Chapter 3 SUMMARY

- Energy can cross the boundaries of a closed system in the form of heat or work. For control volumes, energy can also be transported by mass.

- If the energy transfer across the boundaries of a closed system is due to a temperature difference, it is *heat*; otherwise, it is *work*.

- Various forms of work are expressed as follows:

Electrical work: $W_e = VI\Delta t$

Boundary work:

(1) General $W_b = \int_1^2 P dV$

(2) Isobaric process $W_b = P_0\left(V_2 - V_1\right)$

($P_1 = P_2 = P_0$)

(3) Polytropic process $W_b = \dfrac{P_2V_2 - P_1V_1}{1-n}$ $(n \neq 1)$

(Pv^n = constant)

(4) Isothermal process $W_b = P_1V_1 \ln\dfrac{V_2}{V_1} = mRT_0 \ln\dfrac{V_2}{V_1}$

($PV = mRT_0$ = constant)

Gravitational work (=ΔPE): $W_g = mg(z_2 - z_1)$

Acceleration work (=ΔKE): $W_a = \dfrac{1}{2}m(\vec{V}_2^{\,2} - \vec{V}_1^{\,2})$

Shaft work: $W_{sh} = 2\pi\, n\, \mathbf{T}$

Spring work: $W_{spring} = \dfrac{1}{2}k_s(x_2^2 - x_1^2)$

- The *conservation of mass* principle states that the net mass transfer to or from a system during a process is equal to the net change (increase or decrease) in the total mass of the system during that process, and is expressed as

$$m_{in} - m_{out} = \Delta m_{system} \quad \text{and} \quad \dot{m}_{in} - \dot{m}_{out} = dm_{system}/dt$$

where $\Delta m_{\text{system}} = m_{\text{final}} - m_{\text{initial}}$ is the change in the mass of the system during the process, $\dot{m}_{\text{in}}$ and $\dot{m}_{\text{out}}$ are the total rates of mass flow into and out of the system, and dm_{system} / dt is the rate of change of mass within the system boundaries. The relations above are also referred to as the *mass balance* or *continuity equation*, and are applicable to any kind of system undergoing any kind of process.

- Mass flow through a cross section per unit time is called the *mass flow rate* and is denoted $\dot{m}$. It is expressed as

$$\dot{m} = \rho \vec{V} A$$

where	ρ	= density (= *1/v*)
	$\vec{V}$	= average fluid velocity normal to *A*
	A	= cross-sectional area

- The fluid volume flowing through a cross section per unit time is called the *volume flow rate* $\dot{V}$. It is given by

$$\dot{V} = \vec{V}A = \dot{m} / \rho$$

- The mass and volume flow rates are related by

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{v}$$

- For steady flow systems, the conservation of mass principle is expressed as

Steady Flow: $$\sum \dot{m}_{\text{i}} = \sum \dot{m}_{\text{e}}$$

Steady Flow (single stream): $$\dot{m}_1 = \dot{m}_2 \quad \to \quad \rho_1 \vec{V}_1 A_1 = \rho_2 \vec{V}_2 A_2$$

For incompressible fluids, they simplify to

Steady Incompressible Flow: $$\sum \dot{V}_{\text{i}} = \sum \dot{V}_{\text{e}}$$

Steady Incompressible Flow (single stream): $$\dot{V}_1 = \dot{V}_2 \quad \to \quad \vec{V}_1 A_1 = \vec{V}_2 A_2$$

- The work required to push a unit of mass of fluid into or out of a control volume is called *flow work* or *flow energy*, and is expressed as $w_{\text{flow}} = Pv$. In the analysis of control volumes, it is convenient to combine the flow energy and internal energy in *enthalpy*. Then the total energy of a flowing fluid is expressed as

$$\theta = h + ke + pe = h + \frac{\vec{V}^2}{2} + gz$$

- The total energy transported by a flowing fluid of mass *m* with uniform properties is $m\theta$. The rate of energy transport by a fluid with a mass flow rate of $\dot{m}$ is $\dot{m}\theta$.

- When the kinetic and potential energies of a fluid stream are negligible, the amount and rate of energy transport become $E_{\text{mass}} = mh$ and $\dot{E}_{\text{mass}} = \dot{m}h$, respectively.

- Heat is transferred in three ways: conduction, convection, and radiation. *Conduction* is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. *Convection* is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. *Radiation* is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

- The three modes of heat transfer are expressed as

$$\dot{Q}_{cond} = -k_t A \frac{dT}{dt}$$

$$\dot{Q}_{conv} = hA(T_s - T_f)$$

$$\dot{Q}_{rad} = \varepsilon\alpha A(T_s^4 - T_{surr}^4)$$