INTERNAL ENERGY, ENTHALPY, AND SPECIFIC HEATS OF SOLIDS AND LIQUIDS

Incompressible substance: A substance whose specific volume (or density) is constant. Solids and liquids are incompressible substances.

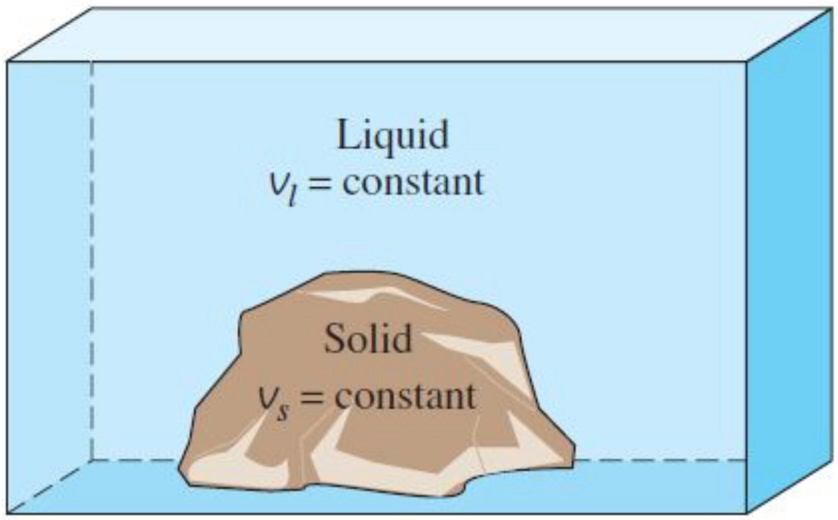


FIGURE 4–33
The specific volumes of incompressible substances remain constant during a process.

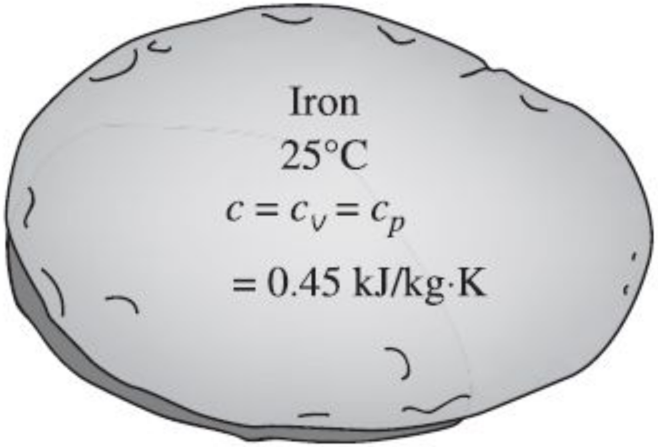


FIGURE 4–34
The c_v and c_p values of incompressible substances are identical and are denoted by c.

Internal Energy Changes

$$du = c_v\,dT = c(T)\,dT$$

$$\Delta u = u_2 - u_1 = \int_1^2 c(T)\,dT \qquad \text{(kJ/kg)}$$

$$\Delta u \cong c_{\text{avg}}(T_2 - T_1) \qquad \text{(kJ/kg)}$$

Enthalpy Changes

$$h = u + Pv$$

$$dh = du + v\,dP + P\,\overset{\nearrow 0}{dv} = du + v\,dP$$

$$\Delta h = \Delta u + v\,\Delta P \cong c_{\text{avg}}\,\Delta T + v\,\Delta P \qquad \text{(kJ/kg)}$$

For *solids*, the term $v\,\Delta P$ is insignificant and thus $\Delta h = \Delta u \cong c_{\text{avg}}\Delta T$. For *liquids*, two special cases are commonly encountered:

1. *Constant-pressure processes,* as in heaters ($\Delta P = 0$): $\Delta h = \Delta u \cong c_{\text{avg}}\Delta T$
2. *Constant-temperature processes,* as in pumps ($\Delta T = 0$): $\Delta h = v\,\Delta P$

$$h_{@P,T} \cong h_{f@T} + v_{f@T}(P - P_{\text{sat}@T})$$

The enthalpy of a compressed liquid

Usually amore accurate relation than $h_{@P,T} \cong h_{f@T}$

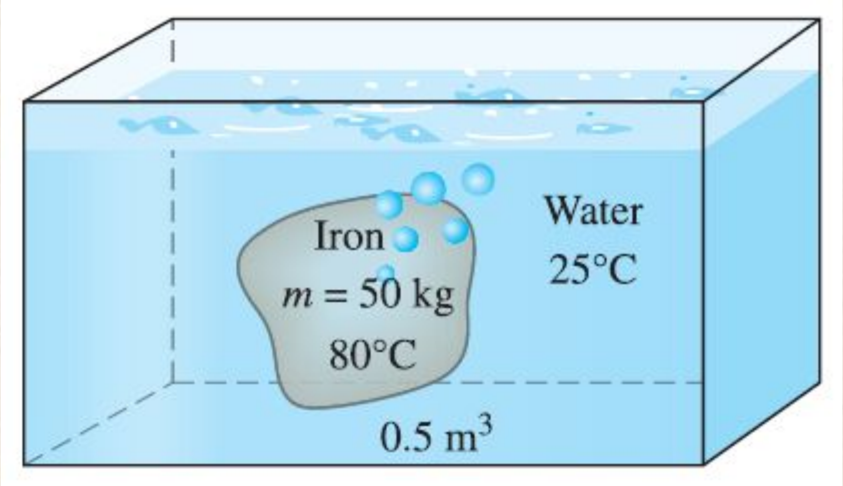
Cooling of an Iron Block by Water

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

$$0 = \Delta U$$

$$\Delta U_{sys} = \Delta U_{iron} + \Delta U_{water} = 0$$

$$[mc(T_2 - T_1)]_{iron} + [mc(T_2 - T_1)]_{water} = 0$$



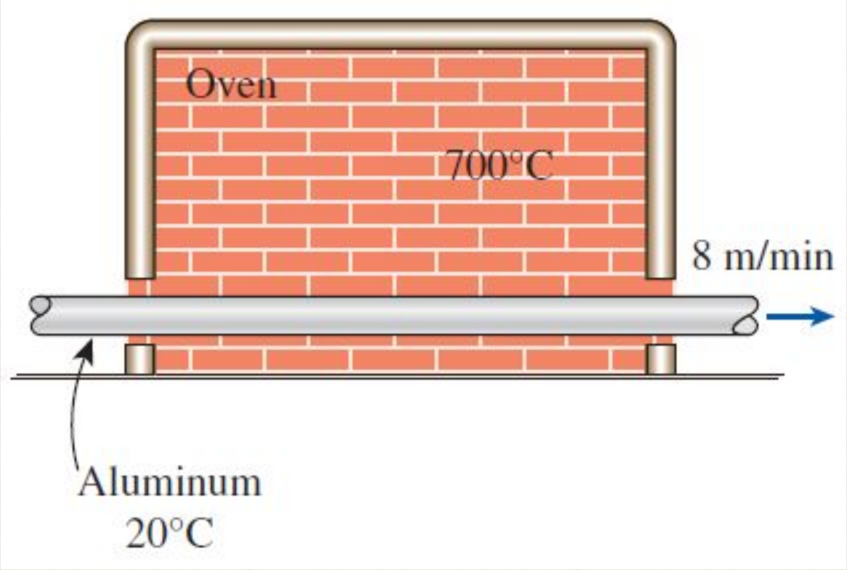
Heating of Aluminum Rods in a Furnace

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

$$Q_{in} = \Delta U_{rod} = m(u_2 - u_1)$$

$$Q_{in} = mc(T_2 - T_1)$$

$$\dot{Q}_{in} = Q_{in} / \Delta t$$



Summary

- Moving boundary work
  - ✔ W_b for an isothermal process
  - ✔ W_b for a constant-pressure process
  - ✔ W_b for a polytropic process
- Energy balance for closed systems
  - ✔ Energy balance for a constant-pressure expansion or compression process
- Specific heats
  - ✔ Constant-pressure specific heat, c_p
  - ✔ Constant-volume specific heat, c_v
- Internal energy, enthalpy, and specific heats of ideal gases
  - ✔ Specific heat relations of ideal gases
- Internal energy, enthalpy, and specific heats of incompressible substances (solids and liquids)

