CH365 Chemical Engineering Thermodynamics

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

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Measures of Flow

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

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

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

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

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

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

2.23a

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

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

2.23b – M is missing on p. 47

Equation of Continuity

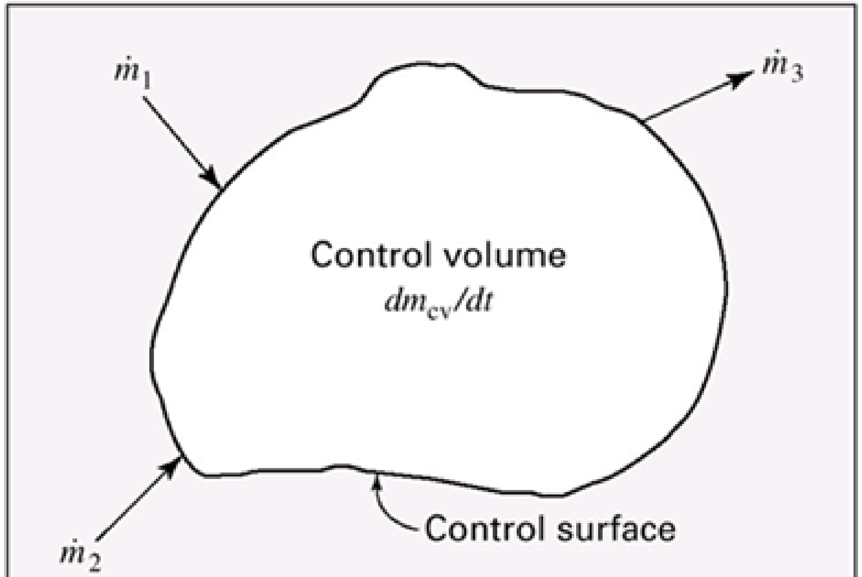


