Chapter - 1°

- $PV = nRT = mrT$ (n: N°Kmole; m: kg; $r = \frac{R}{H}$)
- $\delta Q = cdt \Rightarrow Q = mC\Delta T = NC\Delta T$ (C: specific heat (heat needed to change temp. by 1°); C: J/Kg°K; NC: J/Kmole)
- isochoric = constant Volume ; isobaric = constant pressure
- $\delta W = P_e dU$ → { Compression ⇒ $W > 0$. Expansion - detente ⇒ $W < 0$.
- at reversible since there's an infinitesimal change ⇒ $W = -\int P dU$.
- $\boxed{\delta Q + \delta W = dU} \Rightarrow \boxed{Q + W = \Delta U}$
- $\Delta U = m C_v \Delta T$; $\Delta H = m C_p \Delta T$.
- $\boxed{Q + \int v dp = \Delta H}$
- $R = C_p - C_v$.
- Isothermal: $W = -NRT \ln\left(\frac{V_2}{V_1}\right) = NRT \cdot \ln\left(\frac{P_2}{P_1}\right) = PV \ln\left(\frac{P_2}{P_1}\right)$.
- Adiabatic (no heat exchange): $PV^\gamma = cte$; $\gamma = \frac{C_p}{C_v}$
  - $TV^{\gamma-1} = cte$
  - $\frac{T^\gamma}{P^{\gamma-1}} = cte$.
  - $W = \frac{P_2V_2 - P_1V_1}{\gamma - 1}$
  - $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$.
- Isolated ⇒ $Q = 0$.

Formulas of ΔS: $dS \geq \frac{\delta Q}{T}$.

$$\Delta S = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right) = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

Isolated system: $dS \geq 0$
(rev. $dS = \frac{dQ}{T}$)
(irrev. $dS > \frac{dQ}{T}$).

in adiabatic ⇒ $\Delta S = \frac{Q}{T} = 0$.

• Polytropic transformation: $PV^n = cte.$

$$n = \frac{C - C_p}{C - C_v} \quad ; \quad C = \frac{n-\gamma}{n-1} C_v = \frac{n-\gamma}{\gamma-1} C_p.$$

$$W = \frac{P_2V_2 - P_1V_1}{n-1} \quad ; \begin{cases} Q = \frac{n-\gamma}{n-1} \Delta U \\ Q = \frac{n-\gamma}{\gamma-1} W. \end{cases}$$

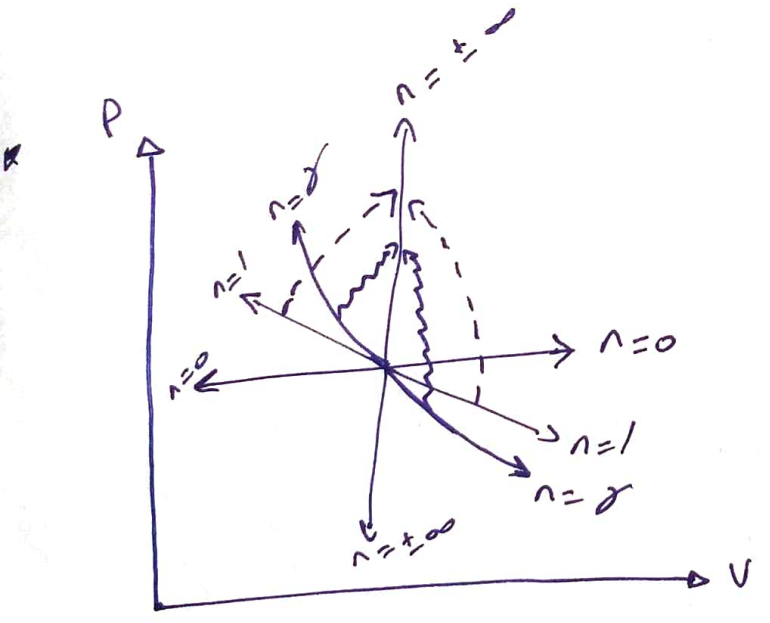
Conclusion:

