CHAPTER

5

MEC Thermodynamics

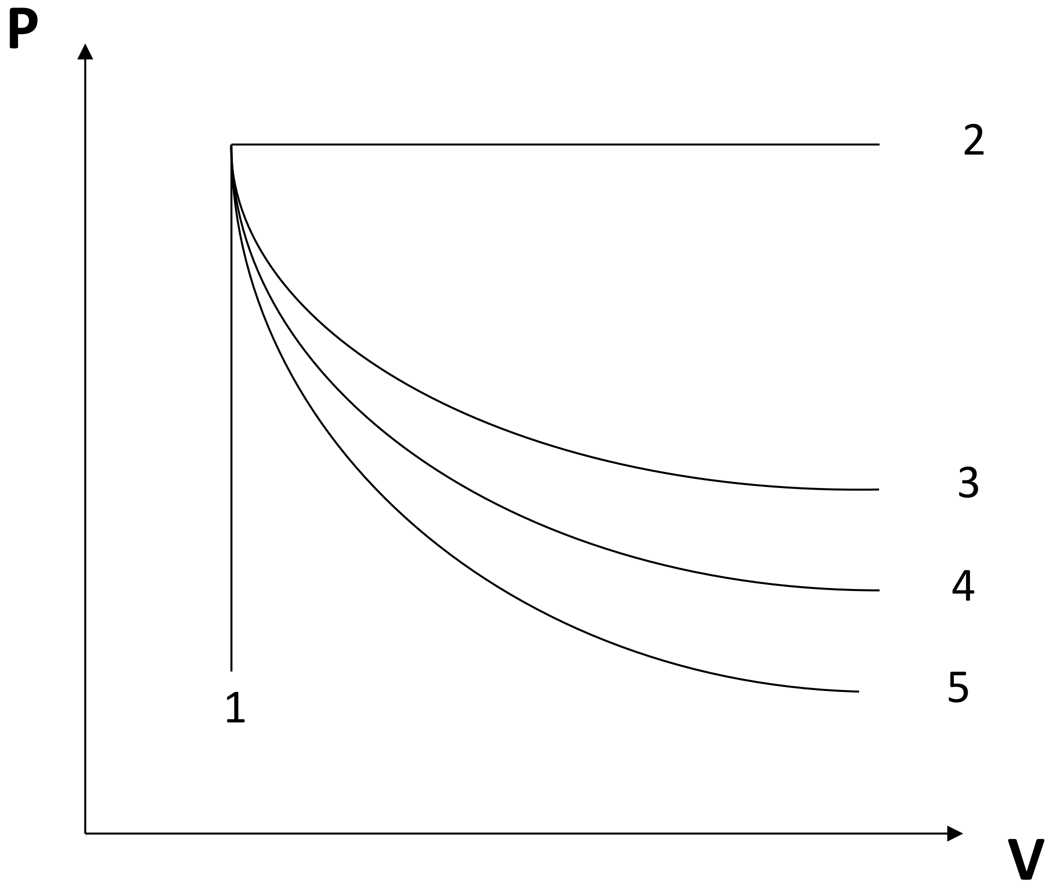
Closed System First Law of a Cycle

- Some thermodynamic cycle composes of processes in which the working fluid undergoes a series of state changes such that the final and initial states are identical.
- For such system the change in internal energy of the working fluid is zero.
- The first law for a closed system operating in a thermodynamic cycle becomes

$$Q_{net} - W_{net} = \Delta U_{cycle}$$

$$Q_{net} = W_{net}$$

Boundary Works



According to a law of $PV^n = \text{constant}$

No	Value of n	Process	Description	Result of IGL
1	∞	iso***cho***ric	constant volume ($V_1 = V_2$)	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
2	0	iso***bar***ic	constant pressure ($P_1 = P_2$)	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
3	1	iso***thermal***	constant temperature ($T_1 = T_2$)	$P_1V_1 = P_2V_2$
4	$1<n<\gamma$	polytropic	-none-	$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n = \left(\frac{T_1}{T_2}\right)^{\frac{n}{n-1}}$
5	γ	i***sentropi***c	constant entropy ($S_1 = S_2$)	

- Various forms of work are expressed as follows

Process	Boundary Work
iso***cho***ric	$W_{12} = P(V_2 - V_1) = 0$
iso***bar***ic	$W_{12} = P(V_2 - V_1)$
iso***thermal***	$W_{12} = P_1 V_1 \ln \frac{V_2}{V_1}$
polytropic	$W_{12} = \frac{P_2 V_2 - P_1 V_1}{1 - n}$
i***sentropi***c	

Example 3.4

Sketch a P-V diagram showing the following processes in a cycle

Process 1-2: isobaric work output of 10.5 kJ from an initial volume of 0.028 m^3 and pressure 1.4 bar,

Process 2-3: isothermal compression, and

Process 3-1: isochoric heat transfer to its original volume of 0.028 m^3 and pressure 1.4 bar.

