Module

4

Lecture

5

Asansol Engineering College

Department of Mechanical Engineering

Thermodynamics

Transient Processes

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Topics of present discussion

- **Transient Processes**
- **Solved Example on Transient Processes**

UNSTEADY-FLOW (TRANSIENT) PROCESSES

- During a steady-flow process, no changes occur within the control volume with time
- Many processes of interest, however, involve *changes* within the control volume with time. Such processes are called *unsteady-flow, or transient-flow, processes.*
- When an unsteady-flow process is analyzed, it is important to keep track of the mass and energy contents of the control volume as well as the energy interactions across the boundary.

- Some familiar *unsteady-flow* processes are

  - the charging of rigid vessels from supply lines (Fig. 4.15),
  - discharging a fluid from a pressurized vessel,
  - driving a gas turbine with pressurized air stored in a large container,
  - inflating tires or balloons, and
  - cooking with an ordinary pressure cooker.

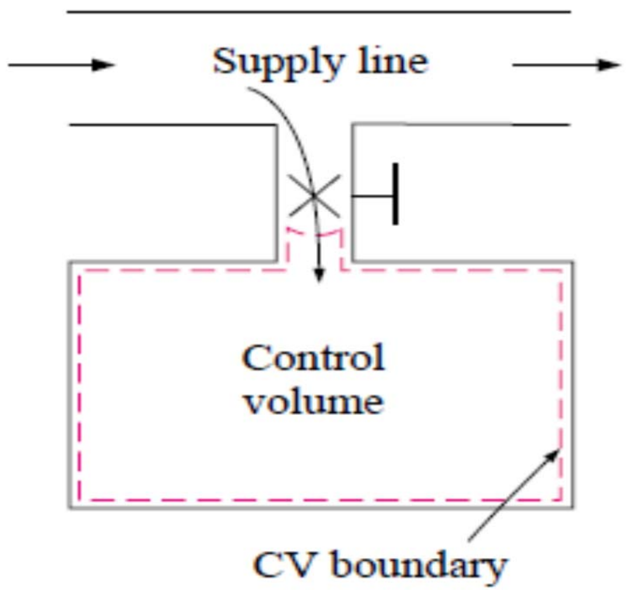

Fig. 4.15: Charging of a rigid tank from a supply line is an unsteady flow process since it involves changes within the control volume.

- Unlike steady-flow processes, unsteady-flow processes start and end over some finite time period instead of continuing indefinitely.

- We deal with changes that occur over some time interval Δt instead of with the rate of changes (changes per unit time)

- Steady- flow systems is that steady-flow systems are fixed in space, size, and shape, but unsteady-flow systems are not fixed in space, size, and shape as shown in Fig. 4.16.

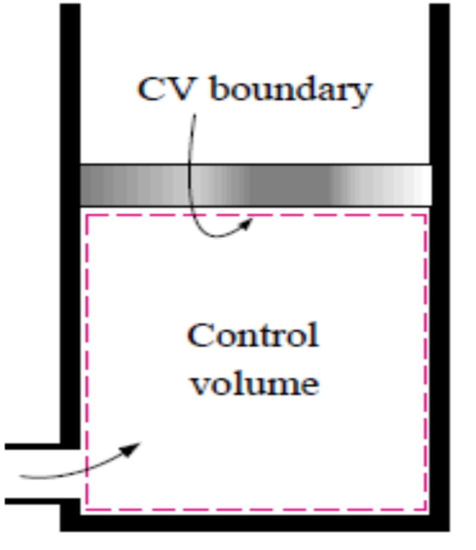

Fig. 4.16: The shape and size of a control volume may change during an unsteady-flow process.

- They are usually stationary; that is, they are fixed in space, but they may involve moving boundaries and thus boundary work.

Mass Balance

- Unlike the case of steady-flow processes, the amount of mass within the control volume *does* change with time during an unsteady-flow process.
- The magnitude of change depends on the amounts of mass that enter and leave the control volume during the process.
- The mass balance for a system undergoing any process can be expressed as

Mass balance: $$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}}$$

Where $\Delta\, m_{system} = m_{final} - m_{initial}$ is the change in the mass of the system during the process.

The mass balance for a control volume can also be expressed more explicitly as

$$\sum m_i - \sum m_e = (m_2 - m_1)_{\text{system}}$$

where i = inlet, e = exit, 1= initial state, and 2 = final state of the control volume; and the summation signs are used to emphasize that all the inlets and exits are to be considered.

- Often one or more terms in the equation above are zero.

