

# CH365 Chemical Engineering Thermodynamics

## Lesson 7

### Enthalpy, Heat Capacity, and Open Systems – Part 2

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# Measures of Flow

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

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

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

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

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

$M$  = molar mass

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

$$\dot{m} = uA\rho \quad A = \text{cross-sectional area} = \frac{\pi D^2}{4} \quad \rho = \text{density} = \frac{1}{V} [=] \frac{\text{kg}}{\text{m}^3}$$

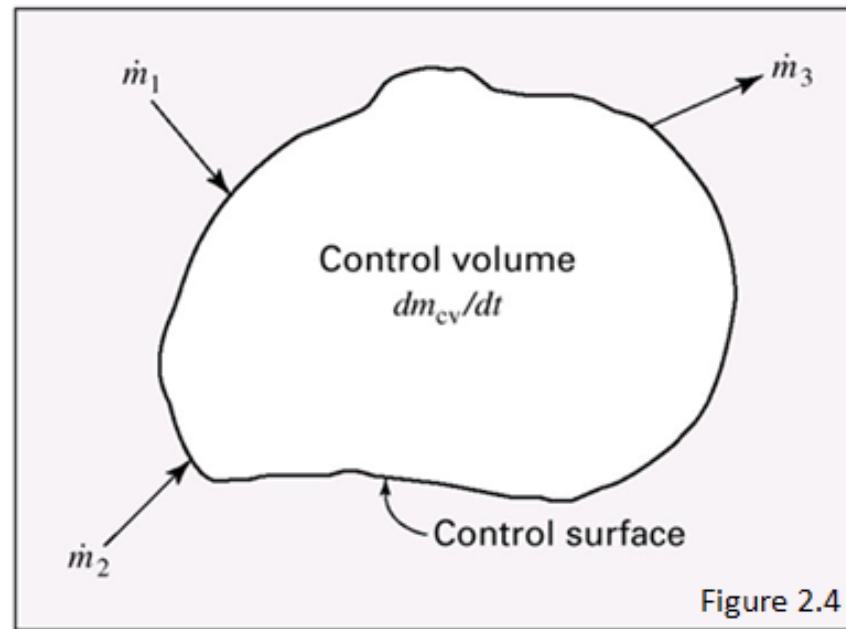
2.23a

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

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

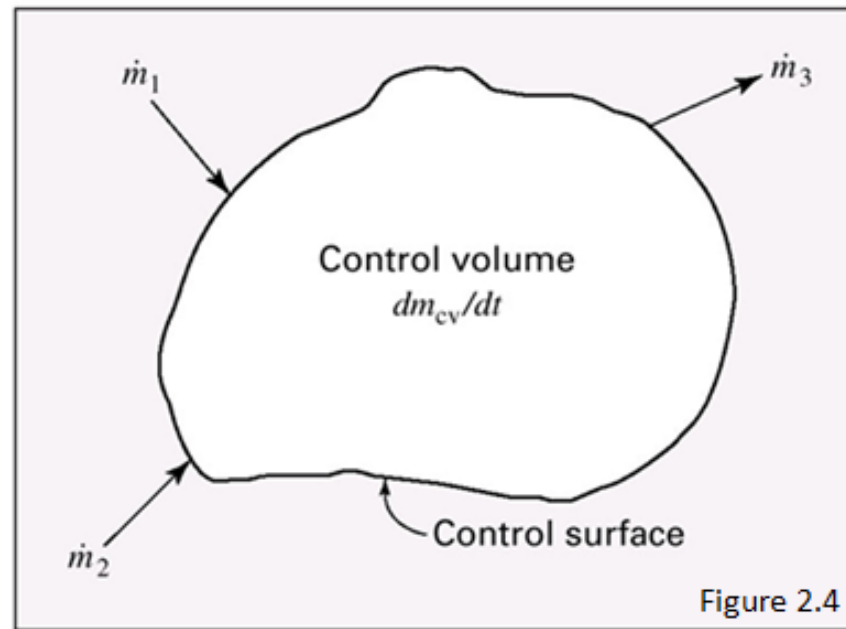
2.23b –  $M$  is missing on p. 47

# Equation of Continuity



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

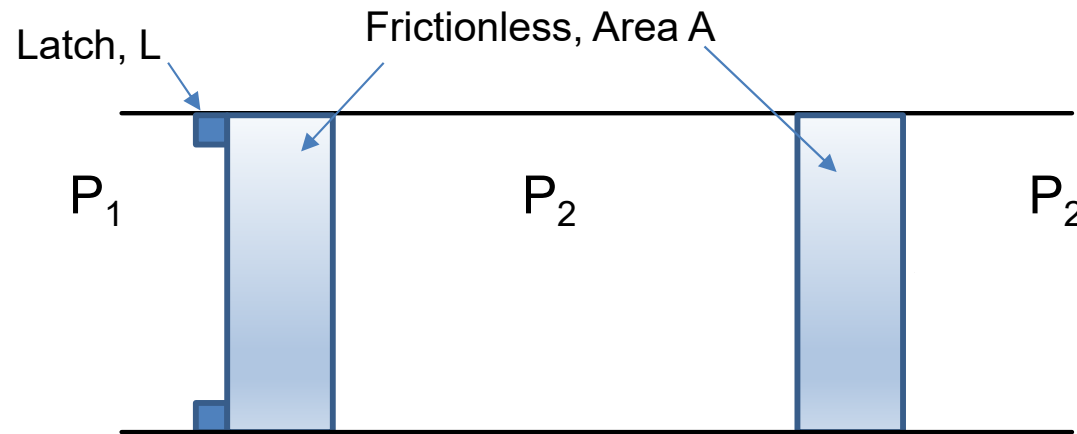
# Mass Balance for Open Systems



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

