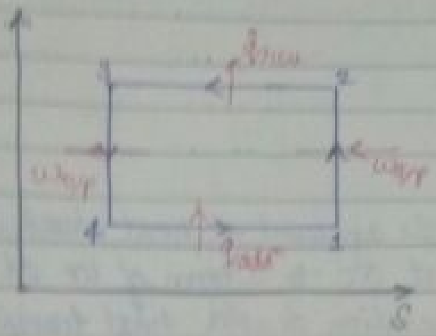
RAC

Reverse Carnot Cycle - or Ideal Refrigeration Cycle -



1→2 : Isentropic Comp.
2→3 : Rev. isothermal heat rej. (Comp)
3→4 : Isentropic exp.
4→1 : Rev. isothermal heat add. (exp)

Refrigeration - It is the process of maintaining its space at a lower temp. compared to the surroundings.

→ The fluid used which circulates through the refrigeration equipments to provide the refrigeration effect is called refrigerant.

Refrigeration effect - It is the amount of heat absorbed to maintain a place at a lower temp. compared to surroundings. Refrigeration effect is generally calculated (in kJ per kg) of refrigerant.

Heating Effect - It is the heat rejected at the higher temp. by the refrigerant. It is also calculated (kJ/kg) of refrigerant.

→ Heat absorbed per sec is called refrigeration capacity & heat rejected per sec is called heating capacity.

$$\boxed{R.C = R.E \times \dot{m}}$$

R.C → kJ/sec, R.E → kJ/kg, $\dot{m}$ → kg/s

$$\boxed{H.C = H.E \times \dot{m}}$$

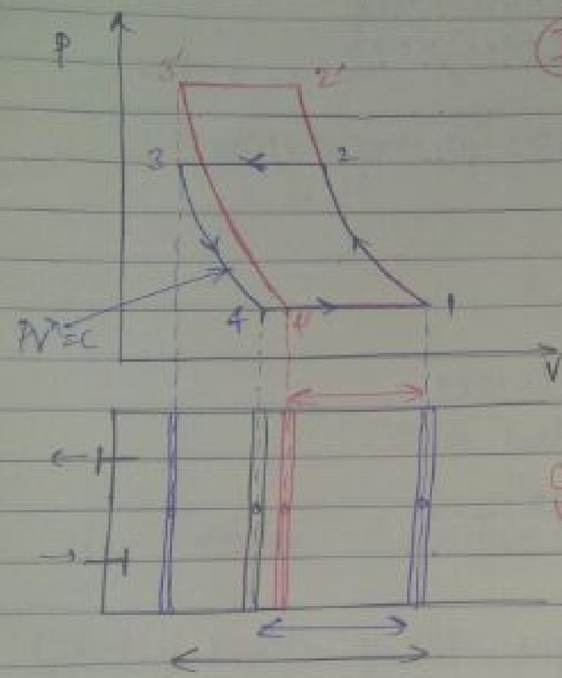
H.C → kJ/sec, H.E → kJ/kg, $\dot{m}$ → kg/s

$h_2 - h_a = C_{pv}(t_2 - 35)$.

$205.68 - 201.5 = 0.6155\,(t_2 - 35)$.

$$\boxed{t_2 = 41.79^\circ C}.$$

Volumetric Efficiency for Reciprocating Compressor-



(I) $\eta_v = \dfrac{V_1 - V_4}{V_1 - V_3}$

$\eta_v = \dfrac{V_1 - V_4 - V_3 + V_3}{V_1 - V_3}$

$\eta_v = \dfrac{(V_1 - V_3) - (V_4 - V_3)}{(V_1 - V_3)}$

$\eta_v = 1 - \dfrac{V_3\left(\dfrac{V_4}{V_3} - 1\right)}{V_1 - V_3}$.

Clearance Vol. → $\dfrac{V_3}{V_1 - V_3} = C$ ← Clearance factor or Clearance ratio

Swept Vol.

$\eta_v = 1 - C\left[\dfrac{V_4}{V_3} - 1\right]$.

$\underline{3 \to 4}$: $P_3 V_3^n = P_4 V_4^n$

$\dfrac{V_4}{V_3} = \left(\dfrac{P_3}{P_4}\right)^{1/n} = \left(\dfrac{P_2}{P_1}\right)^{1/n}$.

$\therefore \eta_v = 1 - C\left[\left(\dfrac{P_2}{P_1}\right)^{1/n} - 1\right]$.

$\therefore$ $\boxed{\eta_v = 1 + C - C\left\{\dfrac{P_2}{P_1}\right\}^{1/n}}$ $n \to$ Polytropic index of exp.

(II) $$\eta_v = \frac{\overbrace{(\dot m \times 60)}^{kg/sec} \times \overbrace{v_1}^{m^3/kg}}{\underbrace{\left(\frac{\pi}{4}D^2\right)\times L}_{m^3/sec} \times \underbrace{N}_{rev/min} \times K}$$

v_1 ← I inlet specific volume.

K → No. of cylinders

9- $C = 0.03$.

$$1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n} = \frac{(\dot m \times 60)\times v_1}{\left(\frac{\pi}{4}D^2 \times L\right)\times N \times K}$$

$$\eta_v = 1.03 - 0.03\left(\frac{7.45}{1.5}\right)^{1/1.15} = 1.03 - 0.1209 = 0.9091.$$

$$\eta_v = \frac{\dot m \times v_1}{\dot V_d}$$

$$0.9091 = \frac{\dot m \times 0.1089}{\dot V_d}.$$

$$\dot m \times \underset{(176.65)}{RE} = RC^{\,2\times 3.5167}$$

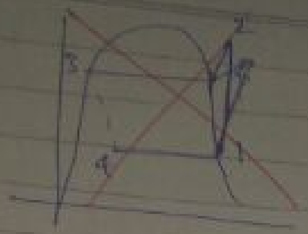
$$\dot m = 0.063 \text{ kg/sec.}$$

$$\therefore 0.9091 = \frac{0.063 \times 0.1089}{\dot V_d}$$

$$\dot V_d = 7.58 \times 10^{-3} \text{ m}^3/\text{sec}.$$

Note: Volumetric efficiency gives actual value of all the terms. If assumed '1' then that can be correct or not.

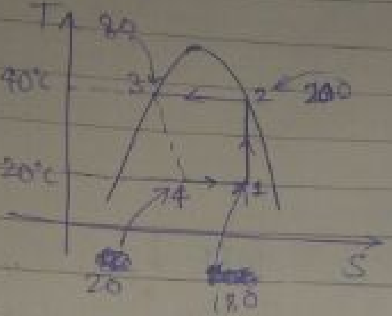
19-



~~$COP = \frac{Q_L}{W}$~~

$Q_L = \cancel{200-40} =$ $180 - 20 = 160.$

~~$W = 200$~~



$s_1 = s_2$

$$\underbrace{s_f + x_1[s_{fg}]}_{-20°C} = \underbrace{s_g}_{+40°C}$$

$$0.07 + x_1(0.7366 - 0.07) = 0.67.$$

$$\underline{x_1 = 0.90}$$

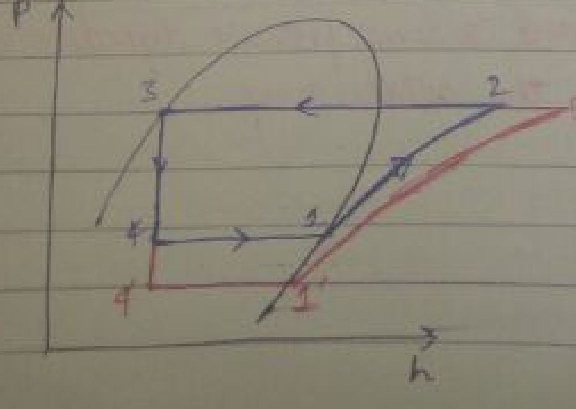
$$h_1 = h_f + x_1 h_{fg}$$
$$= 20 + 0.90(180 - 20) = 164.$$

$$COP = \frac{h_1 - h_4}{h_2 - h_1} = 2.33.$$

(ii) $R.C = \dot{m} \times R.E = 0.025(h_1 - h_4) = 2.10\ kW.$

Effect of Variation of Various properties on the performance of Vapour Compression (V-C) cycle -