- For example, $m_i = 0$ if no mass enters the control volume during the process, $m_e = 0$ if no mass leaves the control volume during the process, and $m_1 = 0$ if the control volume is initially evacuated.

Energy Balance

- The energy content of a control volume changes with time during an unsteady-flow process.

- The magnitude of change depends on the amount of energy transfer across the system boundaries as heat and work as well as on the amount of energy transported into and out of the control volume by mass during the process.

- Note that unlike the steady-flow systems, the state of an unsteady-flow system may change with time, and that the state of the mass leaving the control volume at any instant is the same as the state of the mass in the control volume at that instant.

- The initial and final properties of the control volume can be determined from the knowledge of the initial and final states, which are completely specified by two independent intensive properties for simple compressible systems.

Then the energy balance for a uniform-flow system can be expressed explicitly as

$$\left(Q_{\text{in}} + W_{\text{in}} + \sum m_i\theta_i\right) - \left(Q_{\text{out}} + W_{\text{out}} + \sum m_e\theta_e\right) = (m_2e_2 - m_1e_1)_{\text{system}}$$

where $\theta = h$ + ke + pe is the energy of a flowing fluid at any inlet or exit per unit mass, and $e = u$ + ke + pe is the energy of the non-flowing fluid within the control volume per unit mass.

When the kinetic and potential energy changes associated with the control volume and fluid streams are negligible, as is usually the case, the energy balance above simplifies to

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

Note that if no mass enters or leaves the control volume during a process ($m_i = m_e = 0$, and $m_1 = m_2 = m$), this equation reduces to the energy balance relation for closed systems

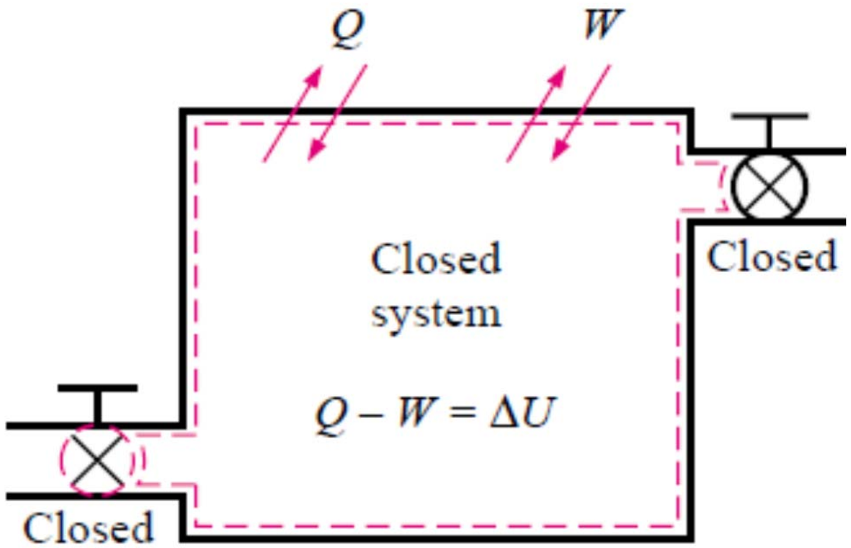

Fig. 4.17: The energy equation of a uniform flow system reduces to that of a closed system when all the inlets and exits are closed.

Example 4.5: Charging of a Rigid Tank by Steam

A rigid, insulated tank that is initially evacuated is connected through a valve to a supply line that carries steam at 1 MPa and 300°C. Now the valve is opened, and steam is allowed to flow slowly into the tank until the pressure reaches 1 MPa, at which point the valve is closed. Determine the final temperature of the steam in the tank.

Solution: We take the *tank* as the system (Fig. 4.18). This is a *control volume* since mass crosses the system boundary during the process.