Figure 2.4

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

Mass Balance for Open Systems

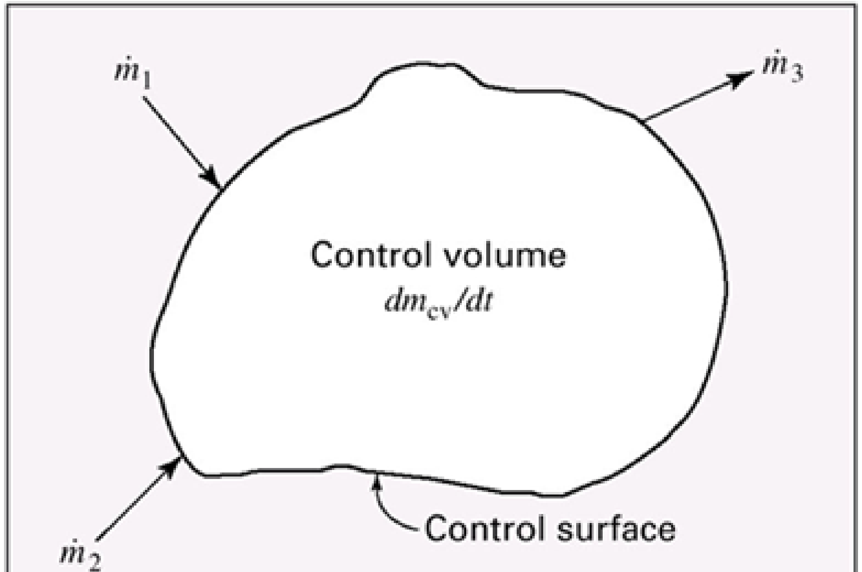


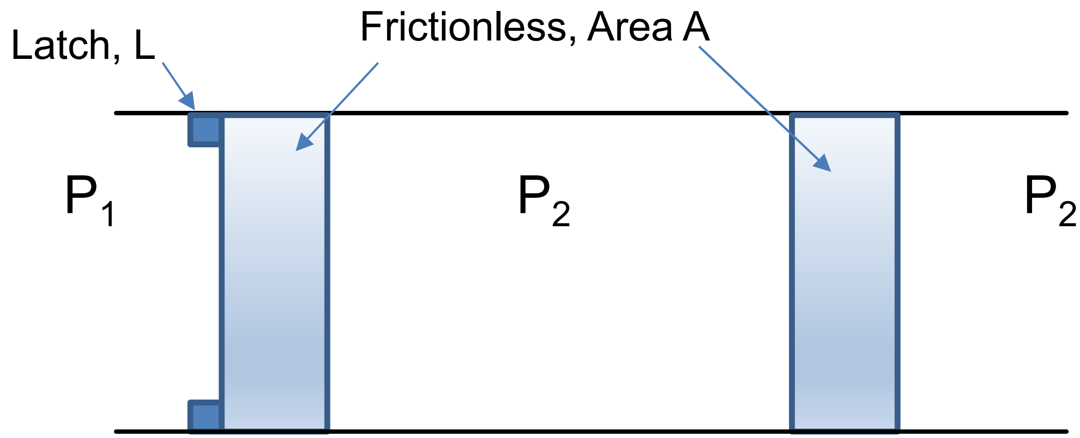
Figure 2.4

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?

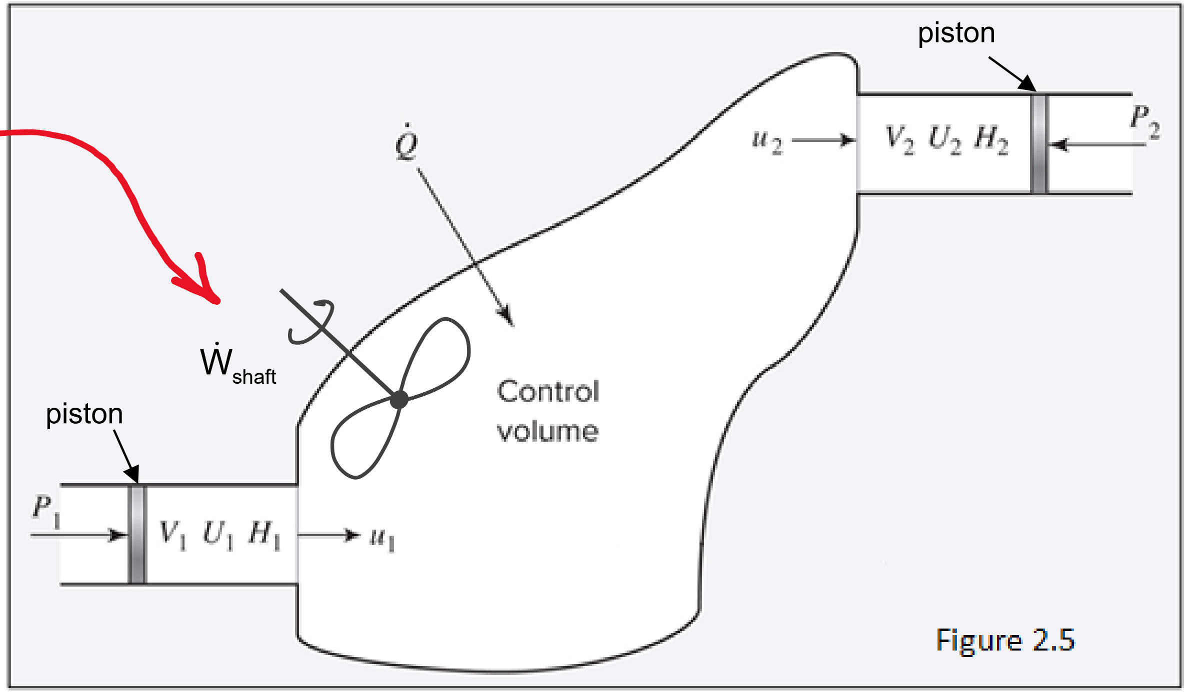


Figure 2.5

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

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 CO_2 flows through a 4-inch-diameter pipe with a velocity of 20 (ft) $(s)^{-1}$, and is discharged through a 1-inch-diameter pipe. The shaft work supplied to the compressor is 5,360 (Btu) $(\text{lb mol})^{-1}$. What is the heat-transfer rate from the compressor in (Btu) $(\text{hr})^{-1}$?