1- Reduction in Evaporator pressure -

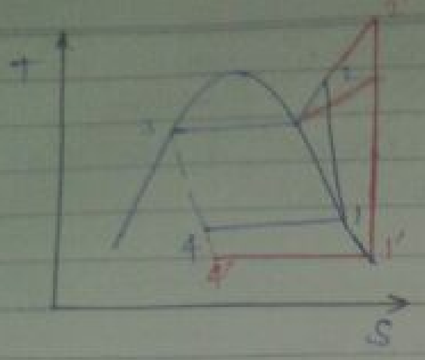


(i) R.E. ↓

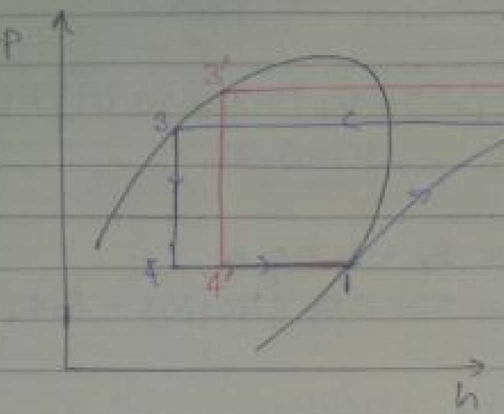
(ii) $W_{I/P}$ ↑

(iii) ↓↓ $COP = \frac{RE\downarrow}{W_{I/P}\uparrow}$

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



2- Increase in condenser pressure-

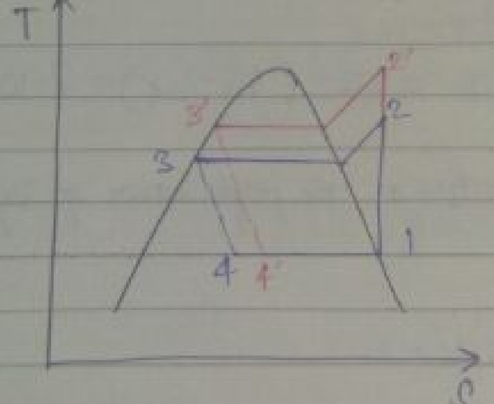


(i) RE ↓

(ii) $W_{c/p}$ ↑

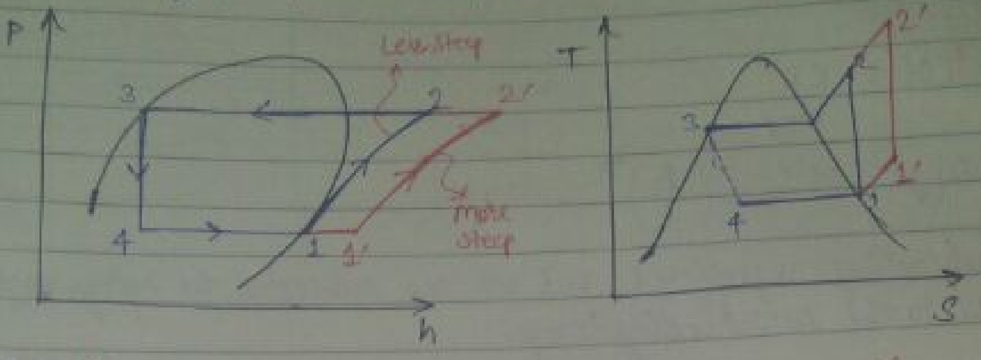
(iii) ↓ $COP = \frac{RE\downarrow}{W_{c/p}\uparrow}$

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



Note: The evaporator pressure and condenser pressure depends on the refrigeration temperatures and the outside temp.

3- Superheating of vapour in evaporator -



(i) RE ↑

(ii) $W_{I/P}$ ↑ → Due to increase in swept volume.

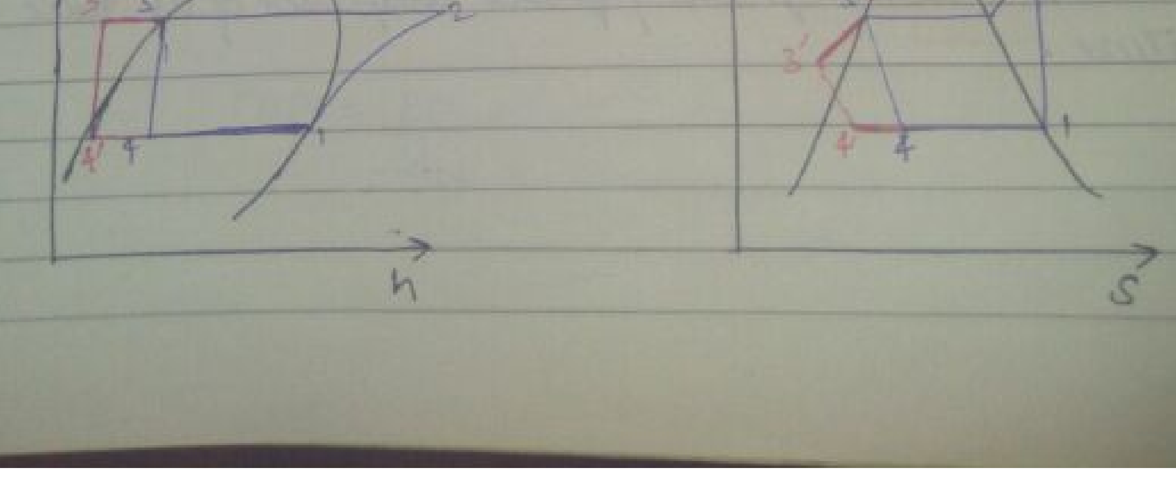
(iii) $COP = \frac{RE}{W_{I/P}}$ → R_{12} ↑, R_{134a} ↑ ; → R_{22} ↓

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

→ In this case both RE and $W_{I/P}$ increases. Hence COP may increase or decrease depending on the refrigerant.

→ Slight superheat is generally preffered.

4- Subcooling of Liquid Refrigerant in Condenser -



(i) RE ↑

(ii) $W_{I/P}$ → Same

(iii) ↑ $COP = \frac{RE \uparrow}{W_{I/P}}$

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

* Subcooling is preffered but we can subcooled the refrigerant only near to the surrounding temp.

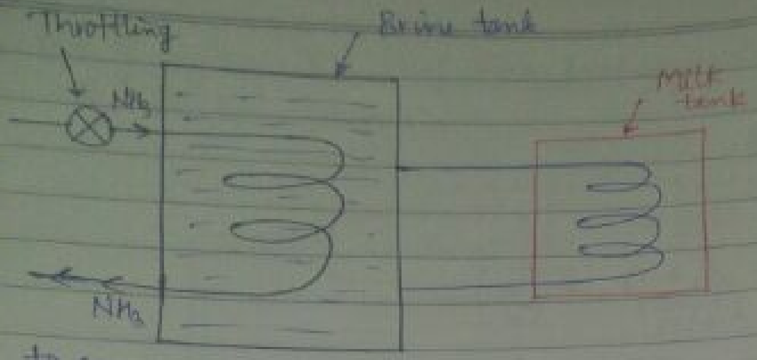
Primary Refrigerant and secondary Refrigerant -

→ The refrigerant which circulates through the refrigeration equipment is called primary refrigerant.

→ The refrigerant which absorbs heat from the refrigerated space and tranfers it to the primary refrigerant is called secondary refrigerant. secondary refrigerant in air conditioning process is air.

→ Secondary refrigerant ~~are~~ used in milk chilling plants is brine solution.

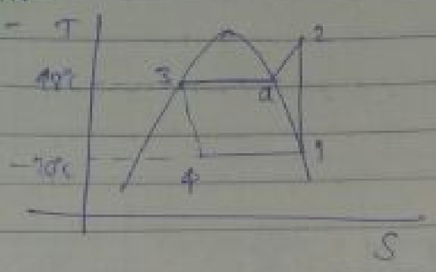
→ The use of secondary refrigerants helps in reducing the refrigeration cost by reducing the amount of primary refrigerant used. It also enables us in using a good refrigent having favourable thermodynamic properties irrespective of its toxic nature.



to compressor

~~Ch-2 ***~~

20 -



35°C → -8°C.

$Q = 8640(4.186 \times 35 + 334.72 + 2.26 \times 8) = 4314.03\ MJ.$

Total $Q = 4745.433\ MJ$ $\quad m c_p \times 68 \times 10^3$ ($c_p = 0.82$)

$Q + 0.10Q$

$\cancel{4745.433 \times 10^3 = 0.82 \times (T_2 + 20)}$.