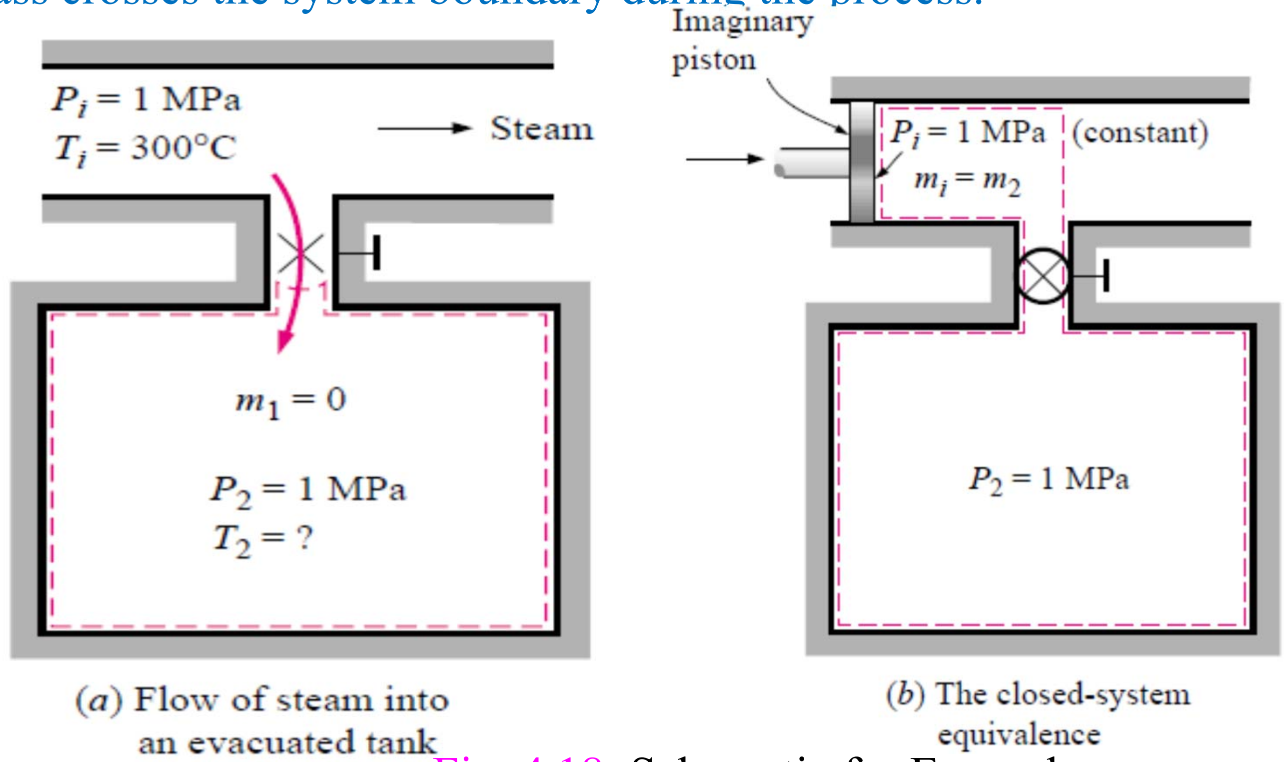

Fig. 4.18: Schematic for Example

We observe that this is an unsteady-flow process since changes occur within the control volume. The control volume is initially evacuated and thus $m_1 = 0$ and $m_1u_1 = 0$. Also, there is one inlet and no exits for mass flow.

Assumptions:

1. This process can be analyzed as a *uniform-flow process* since the properties of the steam entering the control volume remain constant during the entire process.

2. The kinetic and potential energies of the streams are negligible, ke = pe = 0.

3. The tank is stationary and thus its kinetic and potential energy changes are zero; that is, $\Delta KE = \Delta PE = 0$ and $\Delta E_{system} = U_{system}$.

4. There are no boundary, electrical, or shaft work interactions involved.

5. The tank is well insulated and thus there is no heat transfer.

Analysis: Noting that microscopic energies of flowing and non-flowing fluids are represented by enthalpy *h* and internal energy *u*, respectively, the mass and energy balances for this uniform-flow system can be expressed as

Mass balance: $m_i - m_e = \Delta m_{\text{system}} \rightarrow m_i = m_2 - \cancelto{0}{m_1} = m_2$

Energy balance:

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

$$m_i h_i = m_2 u_2 \qquad (\text{since } W = Q = 0,\ \text{ke} \cong \text{pe} \cong 0,\ m_1 = 0)$$

Combining the mass and energy balances gives

$$u_2 = h_i$$

That is, the final internal energy of the steam in the tank is equal to the enthalpy of the steam entering the tank. The enthalpy of the steam at the inlet state is

$$\left.\begin{array}{l} P_i = 1 \text{ MPa} \\ T_i = 300°\text{C} \end{array}\right\} \quad h_i = 3051.2 \text{ kJ/kg} \qquad \text{(Table A–6)}$$

which is equal to u_2. Since we now know two properties at the final state, it is fixed and the temperature at this state is determined from the same table to be

$$\left.\begin{array}{l} P_2 = 1 \text{ MPa} \\ u_2 = 3051.2 \text{ kJ/kg} \end{array}\right\} \quad T_2 = \mathbf{456.2°C}$$

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.

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

New Chapter in next lecture

Second Law of Thermodynamics:

- **Thermal Energy Reservoir,**
- **Heat Engine,**
- **Refrigerator and**
- **Heat Pump**

Thank You