Lecture 5

Topic 2

First Law of Thermodynamics

Topics

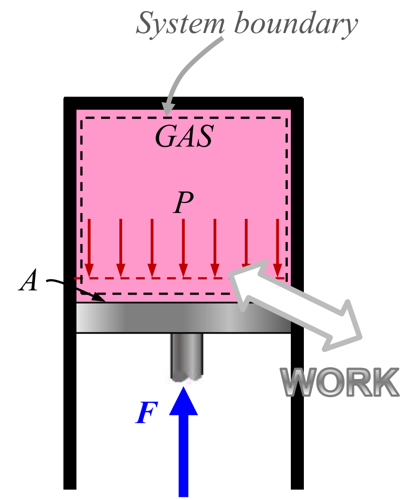
– **2.3 First Law analysis of closed systems**

Reading:
Ch 3.7-3.8 Borgnakke & Sonntag Ed. 8
Ch 4 Cengel and Boles Ed. 5

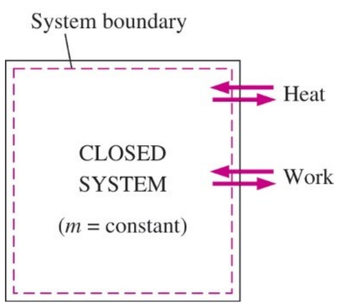
2.3 Energy analysis of closed systems

- First law of thermodynamics

$$\underbrace{\Delta U \;+\; \Delta KE \;+\; \Delta PE}_{total\ change\ of\ energy\ of\ system} = \underbrace{Q_{net} - \; W_{net} + \left(E_{mass,in} - E_{mass,out}\right)}_{Energy\ transfer\ by\ heat,work,mass}$$



  - Sign convention:
    - Heat/work TO the system is energy ENTERING the system.
    - Heat/work BY the system is energy LEAVING the system.
  - In above equation:
    - $Q_{net} = (Q_{in} - Q_{out})$
    - $W_{net} = (W_{out} - W_{in})$
  - Closed system: $\Delta E_{mass} = 0$ (no mass exchange).



2.3 Energy analysis of closed systems

- First law of thermodynamics:

$$\Delta U + \Delta KE + \Delta PE = Q_{net} - W_{net} + \left(E_{mass,in} - E_{mass,out}\right)$$

- Internal Energy (U)
  - Energy contained within molecules of the system
  - $U = mu;\ \Delta U = m(u_2 - u_1)$
  - Intensive property: (u) – can be used to help define the thermodynamic state
  - Use tables to determine u value
    - E.g. saturated liquid-vapor: $U = mu = m_{liq}u_f + m_{vap}u_g$ (i.e. $u = u_f + xu_{fg}$)
    - If superheated vapor or compressed liquid, use entries directly from table

Saturated liquid-vapor

Temp. (°C)	Press. (kPa)	Internal Energy, kJ/kg Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapor u_g
0.01	0.6113	0	2375.33	2375.33
5	0.8721	20.97	2361.27	2382.24
10	1.2276	41.99	2347.16	2389.15
15	1.705	62.98	2333.06	2396.04
20	2.339	83.94	2318.98	2402.91
25	3.169	104.86	2304.90	2409.76

Superheated Vapor

Temp. (°C)	v (m³/kg)	u (kJ/kg)	h (kJ/kg)
	800 kPa (170.43°C)		
700	0.56007	3476.22	3924.27
800	0.61813	3661.14	4155.65
900	0.67610	3852.77	4393.65
1000	0.73401	4051.00	4638.20
1100	0.79188	4255.57	4889.08
1200	0.84974	4466.05	5145.85

Compressed Liquid

Temp. (°C)	v (m³/kg)	u (kJ/kg)	h (kJ/kg)
	500 kPa (151.86°C)		
Sat.	0.001093	639.66	640.21
0.01	0.000999	0.01	0.51
20	0.001002	83.91	84.41
40	0.001008	167.47	167.98
60	0.001017	251.00	251.51
80	0.001029	334.73	335.24

Example 2.2 - 1st Law applied to a closed system

A rigid container has 0.75 kg water at 300^{o}C, 1200 kPa. The water is now cooled to a final pressure of 300 kPa. Find:

(a) The work involved in this process

(b) The heat transfer involved in this process

(c) The final temperature

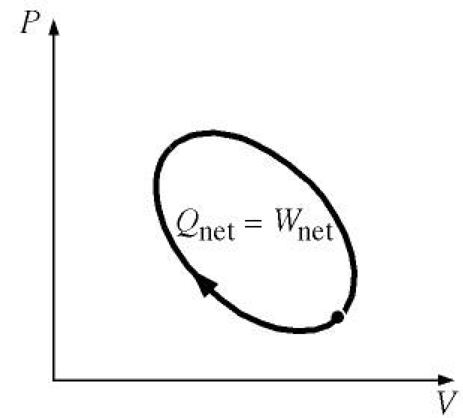
(d) Assume a liquid trap exists that can remove liquid after the process. How much mass would be removed?

Solution:

2.3.1 Closed system cycle

Thermodynamic cycle

- Set of processes that cause the working fluid to undergo a series of state changes such that the final and initial states are identical.
- The change in internal energy of the working fluid is ZERO for a cycle.



