R_w = gas constant for water vapor = 1545.31 ÷ 18.016 = 85.774 (ft/F).

This expression is of the form of Equation 4.

According to Dalton's Rule the enthalpy of moist air is the sum of separate contributions from the dry air and the water vapor; thus,

$$h = h_a + \mu(W_s h_w) \tag{19}$$

where, to be consistent, the specific enthalpies h_a and h_w should be allowed to vary with temperature only, not with pressure or composition. This expression is of the form of Equation 5.

Within the accuracy of Dalton's Rule the following empirical equations give suitable values of h_a and h_w:

$$\begin{aligned} h_a &= 0.240t \\ h_w &= 0.444t + 1061 \end{aligned} \tag{20}$$

Equation 7 defining thermodynamic wet-bulb temperature may be written in the form,

$$h - h' + (W_s^* - W)h_w^* = h_s^* - h'$$

If the quantity h' that has been subtracted from both sides is understood to be the enthalpy at the thermodynamic wet-bulb temperature t^* but at the humidity ratio W, then within the accuracy of Dalton's Rule

$$\begin{aligned} h - h' &= (0.240 + 0.444W)(t - t^*) \\ h_s^* - h' &= (1061 + 0.444t^*)(W_s^* - W) \\ h_w^* &= t^* - 32 \end{aligned}$$

With these approximations Equation 7 becomes

$$W_s^* - W = \frac{0.240 + 0.444W}{1093 - 0.556t^*}(t - t^*) \tag{21}$$

Carrier[6] has modified Equation 21 by introducing further approximations as follows,

$$\begin{aligned} W_s^* &= 0.6220p_s^*/(p - p_s^*) \\ W &= 0.6220p_w/(p - p_s^*) \\ 0.444\,W &= 0 \end{aligned}$$

the first of which is part of Dalton's Rule. The result is

$$p_w = p_s^* - \frac{p - p_s^*}{2830 - 1.44t^*}(t - t^*) \tag{22}$$

except that the numerical values of the constants in the denominator of the rightmost term are somewhat different than Carrier's.

Equation 22 permits direct calculation of the partial pressure p_w from observed values of pressure p, temperature t, and wet-bulb temperature t^*, assuming that information is available regarding the saturation pressure p_s. The ratio p_w/p_s is the so-called relative humidity.

Example 18. Find the relative humidity of moist air at 90 F dry-bulb, and 63 F (thermodynamic wet-bulb).

Solution. At 63 F the value of the saturation pressure is 0.58002 in. Hg. Therefore, at atmospheric pressure (29.921 in. Hg),

$$p_w = 0.58002 - 29.341 \times 27/2739 = 0.2908 \text{ in. Hg}$$

The relative humidity is

$$\varphi = 0.2908/1.4219 = 0.2045$$

the denominator being the value of saturation pressure at 90 F.

From Equation 16 may be computed the corresponding degree of saturation, the result being

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

in remarkably close agreement with the answer to Example 2.

STEADY FLOW ENERGY EQUATION

In steady flow, the energy convected by the fluid at any section is the sum of (*a*) kinetic energy due to velocity; (*b*) gravitational energy due to elevation; (*c*) enthalpy due to the condition of pressure, temperature and composition of the fluid.

Kinetic Energy

There are reasons to believe that the so-called *velocity pressure* h_v read by a Pitot tube is simply the kinetic energy per unit volume of the fluid immediately upstream from the tube, as application of Bernoulli's Equation suggests. Thus

$$V = 1097.3\sqrt{\frac{h_v}{\rho}} \tag{23}$$

where

V = velocity, feet per minute.

h_v = velocity pressure, inches of water at 60 F.

ρ = density of fluid, pounds per cubic foot.

In the case of flow through a duct, the velocity pressure is found to vary considerably over the section and a traverse has to be made. The cross-sectional area of the duct is divided into a number of equal concentric areas, and measuring stations are located at centroidal points in each area along two perpendicular diameters. Usually the ultimate object is to determine an *average* velocity $\overline{V}$ from which the weight of fluid crossing the section per unit time can be obtained on multiplying by the cross-sectional area of the duct and by the density of the fluid. This is obtained by simply averaging the square roots of all measured velocity pressures as follows:

$$\overline{V} = \frac{1097.3}{\sqrt{\rho}}\left(h_v^{1/2}\right)_{av} \tag{24}$$

where

$\overline{V}$ = average velocity, feet per minute.

$(h_v^{1/2})_{av}$ = arithmetic average of the square roots of all measured velocity pressures, inches of water at 60 F.

But the item of present importance is the *average kinetic energy* convected with each pound of fluid. Consistently with the previous discussion, this can be shown to be

$$\overline{KE} = 0.006678\,v\,\frac{(h_v^{3/2})_{av}}{(h_v^{1/2})_{av}} \tag{25}$$