

mixing or separating air and water vapor at fixed constituent states, and neglecting the solubility of air in water and ice, the fluid enthalpy magnitude can be written as

$$Gh = G_a(h_a + Wh_a) + Lh_l + Sh_i \quad (5)$$

where

- h_a = enthalpy of dry air, Btu per pound.
- h_l = enthalpy of liquid water, Btu per pound.
- W = humidity ratio, pounds of water vapor per pound of dry air.
- h_i = enthalpy of ice, Btu per pound.
- L = flow rate of liquid water in the mixture, pounds per hour.
- S = flow rate of ice in the mixture, pounds per hour.

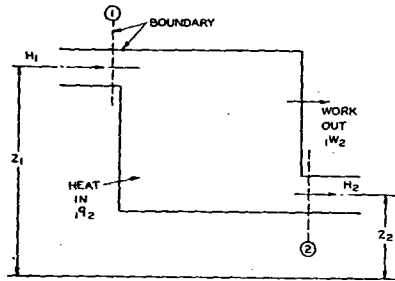


Fig. 1 . . . Energy Change between Two Sections of a Steady-Flow System

If there should be more than one inflow or outflow stream, Equations 3 or 4 are written as a summation over all streams involved.

The corresponding steady-flow equation for the conservation of mass is

$$G_a(1 + W_1) + L_1 + S_1 = G_a(1 + W_2) + L_2 + S_2 \quad (6)$$

As before, it is essential that mass conservation be summed over all entering and leaving streams.

The case of water being deposited or picked up at a constant rate within the external envelope of a system can be handled by adding such a mass-rate term to Equation 6. The corresponding change must be made in the mass rate factors of Equations 3, 4, and 5 for energy conservation; and further in this case any heat or work exchanges with the surroundings associated with such storage already are included in the broad definitions of Q_1 and W_1 .

There are two generally significant observations pertaining to the preceding formulations, namely:

1. Enthalpy is the only fluid property entering steady-flow or constant-pressure nonflow processes.
2. The composition of the fluid introduces the mixture ratios, W , L/G , and S/G .

The vapor-to-air mixture ratio W is called *humidity ratio* in air-conditioning problems.

A process of some air-conditioning importance involves

compression or expansion. In such a process *entropy* becomes a property of importance.

THERMODYNAMIC PROPERTIES OF MOIST AIR

Air and water are the working substances involved in the usual air-conditioning processes. The thermodynamic properties of liquid and solid water are well known, and hence will not be discussed in detail except to point out that the solubility of air in phases of liquid water and ice is small enough to be neglected for air-conditioning problems of the type considered in this chapter.

Dry Air has the following exact composition, adopted by the International Joint Committee on Psychrometric Data, and expressed in mol fractions: oxygen, 0.2095; nitrogen, 0.7809; argon, 0.0093; carbon dioxide, 0.0003. Traces of other rare gases are neglected. In all calculations to be discussed here, air is treated as a single gas having a molecular weight of 28.966.

The common designation *air* generally means *moist air*; however, in air conditioning the term *dry air* is also used to indicate the water-free constituents of air having any degree of moisture. Terms used to describe the condition of mixtures of air and water vapor are defined in the following paragraphs.

Saturation. Moist air is said to be saturated when its condition is such that it can coexist in neutral equilibrium with an associated condensed moisture phase presenting a flat surface to it.

The word *neutral* is necessary to avoid metastable states. A flat surface is necessary to avoid any influence of surface tension.

Humidity Ratio is the mass of water vapor per unit mass of dry air in a vapor-air mixture. The units are pounds of water vapor per pound of dry air. Humidity ratio has been called *specific humidity* and this term still is occasionally used.

Degree of Saturation μ is the ratio of the prevailing humidity ratio to the saturation humidity ratio at the same dry-bulb temperature and pressure.

Dew-Point Temperature is the saturation temperature corresponding to the existing humidity ratio and barometric pressure. (In practice, dew-point temperature is the temperature at which condensation will just begin when the moist air mixture under consideration is cooled at constant pressure.)

Mol. One mol of any substance is the number of pounds of that substance equal to its molecular weight. For example, the molecular weight of water is 18.016, and one mol of water is 18.016 pounds of water.

