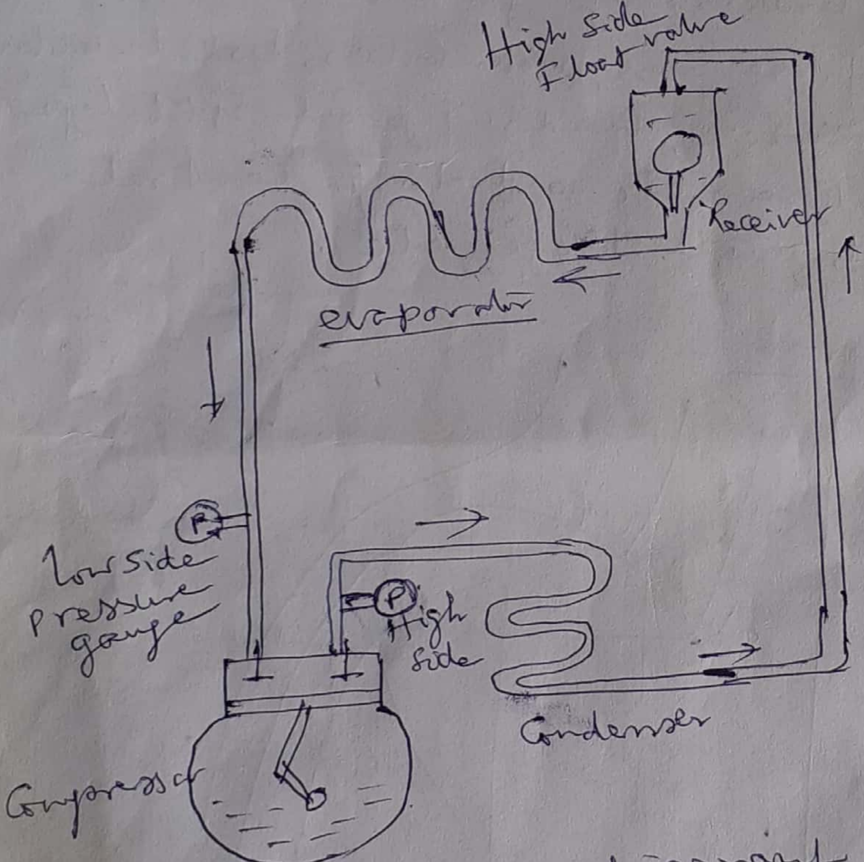
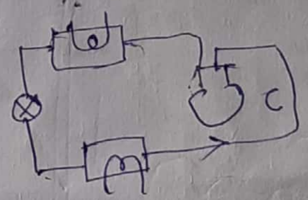
Simple Vapour Compression Refgm System.

In this system, the vapour undergoes a change of phase from vapour to liquid and liquid to vapour during the cycle. Because of this the latent heat of vapourization is utilised which is quite high compared to the air cycle where only sensible heat of air is important.

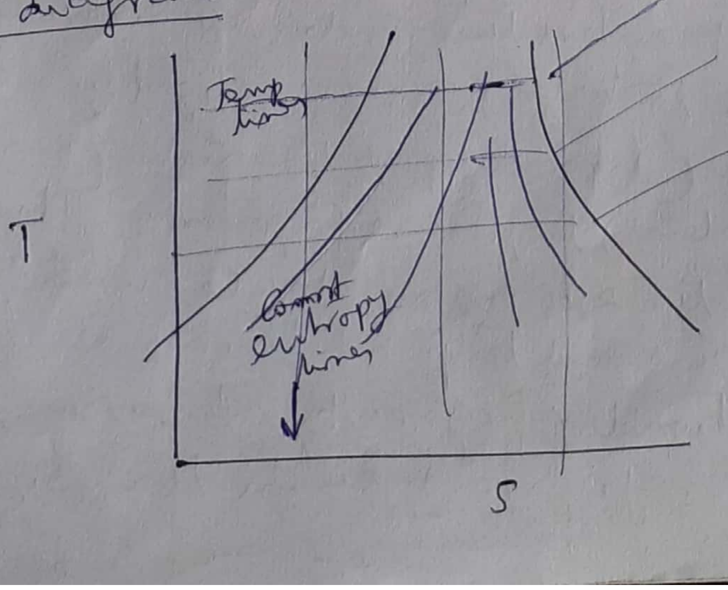


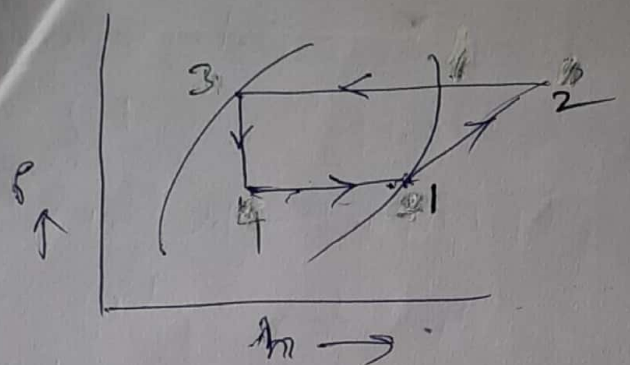
low pressure, low temp refrigerant vapour enters the compressor. High temp, high pressure refrigerant comes out of the compressor. This refrigerant enters the condenser where it gets cooled to high pressure, slightly high temperature (depending on the cooling medium air or water) liquid refrigerant. Then it enters into the expansion device where it loses its pressure and temp and becomes a low temp low pressure liquid refrigerant with some vapour also. This refrigerant enters the evaporator and takes the heat load from the product to be cooled. The refrigerant becomes a low press vapour and enters the suction side of the compressor. When once the refrigerant is charged into the system and sealed, it will be circulating throughout the system. Thus the refrigeration system function. This principle of vapour compression cycle is used universally for domestic appliances like Refrigerators, water coolers, bottle coolers, Deep Freezers, window Type and Split type Air conditioners etc. and also for Central A/c plants, cold storages etc.

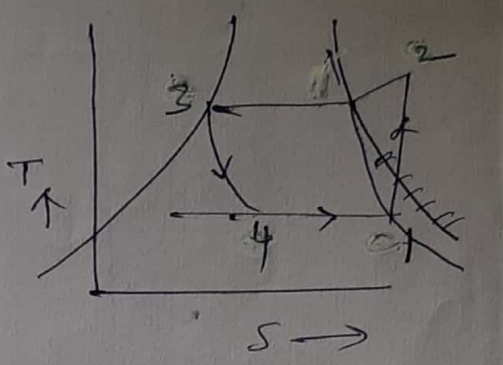


P-h. diagram

T-S. diagram







Simple cycle

4-1 — evaporation
1-2 — Compression
2-3 — Condensation
3-4 — expansion

If T is Tons of refrigeration load,
mass of refgnt = m_r kg/sec

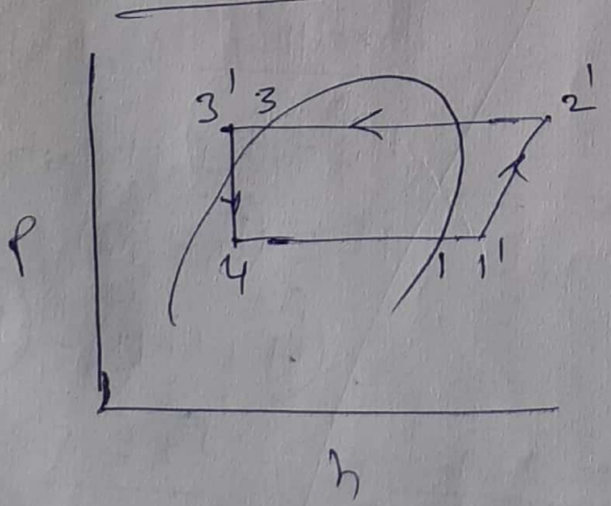
$$m_r = \frac{3.5\,T}{h_1 - h_4}$$

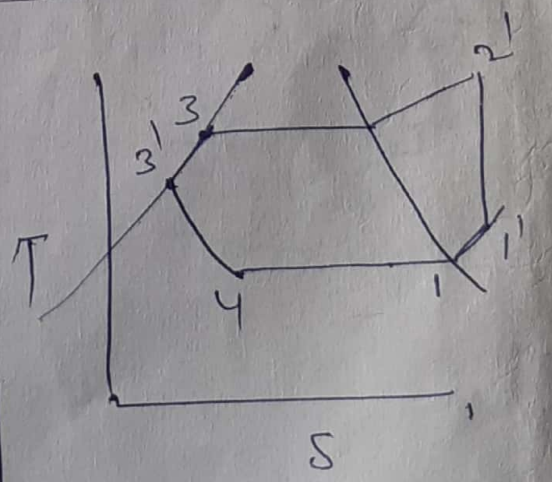
Power required to run the compr kW = $\frac{m_r (h_2 - h_1)}{1}$

C.O.P = Co-efft of performance

$$C.O.P = \frac{RE}{W}$$

Superheating & under cooling

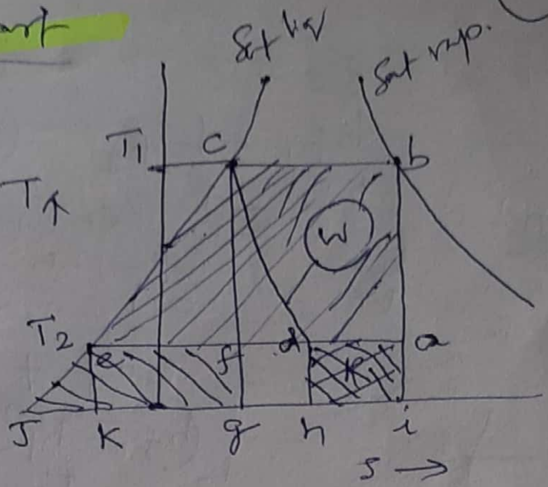




1-1' — Superheating at entry to Compr

3-3' — Sub cooling after Condenser.

