lating spray water. Find the amount of water added and the change in enthalpy.

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 2*, 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. 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 ASHAE 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. 15 is a schematic representation of a system operating at constant pressure, *where*

G_1 is the rate of flow of dry air, pounds per minute.

G_w is the rate of evaporation of the water, pounds per minute.

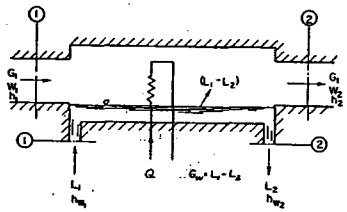


Fig. 15 .... Illustration of Addition of Heat and Water Vapor to an Air Stream in Steady Flow

h_w is the enthalpy of the liquid water entering, Btu per pound.

Q is the rate of heat addition, Btu per minute.

An energy balance for the system gives

$$G_1h_1 + Q + G_wh_w = G_2h_2 \tag{37}$$

A mass balance gives

$$G_1 + G_1W_1 + G_w = G_2 + G_2W_2$$

or

$$G_1W_1 + G_w = G_2W_2 \tag{38}$$

Combining Equations 37 and 38 and solving for the ratio $(h_2 - h_1)/(W_2 - W_1)$,

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{Q}{G_w} + h_w \tag{39}$$

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 at 55 F is supplied. If the air-flow rate is 20,000 cfm at the initial conditions, how much heat is required?

Solution a: From the data of Table 2. The initial humidity ratio is 0.80(0.002152) = 0.00172; the initial enthalpy is 4.804 + 0.80(2.302) = 6.6456; the initial specific volume is 12.084 + 0.80(0.042) = 12.118. The degree of saturation at the final

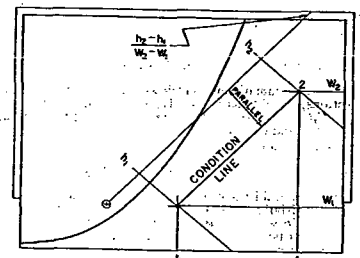


Fig. 16 .... Solution of *Example 8* on ASHAE Psychrometric Chart

state may be determined from Equation 8 which may be rewritten as

$$h_{as} + \mu h_{as} + h_w^*(W^* - \mu W_s) = h^*$$

The values of these properties are: $h^* = 35.39$; $W^* = 0.01668$; $h_w^* = 39.61$; $h_{as} = 90.70$; $W_s = 0.08149$; $h_s = 28.84$.

Making the proper substitutions and solving for degree of saturation,

$$\mu = 0.0681$$

The final humidity ratio is therefore 0.0681(0.08149) = 0.005549; the final enthalpy is 28.84 + 0.0681(90.70) = 35.02 Btu per lb dry air.

The rate of water addition is obtained from Equation 38.

$$G_w = \frac{20{,}000}{12.12}(0.005549 - 0.00172)$$

$$= 6.32 \text{ lb per min.}$$

The heat supplied is obtained from Equation 37.

$$Q = G_1(h_2 - h_1) - G_wh_w$$

$$= \frac{20{,}000}{12.12}(35.02 - 6.65) - 6.32(28.08)$$

$$= 46{,}667 \text{ Btu per min.}$$

Solution b: From the ASHAE Chart. Locate the initial and final states on the chart and connect them with a straight line. Through the reference point on the chart, draw a line parallel to the line connecting the initial and final state points, the condition line, and read the value of the ratio $(h_2 - h_1)/(W_2 - W_1)$ as 7500 from the protractor on the chart (Fig. 16). From Equation 39

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{Q}{G_w} + h_w = 7500$$

The rate of water supply was determined in *Solution a*, but will be found from the chart. It is

$$G_w = \frac{20{,}000}{12.1}(0.0055 - 0.0017)$$

$$= 6.28 \text{ lb per min}$$

$$Q = G_w(7500 - h_w)$$

$$= 6.28(7500 - 23)$$

$$= 46{,}900 \text{ Btu per min.}$$

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 limit of the isothermal atmosphere at 35,332 ft. Thus,

$$T = T_o - 0.003566\,Z \tag{40}$$

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.

