Thermodynamic Variables

We begin this brief but necessary review of thermodynamics with a listing of thermodynamic variables and their definitions. Other than the pressure and density defined in sections (Aba) and (Abb), the following definitions will be needed:

Temperature

The temperature of a substance is a measure of the kinetic energy associated with the translational random motions of the particles that make up that substance. The molecules, atoms and other particles that make up the substance may exhibit random motions other than the random translational motions but these other random motions are not included in the evaluation of the temperature. For example the relative vibrational motions of two (or more) atoms in a molecule are not included. As we shall describe in a later section, the quantity known as the internal energy is similar in basic concept to the temperature except that it also includes the energy of the vibrational motions. Moreover the energy associated with the global or common translation motion is not included in either the temperature or the internal energy but is included in the energy evaluation of the substance as a separate item, the kinetic energy of the object or fluid element that contains the molecules or atoms.

There are three other practical differences between the energy measures we call temperature and internal energy. The first is that the scales and units used to express those quantities are different. The various measures of temperature use rather arbitrary scales and units based on the freezing and boiling temperatures of water at normal pressures. The Celsius or centigrade temperature chooses the freezing temperature as its origin and denotes that by 0^oC; it also labels the boiling temperature as 100^oC, thus defining one unit as the one-hundredth of the difference. The Fahrenheit unit defines freezing as 32^oF and boiling as 212^oF. Later when it became apparent that the random translational kinetic energy became zero at -273.15^oC, the Kelvin or absolute scale of temperature was proposed for which a degree Kelvin was the same as a degree Celsius and a temperature T^oK became equal to $(T + 273.15)^oC$.

The second practical difference between the temperature and the internal energy is, as stated earlier, that the evaluation of the latter includes the kinetic energies associated with the relative vibrational motions between the atoms that make up the molecules of the substance.

The third practical difference derives from the fact that these kinetic energies must be evaluated for a particular mass or a particular number of particles, atoms or molecules. Thus the temperature is essentially a measure per unit molecule whereas the internal energy is per unit mass.

Internal Energy

The thermodynamic quantity that we call the *internal energy* of a substance is a measure of the total random kinetic energy associated with the disordered motions of the atoms and molecules that make up that substance (we exclude the kinetic energy associated with the common global translation or rotational motion of the substance). The units of kinetic energy are those of mass times velocity squared. However in fluid mechanics we will be primarily be concerned with the internal energy per unit mass or *specific internal energy*, a quantity we will denote by e, and the units of e will be quoted in $Joules/kg$ or m^2/s^2 ($1 Joule/kg = 1 m^2/s^2$), the latter being a little more convenient in fluid mechanics.

Enthalpy

The enthalpy is another measure of the energy contained in a substance. The enthalpy per unit mass or *specific enthalpy* is denoted by h and is related to the specific internal energy, e, the pressure, p, and the density, ρ by

$$h = e + \frac{p}{\rho} \tag{Aca1}$$

As will be demonstrated in a later section the specific enthalpy h is particularly useful in flowing systems in which the pressure and/or density change as the substance flows.

We note that, in addition to the specific internal energy, e, a assay of the energy in a flowing fluid would also include the gravitational energy per unit mass, gz (where z is the vertically upward elevation or coordinate), and the translational kinetic energy per unit mass, $|u|^2/2$ (where $|u|$ is the magnitude of the translational velocity). Consequently it is convenient to define a quantity called the *total enthalpy* where the total enthalpy per unit mass or *specific total enthalpy* is denoted by h^* and defined as

$$h^* = e + \frac{p}{\rho} + gz + \frac{|u|^2}{2} \tag{Aca2}$$

Entropy

Entropy is a thermodynamic variable representing the unavailability of a system's thermal energy for conversion to mechanical work. It is often interpreted as the degree of disorder or randomness of a thermodynamic system. It is best understood in the framework of the laws of thermodynamics that are stated in the sections that follow. In these sections the entropy per unit mass or *specific entropy* is denoted by s. In any reversible process, entropy can be defined as

$$dq = Tds \tag{Aca3}$$

though according to the second law of thermodynamics, in an irreversible process

$$Tds > dq \tag{Aca4}$$

Other Thermodynamic Variables

Only two thermodynamic variables are needed to fully define the state of a substance. Often the choice is the pressure and temperature but other choices may be more convenient in other contexts. There are many other thermodynamic variables such as the chemical potential or Gibbs free energy that are not needed in this presentation.