Mol Fraction of a substance in a given amount of a homogeneous-phase mixture is the ratio of the number of mols of the substance in the given amount of mixture to the total num-

Table 1 . . . Magnitudes of f_s for the Range 0 to 125 F (Standard Barometric Pressure, 29.921 in. Hg)

Temp. F	f_s	Temp. F	f_s
0	1.0048	70	1.0045
10	1.0046	80	1.0047
20	1.0046	90	1.0048
30	1.0045	100	1.0050
40	1.0044	110	1.0053
50	1.0044	120	1.0055
60	1.0044	125	1.0057

Note: The original source gives f_s to seven significant figures over the temperature range -200 F to $+200$ F and over the pressure range 20 to 25 in. Hg.

Thermodynamics

ber of mols of all substances present in the given amount of mixture. For example, if a particular amount of moist air contains n_a mols of air and n_w mols of water, the mol fraction of air in the mixture is $n_a / (n_a + n_w)$.

Partial Pressure of any substance in a given vapor-phase mixture is defined as the product of the mol fraction of that substance and the total pressure of the mixture.

Relative Humidity, ϕ , of any mixture of air and water vapor is the ratio of the mol fraction of water vapor in the mixture to the mol fraction of water vapor in saturated air at the same dry-bulb temperature and (barometric) pressure.

Relative humidity and degree of saturation are related as follows:

$$\phi = \frac{\mu}{1 - (1 - \mu)f_s \frac{P_a}{P_s}} \quad (7)$$

where

- ϕ = relative humidity, expressed as a decimal.
- μ = degree of saturation, expressed as a decimal.
- P_a = observed (or barometric) pressure of the moist air.
- P_s = saturation pressure of pure water at the prevailing temperature, inches of mercury.
- f_s = a dimensionless factor which may be regarded as accounting for influences arising when air and water are intermixed. Magnitudes of f_s have been reported by Goff and Gratch¹ and by Goff.² Table 1 gives values of f_s for a limited range of conditions.

Fig. 2 shows the relationship between ϕ and μ for the range of the ASHRAE PSYCHROMETRIC CHART.

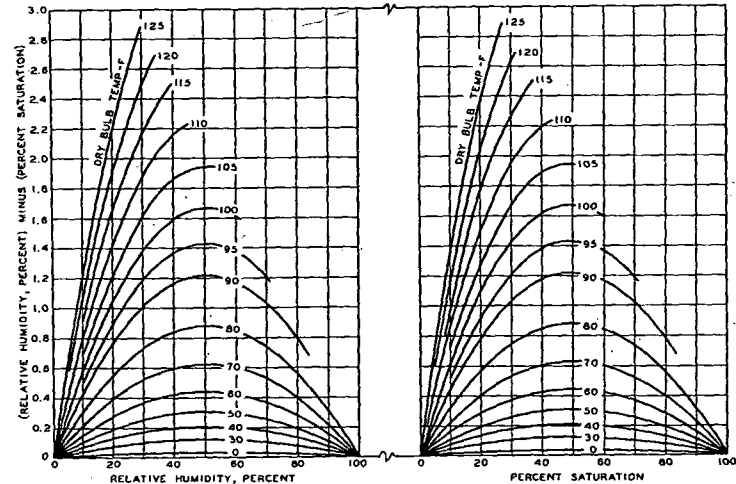


Fig. 2 . . . Comparison of Relative Humidity and Percent Saturation Within the Range of the ASHRAE PSYCHROMETRIC CHART.

Dry-Bulb Temperature is the temperature of the mixture of air and water vapor at rest; it is to be measured by an instrument whose reading is not affected by the humidity ratio or by thermal radiation.

Thermodynamic Wet-Bulb Temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

Consider an adiabatic system as shown in Fig. 3. Unsaturated air at the state h_1, W_1 , enters the system at Section 1, and saturated air at the state h^*, W^* , leaves the system at Section 2. Liquid water at the state h_w , corresponding to the temperature of the saturated air leaving the system is supplied. Then, since no work is done and the system is strictly adiabatic, the energy equation becomes

$$h_1 + (W^* - W_1)h_w = h^* \quad (8)$$

where

* indicates condition at thermodynamic wet-bulb temperature.

The temperature corresponding to h^* for given values of h_1 and W_1 is called the thermodynamic wet-bulb temperature, or the temperature of adiabatic saturation.

The temperature indicated by an ordinary wet-bulb thermometer is affected by nonthermodynamic factors not accounted for in Equation 8, and hence, may be quite different from the true temperature obtained from Equation 8. The measured wet-bulb temperature is influenced by (a) radiation from the surroundings to the wick; (b) conduction of heat along the stem of the thermometer; (c) impurities in the water or on the wick; and (d) impact of the air on the wick or bulb