Additional Information:

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

$H_2 = 330\ (\text{Btu})\ (\text{lb}_m)^{-1}$ 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 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 (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, Cv=(5/2)R, and Cp=(7/2)R. (Values of R are given in App. A.)

Old Slides – Not Used

Flow Calorimeter

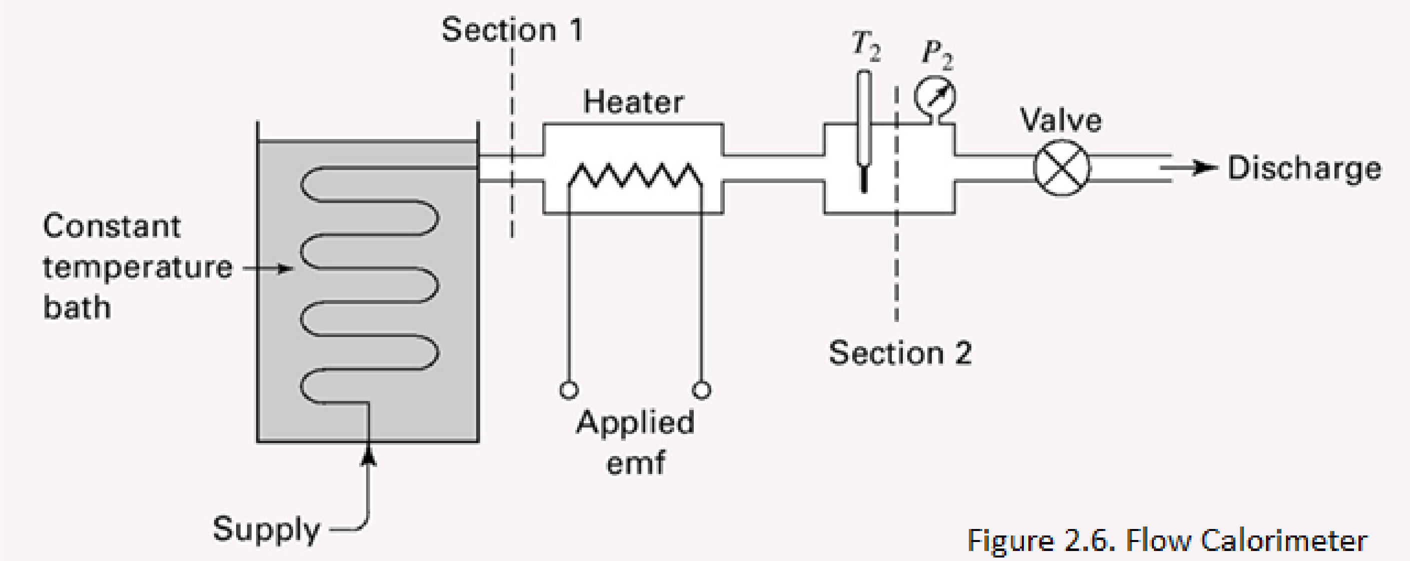


Figure 2.6. Flow Calorimeter

Designed for minimum velocity and elevation changes from 1 to 2.

$$\Delta H + \cancel{\frac{\Delta u^2}{2}} + \cancel{g\Delta z} = Q + W_S$$

$$\Delta H = H_2 - H_1 = Q$$

$$\Delta H = H_2 - H_1 = Q$$

$$H_2 = H_1 + Q = 0 + Q$$

Used to generate steam tables.