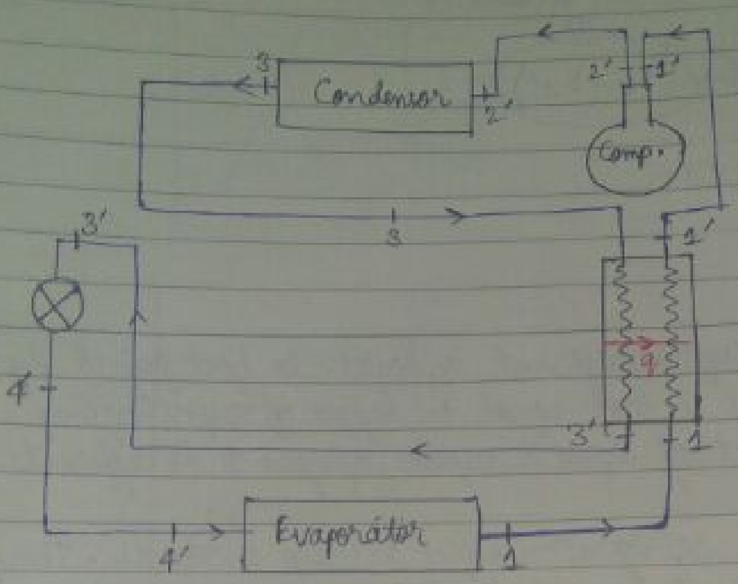
$m = 85.104\ kg.$

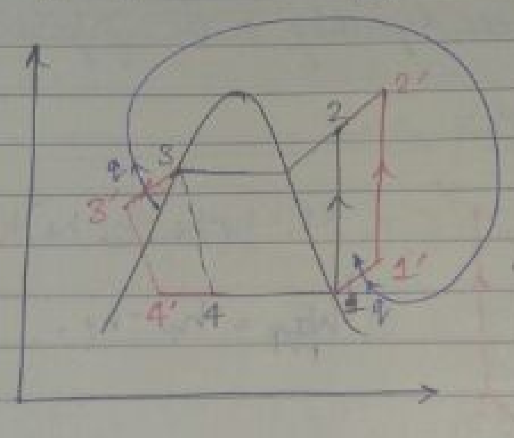
In a day → $Q = 4745.433\ MJ.$

per sec → $Q = \frac{4745.433 \times 10^6}{24 \times 3600} = 54.901\ kW = RC.$

$COP = \frac{RC}{\dot{W}_{i/p}}.$

Use of Regenerative Heat ~~Exat~~ Exchanger (Subcooling Heat Exchanger or Liquid ~~line~~ line Heat Exchanger) in VC cycle -





$$q_{lost} = q_{gained}$$

$$h_3 - h_3' = h_1' - h_1$$

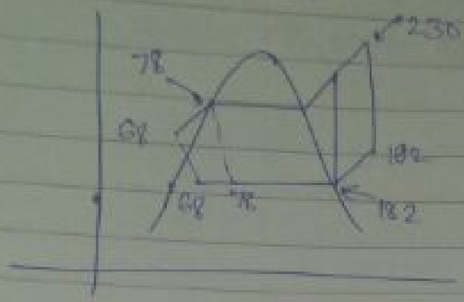
$$C_{P_l} \underbrace{(T_3 - T_3')}_{\text{Degree of subcooling}} = C_{P_v} \underbrace{(T_1' - T_1)}_{\text{Degree of superheating}}.$$

Degree of ~~superheating~~ subcooling

Degree of super ~~cooling~~ heating

compare to superheating in evaporator.

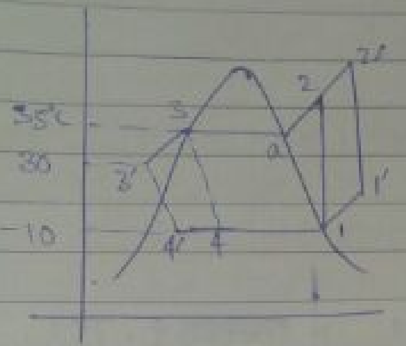
13-



$$COP = \frac{114}{38} = 3.$$

$$\begin{array}{r} 38 \\ 3 \\ \hline 114 \end{array}$$

22-



RC = 50kW.

$$COP = \frac{1450.22 - h_{4'}}{h_{2'} - h_{1'}}$$

$$S_1' = S_2'.$$

$$\cancel{S_1 + C_{pv}(T_1' - T_1) = S_a + C}$$

$$S_1 + C_{pv} \ln\left(\frac{T_1'}{T_1}\right) = S_a + C_{pv} \ln\left(\frac{T_2'}{T_a}\right).$$

$$C_{pv}(T_1' - T_1) = C_{pl}\,\cancel{(3)}\times 5$$

$$T_1' + 10 = \frac{4.556}{2.492} \times 5$$

$$T_1' = -0.858°C = 272.15 K.$$

$$5.755 + 2.492 \ln\left(\frac{-0.858+273}{-10+273}\right) = 5.2086 + 2.903 \ln\left(\frac{T_2'}{35+273}\right)$$

$$T_2' = \cancel{88.452°C}\ 382.85 K = 109.85°C$$

$$h_{2'} - h_a = C_{pv}(T_2' - T_a).$$

$$h_2' - \cancel{88}\,1488.57 = 2.903(\cancel{88.452}\ 109.85 - 35)$$

$$h_2' = \cancel{1842.74}\ 1705.868.$$

→ But wet compression is only preffered with rotary compressors because in reciprocating compressors ~~to~~ the liquid molecules in the refrigerant may cause following problems -

(i) liquid particles wash away the lubricating oils, hence increasing the wear & tear in compressor.

(ii) The liquid molecules gets trapped and obstruct the opening & closing of valves. Hence causing valve damage in the long run.

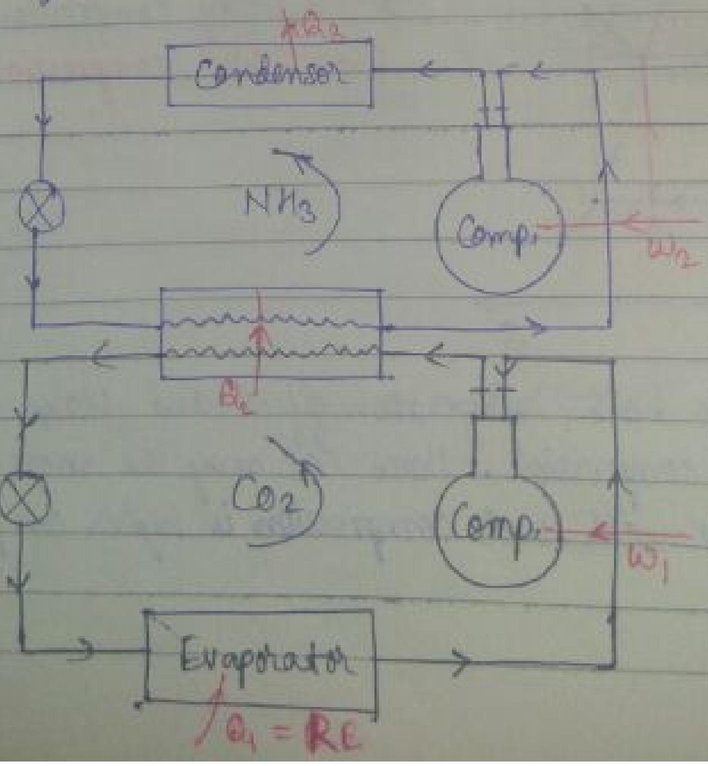
Cascade Refrigeration System -

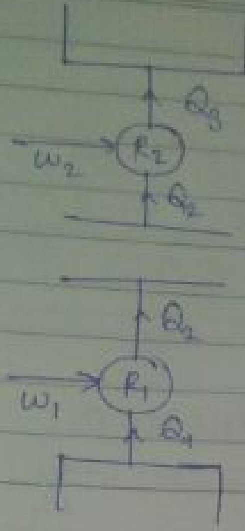
→ For producing very low temperatures the corresponding pressure ratios in a single refrigeration cycle increases drastically. This results in very low volumetric efficiencies. Hence drastically increasing the compressor size.

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

→ To avoid this cascading of refrigeration system is done.

→ Cascade Refrigeration systems are commonly used in medical industry.



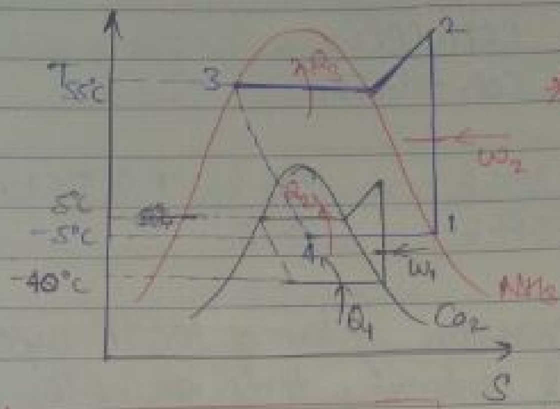


$$COP_1 = \frac{Q_1}{W_1}.$$

$$COP_2 = \frac{Q_2}{W_2}.$$

R.E.

$$COP_* = \frac{Q_1}{W_1 + W_2}.$$



* Only thing to remember is that 4 will be below black line (ie. of CO_2) to make heat exchanging possible.

$$\boxed{COP_* = \frac{COP_1 \cdot COP_2}{1 + COP_1 + COP_2}}$$

* There is no compulsion that 4 will lie in wet region of CO_2. It will lie in wet region of NH_3.

