

**Thermodynamics: An Engineering Approach**  
8th Edition

**Yunus A. Çengel, Michael A. Boles**  
**McGraw-Hill, 2015**

**Topic 9**  
**Steady-Flow Devices (cont.)**

# Objectives

- Solve energy balance problems for common steady-flow devices such as throttling valves, mixers, heaters, and heat exchangers.

# Throttling valves

**Throttling valves** are *any kind of flow-restricting* devices that cause a significant pressure drop in the fluid.

**What is the difference between a turbine and a throttling valve?**

The pressure drop in the fluid is often accompanied by a large drop in temperature, and for that reason throttling devices are commonly used in refrigeration and air-conditioning applications.



(a) An adjustable valve



(b) A porous plug



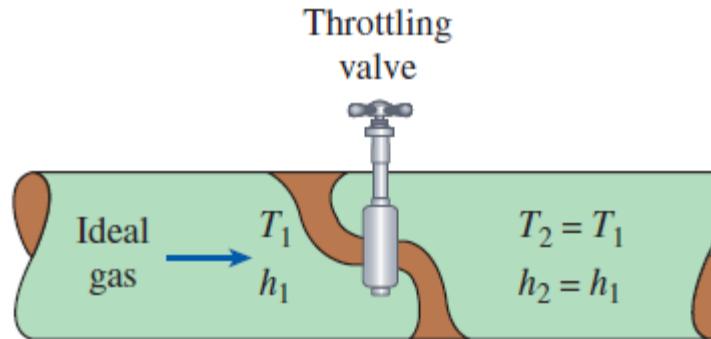
(c) A capillary tube

**FIGURE 5–32**

Throttling valves are devices that cause large pressure drops in the fluid.

$$\begin{array}{ll} \text{Energy} & h_2 \approx h_1 \\ \text{balance} & u_1 + P_1 v_1 = u_2 + P_2 v_2 \end{array}$$

Internal energy + Flow energy = Constant



**FIGURE 5–33**

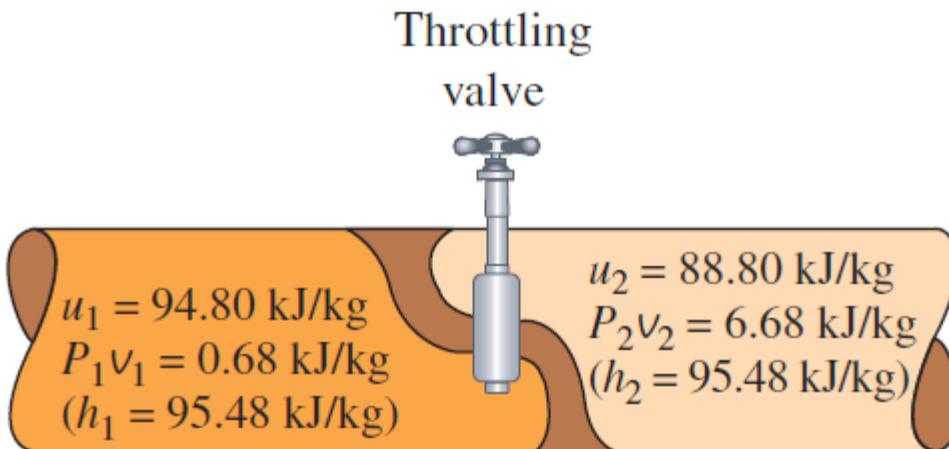
The temperature of an ideal gas does not change during a throttling ( $h = \text{constant}$ ) process since  $h = h(T)$ .

# Expansion of R-134a in a Refrigerator

R-134a enters the capillary tube of a refrigerator as a saturated liquid at 0.8 MPa and is throttled to a pressure of 0.12 MPa. Determine the quality of the R-134a at its final state and the temperature drop during the process.

## Example 1

# Expansion of Refrigerant-134a in a Refrigerator



**FIGURE 5–34**

During a throttling process, the enthalpy (flow energy + internal energy) of a fluid remains constant. But internal and flow energies may be converted to each other.