Example 2.12

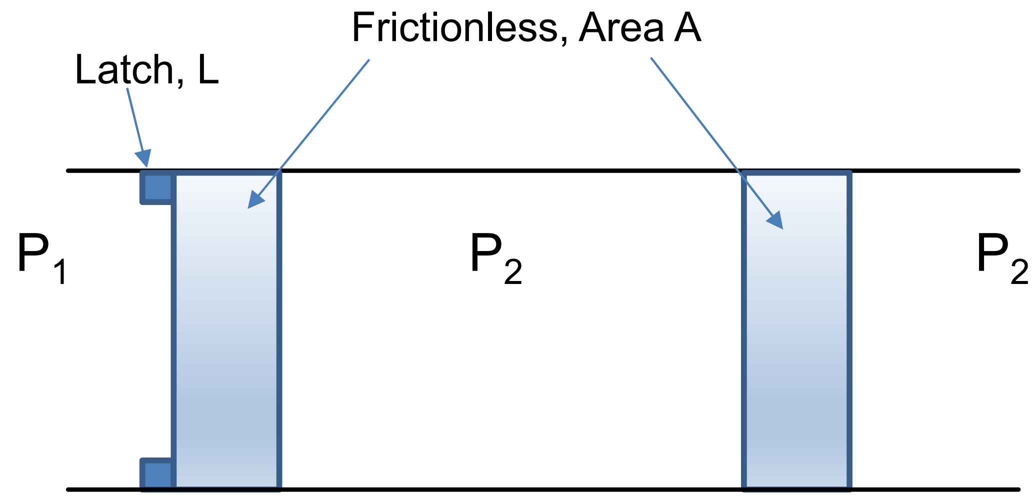
For the flow calorimeter in Figure 2.6, the following data are taken with water as the test fluid:

Flow rate = 4.15 g s^{-1} T_1 = 0 °C T_2 = 300 °C P2 = 3 bar

Rate of heat addition from resistance heater = 12,740 W.

The water is completely vaporized in the process. Calculate the enthalpy of the steam at 300 °C and 3 bar based on H=0 for liquid water at 0 °C.

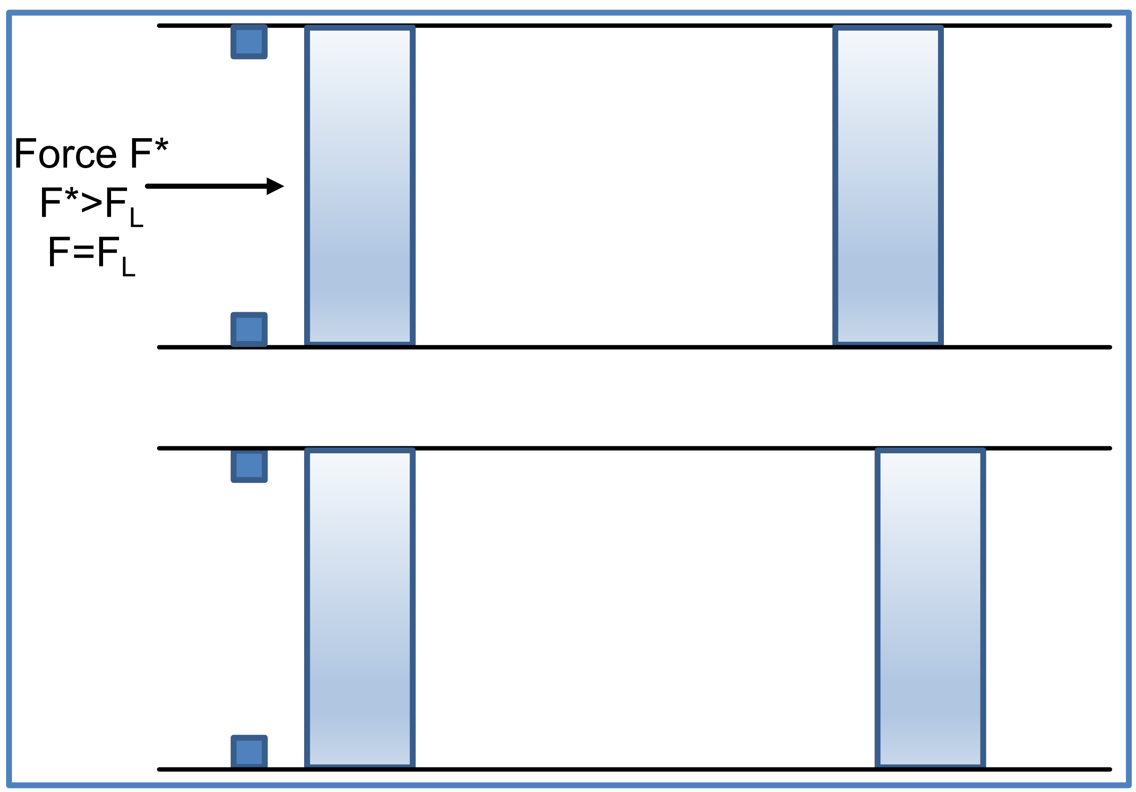
Frictionless "Double Piston"