$$COP = \frac{Q_1}{W_1 + W_2} \cdot \frac{W_1}{W_1}$$

$$COP = \frac{COP_1 \cdot W_1}{W_1 + W_2}$$

$$COP_2 = \frac{Q_2}{W_2}$$

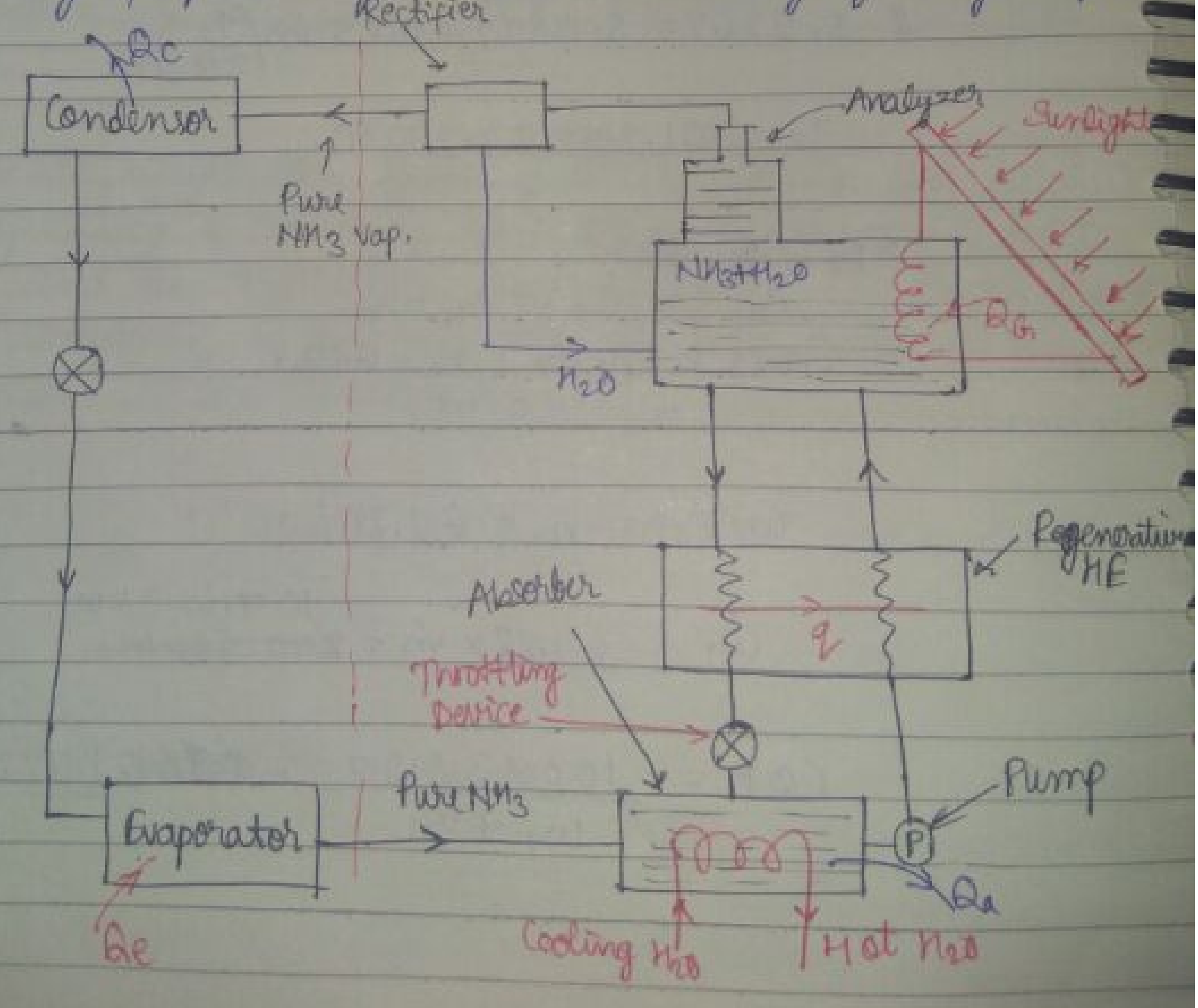
$$\therefore W_2 = \frac{Q_2}{COP_2}.$$

Vapour Absorption Refrigeration System-

→ In Vapour absorption system low grade energy (heat) is used. Hence its COP is less compared to vapour compression system ($(COP)_{VAS}$ is 0.3-0.5)

→ VAS is used where cost of electricity is very high or a lot of waste heat is available.

→ Ammonia water system is the most commonly used system. Other Vapour absorption systems are Lithium Bromide & water and Lithium Chloride & water. In ammonia water absorption system, ammonia acts as refrigerant and water acts as absorbant. In the other two systems, water acts as refrigerant, hence it is used for air conditioning purposes only. Since water has high freezing temp.



→ Pure ammonia vapour enters the absorber where it is absorbed in water. This is an exothermic reaction hence lots of heat is released. Cooling water is continuously circulated to maintain low temp. of the solⁿ in absorber. This is done because solubility of ammonia is inversely proportional to temp. of solution.

→ A solution rich in ammonia is then pumped to generator while absorbing heat in regenerative heat exchanger. In generator as the solution is heated, ammonia separates from water forming high pressure ammonia vapours.

→ Ammonia vapours are passed through analyzer for the removal of water vapour and then further passed through a rectifier which ensures a complete removal of water vapour. Hence pure amonia vapours continue their journey.

→ Since water has high freezing temp., water vapour is removed to ensure the system doesn't gets choked due to freezing of water.

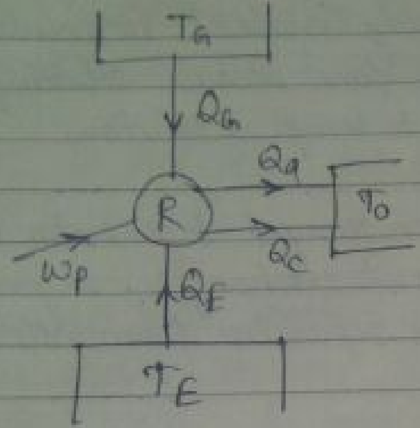
→ In VAS, heat is absorbed in evaporator and generator. Heat is rejected in condensor and absorber.

$$\boxed{COP = \frac{Q_E}{Q_G + W_P}}$$

But $W_P << Q_G$

$$\therefore \boxed{COP = \frac{Q_E}{Q_G}}$$

Maximum COP of VAS-



→ Conv. of energy-

$$Q_G + Q_E + W_P = Q_a + Q_c.$$

W_P is neglected.

$$Q_G + Q_E = Q_a + Q_c \quad \text{—①}$$

$$\rightarrow \oint_{rev.} \frac{\delta Q}{T} = 0$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{Q_a + Q_c}{T_0} = 0 \quad \text{—②}$$

Put ① in ②,

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{Q_a + Q_E}{T_0} = 0.$$

$$Q_E\left[\frac{1}{T_E} - \frac{1}{T_0}\right] = Q_G\left[\frac{1}{T_0} - \frac{1}{T_G}\right]$$

$$\frac{Q_E}{Q_G}\left(\frac{T_0 - T_E}{T_E T_0}\right) = \left(\frac{T_G - T_0}{T_0 T_G}\right)$$

$$\frac{Q_E}{Q_G} = \frac{T_E(T_G - T_0)}{T_G(T_0 - T_E)}$$

$$\boxed{(COP)_{max} = \frac{T_E(T_G - T_0)}{T_G(T_0 - T_E)}}$$

Examples -

1- $CFCl_3$

$m=1$

$n=0$

$p=1$

R 011 ⇒ R 11.

2- R 22

R 022

$C_1H_1F_2Cl$

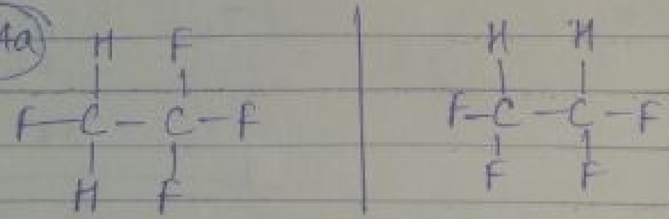
3- R 12

R 012 ⇒ $C_1H_0F_2Cl_2$ ⇒ CF_2Cl_2.

4- $C_2H_2F_4$

R 134.

R134a



Asymmetric

→ The chlorine element present in the refrigerant dissociates in presence of sunlight and reacts with ozone layer which is situated in stratosphere. The ozone layer depletion is undesirable because it filters harmful ultravoilet rays from the sun.

→ Therefore the presence of Cl element in refrigerant is undesirable. This is the reason we have replaced R12 with R134a in domestic refrigerator and R22 with R410a in window Air conditioners.

Case II - Unsaturated Hydrocarbons -
(Double bond)

$C_m H_n F_p Cl_q$.

$2m = n+p+q$.

$\boxed{R\,1\,(m-1)(n+1)p}$

Example -
$C_2H_4 \rightarrow R\,1150$.

Case III - Inorganic Compounds -

$\boxed{R\,(700 + \text{Mol. wt.})}$

$NH_3 \rightarrow R\,717$.
$H_2O \rightarrow R\,718$.
$\text{Air} \rightarrow R\,729$.
$CO_2 \rightarrow R\,744$.
$SO_2 \rightarrow R\,764$.