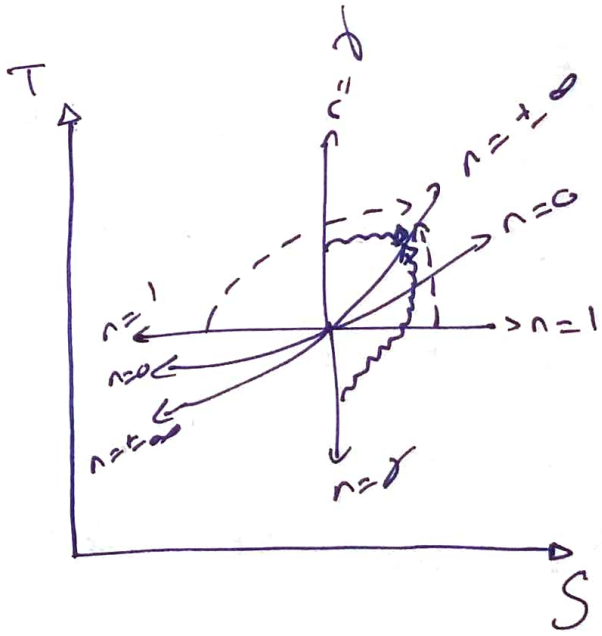
$n=1 \Rightarrow PV = cte \Rightarrow$ isothermal $\Rightarrow C \to \pm\infty$ ($t = cte$)

$n=0 \Rightarrow P = cte \Rightarrow$ isobaric $\Rightarrow C = C_p$

$n=\gamma \Rightarrow PV^\gamma = cte \Rightarrow$ adiabatic $\Rightarrow C = 0$

$n \to \pm\infty \Rightarrow V = cte \Rightarrow$ isochoric $\Rightarrow C = C_v.$





• Compression for $n > \gamma$ or detente for $n < \gamma \Rightarrow S \nearrow \Rightarrow Q > 0.$

• Compression for $n > 1$ or detente for $n < 1 \Rightarrow T \nearrow \Rightarrow \Delta U > 0$

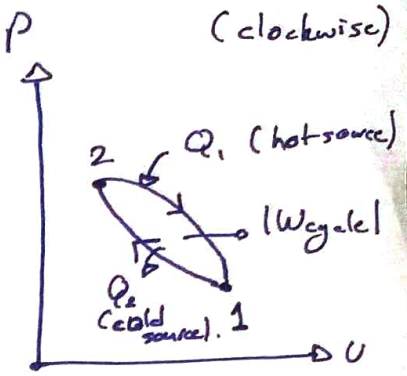
Note:

• Any Area on P-V diagram $\Rightarrow$ Work.

• " " " T-S " $\Rightarrow$ heat

* **Cycles:**

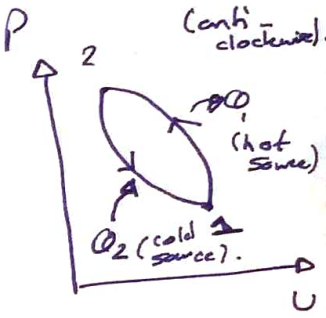
- **Thermal Cycle:**
  - Work of detante > Work of Compression
  - Q_1 : heat gained for hot source.
  - Q_2 : heat given from cold source
  - $|W_{cycle}| = Q_1 - |Q_2|$.



$\Rightarrow$ Cycle's efficiency $= \eta_{th} = \frac{|W_{cycle}|}{Q_1}$

- **Refrigeration Cycle:**
  - expansion Work < Compression Work.
  - Q_1 : heat transfered to hot source.
  - Q_2 : heat taken from cold source.
  - $W_{cycle} = Q_1 - Q_2$

$\Rightarrow$ Performance Coefficient : $e = \frac{Q_2}{W_{cycle}}$



* **Calculation of Work & ΔS in irreversible transformations:**

(non-quasistatic $\Rightarrow$ irreversible).

- $W = -P_e(V_f - V_0) = -P_f(V_f - V_0)$. ($W_{rev} < W_{irreversible}$)
- **Thermostat:** Remains Temp. constant (system not isolated).
- To calculate ΔS, we imagine that it's reversible btw initial & final state.