Reversible

$P_2 > P_1$

Static equilibrium
(all forces balanced)



General Energy Balance

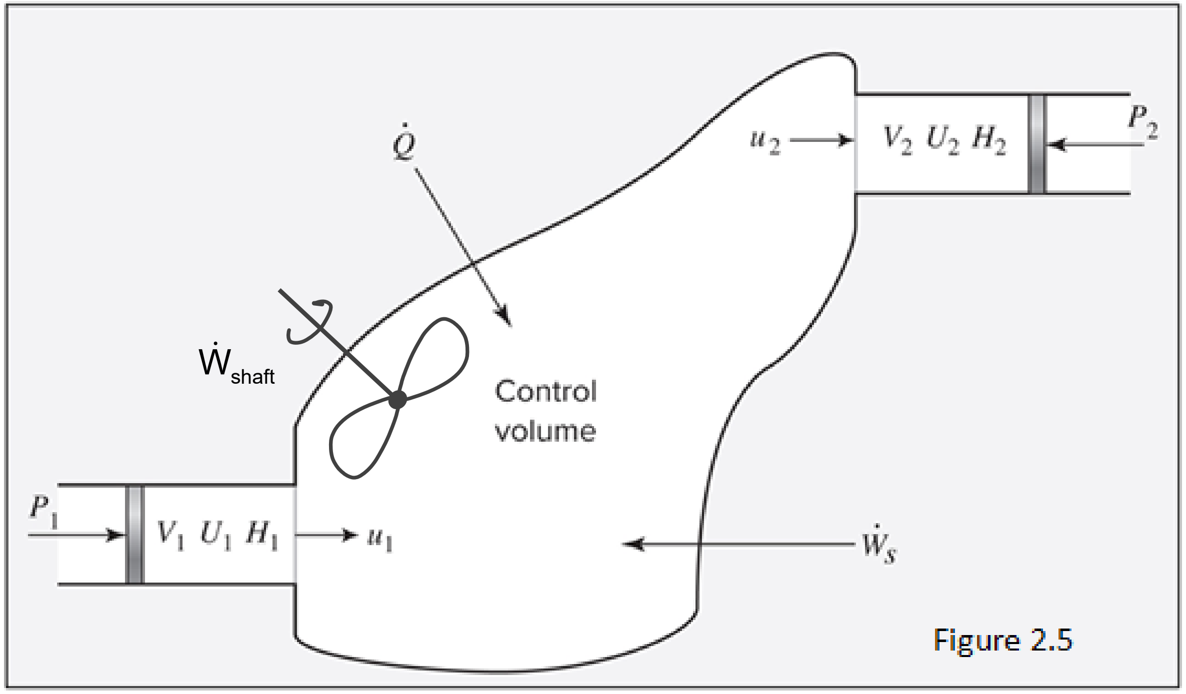


Figure 2.5