Calculate (a) the maximum volume in the cycle, in m^3, (b) the isothermal work, in kJ, (c) the net work, in kJ, and (d) the heat transfer during isobaric expansion, in kJ.

Solution:

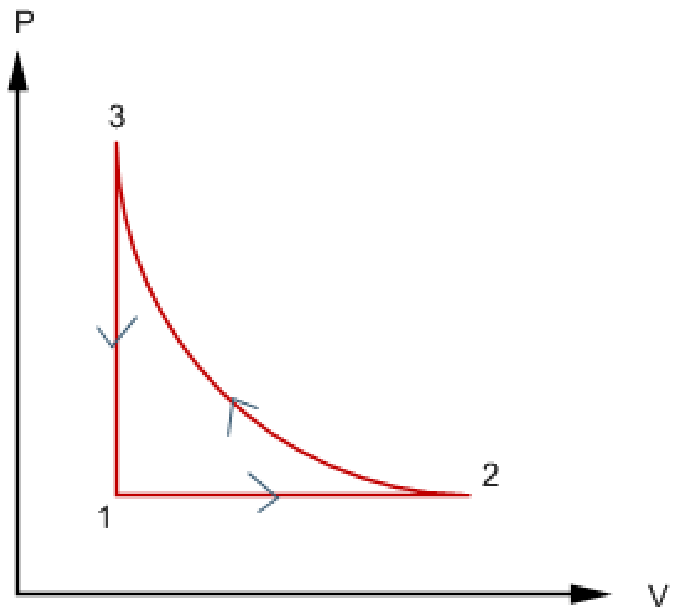
- Process by process analysis,

$$Section\ 1-2\,(isobaric)$$

$$W_{12} = P(V_2 - V_1) = 10.5$$

$$140(V_2 - 0.028) = 10.5$$

$$V_2 = 0.103\,m^3$$



- The isothermal work

$$Section\ 2-3\,(isothermal)$$

$$P_2V_2 = P_3V_3$$

$$P_3 = \left(\frac{0.103}{0.028}\right)(140) = 515\,kPa$$

$$\rightarrow W_{23} = P_2V_2 \ln\frac{V_3}{V_2}$$

$$= 140(0.103)\ln\left(\frac{0.028}{0.103}\right)$$

$$= -18.78\,kJ$$

- The net work

$\text{Section } 3-1(\text{isochoric})$

$$W_{31} = 0$$

$$\therefore W_{net} = W_{12} + W_{23} + W_{31}$$

$$= 10.5 - 18.78$$

$$= \underline{\underline{-8.28\,kJ}}$$

Example 3.5

A fluid at 4.15 bar is expanded reversibly according to a law PV = constant to a pressure of 1.15 bar until it has a specific volume of 0.12 m^3/kg. It is then cooled reversibly at a constant pressure, then is cooled at constant volume until the pressure is 0.62 bar; and is then allowed to compress reversibly according to a law PV^n = constant back to the initial conditions. The work done in the constant pressure is 0.525 kJ, and the mass of fluid present is 0.22 kg. Calculate the value of n in the fourth process, the net work of the cycle and sketch the cycle on a P-V diagram.

Solution:

