Steady-flow Energy Equation

A complete energy accounting takes the form of Equation 31 which is usually referred to as the steady-flow energy equation.

$$_1q_2 = (h_2 + \overline{KE}_2 + \overline{PE}_2) - (h_1 + \overline{KE}_1 + \overline{PE}_1) + {}_1l_2 \quad (31)$$

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$_1l_2$ = shaft work withdrawn *between* sections 1 and 2, Btu per pound dry air.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 31 all quantities are *per pound of dry air*. If Equation 28 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 29 is used, multiplication by $(1 + W)$ as in Equation 30 is required though this is a refinement seldom justified.

Properties of saturated steam are given in Table 8 and for additional definitions refer to Chapter 47.

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,

$$T = T_o - 0.0019812\, Z \quad (32)$$

or

$$\frac{dT}{dZ} = -0.0019812 \text{ (degree Centigrade per foot)} \quad (33)$$

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

$$Pv = BT \quad (34)$$

An horizontal disc of air having unit cross-sectional area (1 sq ft) and vertical thickness dZ (ft) weighs 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 34

$$dZ = \frac{BT\, dP}{P} \quad (35)$$

Equations 33 and 35 can be combined to eliminate Z and then integrated to obtain the relation between pressure and temperature, namely,

$$\frac{T}{T_o} = \left(\frac{P}{P_o}\right)^{0.1903} \quad (36)$$

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

Table 10. 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

Values of pressure and temperature are listed in Table 10 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 32 and 36. For further explanation, reference (11) should be consulted.

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