Properties of Refrigerants :-

1- Normal Boiling Point (NBP) -

→ It is desired to operate the evaporator at slightly higher pressures than atmosphere. This is because if the evaporator pressure is below atmosphere the leakage will cause the surrounding air to leak inside the system. Air brings with itself the water vapour which freezes at low temperatures, hence it is undesirable.

→ To keep evaporator pressures slightly higher than surrounding we require low NBP refrigerant. Therefore low NBP is desirable.

→ Low NBP refrigerants are high pressure refrigerants and high NBP refrigerants are low pressure refrigerant.

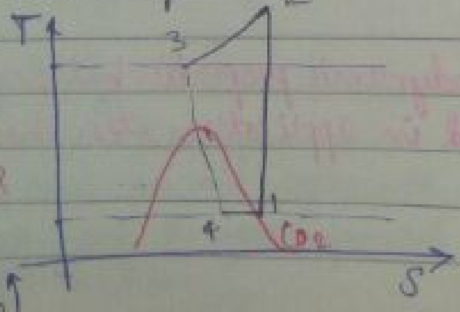
→ Purging - It is the process of removal of trapped air in condensor.

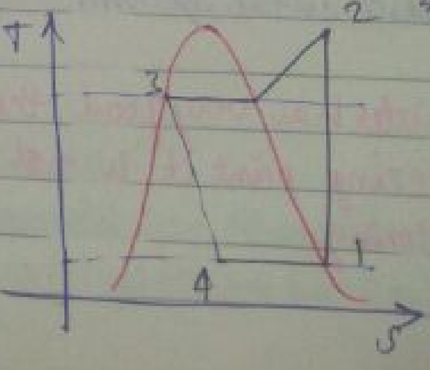
→ Air trapped in the condensor causes the following :-

1- Increase in condensor pressure.
2- —"— power ~~output~~ input.
3- —"— Cooling water jacket temp.

2- Critical Temp. -

T_{cr} ↓
COP ↓
RE ↓
$\dot{m}$ ↑ → ?
$W_{i/p}$ ↑
Vol ↑
Compressor size ↑





7- Compressor Discharge Temp.-

Compressor discharge temp. should not be very high to avoid overheating of compressors. Ammonia has a high compressor discharge temp. Hence ammonia compressors are water cooled.

8- Toxicity and Flammability-

The refrigerant should be non- toxic & non-flammable.

Note: Ammonia is a ~~to~~ good refrigerant but because of its flammable & toxic nature, it is not used in domestic refrigerators.

** (i) Critical temp. of water is among the highest in normally used refrigerants.

** (ii) Ammonia has high latent heat of ~~refrigerati~~ vapourisation.

Reaction with lubricating Oil-

(i) Completely misscible-

If the lubricating oil is completely miscible with the refrigerant then the lubricating oil which gets washed away by the flow of refrigerants reaches the evaporator and evaporates with refrigerant returning back to compressor. ~~Exple~~ Example- R11 & R12.

(ii) Completely Immicible-

In this case an oil separator is ~~[illegible]~~ installed b/w compressor & condenser and the ~~[illegible]~~ separated oil is brought back in compressor.
eg: NH_3 & CO_2.

(iii) Partially miscible-

The refrigerants which are partially ~~immiscible~~ miscible with lubricating oil, creating problem since the refrigerant when evaporates in evaporator separates from the lubricating oil. Hence lubricating oil gets deposited in the evaporator reducing ~~the~~ HT rate in evaporator & causing wear & tear in compressor.

→ In this case synthetic lubricating oils are used - eg. R22.

Reaction with material of construction

→ Ammonia reacts with copper. Hence wherever ammonia is used, copper is not used as a construction material instead wrought iron or steel is used.

→ Freons (Fluoro Carbon) reacts with aluminium. Hence when freons are used, Al is not used as construction material instead Cu is used.

Leak Detection Tests-

1- Halide Torch Method - Freon leakage can be detected using this method. In presence of freons the bluish flame of the hydrocarbon turns bluish green ~~to~~ hence the leakage can be detected.

2- Sulphur stick/ ribbon method - In presence of sulphur ammonia forms white ~~pale~~ fumes of ammonium sulphide. Hence ammonia leakage can be detected.

3- Ammonia swab test - In this test SO_2 leakage is detected. Cloth dipped in ammonia is moved over leaking SO_2, white fumes confirm the leakage.

4- Soap bubble method - This test is generally used for hydrocarbons.

Refrigerant	Use
R-12	Domestic Ref. (Earlier)
R-134a	" (Now) & Car A/Cs.
R-22	Window A/C
R-410a	Window A/C (Now)
NH_3	Industrial Applications (Ice making plants, etc)
R-11	Central A/C units
CO_2 (Dry ice)	Transport refrigeration, Direct contact food refrigeration
Air	Aircraft A/C.

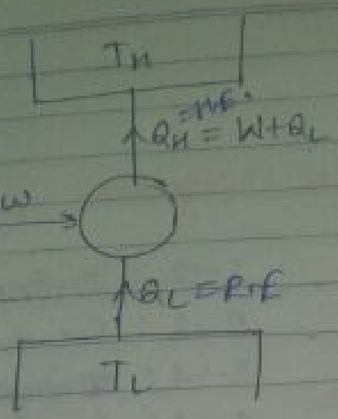
Aircraft Air conditioning Cycle (Bell-Colemen Cycle or Reversed Brayton cycle) -

Gas liquid Cycle (Slight modification)

→ Aircraft flies at high velocity hence lot of heat is generated due to air friction. Therefore cooling of air craft has to ~~be do~~ be done.

→ Gas ~~reff~~ refrigeration cycle is used because it uses air as a refrigerant & hence results in low weight per ton of refrigeration.

→ Since air is used as a refrigerant, it can be sent at a desired pressure in the aircraft cabin which helps in maintaining cabin pressure.



1 Tonn of Refrigeration- It is the amount of heat absorbed to change the 1 Tonn of water at 0°C to 1 tonn of ice at 0°C in 24 hrs. Hence tonn of refrigeration denotes heat transfer rate.

$$1\,T.R = 3.5167\ kW. = 211\ kJ/min. = 50.4\ kcal/min.$$

$1\,kcal = 4.1867\ kJ.$

$$(COP)_{Ref} = \frac{Q_L}{Q_H - Q_L} \longrightarrow [(COP)_{Ref}]_{Rev} = \frac{T_L}{T_H - T_L}$$

$$(COP)_{HP} = \frac{Q_H}{Q_H - Q_L} \longrightarrow [(COP)_{HP}]_{Rev} = \frac{T_H}{T_H - T_L}$$

$$\boxed{(COP)_{HP} - (COP)_{Ref} = 1}$$

2-(a) $\frac{Y}{W} = \frac{W}{Q_L} \Rightarrow \eta = 1 - \frac{300}{600} = \frac{1}{2}.$

$COP = \frac{1}{\eta} = 2 = \frac{300}{150} \Rightarrow$ Heat Pump.

6- $COP_P = \frac{90}{30} = 3.$ (c)

11- $COP_P = \frac{Q_4}{W} = \frac{3Q_1 - Q_2}{Q_1 - Q_2}$ $\quad \frac{W}{Q_1} = 0.4$

$W = 0.4Q_1$

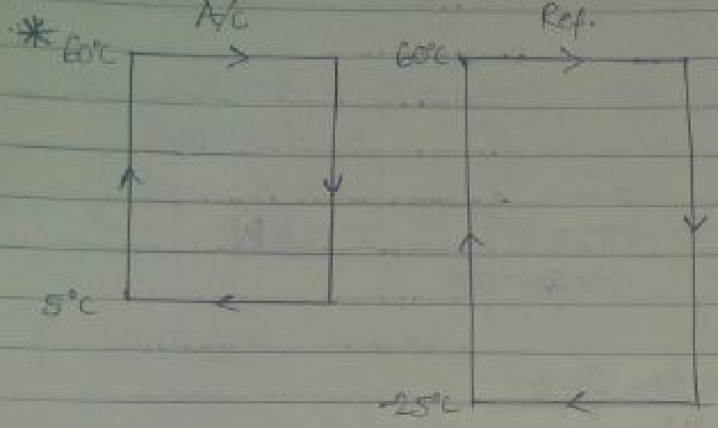
$$COP = \frac{3Q_1 - 0.6Q_1}{0.4Q_1}$$

$$= \frac{2.4}{0.4} = 6. \quad (C)$$

more preferable

Note: To increase the efficiency of heat engine, $T_L \downarrow$ & $T_H \uparrow$.
—— " —— COP of refrigerant or Heat Pump, $\omega \downarrow \Rightarrow T_L \uparrow$ & $T_H \downarrow$

more preferable



$$(COP)_{A/C} > (COP)_{Ref.}$$

$$\underset{\underset{5}{\Downarrow}}{(COP)_{A/C}} = \frac{15\,kW}{W_{I/P}} \Rightarrow W_{I/P} = \underline{\underline{3\,kW}}$$

$$\underset{\underset{2}{\Downarrow}}{(COP)_{Ref.}} = \frac{0.5\,kW}{W_{I/P}} \Rightarrow W_{I/P} = \underline{\underline{0.25\,kW}}$$

→ The COP of A/C units is more than the COP of ice making units. But the power consumption of window air conditioner is more than domestic refrigerator because

(i) Air conditioner has to cool as larger space.
(ii) In air conditioned space heat generation sources are present.
(iii) Heat losses are more from the air conditioned space compare to refrigerator.