$Q + W = \Delta U = 0 \Rightarrow Q = -W$

$$\Delta S = \frac{Q}{T_0} = \frac{-W}{T_0} = \frac{-nRT_0 \ln(\frac{P_2}{P_1})}{T_0} = -nR\ln(\frac{P_2}{P_1}) < 0$$

(In non-isolated ΔS can be negative).

* **note:**

-- ch x 0.736 = -- Kw

* $\Delta S_{12} = nC\ln(\frac{T_2}{T_1})$

* 1 atm = 101.31 J
* 1 bar = 100 J.

* 1 bar = 10^5 Pa
* 4.184 J = 1 cal.
* 1 L = 1 dm^3
* 1 atm = 101325 Pa = 1.01325 bar
* J = Pa.m^3,

Chapter-2:

* In a mixture each gas occupies the entire Volume of the mixture and temp. of the mixture
* Total pressure of mixture = Σ Partial pressures of constituents. $= \Sigma P_i$.
* If we make $P_i = P_T$ for a constituent. → we get Volume $= V_i$ = Partial Volume of this constituent
* mass Composition: $g_i = \frac{m_i}{m_{total}}$; $\Sigma g_i = 1$. (Kg)
* Volume Composition: $v_i = \frac{N_i}{N}$; $\Sigma v_i = 1$. (Kmole)

$P_i = P \cdot v_i$; $V_i = V \cdot v_i$; $g_i = v_i \times \frac{M_i}{M}$ (M_i → Molar mass of Component, M → Total Molar mass.)

$r_i = \frac{R}{M_i}$

* apparent molar mass = $M = \frac{m}{N} = \frac{1}{\Sigma \frac{g_i}{M_i}} = \frac{m}{\Sigma N_i} = \Sigma v_i M_i$.

$g_i = v_i \times \frac{r}{r_i}$

* $r = \Sigma g_i \cdot r_i$; $= \frac{1}{\Sigma \frac{v_i}{r_i}}$

* $C = \Sigma v_i C_i$ (KJ/Kmol)
  $C = \Sigma g_i C_i$ (KJ/Kg)

* ideal mixture: $U = \Sigma N_i C v_i T$; $H = \Sigma N_i C p_i T$.

$$\begin{cases} \Delta U_{mixture} = \Sigma N_i C v_i \Delta t ; \\ \Delta H_{mixture} = \Sigma N_i C p_i \Delta t . \\ \Delta S_{mixture} = \Sigma N_i C_i . \ln\left(\frac{T_2}{T_1}\right) . \end{cases}$$

* Types of ideal gas mixing:

a) Constant Volume: No heat exchange → $\Delta U_{sys} = 0$.

$U = \Sigma U_i$ (U of mixture after mixing ; components before mixing)

$$T = \frac{\Sigma N_i . C v_i^\circ . T_i}{\Sigma N_i C v_i^\circ}$$

$T = \Sigma v_i T_i$ (if atoms of same atomicity (since Cv becomes same))

*Remark: when $NT = \Sigma N_i T_i$ (Same atomicity)

$\Rightarrow PV = \Sigma P_i V_i$

↘ Pressure and Volume before mixing (not partial P & V).

b) Constant Pressure: No heat exchange

(we use masses on pistons to maintain P = cte).

$\Rightarrow \boxed{\Delta H_{sys} = 0}$; $\boxed{H = \Sigma H_i}$

$\Rightarrow \boxed{T = \dfrac{\Sigma N_i C_{p_i} T_i}{\Sigma N_i C_{p_i}}}$

if Same atomicity (Same C_p) $\Rightarrow \boxed{T = \Sigma V_i T_i}$

. In this case, Part of energy in (PV) form transfers into internal energy (U)

c) Complete transformation of energy content of gas into internal energy:

(we don't put mass of final mixage piston, only on initial pistons).

. P = constant

$U = U_0 + \Sigma H_i$ (U_0: after, gas before) $\Rightarrow \boxed{T = T_0 . v_0 + \gamma \Sigma V_i T_i}$

(note: final temp higher than any temp of entering gases).