C.O.P from T.S. Chart



abcda – Cycle
da – evap.
ab – Compn
bc – Condn.
cd – expn.

W = area abcea
= Heat at b – Heat at a
= bcJib – aeJia
= bceab.

RE = Heat at a – Heat at d
= aeJia – deJhd = adhia

h_{f1} = liq Heat at T_1 (c)
h_{f2} = ,, T_2 (e)
h_1 = heat of vap at T_1 (b)
h_2 = ,, ,, T_2 (a)
s_{f1} = entropy of liq at T_1 (at c)
s_{f2} = ,, ,, T_2 (at e)
s_{g1} = ,, vap at T_1 (at b)
s_{g2} = ,, ,, at T_2 (at a)
h_{fg1} = L.H of vap at T_1
h_{fg2} = LH of vap at T_2

$$C.O.P = \frac{RE}{W} = \frac{adhia}{bceab}$$

Throttling (cd)

Total heat at c = Total ht at d
cJgc = deJhd
feJgf is Common area (hatched)
So cef = dfgh

$cef = cJg - eJK - fekg = dfgh.$

$hf_1 - hf_2 - (T_2 \times ef) = (T_2 \times fd)$ — eqn (1)

$hf_1 - hf_2 - T_2(sf_1 - sf_2) = T_2 \times fd$

fd can be calculated

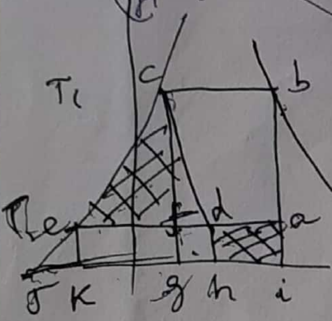
cef = cJg − eJK − ekgf = $(hf_1 - hf_2) - (sf_1 - sf_2)T_2$

$fd = \frac{hf_1 - hf_2 - T_2(sf_1 - sf_2)}{T_2}$

$W = abcea$

$= cef + bcfa$

$= [(hf_1 - hf_2) - T_2(sf_1 - sf_2)] + [(T_1 - T_2)(sg_1 - sf_1)]$ — from previous eqn



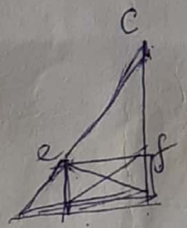
$RE = adhic = T_2(fa - fd)$

$= T_2(ad) = T_2(bc - fd)$

$= T_2[sg_1 - sf_1 - fd]$ — eqn (2)

from eqn (1) we get, $fd = \frac{(hf_1 - hf_2) - T_2(sf_1 - sf_2)}{T_2}$

Substitute in eqn (2)



$RE = T_2\left[sg_1 - sf_1 - \frac{(hf_1 - hf_2) - T_2(sf_1 - sf_2)}{T_2}\right]$

$= T_2[(sg_1 - sf_1)] - (hf_1 - hf_2) + T_2(sf_1 - sf_2)$

$= T_2\{[sg_1 - sf_2] - (hf_1 - hf_2)\}$

$C.O.P = \frac{RE}{W} = \frac{T_2\{[(sg_1 - sf_2) - (hf_1 - hf_2)\}}{(hf_1 - hf_2) - T_2(sf_1 - sf_2) + (T_1 - T_2)(sg_1 - sf_1)}$

but $sg_1 = sf_1 + \frac{hfg_1}{T_1}$.

$W = h_b - h_a$, $R = h_a - h_d = h_a - h_c$

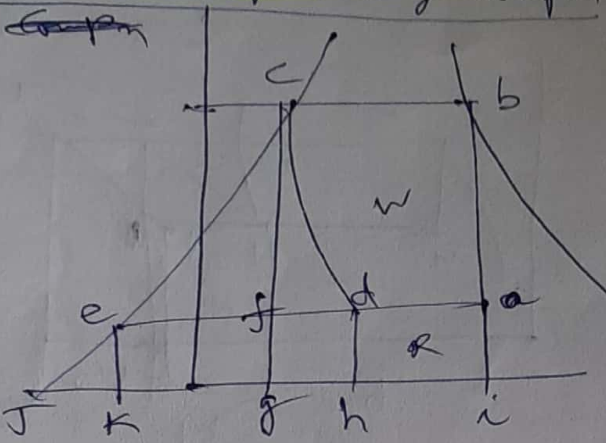
$C.O.P = \frac{R}{W}$.

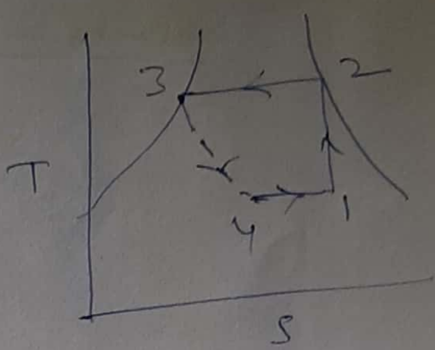
Wet Compn

In work eqn substitute $(sg_1 - sf_1) = \frac{x_1 hfg_1}{T_1}$.

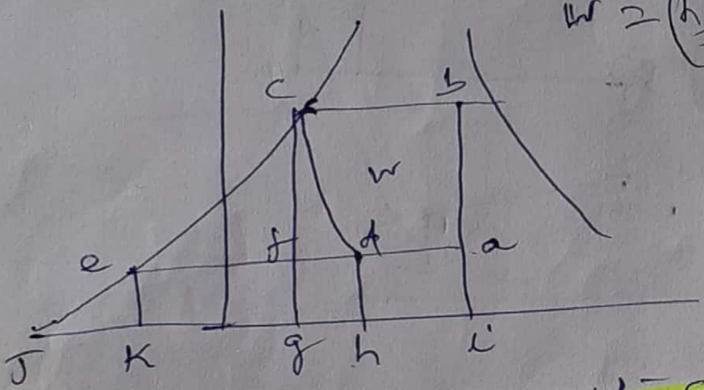
Q = I.T.

a) Dry & Saturated at end of Compn





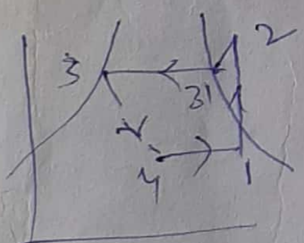
(b) Vap wet at end of Compn

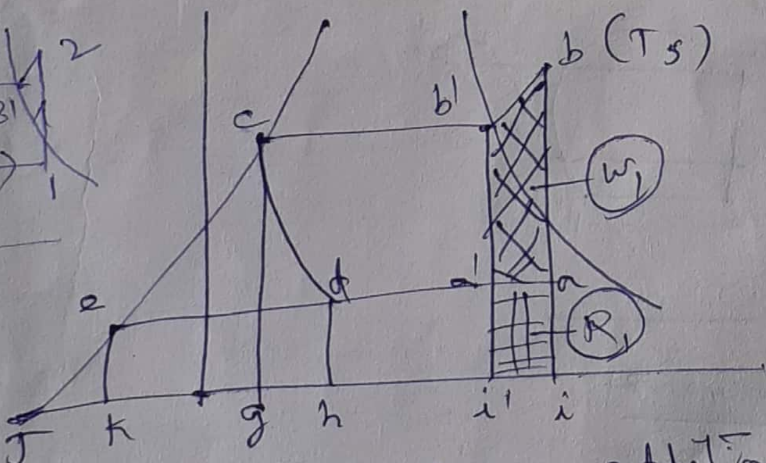


$$W = (h_{f_1} - h_{f_2}) - T_2(s_{f_1} - s_{f_2}) + (s_{g_1} - s_{f_1})(T_1 - T_2).$$

$$\& \quad s_{g_1} - s_{f_1} = \frac{x_1 h_{fg_1}}{T_1}.$$

c) Vap is superheated after compression





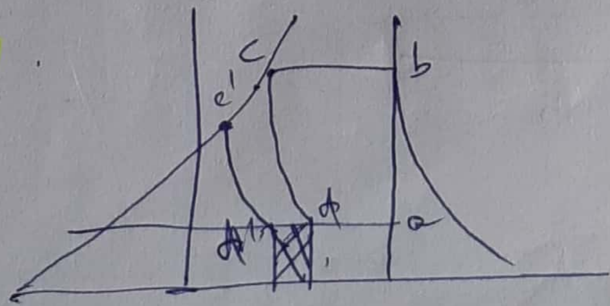
$$C.O.P = \frac{R + R_1}{W + W_1}$$

See page 43

additional work is done, additional RE also.

