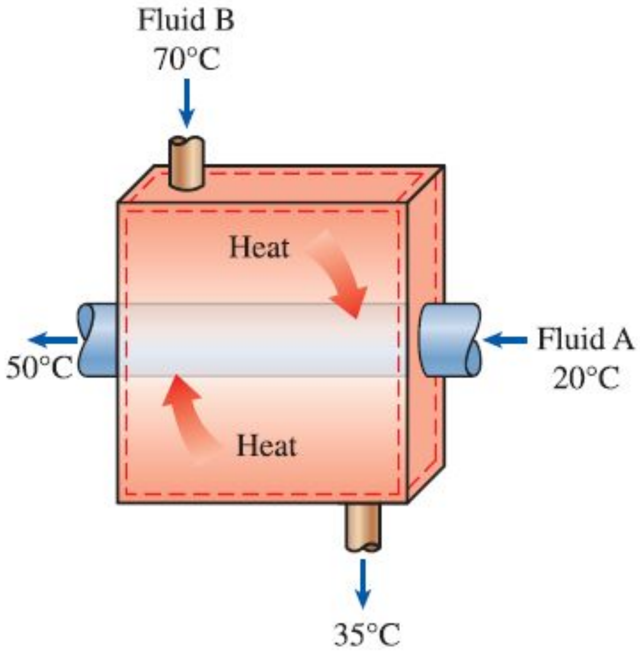


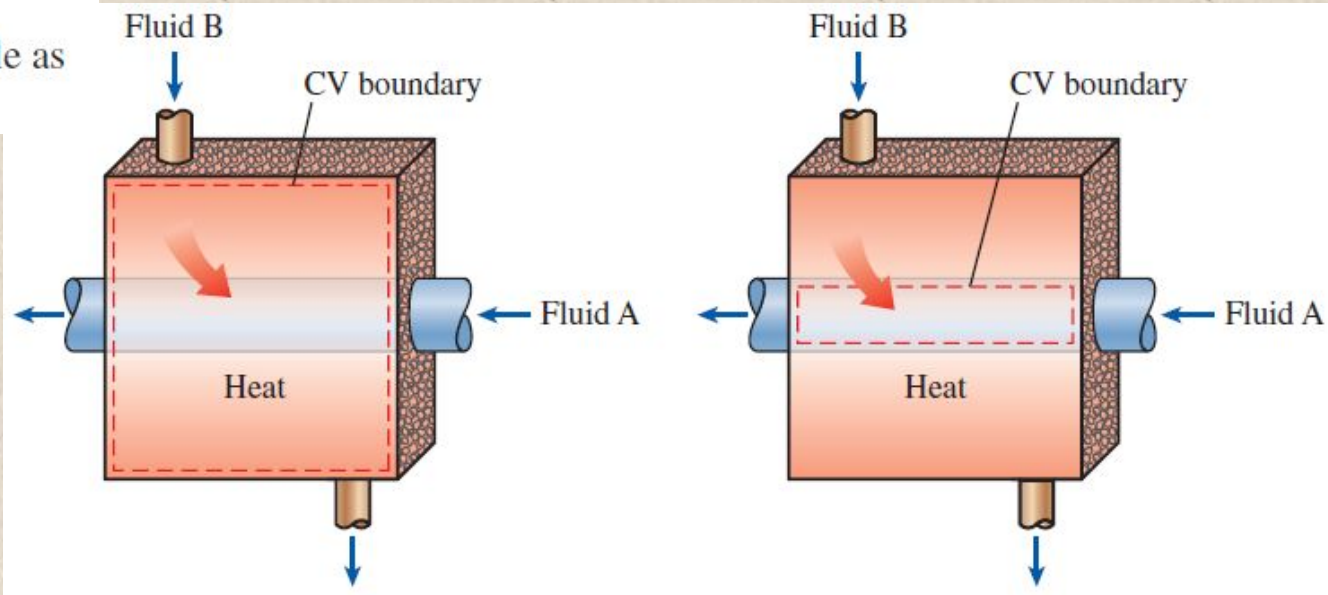
FIGURE 5–38
A heat exchanger can be as simple as two concentric pipes.

Heat exchangers

Heat exchangers are devices where two moving fluid streams exchange heat without mixing.

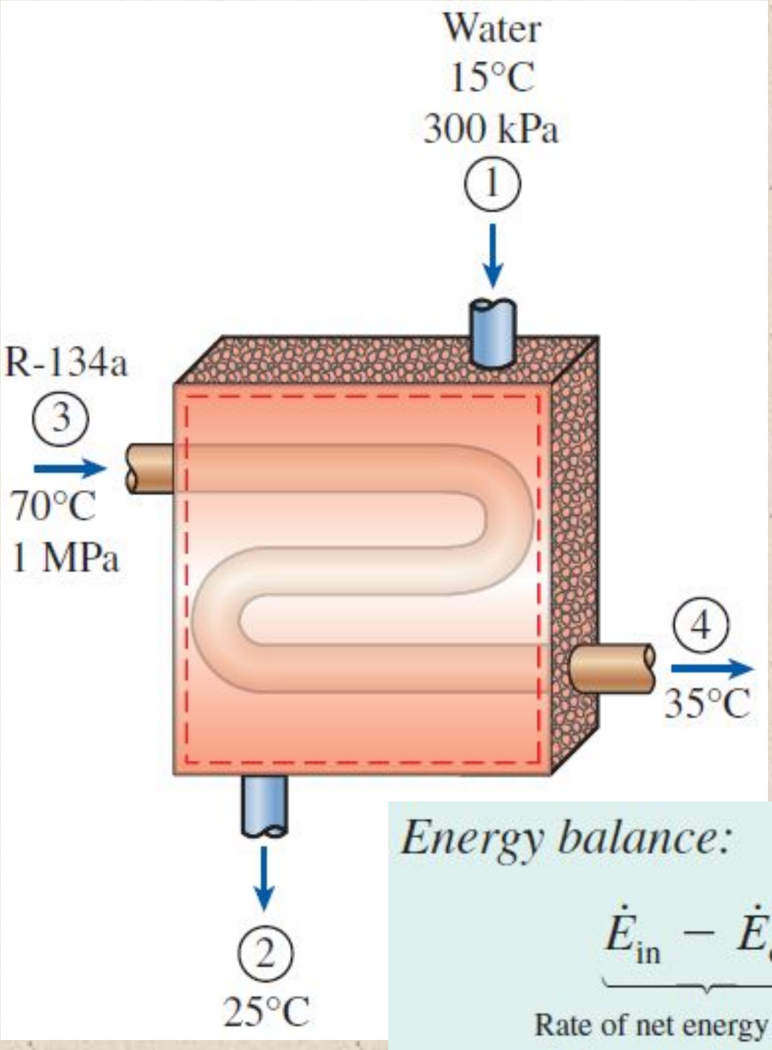
Heat exchangers are widely used in various industries, and they come in various designs.

The heat transfer associated with a heat exchanger may be zero or nonzero depending on how the control volume is selected.



(*a*) System: Entire heat exchanger ($Q_{CV} = 0$)

(*b*) System: Fluid A ($Q_{CV} \neq 0$)



Cooling of Refrigerant-134a by Water

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_w$$

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_R$$

Energy balance:

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4 \quad (\text{since } \dot{Q} \cong 0,\ \dot{W} = 0,\ \text{ke} \cong \text{pe} \cong 0)$$

$$\dot{m}_w (h_1 - h_2) = \dot{m}_R (h_4 - h_3)$$

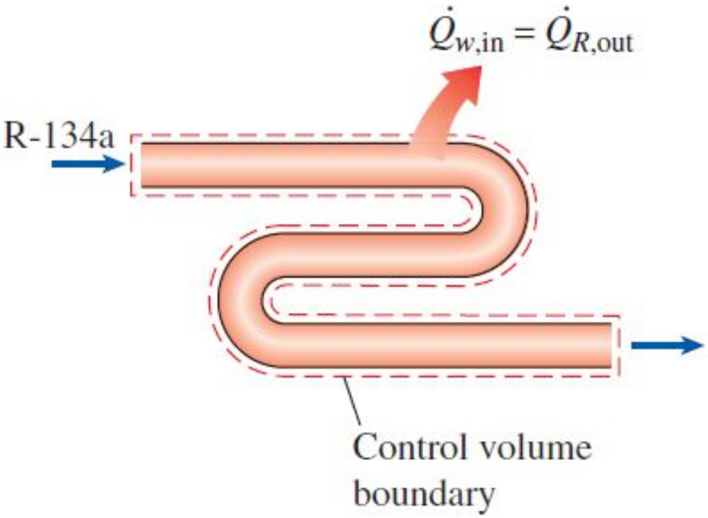


FIGURE 5–41
In a heat exchanger, the heat transfer depends on the choice of the control volume.