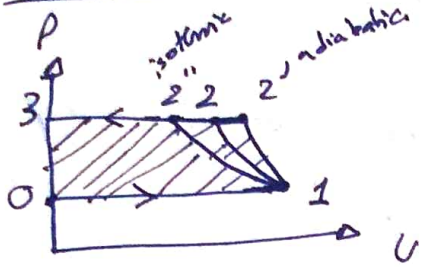
*Note:

* $P = \rho \cdot g \cdot h$
  b N/m^2 d $10\ m/s^2$
* $Kg_f = N/m$
* $N.m = J$.

*Remark:
when we calculate ΔS for a component in mixture we use partial pressure or partial volume.

✱ Chapter-3: les compresseur.

I) ✱ Thermal Work diagram:



0-1 : suction & filling of cylinder (P=cte).

1-2 : gass compression (2 values are lim.).

2-3 : discharge of compressed gas (P=cte).

- $W = \int_1^2 v\,dP$ (Compression Work of cycle)
  (theorichical comp. Work).

This work is called work with transfer.

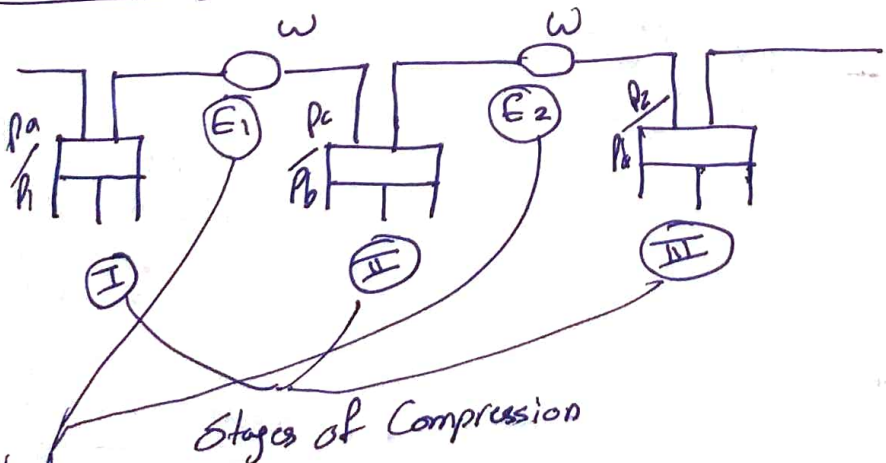
$W =$ → Isothermal: $W_{iso} = W_{12}$.
→ adiabatic: $W_{ad} = \gamma W_{12}$.
→ Polytropic: $W_{pol.} = n\, W_{12}$.

- General formula of Work:

$$W \equiv \frac{n}{n-1}(P_2V_2 - P_1V_1) \begin{cases} = \frac{n}{n-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right] \text{ KJ/cycle.} \\ = \frac{n}{n-1} R (T_2 - T_1) \text{ KJ/Kmol.} \\ = \frac{n}{n-1} r (T_2 - T_1) \text{ KJ/Kg} \end{cases}$$

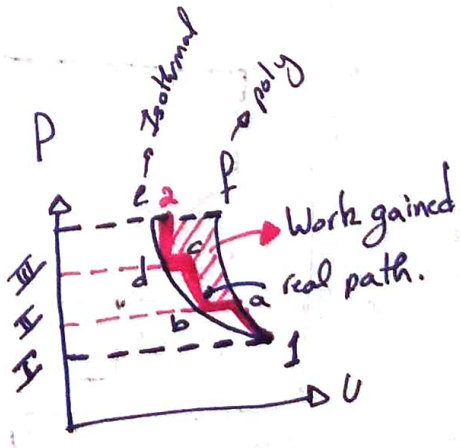
(nrT_1 or mrT_1)

✱ Multi-Stage Compression:



heat exchanger (intermediate cooling at the same pressure).

✱ $T_d = T_b = T_1$



- 1a, bc, d2 : Poly. comp. on stages I, II, III.
- ab, cd Isobaric Cooling

✱ note: We should'nt use many etages to prevent pressure loss while cooling ✱

• Compression on more than 1 etage (same ration $\frac{P_2}{P_1}$) gives us:

→ gain in Work of cycle.

