CH365 Chemical Engineering Thermodynamics

Lesson 7
Enthalpy, Heat Capacity, and Open Systems – Part 2

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Measures of Flow

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

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

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

sometimes v
(lower case)

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

$$\dot{m} = M\dot{n} \qquad M = \text{molar mass} \qquad \text{e.g., } \frac{kg}{s} = \frac{kg}{kmol} \cdot \frac{kmol}{s}$$

$$\dot{m} = uA\rho$$

2.23a

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

V is specific or
molar volume
(upper case)

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

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

2.23b – M is missing on p. 47

Mass Balance for Open Systems

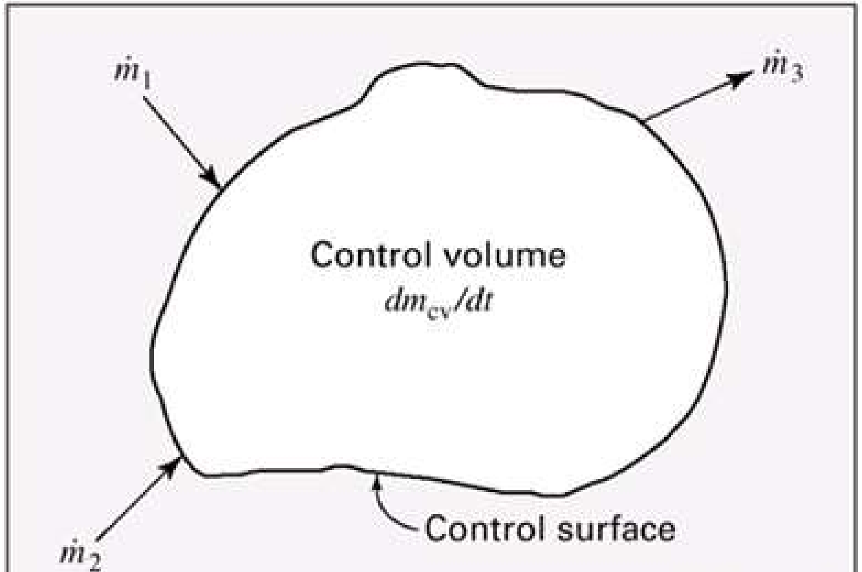


Figure 2.4

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

Mass Balance for Open Systems

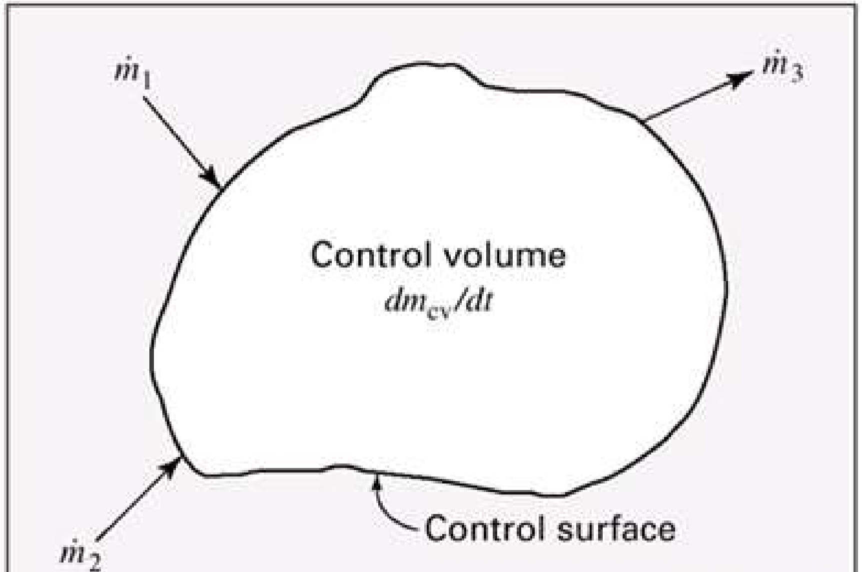