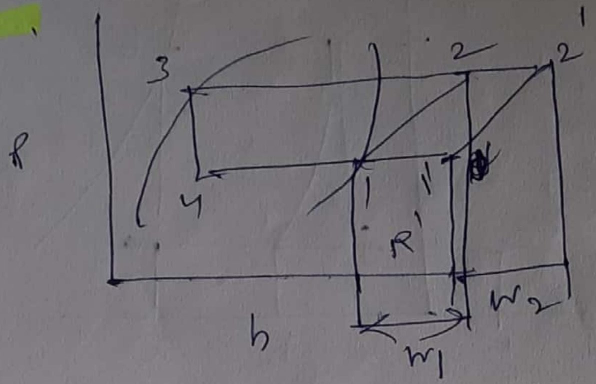
$$W_1 = bb'i'ib - aa'i'ia$$
$$= C_p(T_s - T_1) - T_2 \cdot C_p \cdot \log_e\left(\frac{T_s}{T_1}\right).$$

d) under cooling.



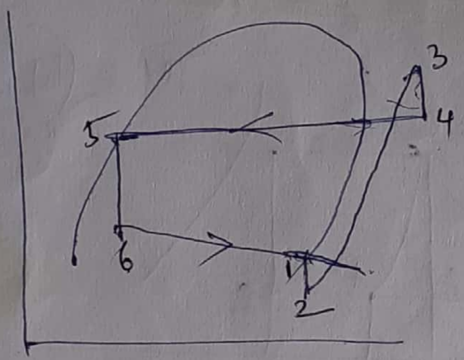
no extra work,
RE increases
COP increases

Superheating.

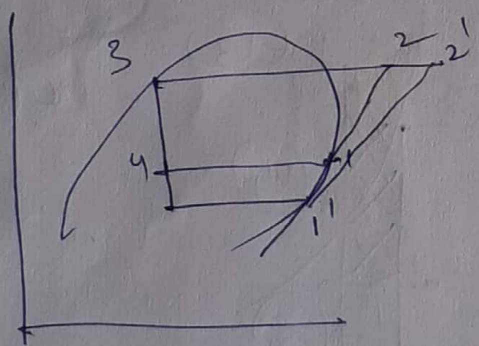


Pressure losses

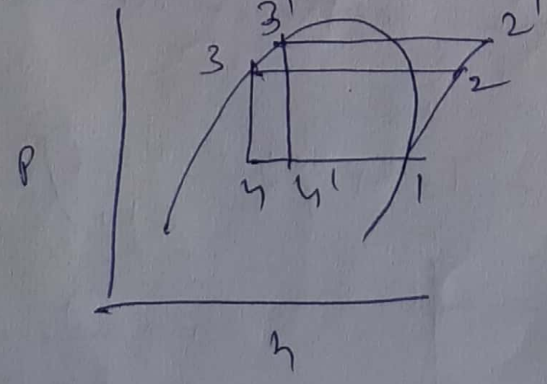
Pressure drops in lines & valves.



Suction pr decreased.

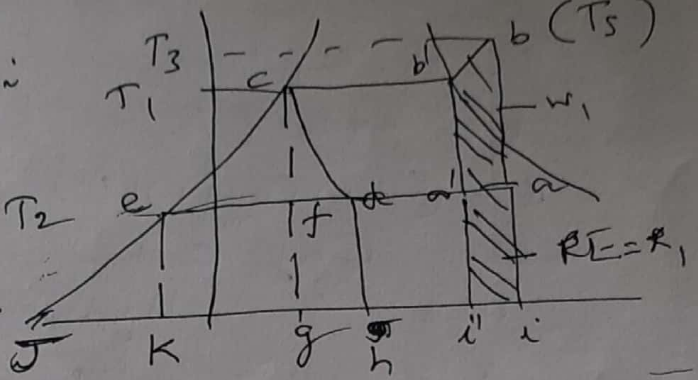


delivery pr increased



C.O.P. decreased

when vap is superheated after compn



$w_1 = bb'i'i - aa'i'i$

$= C_p(T_s - T_1) - T_2 C_p \log_e \frac{T_s}{T_1}$

$R_1 = aa'i'i$

$= T_2 \cdot C_p \cdot \log_e \frac{T_s}{T_1}$

$COP = \frac{R + R_1}{w + w_1}$

Wet vs dry Compn Comparision

1) Liq refrigerant may be trapped in head of cyl of compr & damage the valve plates
2) accelerate wear

But more superheating of suction is undesirable.

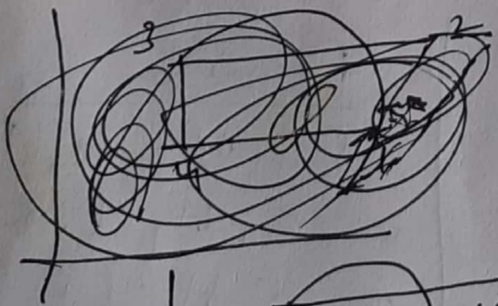
Adv of vap Refgn over Air Ref

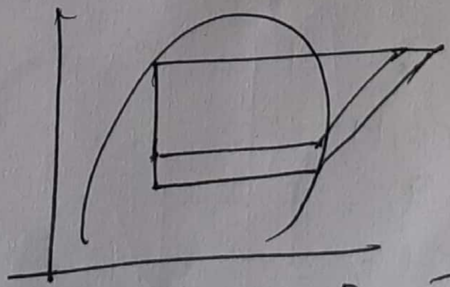
C.O.P is more

By adjusting the throttle valve reqd evap temp is achieved.

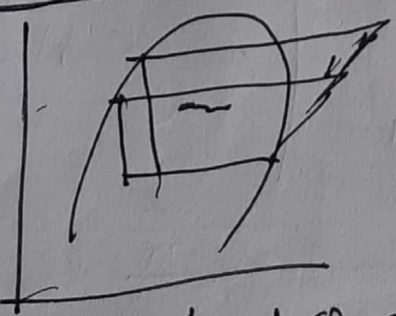
disadvantages

1) First investment is high
2) prevention of leakages is difficult





effect of suction pr



effect of delivery pr.

Designation of Refrigerants

methane or ethane base refrg

$C_m H_n Cl_p F_q$

$n+p+q = 2m+2$

$R = (m-1)(n+1)(q)$

m = No. of Carbon atoms
n = " , Hydrogen "
p = " Chlorine "
q = " fluorine "

ex R_{12}, Dichloro Difluoro methane

CCl_2F_2.

No. of Carbon atoms m = 1
No. of Chlorine " p = 2
No. of hydrogen " n = 0
No. of Fluoro " q = 2

$n+p+q = 2m+2$
$0+2+2 = 2(1)+2$
$4 = 4$

No. of Refrigerant

$R(m-1)(n+1)(q)$
$R(1-1)(0+1)(2)$
R_{012} or R_{12}

R_{22} $R_{022} = R(m-1)(n+1)(q)$

Monochloro difluoro Methane

$m-1 = 0$, $m = 1$
$n+1 = 2$, $n = 1$
$q = 2$

$n+p+q = 2m+2$
$1+p+2 = 2(1)+2$
$p+3 = 4$, $p = 1$

Formula

$C_m H_n Cl_p F_q$
$= C_1 H_1 Cl_1 F_2$
$= CHClF_2$

Green House effect, Future Refrigerant

A green house is a house made of complete glass where the vegetables are cultivated. Solar energy of short wave radiation enters inside through the glass. Short wave radiation strikes the inner earth surface & converts into heat — long wave radiation. But the glass restricts the long wave radiation going out & traps the heat. The trapped heat contributes to the warming of glass house & provides energy for the growth of plants, & keeps the plants green. This effect is known as Green House effect. The atmosphere surrounding earth acts like glass and keeps the earth green. Hence this effect is also ~~pro~~ popularly known as green House effect.

Because of this, warming of atmosphere & earth's surface also takeplace. CO_2, watervapour & other traces of gas contribute in the warmingup.

Green House gases are CO_2, H_2O, CH_4, N_2O, O_3.

Green House effect is helping earth to keep it warm. CO_2 is the important gas. Higher %ge of CO_2 will trap more & increase the earth's surface Temp slowly.

Green House effect from CO_2 & CFCs.

Living beings emit CO_2. Trees use CO_2 and emit O_2 (photosynthesis). This balance is very important for earth & mankind. Large generation of CO_2 & cutting of forests result in global warming.

CFC's

CFC's ascend into stratosphere & destroy O_3 layer. warming effect of earth increases. ~~Hence conventional CFC~~ ~~CFC's are reduced in usage.~~

CFC's in fact destroy's O_3 layer, creates holes through which large amount of harmful heat in the form of ultraviolet rays falls on the earth & increases its temp. This is more serious than the effect caused by CO_2. ~~The released chlorine~~

Global warming potential (GWP)

Ozone depleting potential (ODP).

