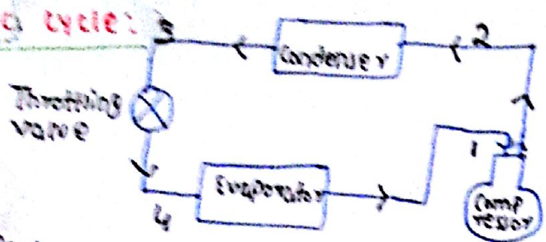
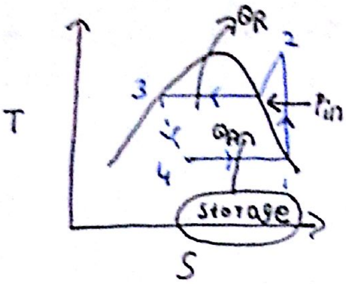
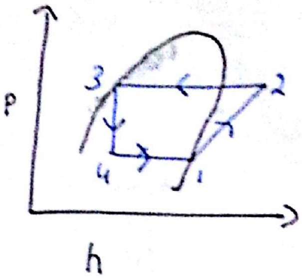
① V-C cycle:







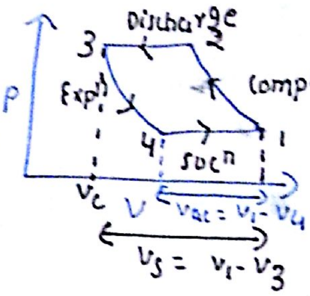
* Apply SFEE to all devices ∴ all are open systems
* condenser, Evaporator - only HE ∴ $W = 0$ + Throttling $h = c$, $Q = W = 0$
* compressor $Q = 0$ [∵ Rev. adiabatic] [Could be Q to avoid] ⟶ irreversible process

$$COP = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_3}{h_2 - h_1}$$

* can't use $h = C_p \cdot T$ ∵ here pure substance not ideal gas

② Rec. compressor:

Clearance Ratio, $C = \frac{V_c}{V_s} = \frac{V_{clearance}}{V_{swept}} = \frac{V_3}{V_1 - V_3}$



volumetric $\eta = \frac{V_{ac}}{V_s} = \frac{V_1 - V_4}{V_1 - V_3} = \frac{V_1 - V_4 + (V_3 - V_3)}{V_1 - V_3} = 1 - \frac{V_4 - V_3}{V_1 - V_3}$

$\eta_v = 1 - C \cdot \left[\frac{V_4}{V_3} - 1\right] = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right]$

$$\eta_v = 1 + C - C \cdot \left(\frac{P_2}{P_1}\right)^{1/n}$$

n = Expansion Exponent.

* In Refrigeration: $\eta_v = \frac{\dot{m} \cdot v_1}{V_{swept}}$

$\dot{m}$ = Ref. mass flow rate
v_1 = specific volume at compressor Entry

$$V_{swept} = \frac{\pi}{4} \cdot D^2 \cdot L \cdot K \cdot \frac{N}{60}$$

N = rpm
K = no. of cylinders
N ⟶ N/2 (4 stroke), N (2 stroke)

③ Open system work:

$W = -V \cdot dP$

where Imp. → if compression is not Rev. adiabatic (Q is also there)

$$(W_{open})_{adia} = \frac{\gamma (P_1 V_1 - P_2 V_2)}{\gamma - 1}$$

$$(W_{open})_{poly} = \frac{n (P_1 V_1 - P_2 V_2)}{n - 1}$$

④ Effects on variation of properties:

1- ↓se in Evaporator pressure
2- ↑se in Condenser "
3- Superheating in Evaporator
4- Undercooling in Condenser

	RE	Win	COP	η_v	QR
1	↓	↑	↓	↓	
2	↓	↑	↓	↓	↑
3	↑	↑	↓ R-12 (1.12) ↑ NH3 (1.31) ↓	↓	
4	↑	↔	↑	↔	↑
				↔	↑

$W_{in} = \frac{\gamma}{\gamma - 1} \cdot (P_1 V_1 - P_2 V_2) = \frac{\gamma \cdot mRT_1}{\gamma - 1}\left(1 - \frac{T_2}{T_1}\right) = \frac{\gamma \cdot mRT_1}{\gamma - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}\right]$

$W_{in} \propto T_1$ (inlet temp. at compressor) ∴ in ③ W_{in} ↑es.

