Thermodynamic Processes

- States of a thermodynamic system can be changed by interacting with its surrounding through work and heat. When this change occurs in a system, it is said that the system is undergoing a **process**.

- A thermodynamic **cycle** is a sequence of different processes that begins and ends at the same thermodynamic state.

- Some sample processes:
    - ➔ Isothermal process: temperature is constant T=C
    - ➔ Isobaric process: pressure is constant, P=C
    - ➔ Isentropic process: entropy is constant, s=C
    - ➔ Constant-volume process, v=C
    - ➔ Adiabatic process: no heat transfer, Q=0

Process-1

- Use ideal gas assumption (closed system):

→ Isothermal process: T=constant

Energy balance ΔU=Q-W, for ideal gas ΔU=ΔH=0

since both are functions of temperature only

$$\text{Q=W, W=}\int \text{P}dV = \int \frac{mRT}{V} dV = mRT\int_1^2 \frac{dV}{V}$$

$$= mRT\ln\left(\frac{V_2}{V_1}\right) = mRT\ln\left(\frac{P_1}{P_2}\right)$$

→ Isobaric process: P=constant

$$\Delta\text{U=Q-W, W=}\int \text{PdV=P}\int_1^2 \text{dV=P(V}_2 - V_1)$$

$$Q = \Delta U + P(V_2 - V_1) = (U_2 - U_1) + P(V_2 - V_1)$$

$$= (U_2 + PV_2) - (U_1 + PV_1) = H_2 - H_1 = \Delta H$$

Process-2

$\longrightarrow$ Constant volume process: V=constant

Q-W=ΔU, W=$\int PdV = 0,$ no work done

Q=ΔU=mΔu=m$\int \mathrm{c_v} dT$

$\longrightarrow$ Adiabatic process: Q=0

Q-W=ΔU, -W=ΔU

-δW=dU (infinitesimal increment of work and energy)

dU+PdV=0, $\mathrm{mc_v} dT + \left(\frac{mRT}{V}\right) dV = 0$

$c_v dT + \left(\frac{RT}{V}\right) dV = 0,\ \frac{c_v}{R}\frac{dT}{T} = -\frac{dV}{V},$ integrate and assume

$\mathrm{c_v}$ =constant

$$\frac{c_v}{R}\ln\left(\frac{T_2}{T_1}\right) = -\ln\left(\frac{V_2}{V_1}\right),\ \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{R/c_v} = \left(\frac{V_1}{V_2}\right)^{k-1}$$

Process-3

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1}$$, from ideal gas relation

PV=RT, $\left(\frac{V_1}{V_2}\right) = \left(\frac{T_1}{T_2}\right)\frac{P_2}{P_1}$, substitute

$$\frac{T_2}{T_1} = \left(\left(\frac{T_1}{T_2}\right)\left(\frac{P_2}{P_1}\right)\right)^{k-1}$$, multiply $\left(\frac{T_2}{T_1}\right)^{k-1}$ from both sides

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$, *and* $\left(\frac{P_2}{P_1}\right) = \left(\frac{V_1}{V_2}\right)^{k}$

Also $P_1V_1^{\mathrm{k}} = P_2V_2^{k}$ and $pV^{k} = cons\tan t$

For an ideal gas undergoing adiabatic process

Process-4

Polytropic Process: its P-V relation can be expressed as PV^n = constant, where n is a constant for a specific process

- Isothermal, T=constant, if the gas is an ideal gas then PV=RT=constant, n=1
- Isobaric, P=constant, n=0 (for all substances)
- Constant-volume, V=constant, V=constant$(P)^{(1/n)}$, n=∞ (for all substances)
- Adiabatic process, n=k for an ideal gas

$$P_1V_1^n = P_2V_2^n = PV^n$$

$$W = \int_1^2 PdV = \int_1^2 (P_1V_1^n)V^{-n}dV$$

$$= (P_1V_1^n)\int_1^2 V^{-n}dV = \frac{(P_1V_1^n)}{1-n}(V_2^{1-n} - V_1^{1-n}) = \frac{P_2V_2 - P_1V_1}{1-n}$$