These two are important factors. Tables are available about this data of each refrigerant

Chemical	Formula	ODP	GWP	estimated atmospheric life of refrigerant (years)
R-11	CCl_3F	1	1300	59
R-12	CCl_2F_2	0.93	3700	122
R-22	$CHClF_2$	0.05	510	18
✓R-134a	CF_3CH_2F	~~[illegible]~~ 0	400	18

AFEAS (Alternative Fluorocarbon Environmental Acceptability study)

Ozone friendly does not ~~[illegible]~~ necessarily mean Greenhouse friendly.

Montreal protocol (1987)

Decided to phase out ODS (Ozone depleting substances).

Equipment

Compressors

3 Types

① Reciprocating ② Rotary ③ Centrifugal.

Reciprocating:

0.25 T to 1000 Tons.

2 Types

a) Single acting Vertical — 1 delivery for 1 rev

b) Double acting Horizontal — 2 deliveries for 1 rev.

Single acting are further classified according to

(i) No. of cyl ii) Arrangement of cyl

iii) Speed iv) Staging of cyl

Hermetically Sealed Compressor:

In ordinary compressor, Crank shaft extends through the compressor housing and connected to driving motor.

Where as in hermetically sealed type, compr and motor are enclosed in one housing.

Suction, discharge, charging connections & electrical connections will be provided on the housing.

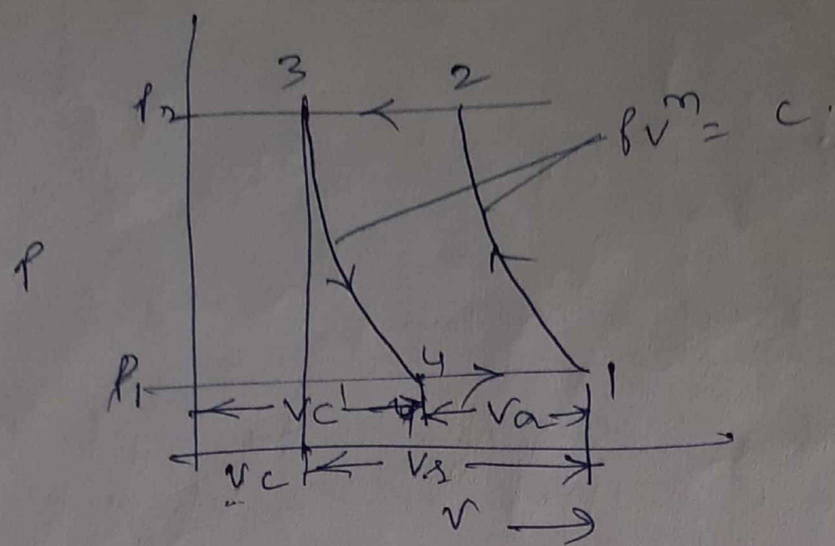
Advantages:

i) leakage of refgnt is avoided

ii) less Noisy iii) More compact, requires less space.

These are used for small appliances & window A/C.

Volumetric η of Rec Compressor



Volume V_c of gas in clearance space re expands upto V_c'.

Full displacement $= V_s$.

But effective piston stroke displacement $= V_a$.

P_2 = del. pr, P_1 = suction pr

V_s = stroke vol, V_a = Actual vol of gas Taken

V_c = clearance vol.

V_c' = vol of gas after re expansion.

n = Index of Compn.

%ge clearance $C = \frac{V_c}{V_s} \times 100$.

(Always presented in terms of stroke vol)

$$\eta_v = \frac{V_a}{V_s} = \frac{V_s - (V_c' - V_c)}{V_s} = \frac{V_s - V_c\left[\frac{V_c'}{V_c} - 1\right]}{V_s}$$

$$P_2 V_c^n = P_1 (V_c')^n$$

$$\left(\frac{V_c'}{V_c}\right)^n = \frac{P_2}{P_1}, \quad \boxed{\frac{V_c'}{V_c} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}}, \quad V_c' = V_c\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

Substituting

$$\eta_v = \frac{V_s - V_c\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]}{V_s} = 1 - \frac{V_c}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$$

But $\frac{V_c}{V_s} = \frac{C}{100}$,

$$\boxed{\eta_v = 1 - \frac{C}{100}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]}$$

η_{va} = Actual volumetric η

P_c = Pr. of vap in cyl at the start of Compr

P_e = Pr. of vap in the evap suction pipe at the entry of Compr.

$P_c < P_e$

T_c = Temp of vap in the cyl at the start of Compr

T_e = Temp of vap in the evap suction pipe at the entry of Compr.

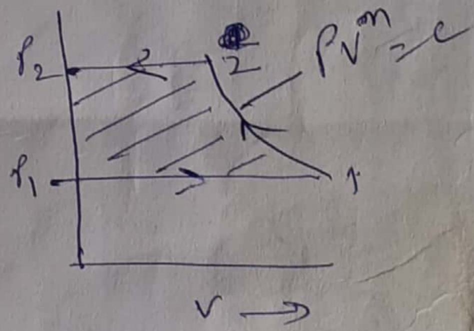
$T_e > T_c$.

~~η_{va}~~ Superheating of gas as it enters the cyl & friction loss through ports & valves, lowers the η_v.

$$\eta_{va} = \eta_v \cdot \frac{P_c}{P_e} = \eta_v \cdot \frac{T_c}{T_e}, \quad \eta_{va} < \eta_v.$$

Power required

Workdone for Compn = area



$$W = \frac{P_2V_2 - P_1V_1}{n-1} + (P_2V_2 - P_1V_1)$$

$$= (P_2V_2 - P_1V_1)\left[\frac{1}{n-1} + 1\right]$$

$$= \frac{n}{n-1}(P_2V_2 - P_1V_1)$$

$$= \frac{n}{n-1} P_1V_1\left[\frac{P_2V_2}{P_1V_1} - 1\right]$$

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}}$$

$$W = \frac{n}{n-1} \cdot P_1V_1 \left[\left(\frac{P_2}{P_1}\right)\left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}} - 1\right]$$

$$W = P_1V_1 \cdot \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$ ✓

m = mass kg/

$$W = mRT_1 \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$ ✓ N.m / sec

m = mass of ref kg/sec

Power reqd = KW = $mRT_1 \cdot \frac{n}{n-1} \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right] \times \frac{1}{1000}$ KW

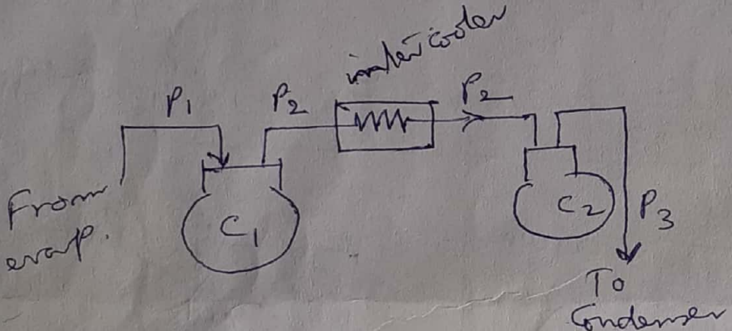
$= P_1 V_1 \cdot \frac{n}{n-1} \cdot \frac{1}{1000} \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$ KW

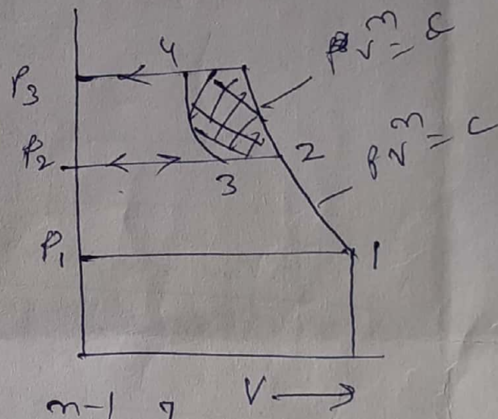
If V_1 = vol in m^3/sec

P_1 & P_2 are N/m^2

$$KW = V_1 \cdot \frac{n}{n-1} \cdot \frac{1}{1000} \cdot P_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

Multi-stage Compression :





$$(KW)_{C_1} = mRT_1 \frac{n}{n-1} \cdot \frac{1}{1000} \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

$$(KW)_{C_2} = mRT_3 \frac{n}{n-1} \cdot \frac{1}{1000} \left[\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1 \right]$$

$$KW_{Total} = mR \cdot \frac{n}{n-1} \cdot \frac{1}{1000} \left[T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + T_3 \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - T_1 - T_3 \right]$$

$P_2 = \sqrt{P_1 P_3}$.