$$h_2 \approx h_1 \quad (\text{kJ/kg})$$

$$u_1 + P_1v_1 = u_2 + P_2v_2$$

Internal energy + Flow energy = Constant

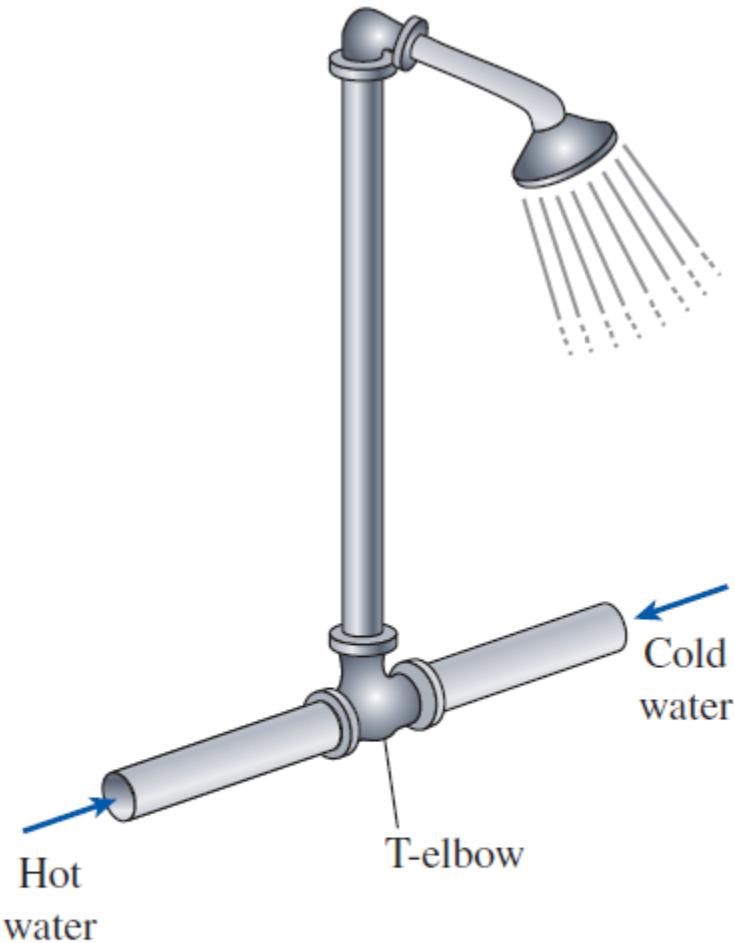
# Mixing chambers

In engineering applications, the section where the mixing process takes place is commonly referred to as a mixing chamber.

The mixing chamber does not have to be a distinct “chamber.” An ordinary T-elbow or a Y-elbow in a shower, for example, serves as the mixing chamber for the cold- and hot-water streams.

The conservation of mass principle for a mixing chamber requires that the sum of the incoming mass flow rates equal the mass flow rate of the outgoing mixture.

The conservation of energy equation is analogous to the conservation of mass equation.



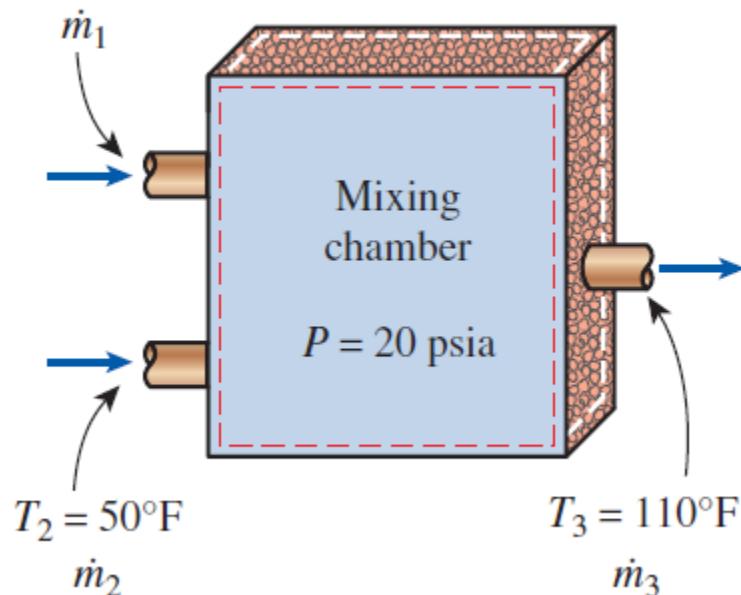
**FIGURE 5–35**

The T-elbow of an ordinary shower serves as the mixing chamber for the hot- and the cold-water streams.

