

CH365 Chemical Engineering Thermodynamics

Lesson 7

Enthalpy, Heat Capacity, and Open Systems – Part 2

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Measures of Flow

$$\dot{m} = \text{mass flow rate} \left(\frac{\text{kg}}{\text{s}}, \frac{\text{lb}_m}{\text{hr}}, \text{etc.} \right)$$

$$\dot{n} = \text{molar flow rate} \left(\frac{\text{mol}}{\text{s}}, \frac{\text{lbmol}}{\text{s}}, \text{etc.} \right)$$

$$\dot{q} = \text{volumetric flow rate} \left(\frac{\text{m}^3}{\text{s}}, \frac{\text{ft}^3}{\text{min}}, \text{etc.} \right) \quad \text{sometimes } v \text{ (lower case)}$$

$$u = \text{velocity} \left(\frac{\text{ft}}{\text{hr}}, \frac{\text{m}}{\text{s}}, \text{etc.} \right)$$

$$\dot{m} = M\dot{n}$$

M = molar mass

$$\text{e.g., } \frac{\text{kg}}{\text{s}} = \frac{\text{kg}}{\text{kmol}} \cdot \frac{\text{kmol}}{\text{s}}$$

$$\dot{m} = uA\rho \quad A = \text{cross-sectional area} = \frac{\pi D^2}{4} \quad \rho = \text{density} = \frac{1}{V} [=] \frac{\text{kg}}{\text{m}^3} \quad \begin{array}{l} V \text{ is specific or} \\ \text{molar volume} \\ \text{(upper case)} \end{array}$$

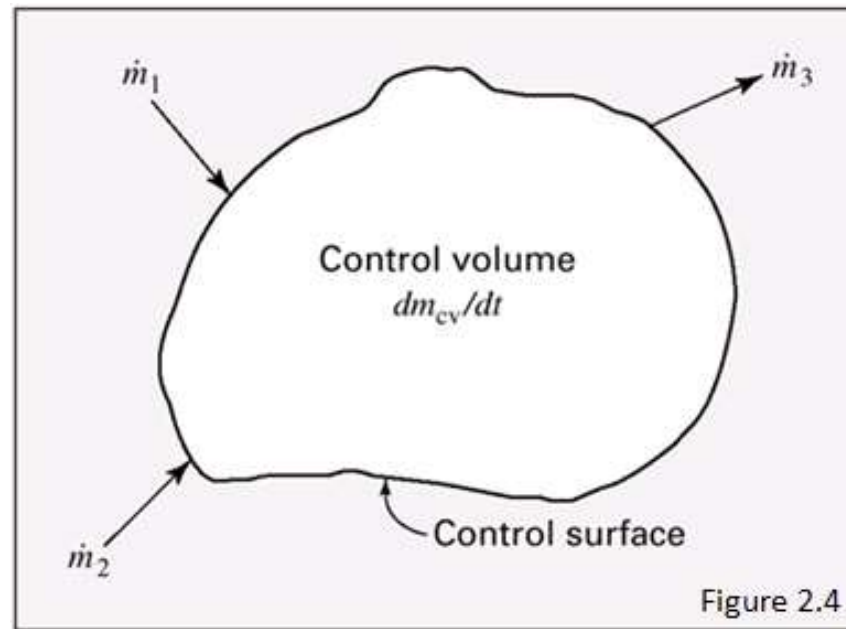
2.23a

$$\dot{n} = uA\rho \cdot \frac{1}{M}$$

$$\text{e.g., } \frac{\text{lb}_m}{\text{sec}} = \frac{\text{ft}}{\text{sec}} \cdot \text{ft}^2 \cdot \frac{\text{lb}_m}{\text{ft}^3}$$