Suction Temp

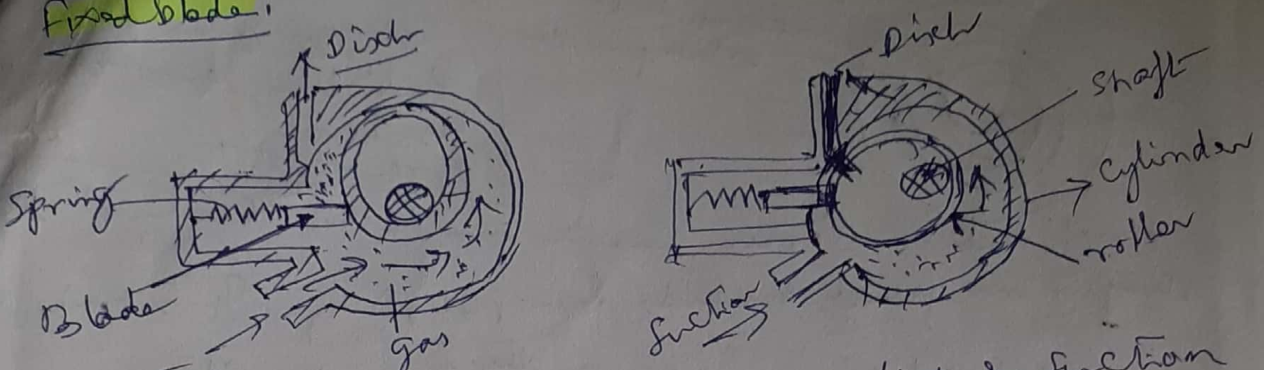
1) Compr Capacity decreases with the decrease in suction (evap) Temp.

2) Keeping the condr temp same, reducing the evap temp increases BP/Ton.

3) Condg Temp :- The Compr B.H.P and BHP/Ton increases with increase in Condr pr, when suction Temp is Const.

Rotary Compr.

Fixed blade:



Compression started & beginning of suction stroke

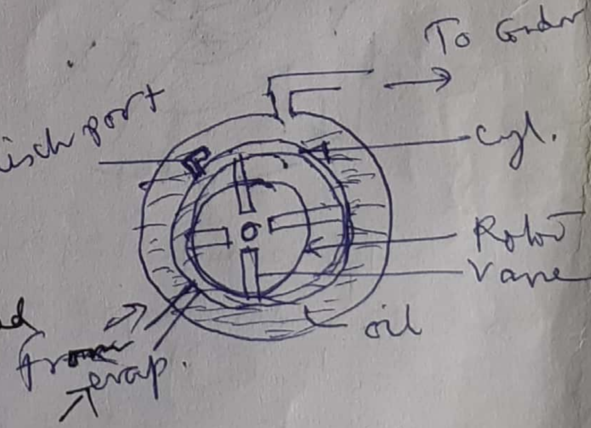
disch & suction are near completion.

2 Types of rotary compressors
1) with one stationary sealing blade and eccentric rotor
2) with sealing blade which rotates with eccentric shaft

roller is eccentric with the cyl. The roller will always touch the cyl wall. A spring loaded blade mounted in the slot of cyl moves in and out of the slot to follow the rotor as the rotor

Rotary Vane Type

A series of blades are mounted on a periphery of a slotted rotor.
The blades are free to move in and out of the slots provided on the rotor.



Suction vapour is entrapped between the adjacent rotating blades. The vapour is compressed & discharged.

1) More silent 2) Satisfactorily used with Refrigerants having high sp. vol at low suction pr.
3) Used in low temp application.

P.T.O

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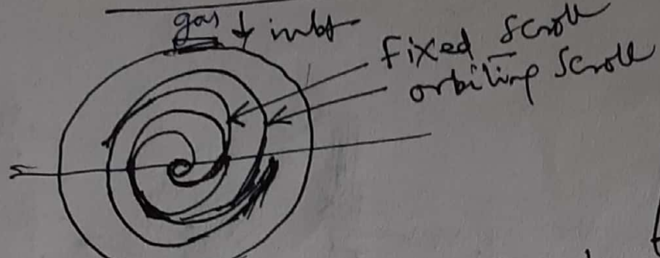
Scroll Compr

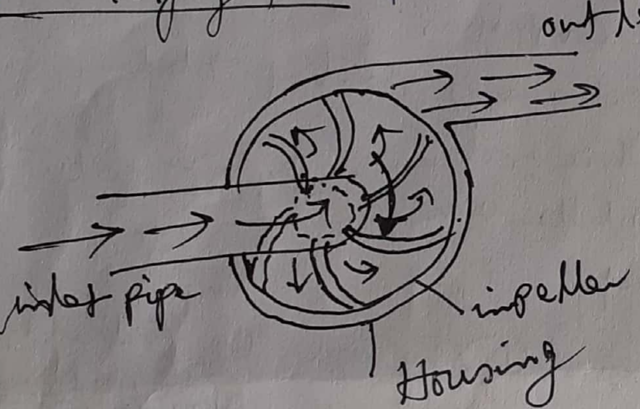


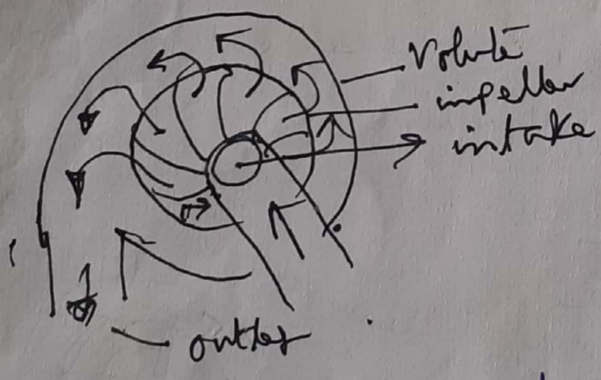
Advn
- Better startability
- energy efficient
- Reliable, durable
- less sound.
- good at A/C.

Archimedean screw can be made in con centric form, pumping the fluid inwards from periphery. It is used for gases.

2 pairs of volutes, one fixed & other driven with an eccentric motion. The volutes are placed in a hermetic shell. Intake gas fill in the voids. gas leaves through axial outlet at centre

Centrifugal compressor





The refrigerant vapour is drawn into the compr and it is discharged with a high velocity at the outside of impeller. High velocity head is further converted into pressure head by passing through the diffuser. Multistage system is used for high compression ratio.

P.T.O

Screw Compressors :-

Archimedian Screw ~~~~ principle is used here.

The Compr Consists of a single screw rotor which meshes with 2 rotary seals.

~~~~ Many designs were made.

In one design metallic cylindrical rotor with 6 flutes are used. The rotor is driven by a motor in a cylindrical housing. Gas entering at one end ~~~~ fills the available flutes. Rotation of the screw ~~~~ rotor traps the gas and the gas is compressed by ~~~~ the rotation, & comes out from discharge port.

Capacity Control of Compressors:

It is always necessary to change the capacity of the Compressor according to the load on the evaporator. Diff methods are

i) Cyl Head bypass ~~~~ :- one ~~~~ or more cyls made ineffective

ii) Hot gas by pass :-

By passing heat of hot gas from discharge side to suction side.

Centrifugal Vs Reciprocating

Adv.

1) Handles large vol of refgnt
2) η is more
3) High speed turbines can be connected & used
4) Good range of Tonnage
5) life is more (6) quiet in operation
7) Vibration is less.

Dis adv.

(1) Refrigerants with high molecular weights are used (R-11)
(2) pressure ~~~~ rise per stage is less.
(3) not practicable for small Capacity
~~~~

Condensers.

Air cooled, water cooled.

Factors to be considered for the cooling medium

i) Quantity of cooling medium
ii) Amount of condensing surface.
iii) velocity of cooling medium
iv) Type of refrgnt.
V) Purity of refrgnt.

Air cooled

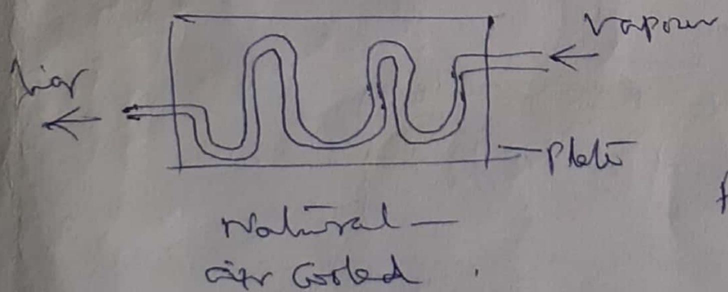
Natural convection, Forced convection
(Domestic Ref, etc)
air is circulated.

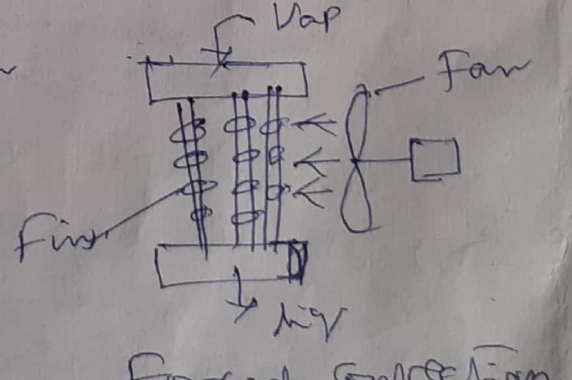
Chassis mounted — Remote air cooled

Chassis mounted

On one base, compr, condr & motor are assembled. Blower is used to force air through the condenser.

Remote :- Arranged on a large floor area (roof area) Both free & forced types are used.





