Chapter 4 SUMMARY

- The first law of thermodynamics is essentially an expression of the conservation of energy principle, also called the energy balance. The energy balance for *any system* undergoing *any process* can be expressed as

$$m_{in} - m_{out} = \Delta m_{system} \qquad \text{(kg)}$$

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}} \qquad \text{(kJ)}$$

- The energy balances for *any system* undergoing *any process* can be expressed in the *rate form* as

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta \dot{m}_{\text{system}} \qquad \text{(kg/s)}$$

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} \qquad \text{(kW)}$$

- Taking heat transfer *to* the system and work done *by* the system to be positive quantities, the energy balance for a closed system can also be expressed as

$$Q - W = \Delta U + \Delta KE + \Delta PE \qquad (kJ)$$

where

$$W = W_{other} + W_b$$

$$\Delta U = m(u_2 - u_1)$$

$$\Delta KE = \frac{1}{2} m(\vec{V}_2^{\,2} - \vec{V}_1^{\,2})$$

$$\Delta PE = mg(z_2 - z_1)$$

- For a *constant-pressure* process, $W_b + \Delta U = \Delta H$. Thus

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE \qquad (kJ)$$

- Thermodynamic processes involving control volumes can be considered in two groups: steady-flow processes and unsteady-flow processes. During a *steady-flow process,* the fluid flows through the control volume steadily, experiencing no change with time at a fixed position. The mass and energy content of the control volume remain constant during a steady-flow process.

- Taking heat transfer *to* the system and work done *by* the system to be positive quantities, the conservation of mass and energy equations for steady-flow processes are expressed as

$$\sum \dot{m}_i = \sum \dot{m}_e \qquad (kg/s)$$

$$\dot{Q} - \dot{W} = \underbrace{\sum \dot{m}_e \left(h_e + \frac{\vec{V}_e^2}{2} + g z_e \right)}_{\text{for each exit}} - \underbrace{\sum \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + g z_i \right)}_{\text{for each inlet}} \qquad \text{(kW)}$$

where the subscript *i* stands for inlet and *e* for exit. These are the most general forms of the equations for steady-flow processes.

- For single-stream (one-inlet--one-exit) systems such as nozzles, diffusers, turbines, compressors, and pumps, the steady flow equations simplify to

$$\dot{m}_1 = \dot{m}_2 \qquad (kg/s)$$

$$\frac{1}{v_1}\vec{V}_1 A_1 = \frac{1}{v_2}\vec{V}_2 A_2$$

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1 + \frac{\vec{V}_2^2 - \vec{V}_1^2}{2} + g(z_2 - z_1) \qquad (kW)$$

In the above relations, subscripts 1 and 2 denote the inlet and exit states, respectively.

- During a uniform-flow process, the state of the control volume may change with time, but it may do so uniformly. Also, the fluid properties at the inlets and the exits are assumed to remain constant during the entire process. If the properties are not constant, they are averaged and treated as constants for the entire process. The conservation of energy equation for a uniform-flow process is expressed as

$$(Q_{\text{in}} + W_{\text{in}} + \sum m_i \theta_i) - (Q_{\text{out}} + W_{\text{out}} + \sum m_e \theta_e) = (m_2 e_2 - m_1 e_1)_{\text{system}}$$

- When the kinetic and potential energy changes associated with the control volume and the fluid streams are negligible, the conservation of energy equation for a uniform-flow process simplifies to

$$(Q_{\text{in}} + W_{\text{in}} + \sum m_i h_i) - (Q_{\text{out}} + W_{\text{out}} + \sum m_e h_e) = (m_2 u_2 - m_1 u_1)_{\text{system}}$$

- When solving thermodynamic problems, it is recommended that the general form of the energy balance $E_{\text{in}} - E_{\text{out}} = E_{\text{system}}$ be used for all problems, and simplify it for the particular problem instead of using the specific relation given above for different processes.