saturation of moist air at 90 F dry-bulb, 63 F thermodynamic wet-bulb, atmospheric pressure.

Solution. Inserting numerical data from Table 1 into Equation 7 gives

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

The solution of this equation is direct and the final answer is

$$\mu = 19.67 \text{ per cent}$$

The per cent saturation may also be read directly at intersection of 90 F dry-bulb and 63 F thermodynamic wet-bulb lines on the Mollier Diagram.

Example 3. Find the temperature to which moist air initially saturated at 40 F and at standard atmospheric pressure must be heated in order to have a thermodynamic wet-bulb temperature of 60 F.

Solution. On the Mollier Diagram follow a horizontal line from the saturation curve at 40 F to its intersection with the 60 F thermodynamic wet-bulb line and read the corresponding temperature directly.

Inserting numerical data from Table 1 into Equation 7, this becomes

$$h_a + 0.005213h_{as}/W_s = 26.46 - (0.01108 - 0.005213) \times 28.12 = 26.295$$

At 85 F the lefthand member of this equation has the value 26.147; at 86 F its value is 26.389; by linear interpolation the answer is: $t = 85.61$ F.

Dew-Point Temperature. Corresponding to any given state of moist air there exists another state on the saturation curve having the same humidity ratio W and same pressure p as the given state. The temperature at this other state on the saturation curve is called the *dew-point temperature* of the given state. Obviously, if moist air is cooled at constant pressure and constant humidity ratio it will reach saturation when its temperature falls to a value equal to its dew-point temperature. This will usually be marked by the first appearance of a coexisting condensed phase. In one type of dew-point apparatus a continuous sample of air is passed over a mirror which can be cooled by external refrigeration and whose temperature can be accurately measured. The measured temperature at which the intensity of light reflected from the mirror is abruptly diminished by condensation is taken to be the dew-point temperature of the air sample. Examples 4 and 5 illustrate the relation between the dew-point, degree of saturation and dry-bulb temperature.