Air cooled Vs water cooled

Adv :- 1) Simplicity (2) No handling problem
3) Piping arrangement for air is not there
4) No problem of disposal of used air.
5) Fouling effects are less
6) flexible 7) Installation, Maintenance cost is less.

dis adv :-

1) Poor heat carrying capacity
2) requires very large qty of air per TR
3) Above 5 TR not used ; because power reqd for fan increases
4) During summer, performance is less

But prefered where water supply is inadequate ; water disposal also is difficult.

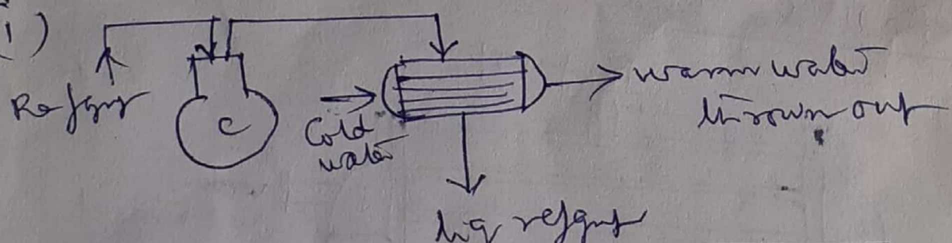
water cooled condensers :-

i) water waste system
ii) recirculated system.

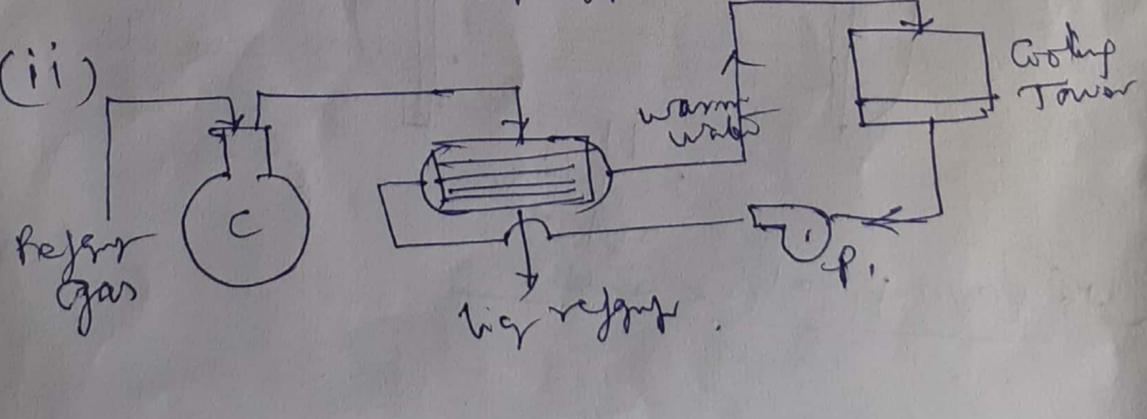
When ample supply of inexpensive water is available, then water is circulated in condenser and thrown out.

When inadequate & expensive supply of water is available then recirculated system is used. The water is cooled & reused here.

(i)



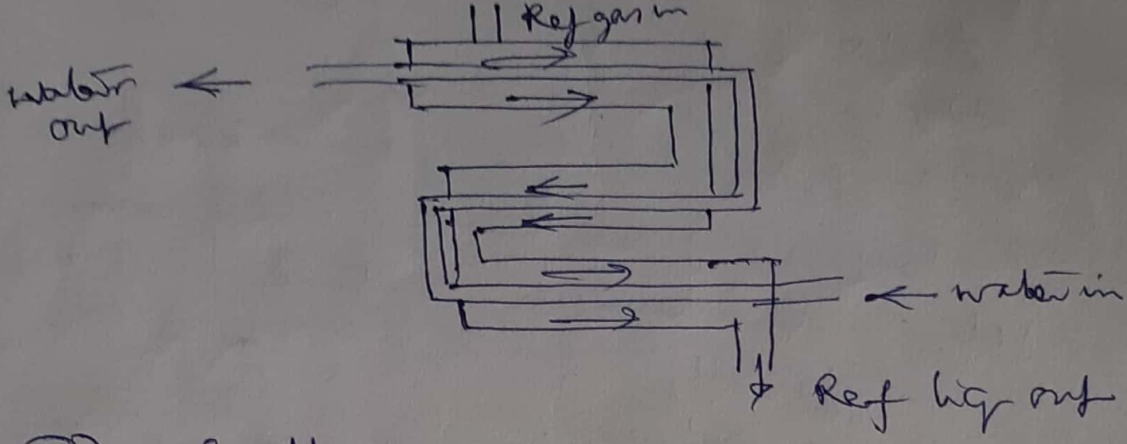
(ii)



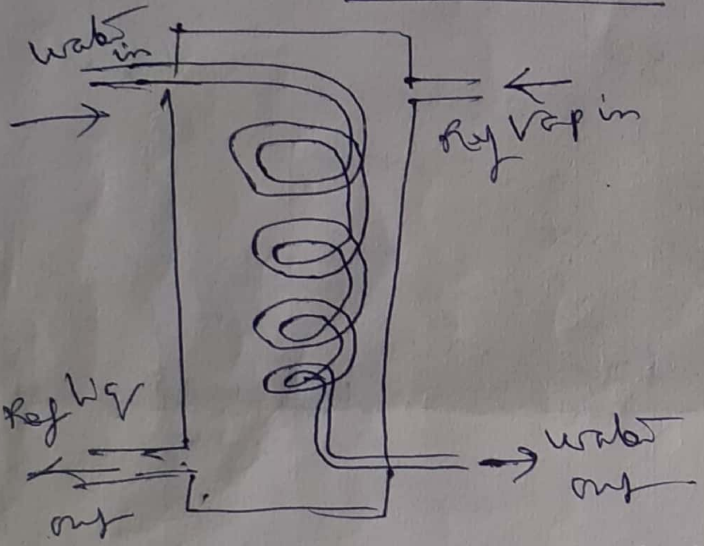
56 (10)