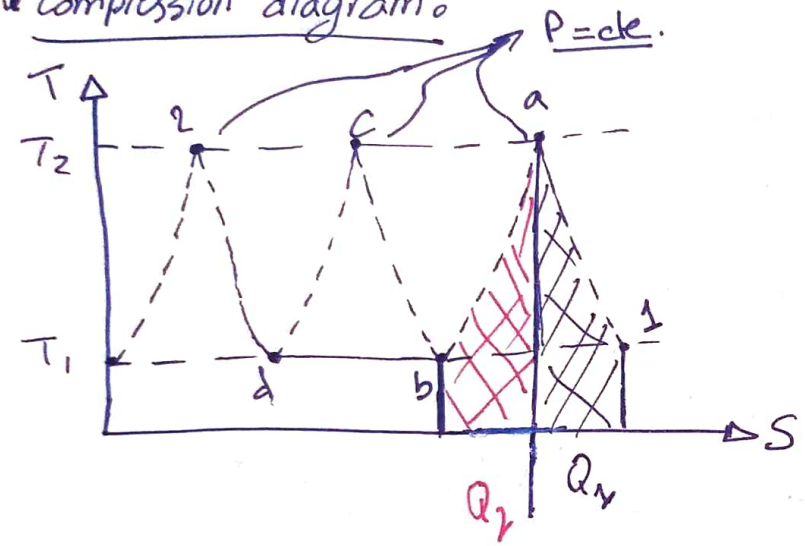
→ a lower temp. of compressed gas.

$\star\star \chi = \frac{P_a}{P_1} = \frac{P_c}{P_a} = \frac{P_2}{P_c}$ (same ratio of pressure) (to find best efficiency).

m: number of etages.

$\star \boxed{T_a = T_1 \left[\underbrace{\left(\frac{P_2}{P_1}\right)^{1/m}}_{\chi} \right]^{n-1/n}}$ $\qquad \boxed{\left(\frac{P_2}{P_1}\right)^{1/m} = \chi}$

$\star$ Compression diagram:



$\star Q_1$ = heat lost during polytropic compression.

$\boxed{Q_1 = C\Delta T}$

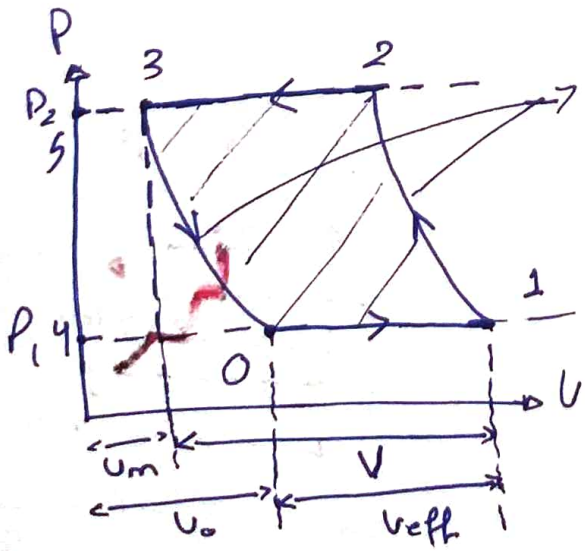
$= C_v \cdot \frac{n-\gamma}{n-1} \Delta T$ KJ/kg

$\star Q_2$ = heat lost during cooling of the 1st stage

$\boxed{Q_2 = C_p \Delta T}$

Note: if we have 10% decrease in pressure in exchanger we use $\chi = \left(\frac{P_2}{P_1 \times 0.9}\right)^{1/m}$ (0.9 times if exchanges) and compute as before

II) Compression Cycle with dead Volume (Volume mort):



PV^n = cte (not necessary same n).

3–o: detante of rise dual gas. (gas left as Um expands to Vo).

• in aspiration:

$\begin{cases} P_1 < P_a \\ T_1 > T_a \end{cases}$

$\star$ n_1: compression

$\star$ n_2: detante

* Percentage of Volume mort: $m = \frac{V_m}{V} \times 100\ \%$ (usually btw 2-15 %).