17 -

$$COP = \frac{20+273}{15\,\cancel{/293}} = \frac{293}{\cancel{293}\,15} = \frac{7.9}{\omega}$$

$$\omega = \frac{7.9 \times \cancel{293}\,15}{293} \; \cancel{=}$$

$$= 0.404\,kW.$$

12- $Q = mC\Delta T + mL$

$= 3600(2 \times 30.? + 0.5 \times 20 + 230)$

$= 3600(60 + 10 + 230) = 1080000 \text{ kJ}$

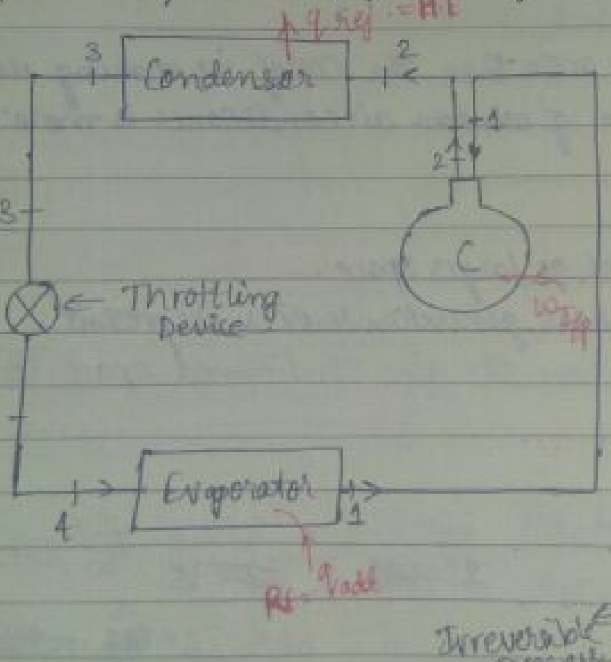
$$\text{Ideal COP} = \frac{-23+273}{27+23} = \frac{\cancel{250}^{5}}{\cancel{50}}$$

$$\text{Actual COP} = \frac{5}{2} = 2.5 = \frac{Q}{W}$$

$$W = \frac{\cancel{1080000}^{216000} \times 2}{\cancel{5}_{1}} = 432000 \times 10^3 = 432 \text{ MJ}$$

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\cancel{432}^{\cancel{72}^{12}} \times 10^{\cancel{6}^{3}}}{\cancel{10} \times \cancel{60} \times \cancel{60}} = \underline{12 \text{ kW}}$$

Vapour Compression Refrigeration Cycle:-

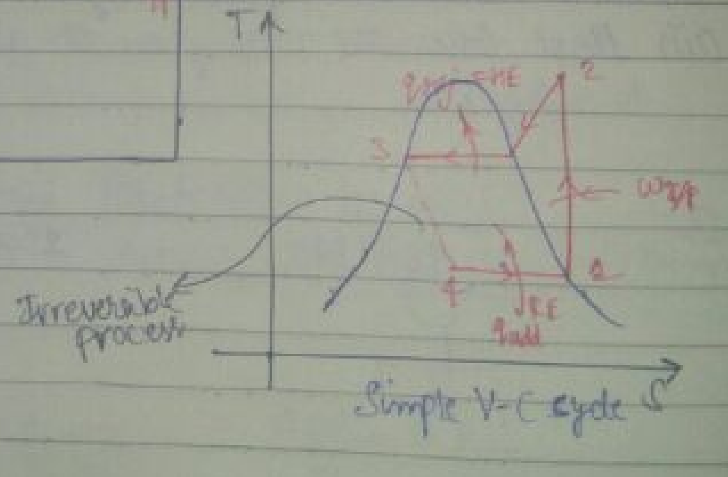


1→2 : Isentropic Comp.

2→3 : Isobaric heat rej.

3→4 : Throttling

4→1 : Isobaric heat absorption.



Simple V-C cycle

Applying SFEE on all devices,

1- Steady flow
2- $\Delta KE = 0$ & $\Delta PE = 0$.

$\therefore h_i + q = h_e + W_{cv}$.

(a) Compressor (isentropic, $q = 0$).

$\therefore W_{cv} = h_i - h_e = h_1 - h_2$.

$$\boxed{W_{I/P} = h_2 - h_1}$$

(b) Condenser ($W_{cv} = 0$).

$q = h_e - h_i = h_3 - h_3$.

$$\boxed{q_{rej} = h_2 - h_3}$$

(c) Throttling

$h_3 = h_4$.

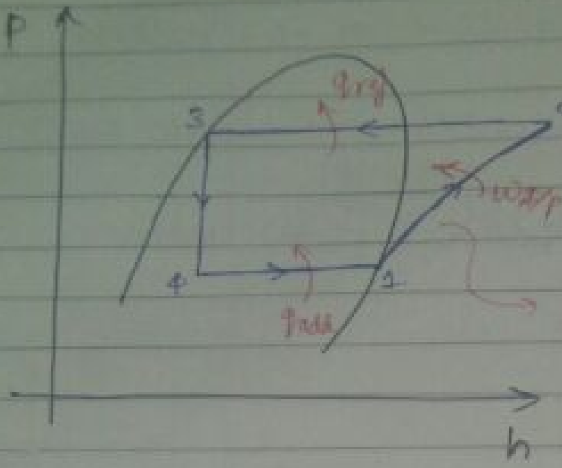
(d) Evaporator ($W_{cv} = 0$).

$$\boxed{q_{ab} = h_1 - h_4}$$

$$COP = \frac{RE}{W_{I/P}} = \frac{h_1 - \cancel{h_4}^{\,h_3}}{h_2 - h_1}$$

$$\boxed{COP = \frac{R.C}{\dot{W}_{I/P}}}$$

Pressure- Enthalpy Curve-



$T\cancel{dS}^{0} = dh - VdP.$

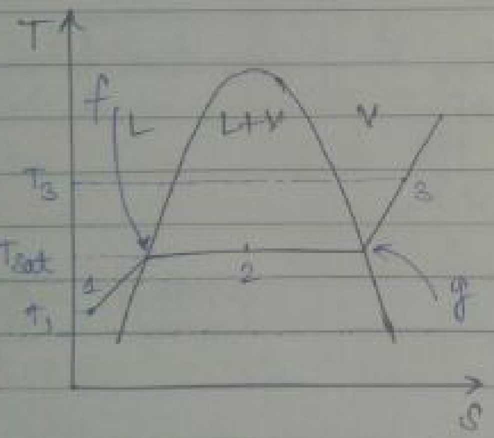
$dh = VdP.$ specific volume.

$\uparrow \frac{dP}{dh} = \frac{1}{V} = \rho \uparrow$

But here $\frac{dP}{dh} \downarrow$ (Remember).

→ Since there are two constant pressure processes and expression for all the devices are in terms of enthalpy. Hence we draw vapour compression cycle on P-h diagram.

*



① Subcooled or Undercooled-

→ $h_f - h_1 = C_{p_L}(T_{sat} - T_1)$

→ $S_f - S_1 = C_{p_L} \ln\left(\frac{T_{sat}}{T_1}\right)$.

② Wet Region-

$h_2 = h_f + x_2 h_{fg}$.

$S_2 = S_f + x_2 S_{fg}$,

$q_p = h_g - h_f$.

$$\boxed{L.H = h_g - h_f}$$

$$\rightarrow \boxed{S_g - S_f = \frac{L.H}{T_{sat}} = \frac{h_{fg}}{T_{sat}}}$$

③ Superheated (Ideal gas)

$\rightarrow h_3 - h_g = C_{pv} (T_3 - T_{sat})$

$\rightarrow S_3 - S_g = C_{pv} \ln \frac{T_3}{T_{sat}} - R \ln \cancel{\frac{P_3}{P_{sat}}}^{0}$

$$\boxed{S_3 = S_g + C_{pv} \ln \frac{T_3}{T_{sat}}}$$

Ch2-

16- (i) $COP = \frac{Q_L}{W}$

$Q_L = 183 - 75 = 108$ kJ/kg.

$W_{i/p} = h_2 - h_1 = 210 - 183 = 27$ kJ/kg.

