3.9 Energy Balances and Irreversible Processes

As a statement of energy conservation, the first law is applicable to any process, whether it is reversible or not. The change of internal energy, ΔU, between the initial and final state is fixed by the initial and final state and independent of the path used to connect them. This difference gives the *net* amount of energy that the system must exchange with its surroundings in order for this change to take place. The exchange is generally a combination of heat and work, but the individual amounts of heat and work depend on the specific path. For mechanically reversible paths, the work is calculated by eq. (3.3). If the process is irreversible and involves work, one must be careful because eq. (3.3) is not applicable. If the process does not involve work, the calculation is done in the usual way. Implicit in all of these calculations is the assumption that the system is internally uniform so that its state can be described by a uniform pressure and temperature.

Example 3.18: Heat Transfer

A 10 kg piece of hot copper at 450 °C is quenched in an open tub that contains 10 kg of water at 20 °C. Calculate the final temperature assuming no heat losses to the environment. The heat capacities of copper and water are $C_{P\mathrm{c}} = 0.38$ kJ/kg K, $C_{P\mathrm{w}} = 4.184$ kJ/kg K, and may be assumed independent of temperature.

Solution This is a constant-pressure process; therefore, the amount of heat is equal to the change in enthalpy. If we take the system to be copper and water together, no heat is exchanged with the surroundings:

$$Q = 0 = \Delta H^{\mathrm{tot}} \quad \Rightarrow \quad \Delta H_{\mathrm{w}}^{\mathrm{tot}} + \Delta H_{\mathrm{c}}^{\mathrm{tot}} = 0.$$

For the enthalpy change of water and copper we use eq. (3.19), and with constant heat capacity, the result is:

$$\Delta H_{\mathrm{w}}^{\mathrm{tot}} = m_{\mathrm{w}} C_{P\mathrm{w}} (T_f - T_{\mathrm{w}})$$

$$\Delta H_{\mathrm{c}}^{\mathrm{tot}} = m_{\mathrm{c}} C_{P\mathrm{c}} (T_f - T_{\mathrm{c}}).$$

where m_{c}, m_{w}, are the mass of copper and water, respectively, T_{c}, and T_{w} are the initial temperatures, and T_f is the common final temperature. Substituting these expression into the energy balance we obtain an equation in which the only unknown is T_f. Solving for the final temperature we obtain

expressions

$$T_f = \frac{m_{\mathrm{c}} C_{P\mathrm{c}} T_{\mathrm{c}} + m_{\mathrm{w}} C_{P\mathrm{w}} T_{\mathrm{w}}}{m_{\mathrm{c}} C_{P\mathrm{c}} + m_{\mathrm{w}} C_{P\mathrm{w}}}.$$

By numerical substitution,

$$T_f = 74.8 \text{ °C}.$$

Comments This process is irreversible because heat is exchanged between systems at different temperatures.