$$P_2 > P_1$$

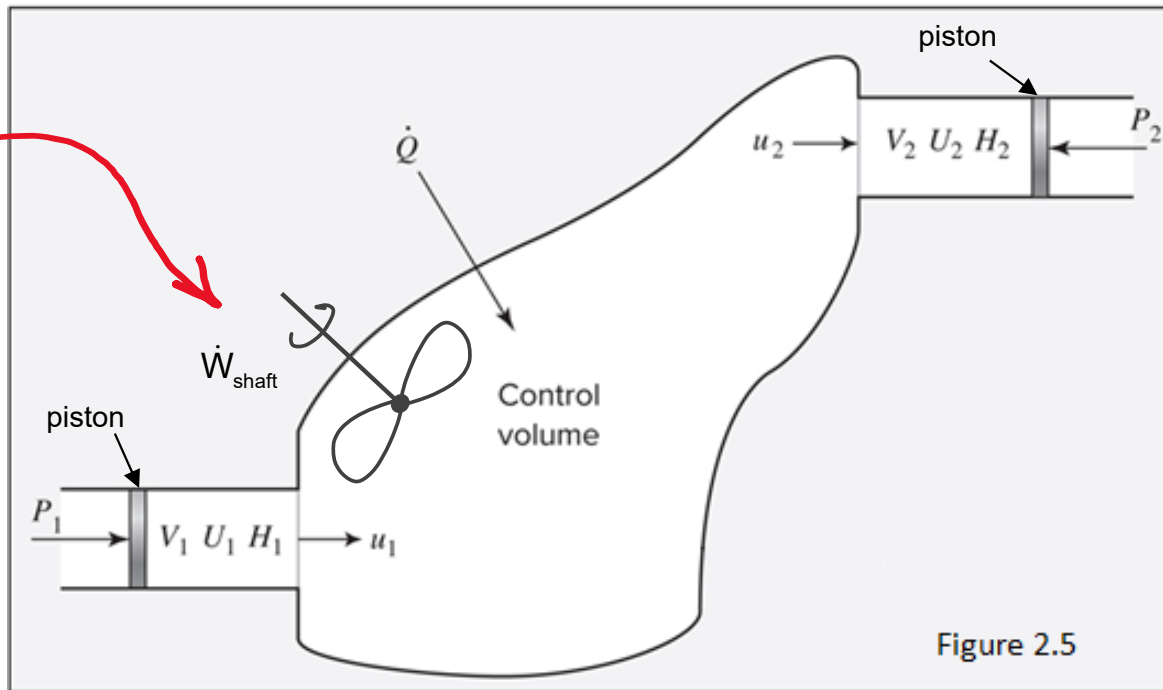
Static equilibrium  
(all forces balanced)

# 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

## Problem 2.38

Carbon dioxide gas enters a water-cooled compressor at conditions  $P_1 = 15$  (psia) and  $T_1 = 50$  (degF), and is discharged at conditions  $P_2 = 520$  (psia) and  $T_2 = 200$  (degF). The entering  $\text{CO}_2$  flows through a 4-inch-diameter pipe with a velocity of  $20 \text{ (ft) (s)}^{-1}$ , 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  $\text{(Btu) (hr)}^{-1}$ ?

Additional Information:

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

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





## Problem 2.28

Nitrogen flows at steady state through a horizontal, insulated pipe with inside diameter of 1.5 (in). 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 (degF), and the average velocity is  $20 \text{ (ft)(s)}^{-1}$ . If the pressure just downstream from the valve is 20 (psia), what is the temperature? Assume for nitrogen that  $PV/T$  is constant,  $C_v = (5/2)R$ , and  $C_p = (7/2)R$ . (Values of  $R$  are given in App. A.)