Water cooled condensers Types

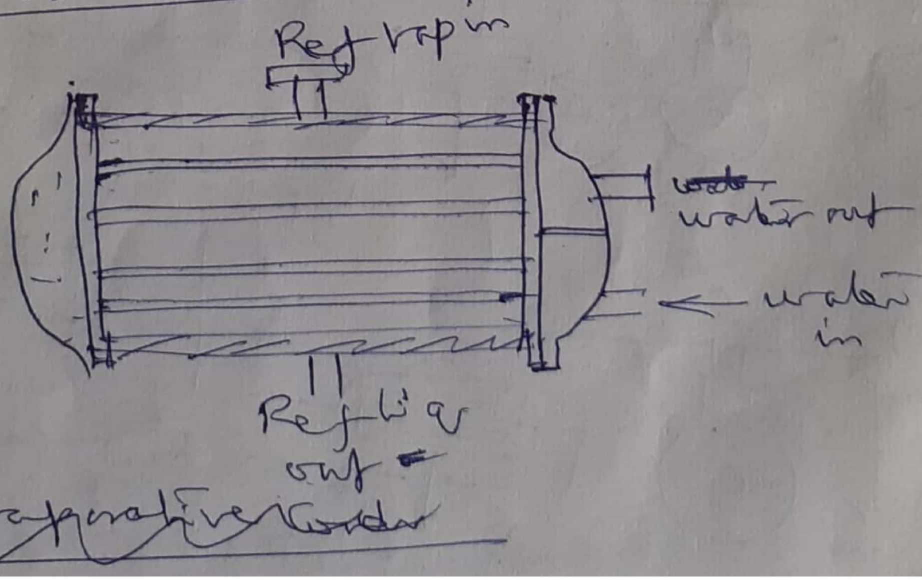
1) Double Tube condenser or Double pipe



(2) Shell & Coil condenser

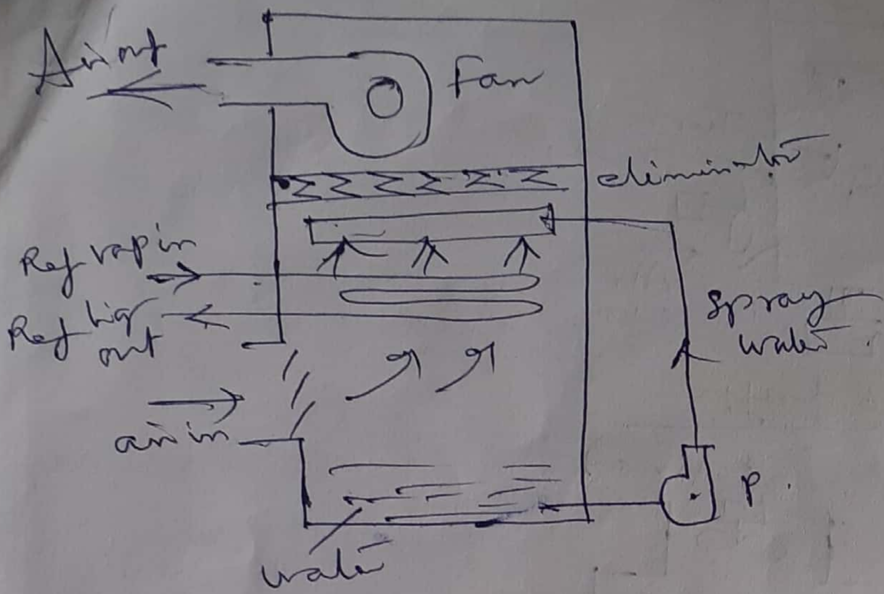


(3) Shell & Tube condenser

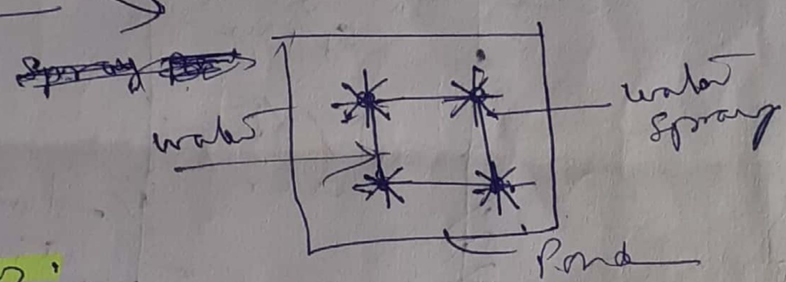


~~(4) Evaporative condenser~~

(4) evaporative Condr

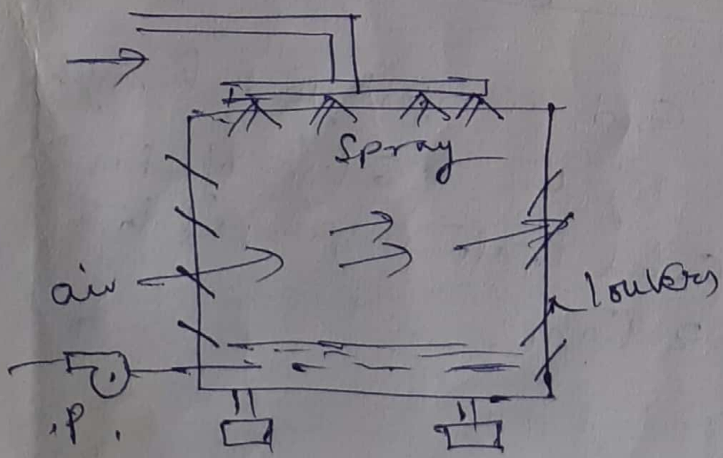


Spray ponds

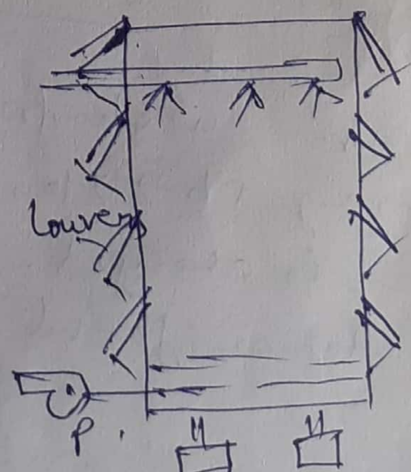


Cooling Towers :

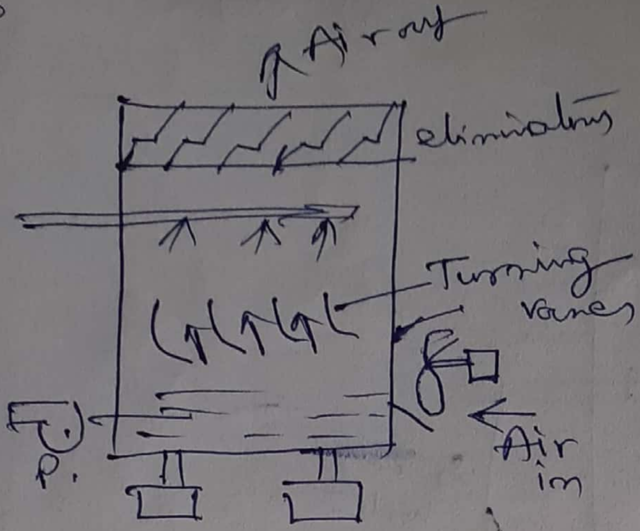
Natural draft



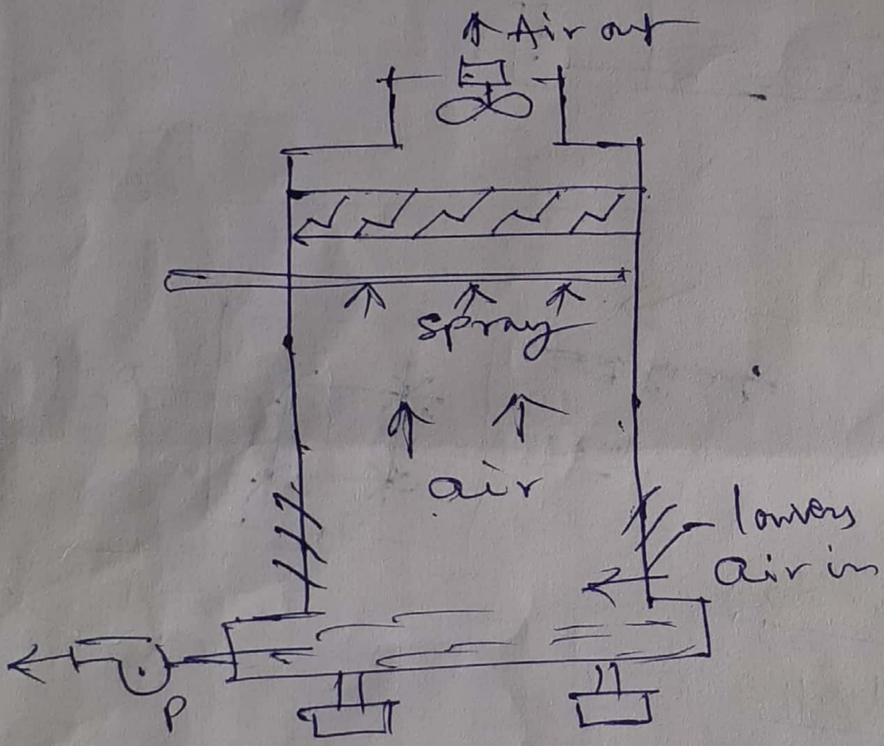
Spray Type



Deck Type



Forced draft



Induced draft

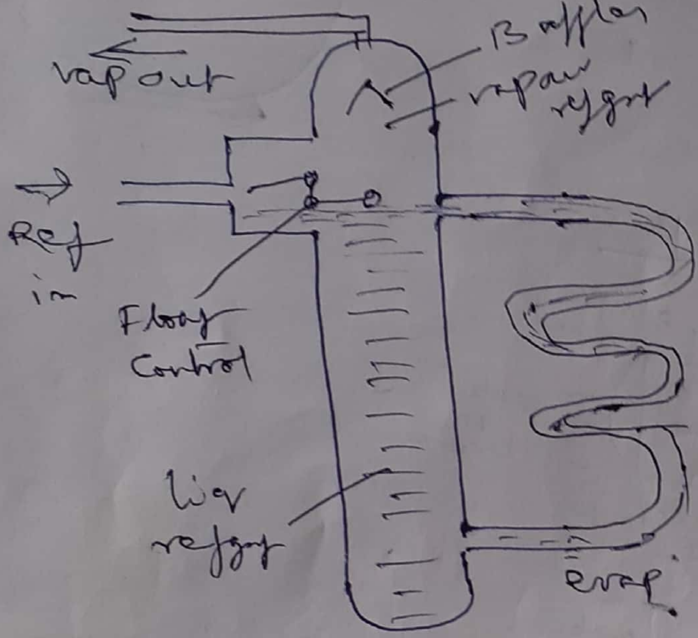
warm water from Condr is sprayed through spray nozzles. By the location of fan name is changed. Cooled water is pumped to condenser for utilization.

P.T.O

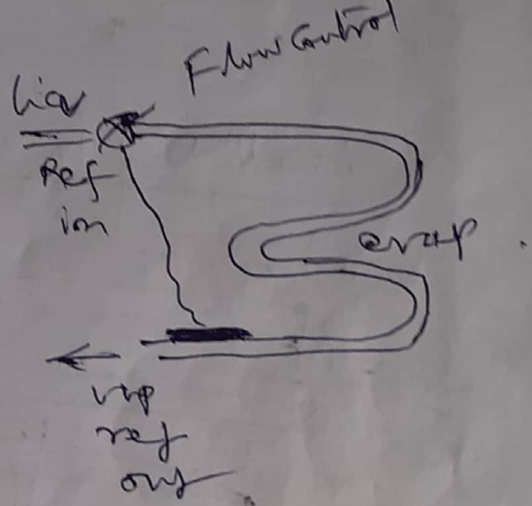
evaporators

Flooded evaporators :

when the evaporator (coil) is always kept filled with liq refgnt, it is known as flooded Type



Flooded



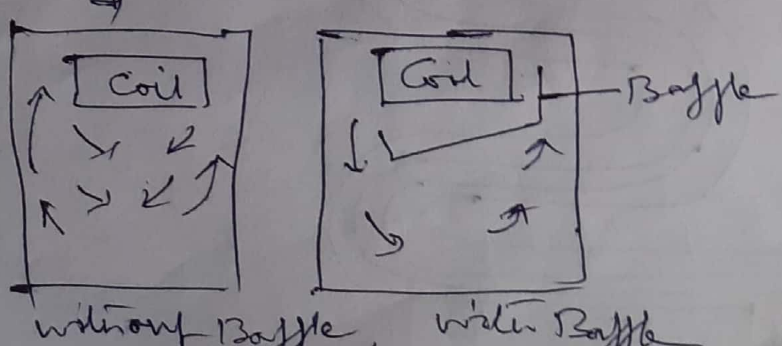
Dry-expansion Type (DX).