$COP = \frac{\cancel{108}^{\cancel{12}4}}{\cancel{27}_{\cancel{3}}} = 4$.

$$\boxed{COP = \frac{h_1 - h_{4'}}{h_{2'} - h_{1'}}}$$ → Only this much change takes place in evaporator.

$$RE = h_1 - h_{4'}$$
$$= (h_1 - h_4) + (h_4 - h_{4'})$$

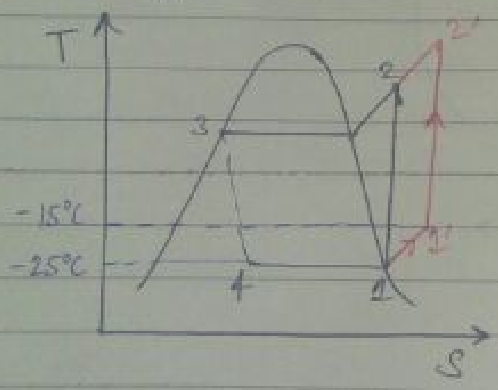
x (lost)

$$W_{I/P} = h_{2'} - h_{1'}.$$

→ Heat lost by the liq. refrigerant is equal to heat gained but degree of subcooling is not equal to degree of superheating because specific heat of liquid & vapour refrigerant is different.

→ In this case both refrigeration effect & $W_{I/P}$ increases. Therefore COP may increase or decrease depending on the refrigerant.

Superheating in Evaporator -



$$RE = h_{1'} - h_4 = (h_1 - h_4) + (h_{1'} - h_1)$$

x

$$W_{I/P} = h_{2'} - h_{1'}.$$

→ The $W_{I/P}$ and RE will be same in both the cases i.e superheating in evaporator or use of heat exchanger. Hence the COP will also be same. But the RE which increases compare to simple cycle is obtained at a lower temp. when we use heat exchanger

Find $v_{1'}$ → In vapour state. Hence assume to be an ideal gas.

Pressure const. process.

$$\frac{V_1}{T_1} = \frac{V_{1'}}{T_{1'}}$$

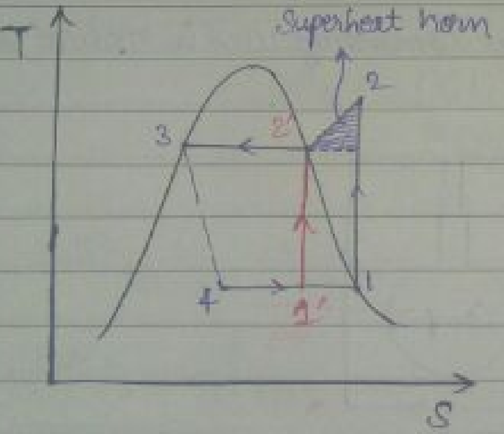
$$\frac{0.41749}{263} = \frac{V_{1'}}{272.15}$$

$$V_{1'} = 0.432.$$

$$\therefore \frac{\pi}{4} D^3 \times 1.2 \times 1000 = 0.0451 \times 60 \times 0.432$$

$$D = 0.1074m.$$
$$L = 1.2 D = 0.1289m.$$

Wet Compression V/S Dry Compression -



1→2 : Dry compression

1'→2' : Wet compression

→ In dry compression both refrigeration effect and $W_{I/P}$ are higher compared to wet compression. Hence COP may be more or less. Generally, the COP with wet compression is higher compared to dry compression.

Electrolux Refrigeration System-

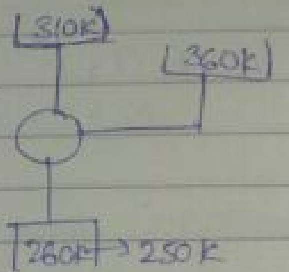
→ It is a three fluid system. Ammonia is used as refrigerant, water as absorbent and hydrogen is used to create low partial pressures of ammonia.

→ No pump is used in this system and circulation takes place due to temp. difference causing the density difference.

13- $(COP)_{max} = \frac{100}{Q_G} = \frac{250}{400}\left(\frac{400}{50}\right)$

$$\boxed{Q_G = 80\,W}$$

T1-



$COP = \frac{260}{360}\left(\frac{50}{50}\right) = \frac{250}{T_G}\frac{(T_G-310)}{60}$

$13T_G = 75T_G - 75\times 310$

$75\times 310 = 62T_G$

$T_G = \frac{75\times 310}{62}$

$$\boxed{T_G = 375\,K}$$

Designation of Refrigerants-

Case I- Saturated Hydrocarbons.

$C_m H_n F_p Cl_q$.

$2m+2 = n+p+q \Rightarrow R_{(m-1)(n+1)p}$.

Case IV - Azeotrope.

$\boxed{R(500 + \text{Random No.})}$

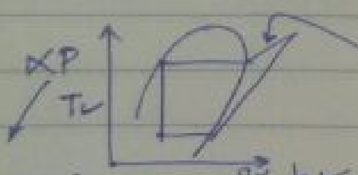
eg.- R502.

→ Azeotrope - It is a mixture of refrigerants behaving as pure substance.

Chapter-2

1-a, 2-c, 3-c, 4-c, 5-c, 6-a, 7-c, 8-d, 9-a, 10-d, 11-a, 12-b
13- 3, 14- 0.75, 15- 5.5, 21-(I)(a) 126.74, (b) 24.97 kg/min, (c) 0.9798 m³/min/cylinder
(d) 5.712, (e) D= 95mm, L=143mm; (II) (a) 0.9437
(b) D= 97.3mm, L= 145.9mm.

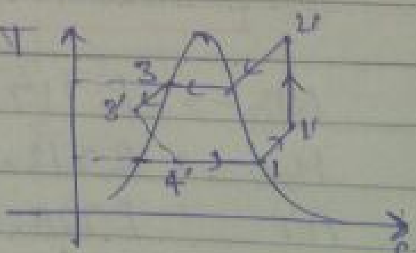
10-



As in condenser pressure is constant and here pressure is not constant in this part.

21- (II) $\frac{T_{2'}}{T_{1'}} = \left(\frac{P_{2'}}{P_{1'}}\right)^{\frac{n-1}{n}}$

$n = 1.157$



3- Latent Heat & Specific Heat-

The latent heat of the refrigerant should be high because for a given refrigeration capacity, it results in lower mass flow rates.

The specific heat for the liquid refrigerant should be low.

- specific heat for vapour refrigerant should be high.

4- Pressure Ratios-

Refrigerants giving lower pressure ratios are desirable because they result in higher volumetric efficiencies.

5- Specific volume at the inlet to the compressor-

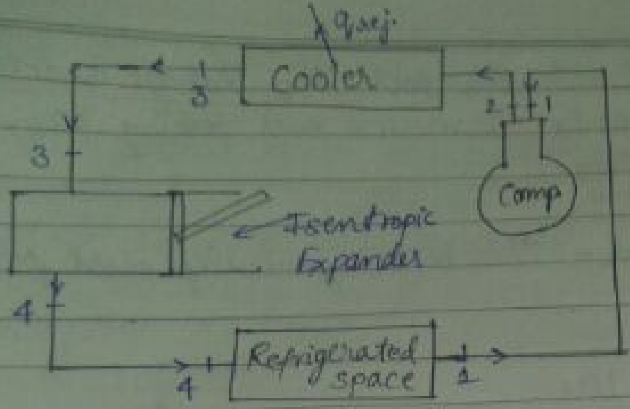
It should be less because higher specific volume results in larger sized compressors.

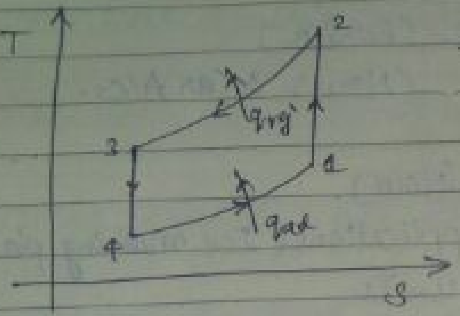
Note: R11 & R113 are used with centrifugal compressors because of high specific volume.

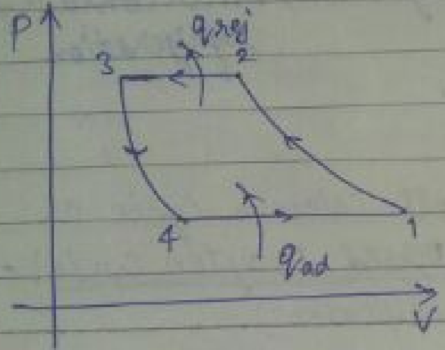
6- Freezing point -

Refrigerant should have low freezing temp. to avoid freezing of refrigerant in the system.

