Module

4

Lecture

1

Asansol Engineering College
Department of Mechanical Engineering

Thermodynamics

First Law for Flow Processes

Dr. Ramesh P Sah
Department of Mechanical Engineering

Contents:

- First Law for Flow Processes - Derivation of general energy equation for a control volume;
- Steady state steady flow processes
- Examples of steady flow devices;
- Unsteady processes;
- Examples of steady and unsteady I law applications for system and control volume.

Objectives:

The objective of this chapter is to:

- Develop the conservation of mass principle
- Apply the conservation of mass principle to various systems including steady and unsteady flow control volumes
- Apply the first law of thermodynamics as the statement of the energy conservation principle to control volumes
- Solve energy balance problems for steady flow devices like nozzles, compressors, turbines, and heat exchangers
- Apply energy balance to general unsteady flow processes

Outcomes:

After completing this chapter, the students will be able to

- Apply the conservation of mass principle to various systems including steady and unsteady flow control volumes
- Apply the energy balance to systems that involve steady flow processes.
- Analyze common steady flow devices like nozzles, compressors, turbines, throttling devices, and heat exchangers
- Apply energy balance to general unsteady flow processes such as charging and discharging of vessels

Mechanisms of Energy Transfer E_{in} and E_{out}

- Energy can be transferred to or from a system in three forms: *heat, work,* and *mass flow*.
- Energy interactions are recognized at the system boundary as they cross it, and they represent the energy gained or lost by a system during a process.
- The only two forms of energy interactions associated with a fixed mass or closed system are *heat transfer* and *work*.

1. Heat Transfer (Q):

- Heat transfer to a system (*heat gain*) increases the energy of the molecules and thus the internal energy of the system, and
- Heat transfer from a system (*heat loss*) decreases it since the energy transferred out as heat comes from the energy of the molecules of the system.

2. Work (W):

- An energy interaction that is not caused by a temperature difference between a system and its surroundings is *work*.

- A rising piston, a rotating shaft, and an electrical wire crossing the system boundaries are all associated with work interactions.
- Work transfer to a system (i.e., work done on a system) increases the energy of the system, and work transfer from a system (i.e., work done by the system) decreases it since the energy transferred out as work comes from the energy contained in the system.
- Car engines and hydraulic, steam, or gas turbines produce work while compressors, pumps, and mixers consume work.

3. Mass Flow (*m*):

- Mass flow in and out of the system serves as an additional mechanism of energy transfer.
- When mass enters a system, the energy of the system increases because mass carries energy with it (in fact, mass is energy).
- Likewise, when some mass leaves the system, the energy contained within the system decreases because the leaving mass takes out some energy with it. For example, when some hot water is taken out of a water heater and is replaced by the same amount of cold water, the energy content of the hot water tank (the control volume) decreases as a result of this mass interaction.

Noting that energy can be transferred in the forms of heat, work, and mass, and that the net transfer of a quantity is equal to the difference between the amounts transferred in and out, the energy balance can be written as

$$\boxed{E_{in} - E_{out} = \Delta E}$$

$$\boxed{\begin{aligned}&(Q_{in} + W_{in} + E_{mass,in}) - (Q_{out} + W_{out} + E_{mass,out})\\ &= E_2 - E_1\end{aligned}}$$

$$\boxed{\begin{aligned}&(\dot{Q}_{in} + \dot{W}_{in} + \dot{E}_{mass,in}) -\\ &(\dot{Q}_{out} + \dot{W}_{out} + \dot{E}_{mass,out}) = \dot{E}_2 - \dot{E}_1\end{aligned}}$$

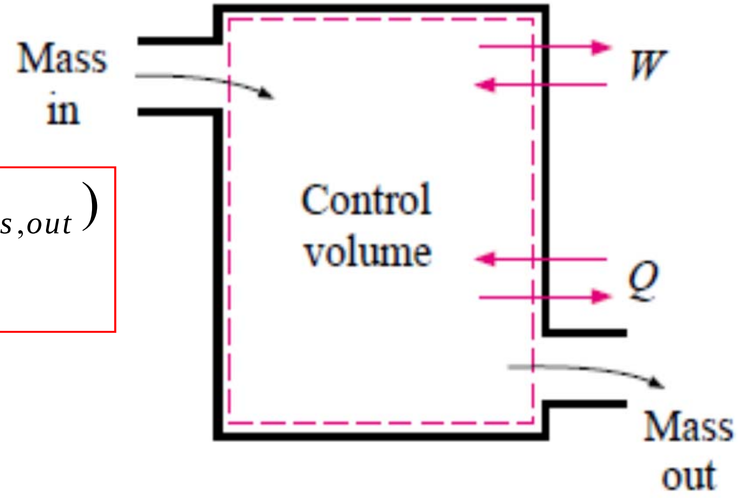

Fig. 4.1: The energy content of a control volume can be changed by mass flow as well as heat and work interactions.