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{ (steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc., energies}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{w,\,in} + \dot{m}_w h_1 = \dot{m}_w h_2$$

$$\dot{Q}_{w,in} = \dot{m}_w(h_2 - h_1)$$

Pipe and duct flow

The transport of liquids or gases in pipes and ducts is of great importance in many engineering applications.

Flow through a pipe or a duct usually satisfies the steady-flow conditions.

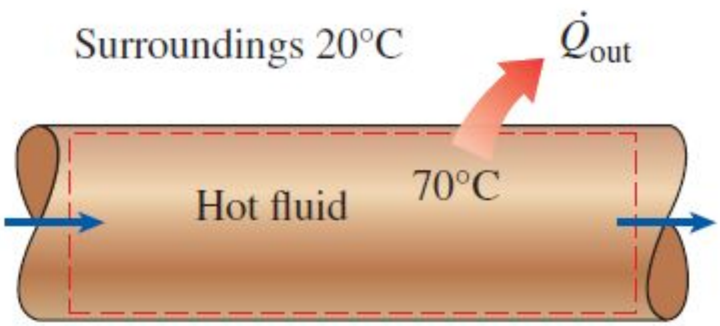


FIGURE 5–42
Heat losses from a hot fluid flowing through an uninsulated pipe or duct to the cooler environment may be very significant.

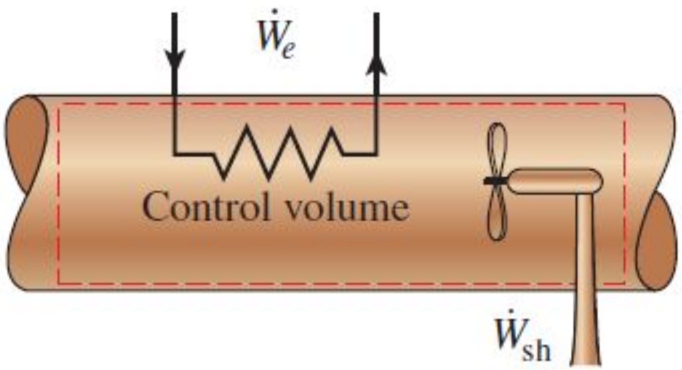
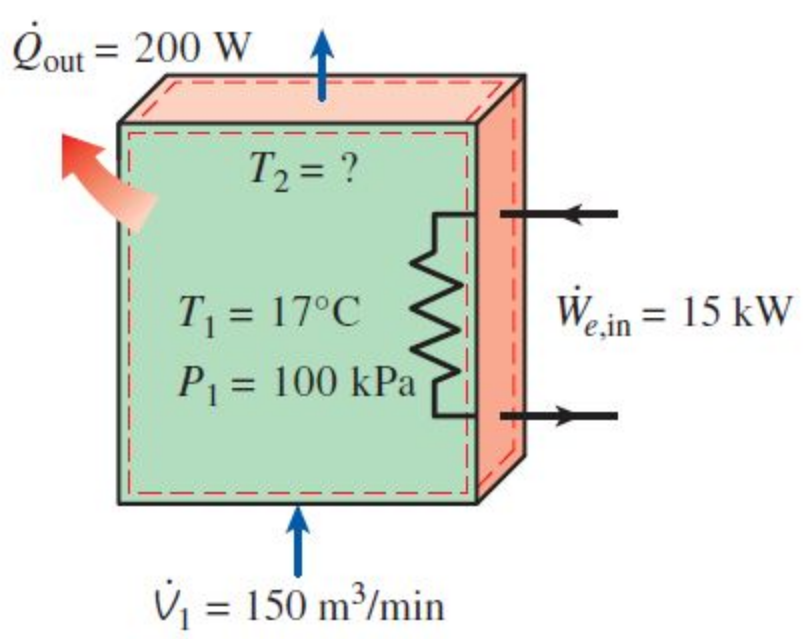


FIGURE 5–43
Pipe or duct flow may involve more than one form of work at the same time.