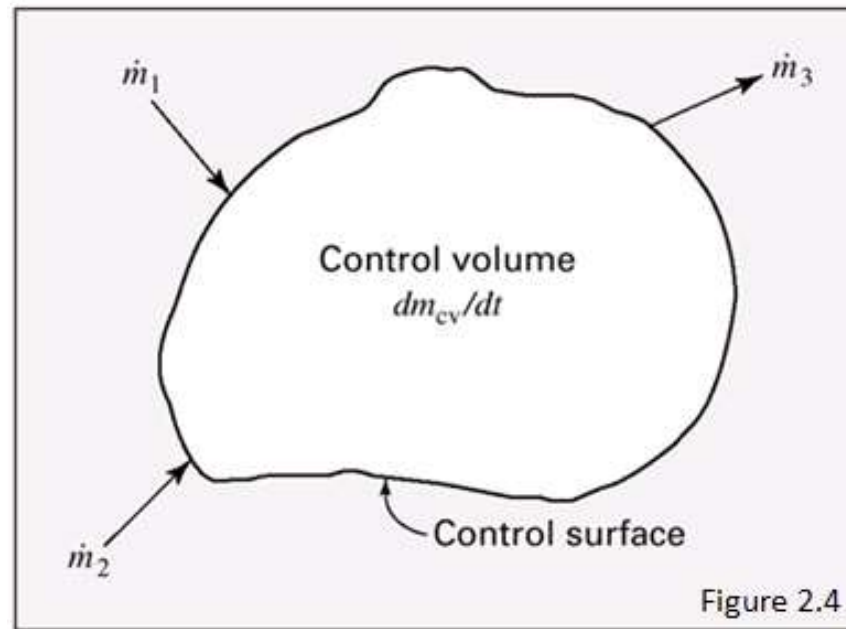
2.23b – M is missing on p. 47

Mass Balance for Open Systems



This diagram changes in Figure 2.5 in a very important way.

Mass Balance for Open Systems

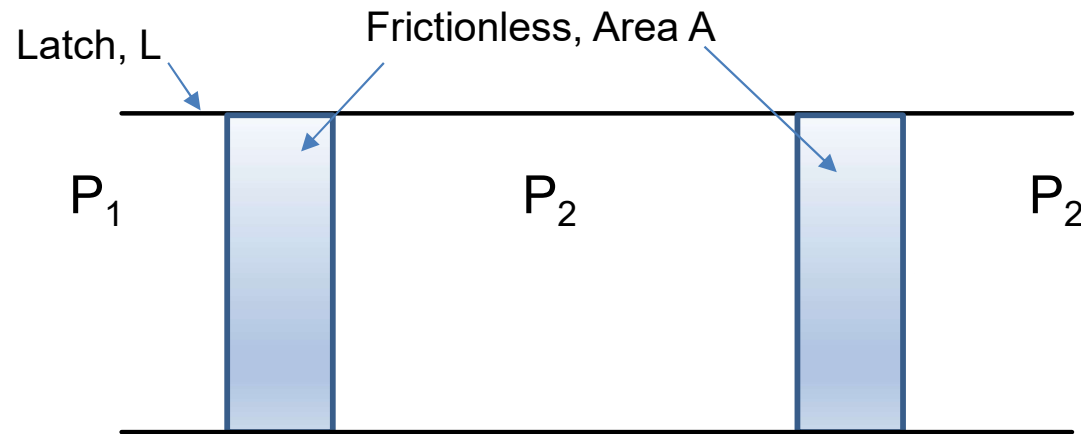


This diagram changes in Figure 2.5 in a very important way with the addition of frictionless pistons, but there is no explanation of this in the textbook.

Frictionless “Double Piston”

Slide 5

Understanding the “pistons” in figure 2.5
Initially at rest, how does the system respond to a push?