* ↓se in condenser pressure ⟶ W_{in}↓, RE↑, COP↑, η_v↑

⑤ Ref. Designation:

① Saturated HC - $[C_m \cdot H_n \cdot F_p \cdot Cl_q]$ $[R - (m-1)(n+1)(P)]$ $[n + P + q = 2m + 2]$

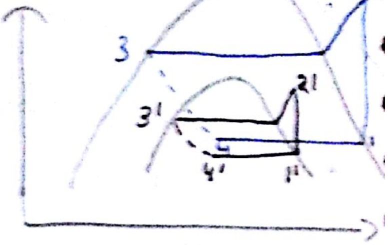
* R-12 : R-012 $C \cdot Cl_2 \cdot F_2$ * R-134 = $C_2 \cdot H_2 \cdot F_4$

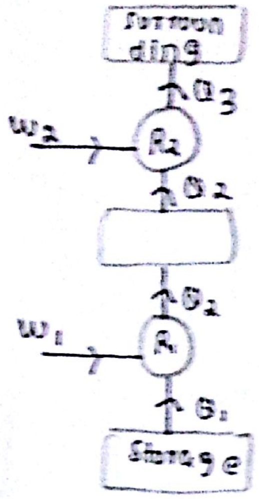
② Unsaturated HC - $[C_m \cdot H_n \cdot F_p \cdot Cl_q]$ $[R - 1(m-1)(n+1)(P)]$ $[n + P + q = 2m]$ * R-1150 : C_2H_4

③ Inorganic - R- 700 + mol. wt. * H_2O = R-718

⑥ **Cascade Ref. System:** * if very ↓ Temp. needed (-40°C) * if done w/o it then the Evaporator pressure also ↓es and thus P_2/P_1 ↑es and η_v ↓es.

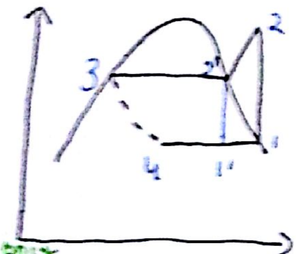
- Heat Rejected in Condenser 2'-3' is absorbed by Evaporator 4-1





$$COP_1 = \frac{Q_1}{w_1} = \frac{Q_1}{Q_2 - Q_1} \qquad COP_2 = \frac{Q_2}{w_2} = \frac{Q_2}{Q_3 - Q_2}$$

$$COP = \frac{Q_1}{w_1 + w_2} = \frac{COP_1 \cdot COP_2}{1 + COP_1 + COP_2}$$



(i) Wet compression represents incomplete vaporisation of Ref. ∴ loss of RE.

(ii) Inside compressor liquid Ref. may wash away lubricating oil ∴ ↑ wear, Tear

⑦ **Dry compression vs wet compression:**

(iii) Liq. Ref. may damage comp. valves.

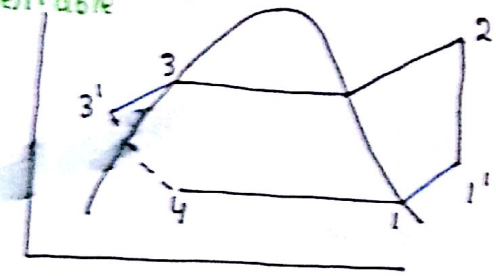
* Slight superheat at entry of comp. is desirable

⑧ **HE in V-C cycle:** < 1-1', 3-3' $h_3 - h_{3'} = h_{1'} - h_1$

Ref. coming out of Condenser at 3 loses heat to Ref. " " " Evaporator at 1

Eva (4-1) HE (1-1') comp (1'-2) Cond (2-3) HE (3-3') T-V (3'-4)

$$COP = \frac{h_1 - h_4}{h_2 - h_{1'}} = \frac{h_1 - h_{3'}}{h_2 - h_{1'}}$$



* Adv. that inlet to comp. is slight superheat.

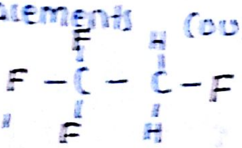
* RE ↑, Win ↑ Can't say about COP

* Can use ideal gas eqn. in 1-1' $u_1/T_1 = u_1'/T_1'$

⑨ **Trends in Ref:** - Cl should be eliminated b/c of threat to ozone

- Replacements could be HC, HFC, FC.

E.g. (i) R-134a ($C_2H_2F_4$)



~~↑ pr. Ref., ↓ ... for ... vapour, ... leakage, ↓ ...~~

- An HFC, could be used beyond 2030
- Some global warming potential
- Replaced R-12

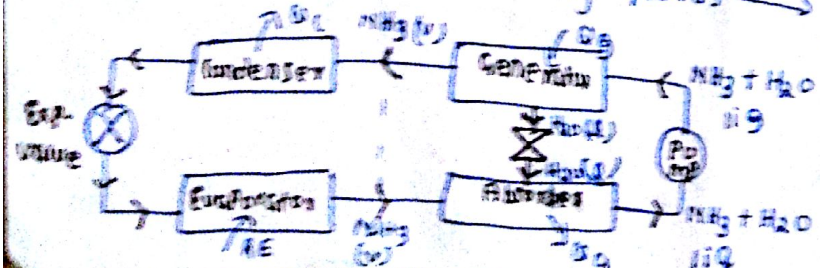
(ii) R-123 ($C_2HF_3Cl_2$) - Shortest atm. life time - very ↓ GW potential.