Electric Heating of Air in a House



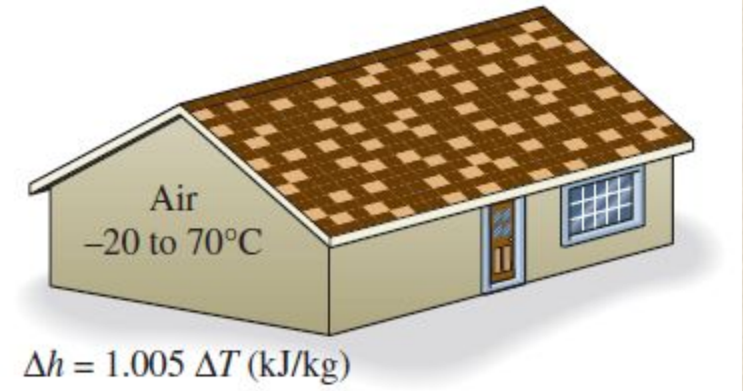


FIGURE 5–45
The error involved in $\Delta h = c_p \Delta T$, where $c_p = 1.005$ kJ/kg·°C, is less than 0.5 percent for air in the temperature range −20 to 70°C.

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{e,in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

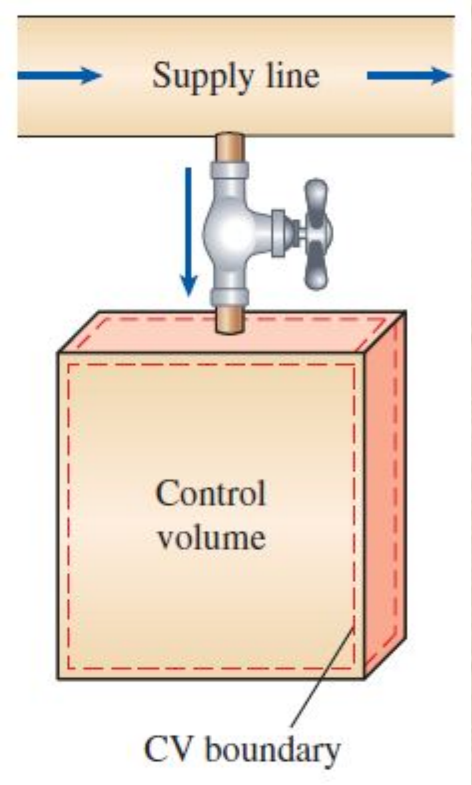
$$\dot{W}_{e,in} - \dot{Q}_{out} = \dot{m}c_p(T_2 - T_1)$$

ENERGY ANALYSIS OF UNSTEADY-FLOW PROCESSES

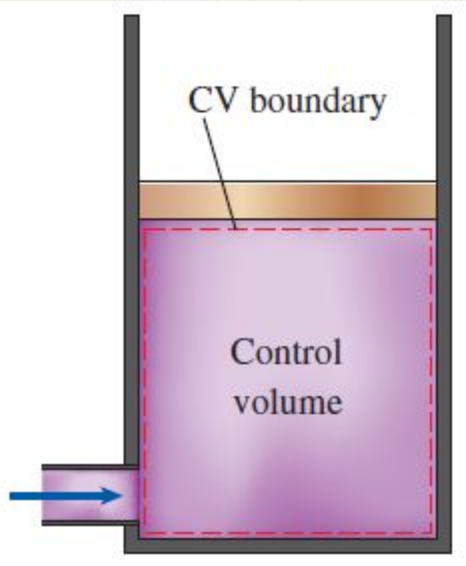
Many processes of interest, involve *changes* within the control volume with time. Such processes are called *unsteady-flow,* or *transient-flow,* processes.

Most unsteady-flow processes can be represented reasonably well by the *uniform-flow process*.

Uniform-flow process: The fluid flow at any inlet or exit is uniform and steady, and thus the fluid properties do not change with time or position over the cross section of an inlet or exit. If they do, they are averaged and treated as constants for the entire process.



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



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

Mass balance

$$m_{in} - m_{out} = \Delta m_{system} \qquad \Delta m_{system} = m_{final} - m_{initial}$$

$$m_i - m_e = (m_2 - m_1)_{CV} \qquad i = \text{inlet},\ e = \text{exit},\ 1 = \text{initial state, and } 2 = \text{final state}$$