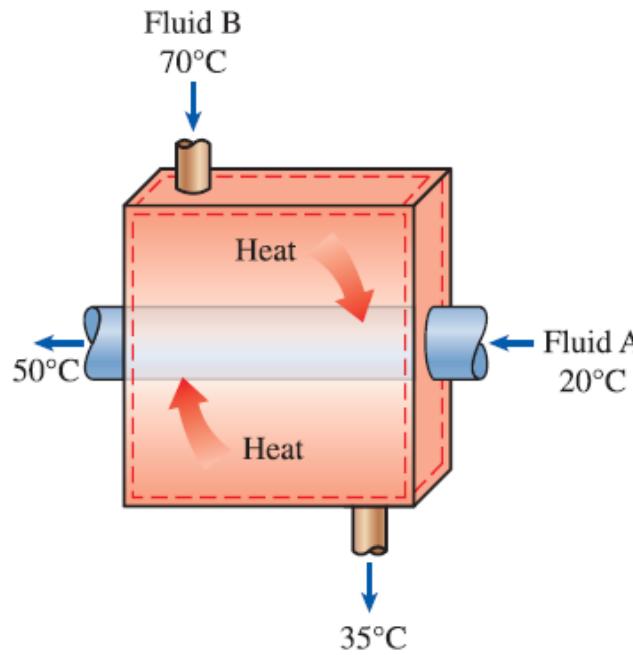
# Mixing Hot and Cold Water in a Shower

In an ordinary shower, hot water at  $140^{\circ}\text{F}$  is mixed with cold water at  $50^{\circ}\text{F}$ . The desired temperature of the water stream leaving the shower head is  $110^{\circ}\text{F}$ . Assuming there is no heat loss and the mixing takes place at a pressure of 20 psia, determine the mass flow rate ratio of hot to cold water.

$$T_1 = 140^{\circ}\text{F}$$



## Example 2



# Heat exchangers

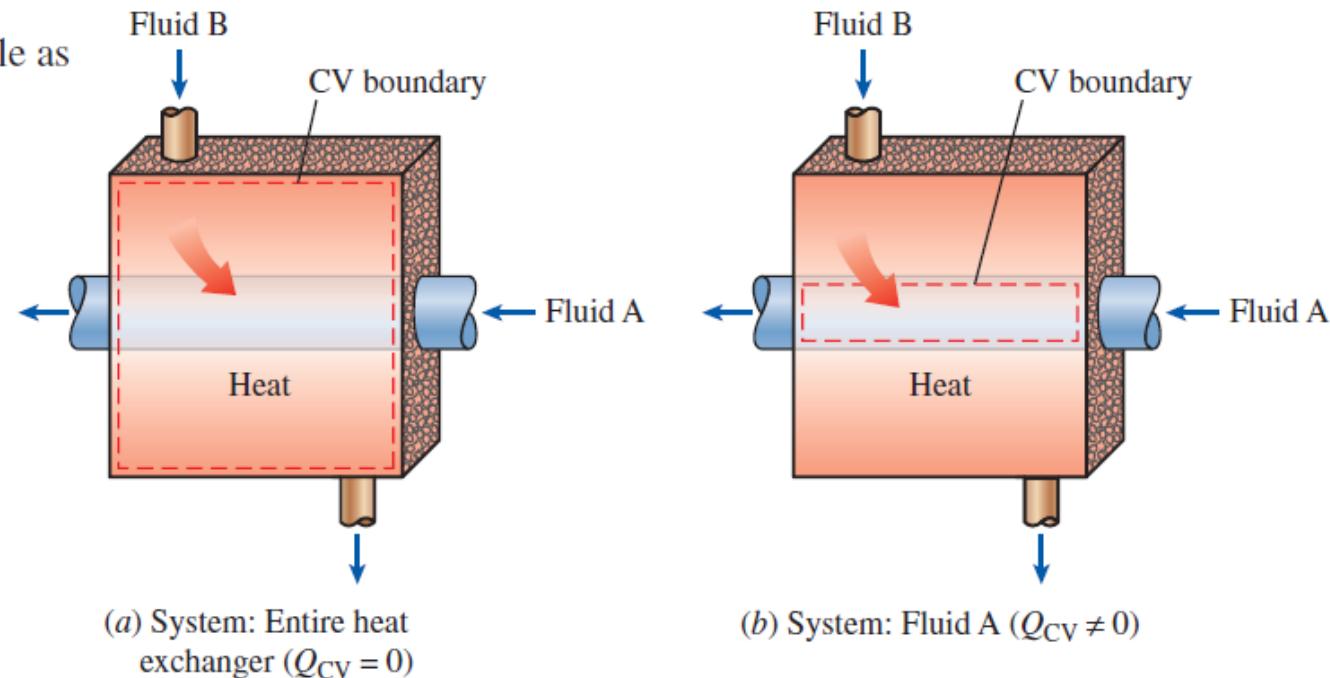
**Heat exchangers** are devices where two moving fluid streams exchange heat without mixing.