Table 6 .... 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

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

Values of pressure and temperature are listed in Table 6 for altitudes in the standard atmosphere from −1000 to 50,000 ft above sea level. For further explanation, References 9 and 10 should be consulted.

LETTER SYMBOLS USED IN CHAPTER 3

μ = degree of saturation (decimal).
ρ = density of fluid, pounds per cubic foot.
ϕ = relative humidity (decimal).
α = ratio of apparent molecular weight of dry air (28.966) to the molecular weight of water (18.016) = 1.6078.
A = coefficient from Table 5 for use in Equation 30 (obtained from Table 5).
B = coefficient to be used in Equation 31 (obtained from Table 5).
C = coefficient for use in Equation 32 (obtained from Table 5).
f_s = factor accounting for effect of mixing air and water, dimensionless.
G = flow rate of dry air, pounds per hour.
G_1 = flow rate of dry air, pounds per minute.
G_w = rate of evaporation of water, pounds per minute.
H = enthalpy of the system.
H = enthalpy of the flowing medium, Btu per pound of dry air.
h = enthalpy of moist air, Btu per pound of dry air.
$\bar{h}$ = enthalpy correction term to be added above 150 F, to enthalpy.
h_a = specific enthalpy of dry air, Btu per pound.
$h_{as} = h_s - h_a$ = the difference between the enthalpy of moist air *at saturation* per pound of dry air, and the specific enthalpy of the dry air itself, Btu per pound of dry air.
h_g = enthalpy of saturated water vapor, Btu per pound.
h_s = enthalpy of moist air at saturation per pound of dry air, Btu per pound of dry air.
h_s^* = enthalpy of moist air at saturation at *thermodynamic wet-bulb temperature* t,* Btu per pound of dry air.
h_w = specific enthalpy of condensed water (liquid or solid) at standard pressure, Btu per pound water.
h_w^* = specific enthalpy of water as added at the *thermodynamic wet-bulb temperature* t,* Btu per pound of dry air.
h_{wl} = enthalpy of liquid water, Btu per pound.
h_{ws} = enthalpy of solid water, Btu per pound.
KE = kinetic energy, Btu per pound.
$\overline{KE}$ = average kinetic energy, Btu per pound.
L = flow rate of liquid water, pounds per hour.
m = weight of dry air crossing any duct section, pounds per minute.
n_a = mols dry air.
n_s = mols of water vapor at saturation.
n_w = mols of water vapor.
P = absolute pressure.
P_a = atmospheric pressure, inches Hg.
P_s = standard atmospheric pressure by definition 29.921 in. Hg.
P_s = saturation pressure of pure water at prevailing temperature.
p = total pressure of a mixture of air and water vapor, pounds per square inch or inches Hg.
p_a = partial pressure of dry air, pounds per square inch or inches Hg.
p_s = saturation pressure of pure water vapor, pounds per square inch or inches Hg.
p_w = partial pressure of water vapor in mixture of air and water vapor, pounds per square inch or inches Hg.
PE = potential energy, Btu per pound dry air.
$\overline{PE}$ = average potential energy, Btu per pound dry air.
Q = total heat added or subtracted, between sections, Btu per minute.
q = ratio of energy added (or removed) to water added (or removed), Btu per pound. Also called specific enthalpy of *water added*.
$_1q_2$ = energy added between points 1 and 2.
$_1q_2$ = heat added between sections 1 and 2, Btu per pound dry air.
R = universal gas constant, 1545 foot-pounds per (Fahrenheit degree) (mol).
R_a = gas constant for dry air.
R_w = gas constant for water vapor.
S = flow rate of solid water, pounds per hour.
s = entropy of moist air per pound of dry air, Btu per (pound) (Fahrenheit degree).