Note: Water has very good thermodynamic properties but because of high freezing point it is not used in applications other than air conditioning.







$$COP = \frac{RE}{W_c - W_e}$$

$$RE = h_1 - h_4 = C_p(T_1 - T_4)$$

$$W_c = h_2 - h_1 = C_p(T_2 - T_1)$$

$$W_e = h_3 - h_4 = C_p(T_3 - T_4).$$

$$COP = \frac{(T_1 - T_4)}{(T_2 - T_1) - (T_3 - T_4)} = \frac{T_1 - T_4}{(T_2 - T_3) - (T_1 - T_4)} = \frac{1}{\left(\frac{T_2 - T_3}{T_1 - T_4}\right) - 1} = \frac{1}{\frac{T_2\left(1 - \frac{T_3}{T_2}\right)}{T_1\left(1 - \frac{T_4}{T_1}\right)} - 1}$$

where,

$r_p \rightarrow$ Pressure ratio

$x = \frac{\gamma - 1}{\gamma}$.

$$\boxed{COP = \frac{1}{\frac{T_2}{T_1} - 1} = \frac{1}{\frac{T_3}{T_4} - 1} = \frac{1}{(r_p)^x - 1}}$$

$$\boxed{COP = \frac{1}{\frac{T_2}{T_1} - 1} \text{ or } \frac{1}{r_p^x - 1}}$$

1 → 2 isentropic

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^x$$

r_p → Press. ratio.

$\frac{\gamma-1}{\gamma} = x$ (Let).

Also,

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^x = \left(\frac{P_2}{P_1}\right)^x$$

$$\frac{T_3}{T_4} = (r_p)^x$$

Works b/w same pressures.

$$\therefore \left(\frac{P_3}{P_4}\right)^x = \left(\frac{P_2}{P_1}\right)^x = \frac{T_3}{T_4} = \frac{T_2}{T_1}$$

$$\frac{T_4}{T_1} = \frac{T_3}{T_2}.$$

$$1 - \frac{T_4}{T_1} = 1 - \frac{T_3}{T_2}.$$

$$1 - \frac{T_4}{T_1} = 1 - \frac{T_3}{T_2}.$$

* For these type of questions, directly go for calculating temperature

Note: The above expression can be used only when both compression and expansion are isentropic.

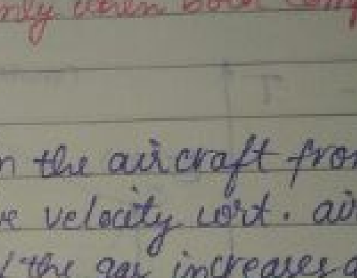
~~B~~ → Rammed air - The air recieved in the aircraft from outside has to be brought to zero relative velocity wrt. aircraft. During this the pressure and temperature of the gas increases and air is called rammed air. Temp. after ramming → $\frac{T_1}{T_0} = \left(\frac{P_1}{P_0}\right)^{\frac{\gamma-1}{\gamma}}$

13 ~~$COP = \frac{1}{\frac{T_2}{T_1} - 1} = \frac{T_1}{T_2 - T_1}$~~

$$COP = \frac{1}{r_p^x - 1} = \frac{1}{\frac{300}{180} - 1}$$

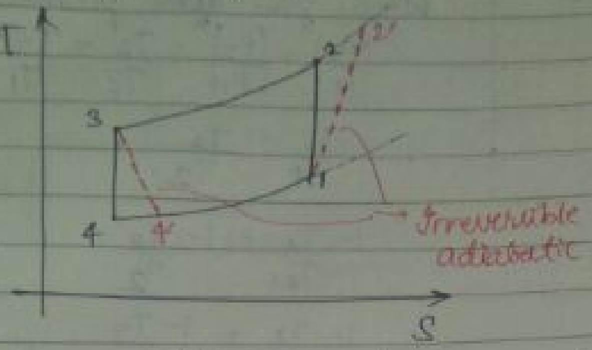
$$= \underline{1.5}$$

$$\frac{T_3}{T_4} = (r_p)^x$$



Note: for air, when $\gamma = 1.4 \Rightarrow x = 0.286$.

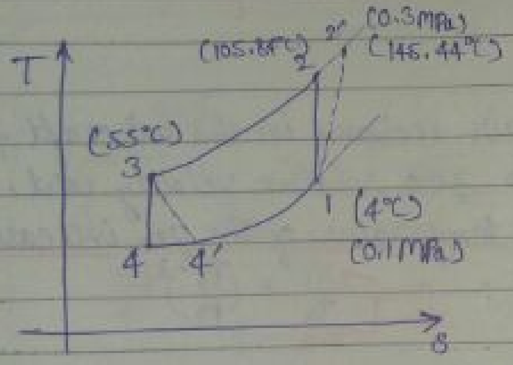
Isentropic efficiency of Compressor & expandor -



$$\eta_{s,c} = \frac{W_{isen}}{W_{actual}} = \frac{h_2 - h_1}{h_{2'} - h_1} = \frac{T_2 - T_1}{T_{2'} - T_1}.$$

$$\eta_{s,T} = \frac{W_{actual}}{W_{isen}} = \frac{h_3 - h_{4'}}{h_3 - h_4} = \frac{T_3 - T_{4'}}{T_3 - T_4}.$$

20-



$$\eta_{s,c} = \frac{W_{isen}}{W_{actual}}$$

~~Wactual =~~

~~$T_2 - T_1 =$~~

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 277(3)^{\frac{0.4}{1.4}}$$

$$= 378.84\,K = 105.84°C.$$

$$T_2' - T_1 = \frac{T_2 - T_1}{\eta_{s,c}}$$

$$T_{2'} = \frac{101.843}{0.72} + 277$$

$$T_{2'} = 418.44\,K = 145.44°C.$$

$$\frac{T_3}{T_4} = (3)^{0.286}$$

$$T_4 = 239.56\,K.$$

$$\eta_{T,c} = \frac{W_{actual}}{W_{isen}}$$

$$W_{actual} = T_3 - T_{4'} = (T_3 - T_4) \times 0.78$$

$$T_{4'} = 259.016\,K$$

$$= -13.98°C$$

$$\cancel{COP = \frac{1}{\frac{T_3}{T_{4'}} - 1} = \frac{1}{\frac{328}{258.016} - 1} = 3.75}$$

$$COP = \frac{RE}{W_c - W_e} = \frac{h_1 - h_{4'}}{(h_{2'} - h_1) - (h_3 - h_{4'})}$$

$$h_1 - h_{4'} = C_p(T_1 - T_{4'}).$$

$$h_{2'} - h_1 = C_p(T_{2'} - T_1).$$

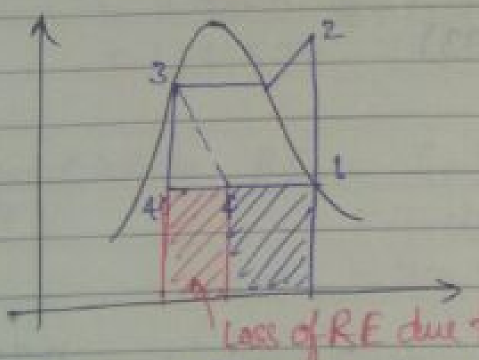
$$h_3 - h_{4'} = C_p(T_3 - T_{4'}).$$

$$\therefore COP = \frac{T_1 - T_{4'}}{(T_{2'} - T_1) - (T_3 - T_{4'})} = \frac{17.984}{141.44 - 68.984} = 0.248.$$

(b) $RC = RE \times \dot{m}. \Rightarrow \dot{m}$ ✓

(c) $COP = \frac{RC}{\dot{W}_{I/P}} \Rightarrow \dot{W}_{I/P}$ ✓

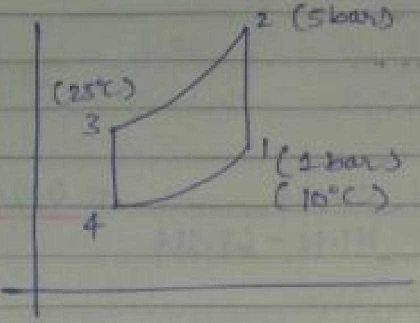
Use of Isentropic Expander v/s Throttling -



→ In gas cycle, since air is used as refrigerant which can be considered as ideal gas, it doesn't result in temp. drop if throttled. Hence throttling can't be used. Use of isentropic expander provides us a lot of work during the expansion of gas, reducing the power input required.

→ In vapour-compression cycle throttling is prefered because most of the substance remains as liquid during expansion hence there is no significant work output and also the expander is very costly device compared to throttling valve.

19-



$$COP = \frac{1}{\frac{T_3}{T_4} - 1}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = (5)^{0.286}$$

$T_4 = \cancel{217.65K}$ 188.06K $=$ −84.93°C.

(i) $COP = \frac{1}{r_p^{\alpha} - 1} = 1.71$

$$\frac{T_2}{T_1} = (5)^{0.286}$$

$T_2 = 448.42K = 175.42°C.$

(ii) $RE = C_p(T_1 - T_4)$

$= 1.005(10+84.93)$

$= \underline{95.4\ kJ/kg}.$

(iii) $\gamma_c = 1.35.$

$\gamma_e = 1.3.$

$$\frac{T_3}{T_4} = 5^{0.23}$$

$T_4 = 205.80K = -67.196°C.$

$$\frac{T_2}{T_1} = 5^{0.259}$$

$T_2 = 429.35K = 156.35°C$