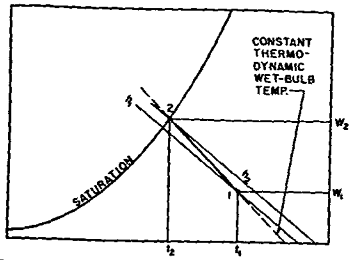

Fig. 15 .... Moisture Added and Temperature Change

Solution a: From the data of Table 2. As previously stated, the final temperature of the mixture will be the thermodynamic wet-bulb temperature at the initial state. This must first be determined by the method of *Example 8*, and is 65.51 F. At this temperature the humidity ratio at saturation and enthalpy at saturation are 0.01350 and 30.45, respectively. The humidity ratio at the initial state is 0.60(0.01882) = 0.01129; the initial enthalpy is 0.60(20.59) + 18.018 = 30.372, neglecting $\bar{h}$. The weight of water added is therefore 0.01350 − 0.01129 = 0.00221 lb per lb of dry air; the enthalpy change is 30.45 − 30.372 = 0.078 Btu per lb of dry air.

Solution b: From the ASHRAE Chart. Since the initial and final states have the same thermodynamic wet-bulb temperature, the results may be read directly from the chart.

Addition of Heat and Water Vapor to an Air Stream in Steady Flow

Fig. 16 is a schematic representation of a system operating at constant pressure.

An energy balance for the system gives

$$G_d h_1 + {}_1q_2 + L_1 h_{w1} = G_d h_2 + L_2 h_{w2} \qquad (41)$$

where

G_d = rate of flow of dry air, pounds per minute.
G_w = rate of evaporation of the water, pounds per minute.
h_w = enthalpy of the liquid water entering, Btu per pound.
L = flow rate of liquid water.
q = rate of heat addition, Btu per minute.

A mass balance gives:

For air, Flow rate = G_d = inflow rate = outflow rate

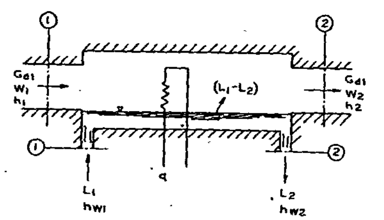

Fig. 16 .... Illustration of Addition of Heat and Water Vapor to an Air Stream in Steady Flow

For water, $G_d W_1 + L_1 = G_d W_2 + L_2$

or, with $G_w = L_1 - L_2$,

$$G_d(W_2 - W_1) = G_w \qquad (42)$$

The *condition line* for this process has a slope which can be determined from a combination of Equations 41 and 42. Thus,

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{{}_1q_2 + L_1 h_{w1} - L_2 h_{w2}}{L_1 - L_2} \qquad (43)$$

If the water enters and leaves at the same temperature, $h_{w1} = h_{w2}$, and Equation 43 becomes

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{{}_1q_2}{G_w} + h_w \qquad (44)$$

If $L_2 = 0$, that is, if all of the water entering is carried away as water vapor, this also leads to Equation 44.

Example 8: Moist air at 20 F dry-bulb temperature and 0.80 degree of saturation is heated and humidified until it is at 120 F dry-bulb temperature and 71.5 F thermodynamic wet-bulb temperature. Water is supplied at 55 F at a rate of 10 lb per min, and the excess water leaves at 65 F. The air flow rate is 20,000 cfm measured at the initial conditions. Find the required rate of heat addition and the rate of water evaporation.

Solution a: Using the data of Table 2. The initial humidity ratio is W_1 = 0.80 (0.002152) = 0.001722; the initial enthalpy is h_1 = 4.804 + 0.80 (2.302) = 6.646, neglecting $\bar{h}$; the initial specific volume is v_1 = 12.084 + 0.80 (0.042) = 12.12, neglecting $\bar{v}$. The degree of saturation at the final state μ_2 is computed from Equation 8, which may be written in the form

$$h_{a2} + \bar{h}_2 + h_{w2}W_2^* + \mu_2(h_{as2} - h_{w2}^*W_{s2}) = h_{s2}^*$$

The properties are: h_{s2}^* = 35.39, W_2^* = 0.01668, h_{w2}^* = 39.61, h_{as2} = 90.70, W_{s2} = 0.08149, h_{a2} = 28.84. The term $\bar{h}_2$ is obtained in two steps: (1) solve for μ_2 assuming $\bar{h}_2$ = 0, (2) compute $\bar{h}_2$ from μ_2 thus determined and see if the correction is warranted. The first step yields μ_2 = 0.0681. Then,

$$\bar{h}_2 = \frac{\mu_2(1 - \mu_2)B}{1 + 1.6078\, W_{s2}\,\mu_2} = \frac{0.0681(0.9319)0.1050}{1 + 1.6078(0.08149)(0.0681)}$$

$$= 0.0066 \text{ Btu per lb.}$$

This correction amounts to 0.01 in the second decimal place (which is not appreciable for most purposes), whereby $h_{a2} + \bar{h}_2$ = 28.85.

A second value of μ_2 now is computed, but the correction is so small that there is no numerical influence. Hence, μ_2 = 0.0681 remains valid.

The final humidity ratio is W_2 = 0.0681 (0.08149) = 0.005549. The final enthalpy is h_2 = 28.84 + 0.01 + 0.0681 (90.70) = 35.03 Btu/lb dry air.

The air rate is G_d = 20,000 ÷ 12.12 = 1650 lb dry air per min.

The rate of water evaporation is found from Equation 42.

$$G_w = G_d(W_2 - W_1) = 1650(0.005549 - 0.001722)$$
$$= 6.32 \text{ lb per min}$$

The rate of water discharge is

$$L_2 = L_1 - G_w = 3.68 \text{ lb per min}$$

The liquid water enthalpies are taken from Table 2 as h_{w1} = 23.12, h_{w2} = 33.11 Btu per lb. This use of Table 2 assumes that the water enters and leaves the apparatus in contact with air at a pressure of 1 atmosphere.