$$\boxed{(\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz)) - (\dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}(h + \frac{v^2}{2} + gz)) = \dot{E}_2 - \dot{E}_1}$$

$$\boxed{(\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz)) - (\dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out}(h + \frac{v^2}{2} + gz)) = \frac{dE}{dt}}$$

$$\boxed{(\dot{Q}_{in} - \dot{Q}_{out}) - (\dot{W}_{out} - \dot{W}_{in}) + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz) - \sum \dot{m}_{out}(h + \frac{v^2}{2} + gz) = \frac{dE}{dt}}$$

$$\boxed{\dot{Q}_{net} - \dot{W}_{net} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz) - \sum \dot{m}_{out}(h + \frac{v^2}{2} + gz) = \frac{dE}{dt}}$$

$$\boxed{\dot{Q} - \dot{W} + \sum \dot{m}_{in}(h + \frac{v^2}{2} + gz) - \sum \dot{m}_{out}(h + \frac{v^2}{2} + gz) = \frac{dE}{dt}}$$

$$\boxed{\dot{Q} - \dot{W} + \dot{m}_{in}(h + \frac{v^2}{2} + gz) - \dot{m}_{out}(h + \frac{v^2}{2} + gz) = \frac{dE}{dt}}$$

$$\boxed{\dot{q} - \dot{w} + (h + \frac{v^2}{2} + gz)_1 - (h + \frac{v^2}{2} + gz)_2 = \frac{dE}{dt}}$$

Energy balance for any system undergoing any kind of process can be expressed as

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

or, in the **rate form,** as

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

For constant rates, the total quantities during a time interval Δt are related to the quantities per unit time as

$$Q = \dot{Q}\,\Delta t, \qquad W = \dot{W}\,\Delta t, \qquad \text{and} \qquad \Delta E = \Delta\dot{E}\,\Delta t$$

The energy balance can be expressed on a per unit mass basis as

$$e_{in} - e_{out} = \Delta\, e_{system}$$

Energy balance can also be expressed in the differential form as

$$\delta E_{in} - \delta E_{out} = dE_{system}$$

or, $$\delta e_{in} - \delta e_{out} = de_{system}$$

ENERGY BALANCE FOR CLOSED SYSTEMS

The energy balance relation in that case for a closed system becomes

$$Q_{\text{net, in}} - W_{\text{net, out}} = \Delta E_{\text{system}} \quad \text{or} \quad Q - W = \Delta E$$

where $Q = Q_{net,in} = Q_{in} - Q_{out}$ is the *net heat input* and $W = W_{net,out} = W_{out} - W_{in}$ is the *net work output.*

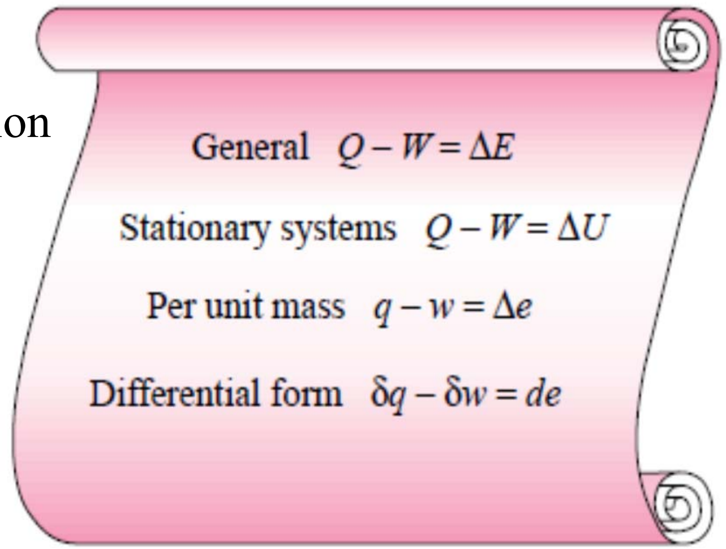

Fig. 4.2: Various forms of the first-law relation for closed systems

References:

1. Sonntag, R. E, Borgnakke, C. and Van Wylen, G. J., 2003, 6th Edition, *Fundamentals of Thermodynamics*, John Wiley and Sons.

1. Jones, J. B. and Duggan, R. E., 1996, *Engineering Thermodynamics*, Prentice-Hall of India

3. Moran, M. J. and Shapiro, H. N., 1999, *Fundamentals of Engineering Thermodynamics*, John Wiley and Sons.

4. Nag, P.K, 1995, *Engineering Thermodynamics*, Tata McGraw-Hill Publishing Co. Ltd.

5. Y. A. Çengel and M. A. Boles, Thermodynamics: *An Engineering Approach*, McGraw-Hill

Thank You