Process vs Cycle: Stationary, closed systems

- Process: $Q_{process} - W_{process} = \Delta U_{process}$
- Cycle: $Q_{cycle} - W_{cycle} = 0 \rightarrow Q_{net,cycle} = W_{net,cycle}$

Example 2-3

Complete the table below for a closed, stationary system undergoing a cycle.

$$Q_{net} - W_{net} = \Delta U$$

$$\Delta U_{cycle} = 0$$

Process	Q_{net} kJ	W_{net} kJ	ΔU kJ
1-2	+5		-5
2-3	+20	+10	
3-1	-5		
Cycle			

2.3.1 Closed system cycle

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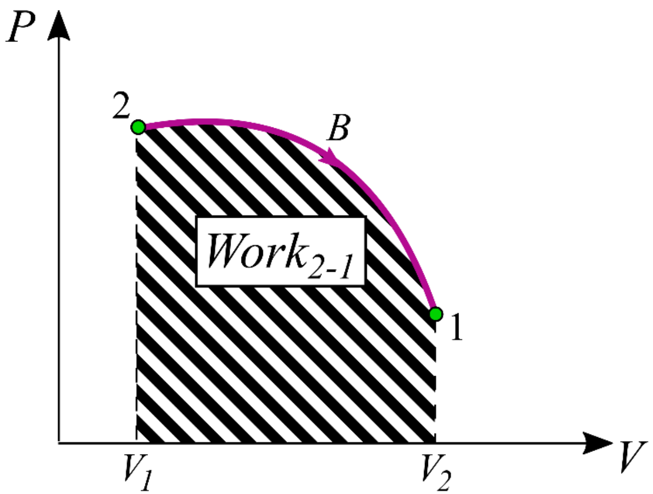
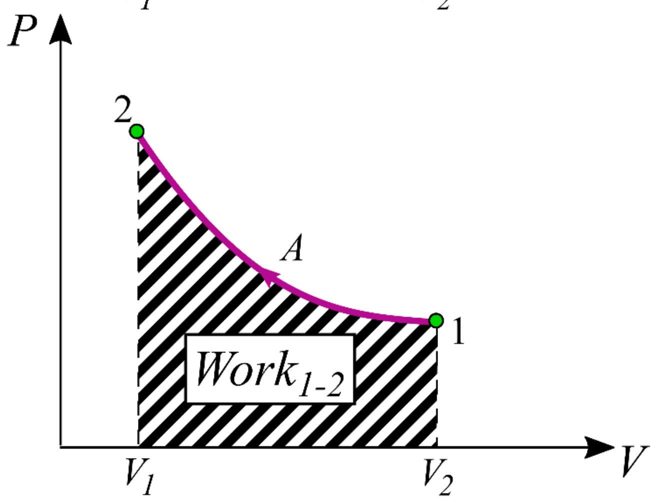
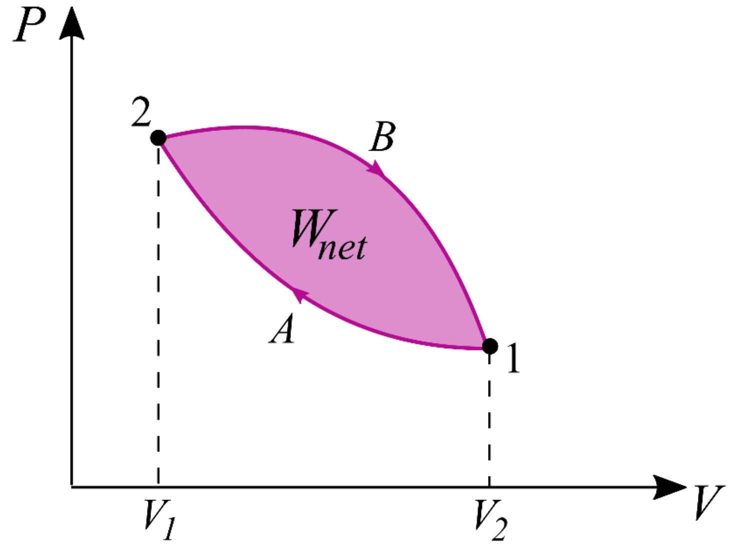
Net work done during a cycle

- $W_{net,cycle} = W_{process:\,1-2} + W_{process:\,2-1} + \cdots$







$W_{net,\,cycle}$: difference between the work done by the system and the work done on the system.

2.3.2 Systematic solution procedure

Methodical solution procedure

1. Define & Sketch the System
   a. Show energy crossing system boundaries
2. Define processes
   a. E.g. constant volume / pressure / temperature / mass, adiabatic, etc.
3. For each process, determine the thermodynamic states
   a. Find thermodynamic variables at each state.
   b. Pure substance (e.g. water, refrigerant) → use thermodynamic tables
   c. Ideal gas → $PV = mRT$
4. For each process, sketch the process diagram
   a. E.g. P-v, T-v
5. For each process, develop enough equations for the unknowns
   a. Solve 1st law, conservation of mass (lecture 8), and 2nd law of thermodynamics (topic 3)

2.3.3 Closed System Example

Example 2-3

A piston-cylinder device contains 1 kg of water at 100°C. The piston rests on lower stops where the volume is 0.835 m^3. The cylinder has an upper set of stops. When the piston rests against the upper stops, the volume reaches 0.9 m^3. A pressure of 175 kPa is required to move the piston. Heat is added to the water until the water exists as a saturated vapor. Does the piston touch the upper stops? How much work is involved in this process?

Solution: