vapor present. The probable reasons for this inaccuracy are due to the effect of:

1. Chemical solution of gas molecules in the water vapor.
2. The finite size of the molecules causing interference with the free passage of other molecules toward the boundaries of the system.
3. Intermolecular forces of attraction and repulsion.

Many attempts have been made to develop an equation of state which would predict the true states of real gases and vapors. The Van der Waal, Maxwell, and Beattie-Bridgman equations are probably the best known. Unfortunately, these expressions rapidly become much too complicated to be used in everyday calculations and, therefore, engineers find it more convenient to use tables of thermodynamic properties for specific working substances, as these can be prepared by physicists using the best laboratory equipment and all the refinements of mathematics.

Mechanical engineers have long been familiar with such tables for the properties of steam. Tables of the properties of moist air, as prepared by Goodenough and others, have been available for some time, but the latest and most precise of such tables are those which have resulted from a cooperative research agreement between the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the *Towne Scientific School* of the *University of Pennsylvania*. These properties are published herein as Table 2, and are taken from a research report by Goff and Gratch.[4] Table 2, which experimentally and mathematically takes into account deviations from perfect gas behavior, such as those listed above, makes the application of the Gibbs-Dalton Rule a less frequent necessity.

In Table 2 there are 15 columns of figures, each column being headed by a suitable symbol. In the following sub-paragraphs brief explanations are given of the data in Table 2 under the appropriate column headings.

t(F) = Fahrenheit temperature defined in terms of absolute temperature T by the relation,

$$T = t + 459.69 \tag{24}$$

Absolute zero of temperature may be defined as the receiver temperature which will enable a Carnot Cycle engine to transform into work all the energy it receives in the form of heat.

W_s = humidity ratio at *saturation*. Saturation is the condition at which the vapor phase (moist air) may exist in equilibrium with a condensed phase (liquid or solid) at the given temperature and pressure (standard atmospheric pressure in the case of Table 2). At given values of temperature and pressure, the humidity ratio W can have any value from zero to W_s.

v_a = specific volume of dry air, cubic feet per pound.

$v_{as} = v_s - v_a$, the difference between the volume of moist air *at saturation*, per pound of dry air, and the specific volume of the dry air itself, cubic feet per pound of dry air.

v_s = specific volume of moist air *at saturation* per pound of dry air, cubic feet per pound of dry air.

h_a = specific enthalpy of dry air, Btu per pound of dry air. The specific enthalpy of dry air has been assigned the value zero at 0 F, standard atmospheric pressure. The energy unit Btu is related to the foot-pound by definition, as follows: 1 Btu = 778.3 ft-lb.

$h_{as} = h_s - h_a$, 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_s = enthalpy of moist air *at saturation* per pound of dry air, Btu per pound of dry air.

s_a = specific entropy of dry air, Btu per (pound) (Fahrenheit degree). It will be noticed that the specific entropy of dry air has been assigned the value zero at 0 F and standard atmospheric pressure.

$s_{as} = s_s - s_a$, the difference between the entropy of moist air *at saturation*, per pound of dry air, and the specific entropy of the dry air itself, Btu per (pound of dry air) (Fahrenheit degree).

s_s = entropy of moist air *at saturation* per pound of dry air, Btu per (pound of dry air) (Fahrenheit degree).

h_w = specific enthalpy of condensed water (liquid or solid) at standard atmospheric pressure, Btu per pound of water. The specific enthalpy of liquid water has been assigned the value zero at 32 F, saturation pressure (0.088586 psia).

s_w = specific entropy of condensed water (liquid or solid) at standard atmospheric pressure, Btu per (pound of water) (Fahrenheit degree). The specific entropy of liquid water has been assigned the value zero at 32 F, saturation pressure (0.088586 psia).

p_s = saturation pressure of pure water vapor, pounds per square inch or inches of Hg (absolute pressure). At a given pressure, moist air can be saturated at any temperature, though this requires that it have a definite humidity ratio W_s and that the coexisting condensed phase contain a *definite*, but very small, quantity of dissolved air. On the other hand, pure water vapor (steam) below the critical temperature, can be saturated at only one temperature for a given pressure. The values of saturation pressure listed in Table 2 have been computed from the formulas of Goff and Gratch.

THERMODYNAMIC PROPERTIES OF WATER AT SATURATION

Since water vapor at low pressures acts almost as a perfect gas, the enthalpy of water vapor should also be a function only of the temperature within these limits. Therefore, the enthalpy of the water vapor may be expressed as being approximately equal to the enthalpy of saturated vapor at the dry-bulb temperature of the mixture. Substituting these values in Equation 22, the enthalpy of the mixture becomes

$$h = 0.24\,t + Wh_g \tag{25}$$

where h_g is the value of the enthalpy of saturated vapor at the temperature t, and is obtained from Table 3.

Table 3 offers revisions to existing steam table data with extensions downward to −160 F. These revisions and extensions were a necessary preliminary to the construction of Table 2. A detailed explanation of the methods employed in the construction of Table 3 is given in a paper by John A. Goff and S. Gratch.[5]

As in Table 2, the temperature scale used as argument in Table 3 is the Fahrenheit scale defined in terms of absolute temperature T by Equation 24. The symbols used as column headings in Table 3 are the same as those used in steam tables, and have the same meanings.

Properties of water above 212 F from Keenan and Keyes[6] are given in Table 4.

DEGREE OF SATURATION

Degree of saturation has previously been defined as the ratio of the actual humidity ratio to the humidity ratio of saturated air at the same dry-bulb temperature and barometric pressure. This may be stated mathematically as

$$\mu = \frac{W}{W_s} \tag{26}$$

Obviously the degree of saturation μ can have any value from zero (dry air) to unity (moist air at saturation). The degree of saturation is con-