Thermodynamics: An Engineering Approach
8th Edition
Yunus A. Çengel, Michael A. Boles
McGraw-Hill, 2015

CHAPTER 5
MASS AND ENERGY ANALYSIS OF CONTROL VOLUMES

Objectives

- 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 conservation of energy principle to control volumes.
- Identify the energy carried by a fluid stream crossing a control surface as the sum of internal energy, flow work, kinetic energy, and potential energy of the fluid and to relate the combination of the internal energy and the flow work to the property enthalpy.
- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, heaters, and heat exchangers.
- Apply the energy balance to general unsteady-flow processes with particular emphasis on the uniform-flow process as the model for commonly encountered charging and discharging processes.

CONSERVATION OF MASS

Conservation of mass: Mass, like energy, is a conserved property, and it cannot be created or destroyed during a process.

Closed systems: The mass of the system remain constant during a process.

Control volumes: Mass can cross the boundaries, and so we must keep track of the amount of mass entering and leaving the control volume.

Mass *m* and energy *E* can be converted to each other according to $E = mc^2$

where *c* is the speed of light in a vacuum, which is $c = 2.9979 \times 10^8$ m/s.

The mass change due to energy change is negligible.

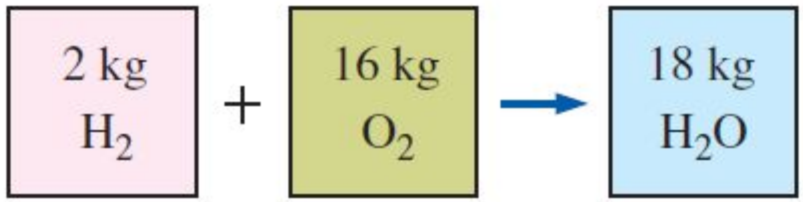


FIGURE 5–1
Mass is conserved even during chemical reactions.

Mass and Volume Flow Rates

$$\delta \dot{m} = \rho V_n \, dA_c$$

$$\dot{m} = \int_{A_c} \delta \dot{m} = \int_{A_c} \rho V_n \, dA_c$$

$$\dot{m} = \rho V_{\text{avg}} A_c \qquad (\text{kg/s})$$

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

Mass flow rate

$$V_{\text{avg}} = \frac{1}{A_c} \int_{A_c} V_n \, dA_c$$

Definition of average velocity

Volume flow rate

$$\dot{V} = \int_{A_c} V_n \, dA_c = V_{\text{avg}} A_c = V A_c \qquad (\text{m}^3/\text{s})$$

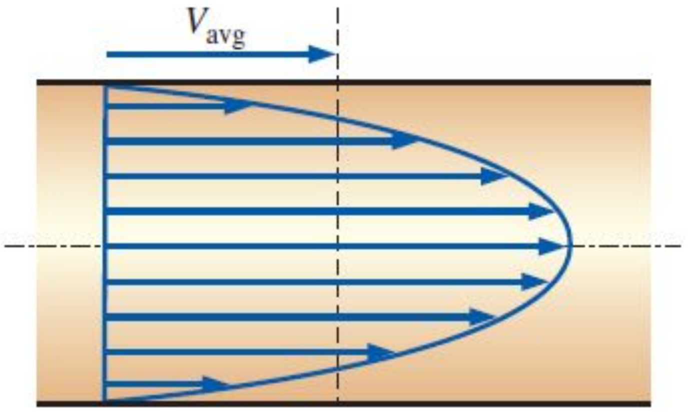


FIGURE 5–3

The average velocity V_{avg} is defined as the average speed through a cross section.