↳ An HCFC ∴ slated to be phase out by 2030 (could continue as exception)

	t_c	P_c	N.B.P.
R-134a	101°C	40.5 bar	-26°C
R-123	183°C	36.7 bar	27°C

Montreal protocol 1987 (i) phase out CFC by 2000 (ii) HCFC by 2030 (iii) HFC, FC not covered

⑩ **V-A cycle:** uses 2 working fluids < Refrigerant - NH_3, H_2O; Absorbent - H_2O, LiBr

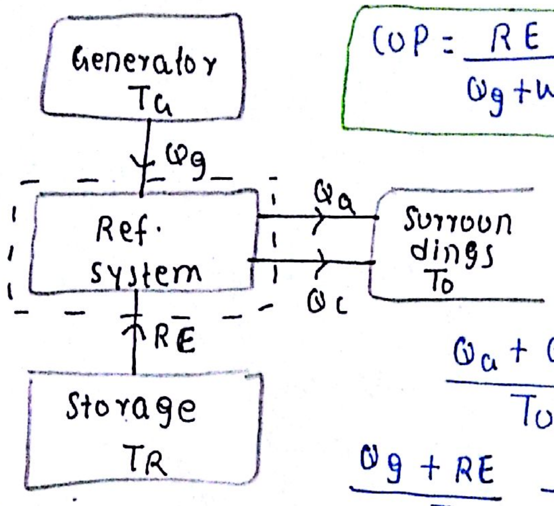


Absorber - Temp. ↓ ∴ ↑ absorbivity ∴ NH_3 mixes with H_2O and pumped easily.

Generator - Reverse ∴ separate.

- pump replaced compressor: $w_{pump} << w_{comp}$ as $v_f << v_g$
↳ + Absorber + generator
- works on ↓ grade energy i.e. heat. E.g. Solar Ref.
- $(COP)_{VC} > (COP)_{VA}$ - Heat rejection at 2 places (condenser, absorber)

COP



$$COP = \frac{RE}{Q_g + W_p} = \frac{RE}{Q_g}$$

1st law: $Q_g + RE = Q_a + Q_c$

2nd law: $\Delta S_{sys} + \Delta S_{sur} \geq 0$

∵ System under cycle ∴ $\Delta S_{sys} = 0$

for sys < Gen., Sto., Surr. } all 3 are surroundings

$$\frac{Q_a + Q_c}{T_0} - \frac{Q_g}{T_g} - \frac{RE}{T_R} \geq 0$$

$$\frac{Q_g + RE}{T_0} - \frac{Q_g}{T_g} - \frac{RE}{T_R} \geq 0$$

$$\frac{RE}{Q_g} \leq \left(\frac{T_G - T_0}{T_G}\right)\left(\frac{T_R}{T_0 - T_R}\right)$$

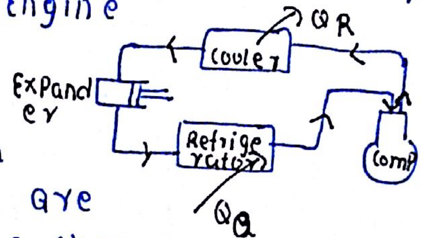
GOOR
G O|R
G|O R

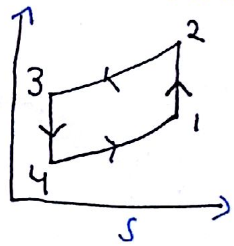
$$COP = \frac{RE}{Q_G} \leq \left(\frac{T_G - T_0}{T_G}\right) \cdot \left(\frac{T_R}{T_0 - T_R}\right)$$

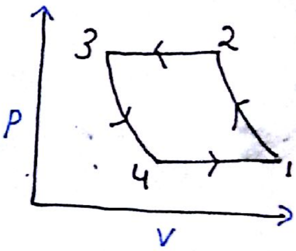
(11) Gas Ref. cycle: working medium - Air or gas ∴ can use $PV = mRT$ and $h = C_p \cdot T$
Cycle used - Rev. Brayton or Bell-Coleman

Application - Air craft Engine
- ↓ wt. per TR

* Here Refrigerator, cooler in place of Eva and cond, Though all are HE but here no phase change

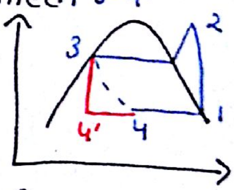






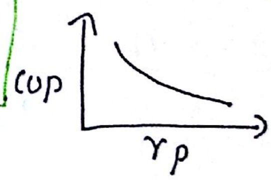
* Here Expander not Throttle valve: As can't use h=c process b/c then T=c and with ↑T heat absorption from storage not possible.

