Steady-flow Energy Equation

A complete energy accounting takes the form of Equation 28 which is usually referred to as the steady-flow energy equation.

$$ {}_1q_2 = (h_2 + \overline{KE}_2 + \overline{PE}_2) - (h_1 + \overline{KE}_1 + \overline{PE}_1) + {}_1l_2 \qquad (28) $$

where

${}_1q_2$ = heat *added* from outside *between* sections 1 and 2, Btu per pound dry air.
h_2 = enthalpy of the mixture *at* section 2, Btu per pound dry air.
$\overline{KE}_2$ = average kinetic energy *at* section 2, Btu per pound dry air.
$\overline{PE}_2$ = average potential energy *at* section 2, Btu per pound dry air.
h_1 = enthalpy *at* section 1, Btu per pound dry air.
$\overline{KE}_1$ = average kinetic energy *at* section 1, Btu per pound dry air.
$\overline{PE}_1$ = average potential energy *at* section 1, Btu per pound dry air.
${}_1l_2$ = shaft work withdrawn *between* sections 1 and 2, Btu per pound dry air.

In Equation 28 all quantities are *per pound of dry air*. If Equation 25 is used in computing average kinetic energy, the result will be in Btu per pound of dry air if v is taken as volume per pound of dry air. If Equation 26 is used, multiplication by $(1 + W)$ as in Equation 27 is required though this is a refinement seldom justified.

Thermodynamic properties of water at saturation are given in Table 2 for the range −160 to +212 F.

U. S. STANDARD ATMOSPHERE

The so-called U. S. Standard Atmosphere is an essential standard of reference in aeronautics and as such has become important to the air conditioning engineer who frequently has to simulate atmospheric conditions at high altitudes in connection with aeronautical research. In defining this standard it is first assumed that temperature T varies linearly with altitude Z above sea level, at any rate up to the lower limit of the isothermal layer at 35,332 ft. Thus,

$$ T = T_o - 0.0019812\,Z \qquad (29) $$

or

$$ \frac{dT}{dZ} = -0.0019812 \text{ (degree Centigrade per foot)} \qquad (30) $$

The second assumption is the validity of the perfect gas laws, namely,

$$ Pv = RT \qquad (31) $$

A horizontal disc of air having unit cross-sectional area (1 sq ft) and vertical thickness dZ (ft) weights dZ/v (lb). This accounts for the difference of pressure dP (lb per sq ft) between the upper and lower faces of the disc; hence, using Equation 31

$$ dZ = \frac{RT\,dP}{P} \qquad (32) $$

Equations 30 and 32 can be combined to eliminate Z and then integrated to obtain the relation between pressure and temperature, namely,

$$ \frac{T}{T_o} = \left(\frac{P}{P_o}\right)^{0.1233} \qquad (33) $$

TABLE 5. 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

The values $T_o = 288\ K$ and $P_o = 29.921$ in. Hg are parts of the definition of the standard atmosphere.

Values of pressure and temperature are listed in Table 5 for altitudes in the standard atmosphere from −1,000 to 50,000 ft above sea level. Values for altitudes below the lower limit of the isothermal layer conform to Equations 29 and 33. For further explanation, reference (7) should be consulted.

LETTER SYMBOLS USED IN CHAPTER 3

μ = degree of saturation or per cent saturation.

ρ = density of fluid, pounds per cubic foot.

φ = relative humidity (decimal).

a = ratio of apparent molecular weight of dry air (28.966) to the molecular weight of water (18.016) = 1.6078.

A = coefficient from Table 4 for use in Equation 4a (obtained from Table 4).

B = coefficient to be used in Equation 5a (obtained from Table 4).

C = coefficient for use in Equation 6a (obtained from Table 4).

h = enthalpy of moist air, Btu per pound of dry air.

$\overline{h}$ = 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_s^* = enthalpy of moist air at saturation at *thermodynamic wet-bulb temperature*, Btu per pound of dry air.