The rate of heat supply is obtained from Equation 41 in the form

$$\begin{aligned} {}_1q_2 &= G_1(h_2 - h_1) + L_2 h_{w2} - L_1 h_{w1} \\ &= 1650(35.03 - 6.646) + 3.68(33.11) - 10(23.12) \\ &= 46{,}730 \text{ Btu/min} \end{aligned}$$

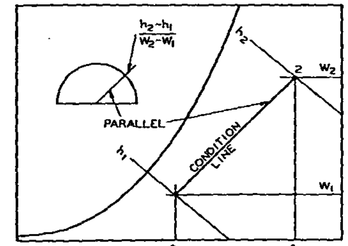

Fig. 17 .... Solution of *Example 8* on ASHRAE Psychrometric Chart

Solution b: From the ASHRAE Chart. Locate the initial and final states on the chart and connect them with a straight line, which is the *condition line* of the process (Fig. 17). On the chart protractor draw a line parallel to the condition line, and read the ratio $(h_2 - h_1)/(W_2 - W_1)$ = 7500. Equation 43 then becomes

$$\frac{h_2 - h_1}{W_2 - W_1} = 7500 = \frac{{}_1q_2 + L_1 h_{w1} - L_2 h_{w2}}{(L_1 - L_2)}$$

The water evaporation rate, $L_1 - L_2 = G_w$, is computed, as before, from Equation 42 and the humidity ratios are read from the chart. This yields G_w = 6.27 lb/min. With L_1, L_2, h_{w1}, h_{w2} all established, the magnitude of Q is computed from the above equation in the form

$$\begin{aligned} {}_1q_2 &= 7500(L_1 - L_2) - L_1 h_{w1} + L_2 h_{w2} \\ &= 7500(6.27) - 10(23.1) + 3.68(33.1) \\ &= 46{,}900 \text{ Btu/min} \end{aligned}$$

The difference between this result and the previous one is due to the limitation in number of significant figures that can be obtained in graphical readings.

U. S. STANDARD ATMOSPHERE

The definition of the U. S. Standard Atmosphere is important to the air-conditioning engineer as an essential standard of reference. The basic assumptions in defining the Standard Atmosphere are:

1. There is a linear decrease in temperature T with altitude up to the lower limit of the isothermal atmosphere at 35,332 ft. Thus,

$$T = T_o - 0.003566\, Z \qquad (45)$$

2. The air is dry.
3. Air is a perfect gas obeying the laws of Charles and Boyle:

$$PV = RT$$

4. Gravity is constant at all altitudes with the standard value.
5. The temperature of the isothermal atmosphere is −66 F.

Standard values at sea level, which are part of the definition of the Standard Atmosphere, are:

Pressure	29.921 in. Hg
Temperature	59 F
Absolute Temperature	518.67 F abs
Gravity	32.1740 ft per (sec) (sec)
Density	0.076505 lb per cu ft

Table 7 .... Pressure and Temperature for Altitudes in U. S. Standard Atmosphere

Altitude Feet Z	*Pressure In. of Hg* P	*Temp F* t
−1,000	31.02	+62.6
−500	30.47	+60.8
0	29.921	+59.0
+500	29.38	+57.2
+1,000	28.86	+55.4
+5,000	24.89	+41.2
10,000	20.58	+23.4
15,000	16.88	+5.5
20,000	13.75	−12.3
25,000	11.10	−30.1
30,000	8.88	−47.9
35,000	7.04	−65.8
40,000	5.54	−67.0
45,000	4.36	−67.0
50,000	3.436	−67.0

Values of pressure and temperature are listed in Table 7 for altitudes in the standard atmosphere from −1000 to 50,000 ft above sea level. For further explanation, References 12 and 13 should be consulted.

Air-conditioning engineers frequently use a *standard air density*, at 1 atmosphere pressure, of 0.075 lb/cu ft. From Table 2, this is represented by *dry air* at 69.4 F. Noting further that the density being employed here is in *lb mixture per cu ft*, the density of 0.075 also corresponds to variously humid air at higher temperatures than 69.4 F; at 70 F this density is achieved with a humidity ratio of 0.001125, for example. The relationship here is expressed in terms of specific volume per lb dry air given on the ASHRAE PSYCHROMETRIC CHART, as (cu ft mixture per lb mixture) = (cu ft mixture per lb dry air) ÷ (lb mixture per lb dry air).

LETTER SYMBOLS USED IN CHAPTER 3

μ = degree of saturation (decimal).
ϕ = relative humidity (decimal).
${}_1w_2$ = work done by the system on the surroundings between states 1 and 2, Btu.
σ = ratio of apparent molecular weight of dry air (28.966) to the molecular weight of water (18.016) = 1.6078.
A = coefficient from Table 6 for use in Equation 34 (obtained from Table 6).
B = coefficient to be used in Equation 35 (obtained from Table 6).
C = coefficient for use in Equation 36 (obtained from Table 6).
c_p = specific heat at constant pressure, Btu per pound.
E_P = fluid potential energy, Btu per pound of dry air.
E_K = fluid kinetic energy, Btu per pound of dry air.
F_C = compressibility factor.
f_s = factor accounting for effect of mixing air and water, dimensionless.
G = mass flow rate, pounds per hour.
G_d = flow rate of dry air, pounds per minute.
G_w = rate of evaporation of water, pounds per minute.
H = enthalpy of the system, Btu.
H = enthalpy of the flowing medium, Btu per pound of dry air.
h = enthalpy of moist air, Btu per pound of dry air.
h' = enthalpy of fluid, Btu per pound.