Expander - Moving Parts, lubrication, maintenence, costly, $w_{o/p}$ obtained, 3-4'
Throttle valve - Simple, stationary, cheap, h=c, 3-4
why use Throttling in V-C? Though work o/p but b/c liquid ∴ not much, Thus not used b/c ↑ cost.



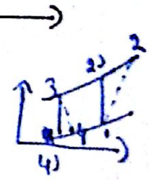
COP: in Ideal cycle

$$\frac{RE}{w_{in}} = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$



* η in Brayton cycle: $1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}$

* Isentropic η of a compressor $\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ $\frac{T_{2s} - T_1}{T_2 - T_1} = \eta_c$
* " " Expander



E.g. Q: if comp. $PV^{1.3} = C$ and expn $PV^{1.35} = C$ Then not use direct formula.

(12) properties of Ref: ① THERMODYNAMIC - ↑ critical T (for ↑ QR in cond.), ↑ Δh_{vap} (Ref. m ↓ size ↓), ↑ Thermal conductivity, Eva. pr. should be low but not below atm. pr., Moderate Cond. Pr., small r_p, ↓↓ Freezing Pt., ↓ v_g, ↑ COP, ↓ comp. discharge T

② Chemical: Toxicity, flammibility, Action with oil: some oil carried by ↑T. Ref. from Comp. to Cond. and finally to Evaporator, where Ref. vaporises and oil separates from it. if accumulated in Evap. then HT ↓es.

- if non-miscible (no problem) (oil separator placed at exit of compressor)
- if miscible (no problem) (∵ separated in Evaporator)
- partially miscible (problem) (Thus synthetic oil is used in place of mineral oil)

③ physical: ↓ viscocity, Leakage detection → Halide Torch method (Freon) (light color change blue → bluish green) ; → Sulphur stick " (NH₃) (white fumes of Amonium sulphide)

NH_3 attacks Cu, Freon attacks Al.

⑬ **CONDENSERS:** - Basically a Heat exchanger (i) Desuperheating: of vapour in discharge line and in 1st few coils of condensers.
(ii) condensation: of vapour at condensing temp. (iii) Subcooling: near the bottom where there is only liq.

Heat Rejection Ratio - loading on condenser per unit of refrigeration

$HRR = \frac{Q_2}{Q_1}$ $COP = \frac{Q_1}{W}$ $Q + W = Q_2$ $\boxed{HRR = 1 + \frac{1}{COP}}$ HRR depends on COP ∴ on Cond., Eva. Temp.

Types - Air cooled, water cooled, Evaporative, ground cooling.

(1) Air cooled - Heat Removed by air → natural cir. ; forced " - Fins on air side
- used in small capacity - not for above 5 TR b/c ↑head pressure, power, Noise ↑ - Ref. inside tube, air outside

(2) water cooled → Shell & Tube ; " " coil ; Double Tube → water thru passes inside tubes and the Ref. condenses in shell → Also serves as Receiver, bottom portion as sub cooler

Shell & coil: ~~Double~~ electrically welded closed shell containing water coil.

Double Tube: Ref. condenses in outer tube and water flows in Inner Tube in opp. direction

* These normally used in conjunction with Cooling Towers. Heated water from cond. is carried to CTs where it is cooled by self Evaporation into a stream of air. After cooling it is pumped back to condenser.
CTs (i) natural draft (ii) forced draft

(3) Evaporative Cond - Ref. $\xrightarrow{\text{Rejects heat to}}$ water $\xrightarrow{\text{Rejects heat to}}$ Air. Air leaves with ↑ humidity as in cooling tower.

Unit of Ref: 1 TR = 1 Tonne of Ref. = Amt. of Energy to be extracted from 1 tonne (1000 kg) of water at 0°C to be converted to 1 tonne of ice at 0°C in 24 hrs.
$\boxed{= 3.5\,KW}$ * $RE\,(KW) = \dot{m} \times RE\,(KJ/Kg)$ * Ref. T in Eva. should be less than storage
" " " Cond. " " more " surr.

Ideal Ref. cycle: * Reversed Carnot cycle $COP = T_L/(T_H - T_L)$ $(COP)_{Rev.C.} = (COP)_{Ideal} = (COP)_{max}$