- Process by process analysis,

$Section\ 1-2\left(isothermal\right)$

$$P_1V_1 = P_2V_2$$

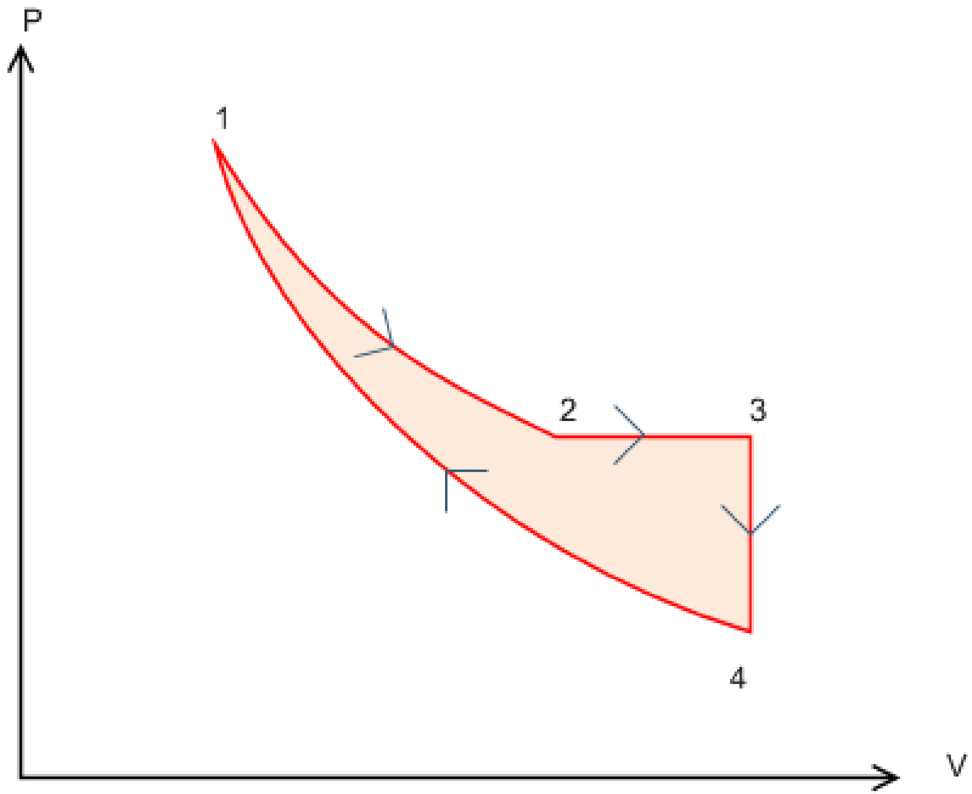
$$V_1 = \left(\frac{115}{415}\right)0.22\left(0.12\right)$$

$$= 0.00732\,m^3$$

$$W_{12} = P_1V_1 \ln\frac{V_2}{V_1}$$

$$= 415\left(0.00732\right)\ln\frac{0.0264}{0.00732}$$

$$= 3.895\,kJ$$



$Section\ 2-3(isobaric)$

$$W_{23} = P(V_3 - V_2) = 0.525\,kJ$$

$$V_3 = \frac{0.525}{115} + 0.0264$$

$$= 0.03097\,m^3$$

$Section\ 3-4(isochoric)$

$$W_{34} = 0$$

$Section\ 4-1(PolytroPic)$

$$\frac{P_4}{P_1} = \left(\frac{V_1}{V_4}\right)^n$$

$$\frac{62}{415} = \left(\frac{0.00732}{0.03097}\right)^n$$

$$\ln 0.1494 = n \ln 0.2364$$

$$n = \underline{\underline{1.3182}}$$

$$W_{41} = \frac{P_1V_1 - P_4V_4}{1-n}$$

$$= \frac{415(0.0072) - 62(0.03097)}{1-1.3182}$$

$$= -3.5124\,kJ$$

❖ The net work of the cycle

$$W_{net} = W_{12} + W_{23} + W_{34} + W_{41}$$

$$= \underline{\underline{0.9076\,kJ}}$$

Supplementary Problems 2

1. A mass of 0.15 kg of air is initially exists at 2 MPa and 350^{o}C. The air is first expanded isothermally to 500 kPa, then compressed polytropically with a polytropic exponent of 1.2 to the initial state. Determine the boundary work for each process and the net work of the cycle.

2. 0.078 kg of a carbon monoxide initially exists at 130 kPa and 120^{o}C. The gas is then expanded polytropically to a state of 100 kPa and 100^{o}C. Sketch the P-V diagram for this process. Also determine the value of n (index) and the boundary work done during this process.

[*1.248,1.855 k*J]

3. Two kg of air experiences the three-process cycle shown in Fig. 3-14. Calculate the net work.

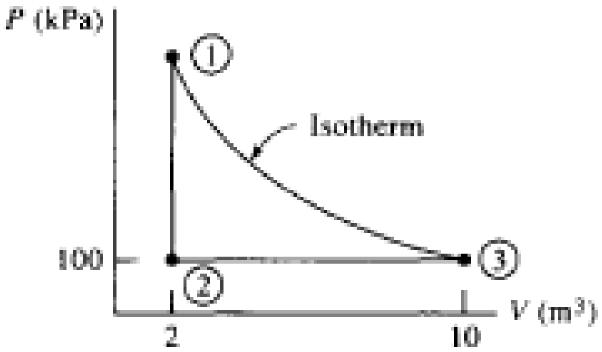


Fig. 3-14

4. A system contains 0.15 m^3 of air pressure of 3.8 bars and 150^0 C. It is expanded adiabatically till the pressure falls to 1.0 bar. The air is then heated at a constant pressure till its enthalpy increases by 70 kJ. Sketch the process on a P-V diagram and determine the total work done.

Use c_p=1.005 kJ/kg.K and c_v=0.714 kJ/kg.K