Energy balance

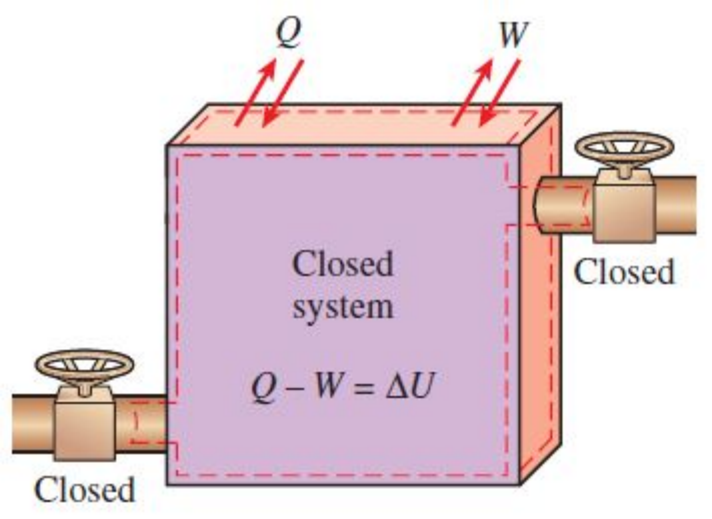
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$\left(Q_{in} + W_{in} + \sum_{in} m\theta\right) - \left(Q_{out} + W_{out} + \sum_{out} m\theta\right) = (m_2e_2 - m_1e_1)_{system}$$

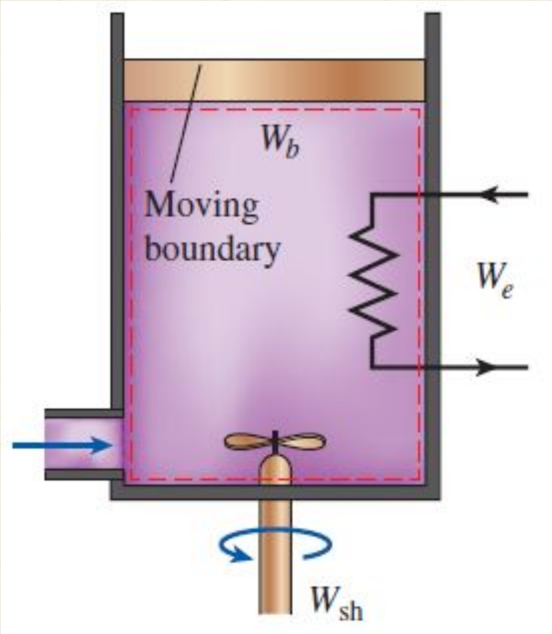
$$\theta = h + \text{ke} + \text{pe}$$

$$e = u + \text{ke} + \text{pe}$$

$$Q - W = \sum_{out} mh - \sum_{in} mh + (m_2u_2 - m_1u_1)_{system} \qquad Q = Q_{net,in} = Q_{in} - Q_{out} \qquad W = W_{net,out} = W_{out} - W_{in}$$

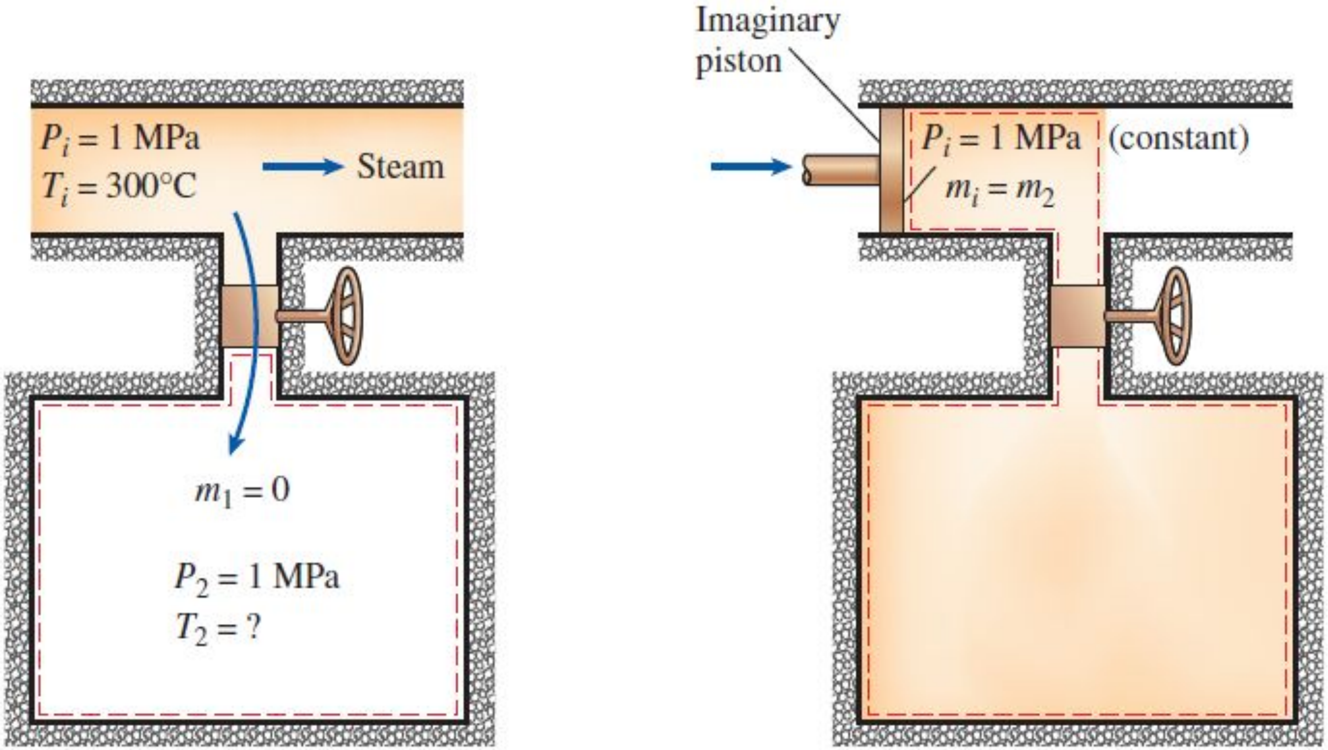


A uniform-flow system may involve electrical, shaft, and boundary work all at once.



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

Charging of a Rigid Tank by Steam



(*a*) Flow of steam into an evacuated tank

(*b*) The closed-system equivalence

Mass balance: $m_{in} - m_{out} = \Delta m_{system} \rightarrow m_i = m_2 - \overset{\nearrow 0}{m_1} = m_2$

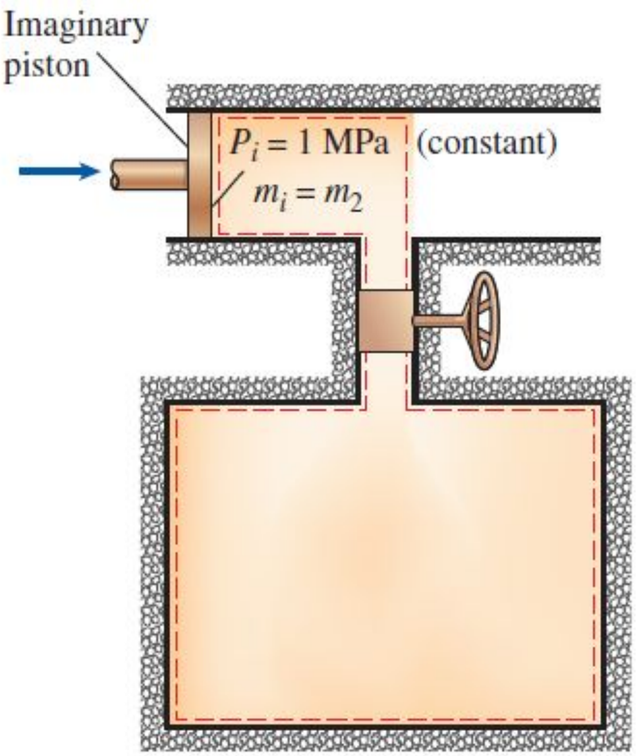
Energy balance:

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

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

$$u_2 = h_i$$

Charging of a Rigid Tank by Steam



(b) The closed-system equivalence

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

$$W_{b,\text{in}} = \Delta U$$

$$m_i P_i v_i = m_2 u_2 - m_i u_i$$

$$u_2 = u_i + P_i v_i = h_i$$

$$W_{b,\text{in}} = -\int_1^2 P_i \, dV = -P_i(V_2 - V_1) = -P_i[V_{\text{tank}} - (V_{\text{tank}} + V_i)] = P_i V_i$$

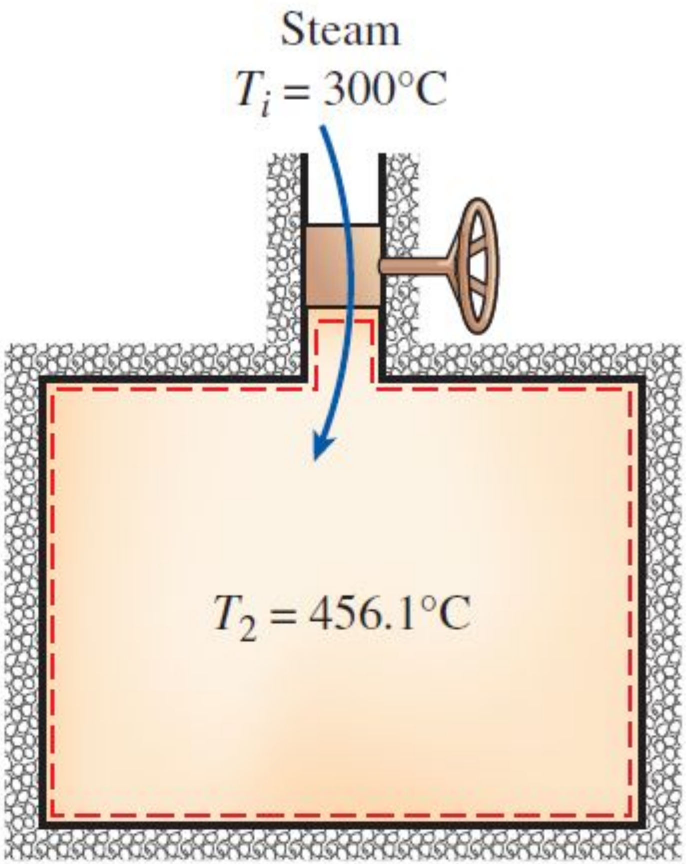
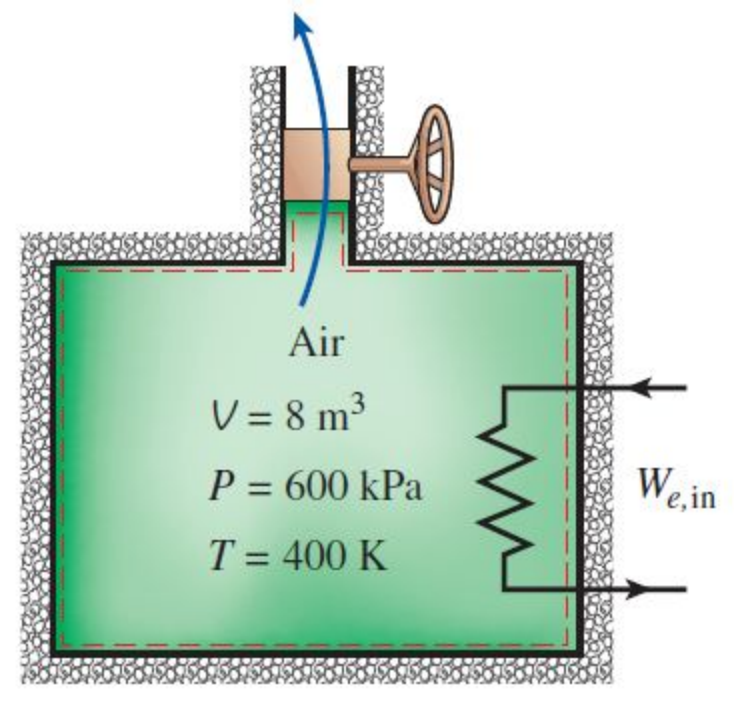


FIGURE 5–51

The temperature of steam rises from 300 to 456.1°C as it enters a tank as a result of flow energy being converted to internal energy.



Discharge of Heated Air at Constant Temperature

Mass balance: $m_{in} - m_{out} = \Delta m_{system} \rightarrow m_e = m_1 - m_2$

Energy balance:

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

$$W_{e,in} - m_e h_e = m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong \text{ke} \cong \text{pe} \cong 0)$$

Summary

- Conservation of mass
  - ✔ Mass and volume flow rates
  - ✔ Mass balance for a steady-flow process
  - ✔ Mass balance for incompressible flow
- Flow work and the energy of a flowing fluid
  - ✔ Energy transport by mass
- Energy analysis of steady-flow systems
- Some steady-flow engineering devices
  - ✔ Nozzles and Diffusers
  - ✔ Turbines and Compressors
  - ✔ Throttling valves
  - ✔ Mixing chambers and Heat exchangers
  - ✔ Pipe and Duct flow
- Energy analysis of unsteady-flow processes