(Volume generated by piston when moving btw extremities)

* Veff: effective Volume actually billed btw opening and closing of Suction Valve.

$V_{eff} = V_m + V - V_o$.

* rendement Volumetrique (Volumetric efficiency): $\eta_v = \frac{V_{eff}}{V} = 1 - m\left[\left(\frac{P_2}{P_1}\right)^{1/n_2} - 1\right]$

* Work = $W = W_{comp} - W_{extension}$

$$= \frac{n_1}{n_1 - 1} \cdot P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n_1 - 1}{n_1}} - 1\right] - \frac{n_2}{n_2 - 1} P_2 V_o \left[\left(\frac{P_2}{P_1}\right)^{\frac{n_2 - 1}{n_2}} - 1\right]$$

* filling (remplissage) efficiency: $\eta_r = \eta_v \times \frac{P_1}{P_a} \times \frac{T_a}{T_1}$; P_a, T_a parameters of air atmosphere.

* Compressor Output (productivite): $V_{comp} = V \times \eta_r \times N$ or $V \times \eta_v \times N$

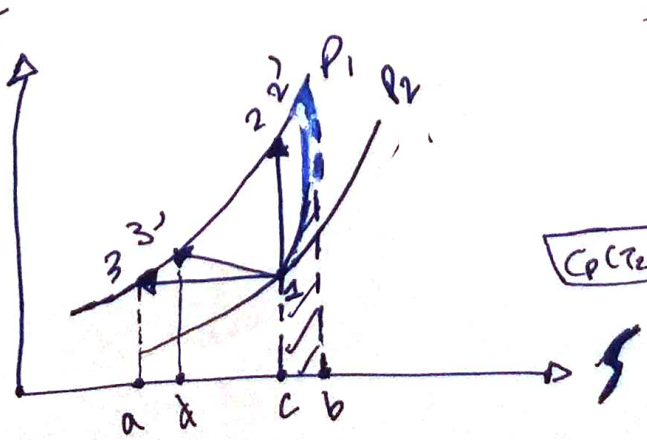
(m^3/s) (m^3/cycle) (tr/s) (cycle/s)

* Power: $P = W \times N$ or $P = W \times m$

Kw KJ/cycle tr/s or RPM (convert to S) Kw KJ/Kg Kg/s

III) Real evolution of gas in a Compressor (with friction):

a) non-Refrigeration machines



1-2 : adiabatic

1-2' : polytropic.

- $W_{ad} = \frac{\gamma}{\gamma - 1} \cdot r (T_2 - T_1) = \Delta H_{12}$ = area 23ac

$C_p (T_2 - T_1)$

- $W_{poly} = \frac{n}{n - 1} \cdot r (T_2 - T_1)$ = area 12'3ac = $\Delta H_{12'} - Q_{12'}$

- $W_{irr} = W_{pol.} + W_f = \Delta H_{12'} = \text{area } 2'3ab = c_p(T_{2'} - T_1)$

  W_{irr}: Work really absorbed; W_f: friction work

- $\eta_{poly} = \frac{W_{poly.}}{W_{irr}}$ | $\eta_{ad.} = \frac{W_{ad}}{W_{irr}}$

b) Refrigeration machine:

1-3: isothermal (ideal)
1-3': polytropic (real).

- $W_{isotherm} = rT \ln\left(\frac{P_2}{A}\right)$

  $= \text{area } 13ac$

  $= -Q_{13}$.

$W_{poly} = \frac{n}{n-1} \cdot r(T_{3'} - T_1)$

$= \text{area } 13'3adc.$

$W_{irr} = W_{poly} + W_f$ (calculated before)

- $\eta_{poly} = \frac{W_{poly.}}{W_{irr.}}$ | $\eta_{iso} = \frac{W_{isotherm}}{W_{irr}}$ | $\eta_{ad} = \frac{W_{ad.}}{W_{irr.}}$

- $W_{ad} = \frac{W_{ad}}{W_{irr}} = \frac{\Delta H_{12}}{\Delta H_{12'}} = \frac{\dot{m} c_p \Delta T}{\dot{m} R \Delta T} = \frac{T_2 - T_1}{T_{2'} - T_1}$