Reversible

$$P_2 > P_1$$

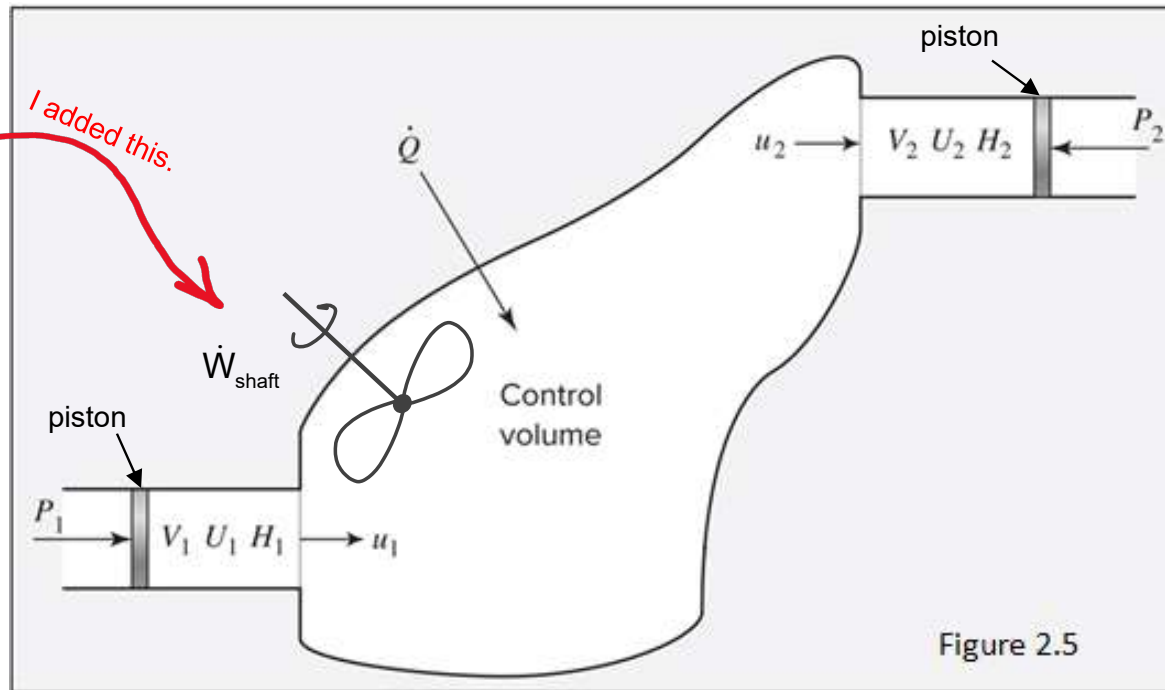
Static equilibrium
(all forces balanced)

General Energy Balance

Slide 6

Shaft work is not illustrated in Figure 2.5 but is used in the equations.

Question: How does the system respond to a “push” on the left-hand piston?



Steady-State Systems

$$\Delta \left[\left(H + \frac{u^2}{2} + gz \right) \dot{m} \right]_{fs} = \dot{Q} + \dot{W}_s$$

2.29

general open system steady-state energy balance

$$\Delta \left(H + \frac{u^2}{2} + gz \right) \dot{m} = \dot{Q} + \dot{W}_s$$

2.30

constant flow open system energy balance (constant density) with one inlet and one outlet.

SI units:
$$\Delta H + \frac{\Delta(u^2)}{2} + g\Delta z = Q + W_s$$

2.31

First law of thermodynamics for steady-state, steady flow, constant density process with one inlet and one outlet

English units:
$$\Delta H + \frac{\Delta(u^2)}{2g_c} + \frac{g}{g_c} \Delta z = Q + W_s$$

all properties are energy per mass

$$\frac{\dot{Q}}{\dot{m}} = Q \quad \frac{\dot{W}_s}{\dot{m}} = W_s$$

$$\Delta H = Q + W_s$$

2.32

Ignoring kinetic and potential energy changes

Questions?

Problem 2.38

Carbon dioxide gas enters a water-cooled compressor at conditions $P_1 = 15$ psia and $T_1 = 50$ °F, and is discharged at conditions $P_2 = 520$ psia and $T_2 = 200$ °F. The entering CO_2 flows through a 4-inch-diameter pipe with velocity 20 ft/s^{-1} and is discharged through a 1-inch-diameter pipe. The shaft work supplied to the compressor is $5,360 \text{ Btu/lb-mol}^{-1}$.

What is the heat transfer rate from the compressor in Btu/hr^{-1} ?

Additional Information:

$$H_1 = 307 (\text{Btu})(\text{lb}_m)^{-1} \text{ and } V_1 = 9.25 (\text{ft})^3 (\text{lb}_m)^{-1}$$

$$H_2 = 330 (\text{Btu})(\text{lb}_m)^{-1} \text{ and } V_2 = 0.28 (\text{ft})^3 (\text{lb}_m)^{-1}$$

Problem 2.28

Nitrogen flows at steady state through a horizontal, insulated pipe with an inside diameter of 1.5 inches. A pressure drop results from flow through a partially opened valve. Just upstream from the valve, the pressure is 100 psia, the temperature is 120 °F, and the average velocity is 20 ft/s. If the pressure just downstream from the valve is 20 psia, what is the temperature? Assume for nitrogen that PV/T is constant, with $C_v=(5/2)R$, and $C_p=(7/2)R$. (Values of R are given in App. A)