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

**FIGURE 5–38**

A heat exchanger can be as simple as two concentric pipes.

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



# Cooling of R-134a by Water

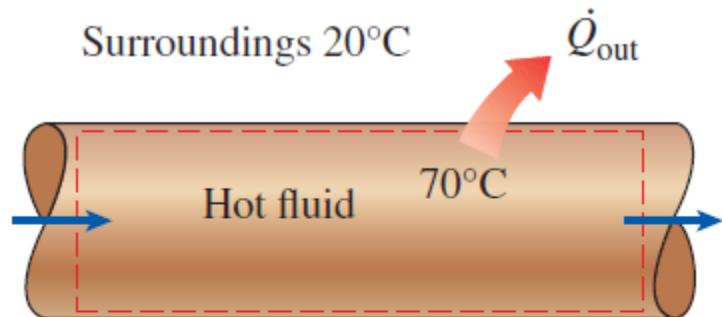
R-134a is to be cooled by water in a condenser. R-134a enters the condenser with a mass flow rate of 6 kg/min at 1 MPa and 70°C and leaves at 35°C. The cooling water enters at 300 kPa and 15°C and leaves at 25°C. Assuming the pressure drop is negligible, determine the mass flow rate of the cooling water and the rate of heat transfer from R-134a to the water.

## Example 3

# Pipe and duct flow

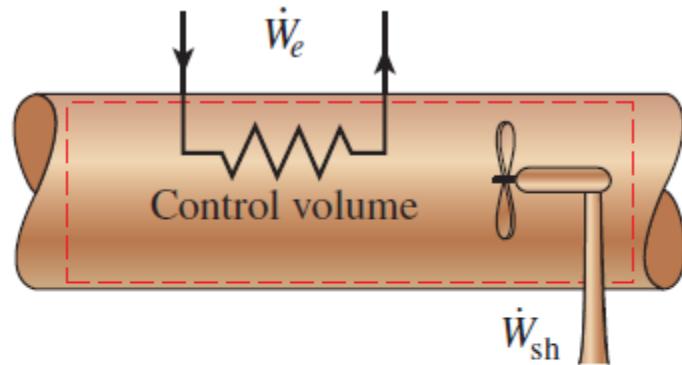
The transport of liquids or gases in pipes and ducts is of great importance in many engineering applications.

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.

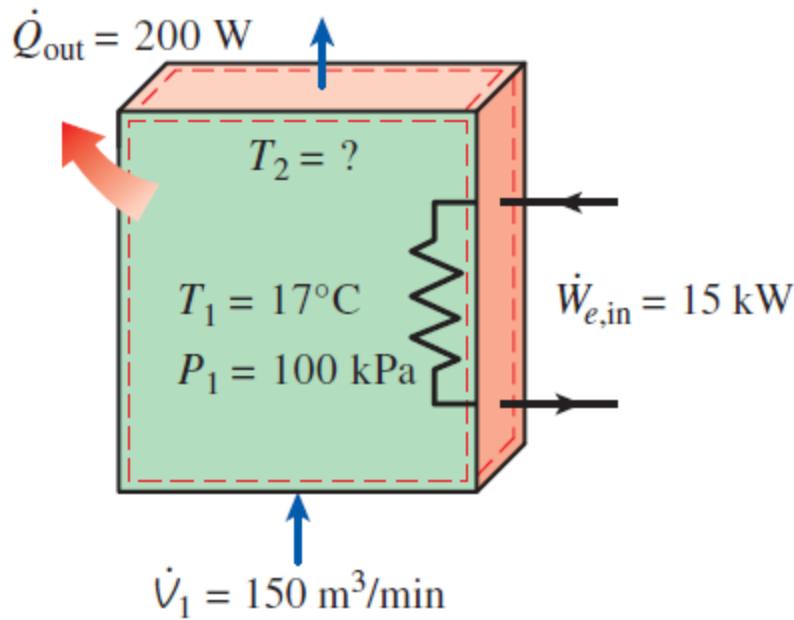


**FIGURE 5–43**

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

# Electrical Heating of Air in a House

The electrical heating systems used in many houses consist of a simple duct with resistance heaters. Air is heated as it flows over the resistance wires. Consider a 15-kW electric heating system where air enters at 100 kPa and 17°C with a flow rate of 150 m<sup>3</sup>/min. If the rate of heat loss from the air duct to the surroundings is 200 W, determine the final temperature of the air.



**Example 4**

# Summary

- Some steady-flow engineering devices
  - ✓ Mixing chambers and Heat exchangers
  - ✓ Pipe and Duct flow