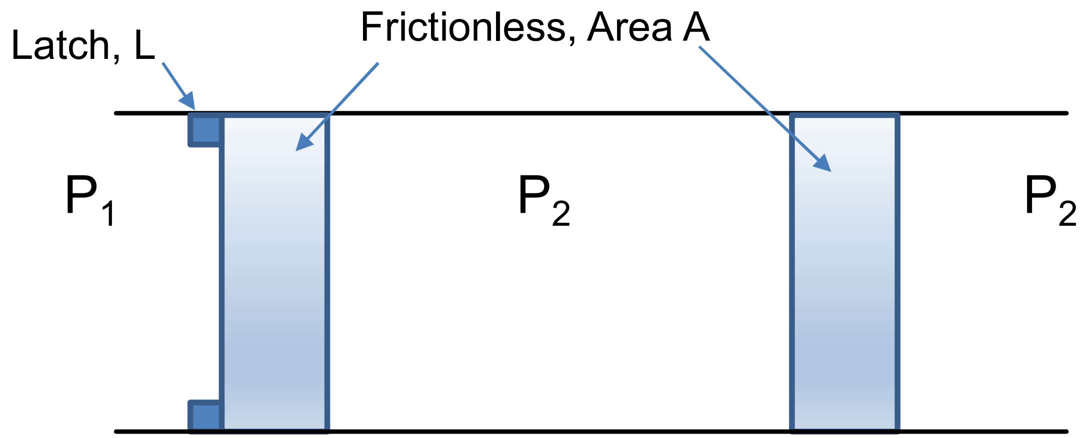
Figure 2.4

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"

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

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?

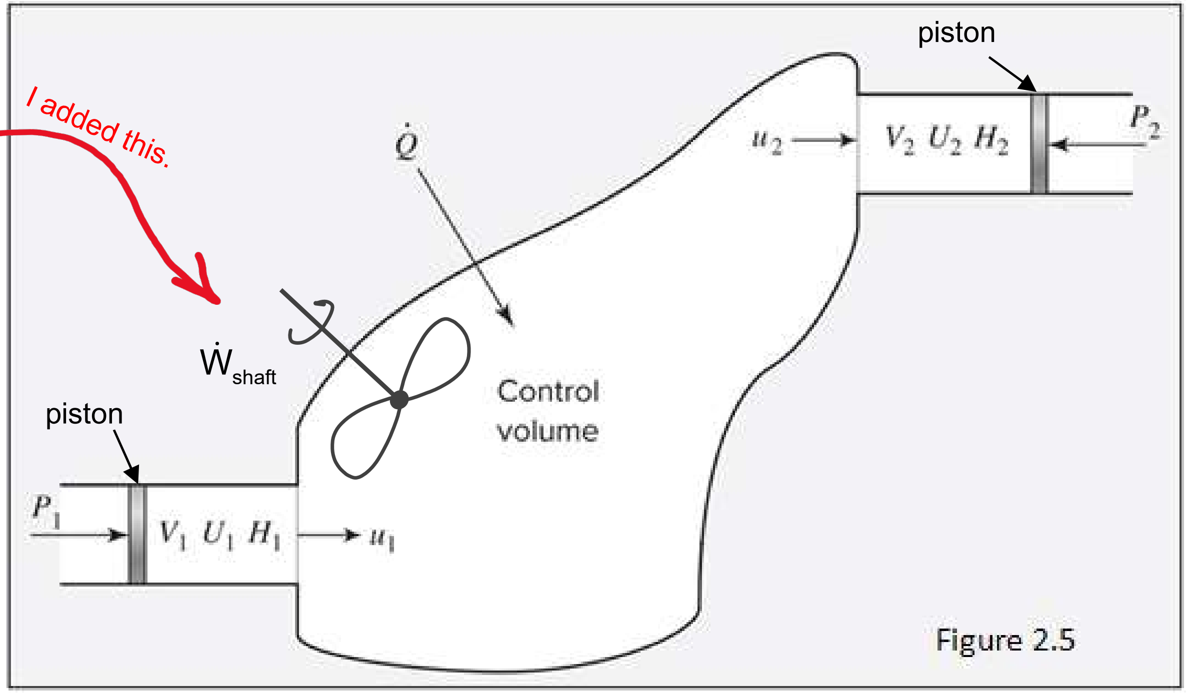


Figure 2.5

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: $$\Delta H+\frac{\Delta\left(u^2\right)}{2}+g\Delta z=Q+W_S$$

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

2.31

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

all properties are energy per mass

$$\frac{\dot{Q}}{\dot{m}}=Q \qquad \frac{\dot{W}_S}{\dot{m}}=W_S$$

$$\Delta H=Q+W_S$$

2.32

Ignoring kinetic and potential energy changes

Questions?

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)

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 $Btu/lb\text{-}mol^{-1}$.

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

Additional Information:

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

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