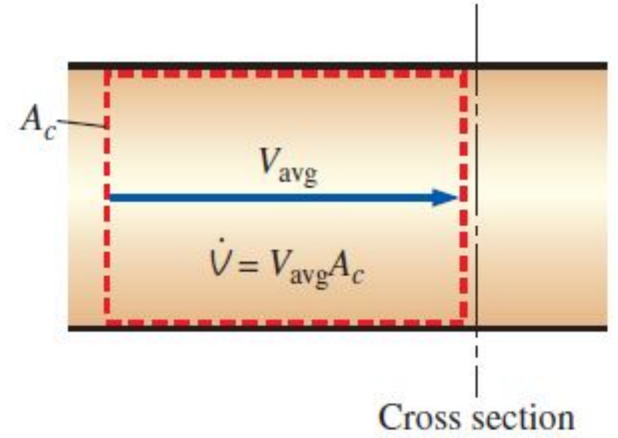


FIGURE 5–4

The volume flow rate is the volume of fluid flowing through a cross section per unit time.

Conservation of Mass Principle

$$\begin{pmatrix}\text{Total mass entering}\\ \text{the CV during } \Delta t\end{pmatrix} - \begin{pmatrix}\text{Total mass leaving}\\ \text{the CV during } \Delta t\end{pmatrix} = \begin{pmatrix}\text{Net change of mass}\\ \text{within the CV during } \Delta t\end{pmatrix}$$

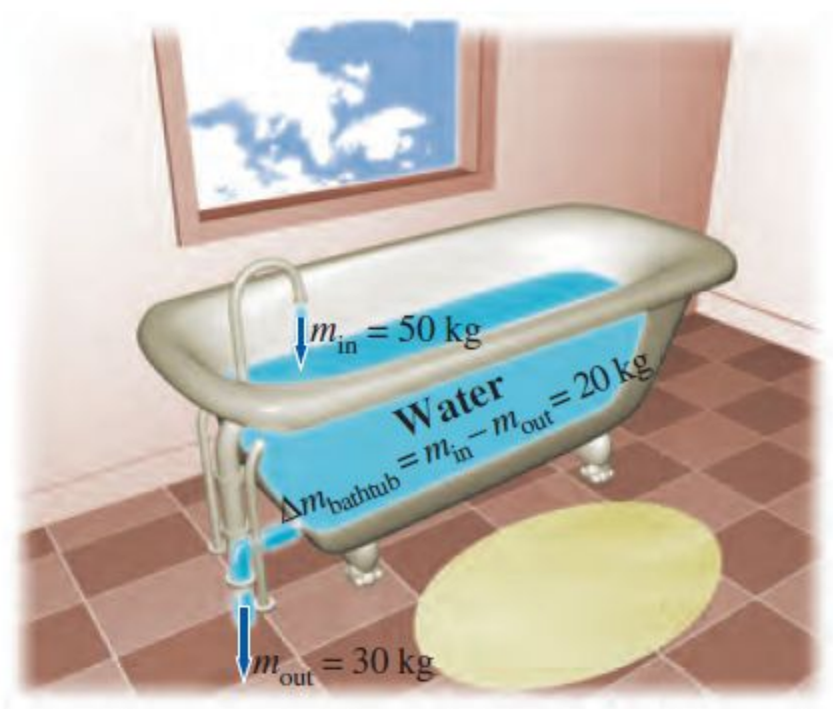


FIGURE 5–5
Conservation of mass principle for an ordinary bathtub.

The conservation of mass principle for a control volume: The net mass transfer to or from a control volume during a time interval Δ*t* is equal to the net change (increase or decrease) in the total mass within the control volume during Δ*t*.

$$m_{in} - m_{out} = \Delta m_{CV} \qquad (\text{kg})$$

$$\Delta m_{CV} = m_{final} - m_{initial}$$

$$\dot{m}_{in} - \dot{m}_{out} = dm_{CV}/dt \qquad (\text{kg/s})$$

These equations are often referred to as the **mass balance** and are applicable to any control volume undergoing any kind of process.