Flooded

This gives high heat transfer rate

DX :- liq refgnt is fed into the dry expn evap through an expn device which meters (Control) the liq into evap at a rate such that all liq is vaporized by the time it leaves the evaporator.

i) Natural convection evap   ii) Forced convection evap.

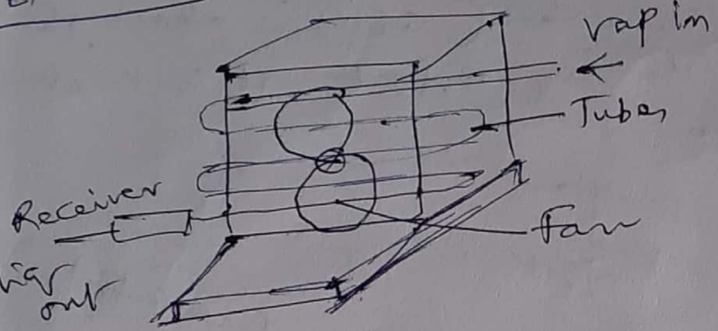


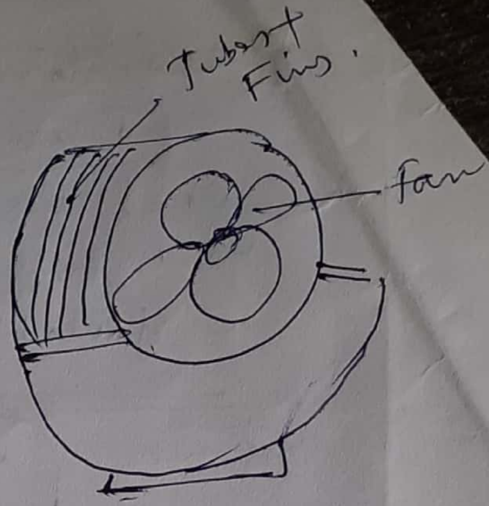
without Baffle,   with Baffle

60/

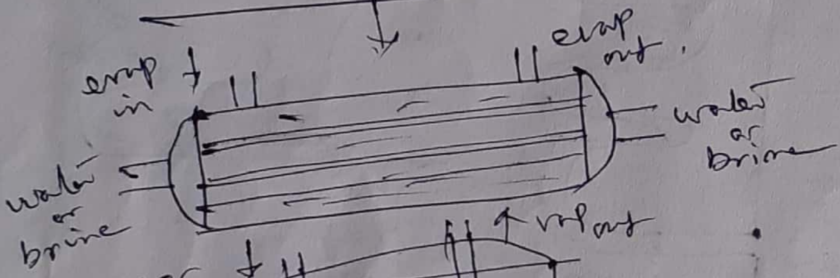
Forced Convection

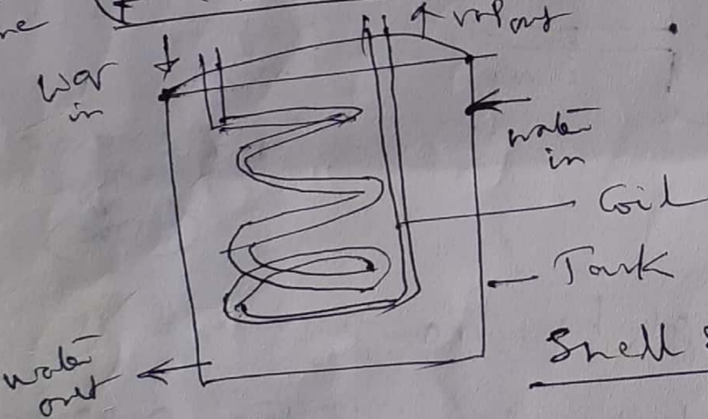
Ex Condenser.





Shell & Tube evap.





Shell & Coil

Double pipe

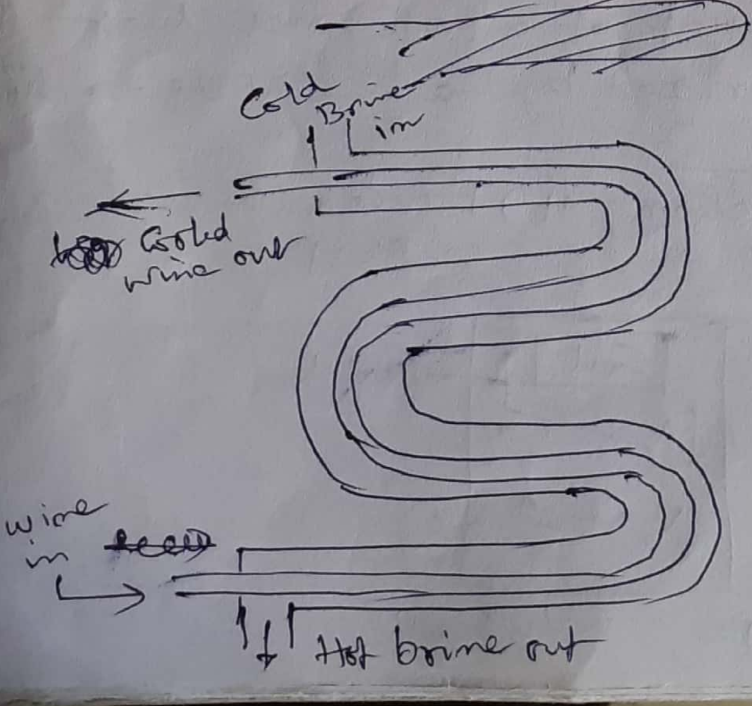
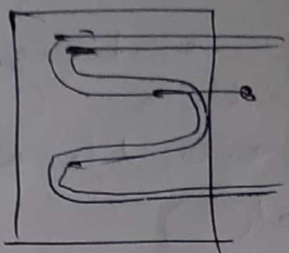
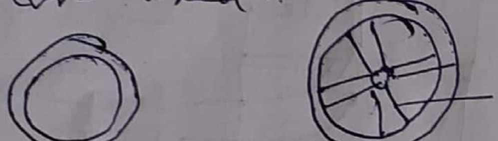


Plate evap



Baudelot cooler — ref through tubes & liq to be cooled (Milk etc) is allowed to fall from above through headers

Fins. : To increase surface area fins are used.



Plain Tube Tube with Fins.

Secondary evaporator

Refgnt cools the brime & brime cools the water (ice making).

In A/c also Refgnt cools the water & chilled water cools the Air (Indirect cooling).

If Refgnt directly cools the air (direct cooling). Ex: window A/c

Expansion devices

1) Capillary Tube
2) Automatic expansion valve (Pressn control)
3) Thermostatic expn valve
4) Highside float valve
5) lowside float valve
6) Solenoid valve.

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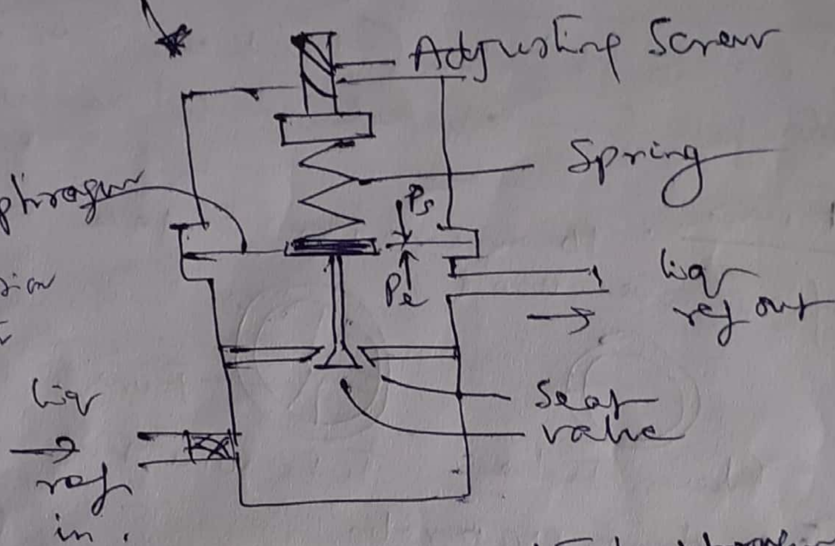
Capillary Tube

Small diameter, long Tube.
Because of resistance to flow
Pr & Temp reduces. (used in small capacity appliances, like Refrigerators, water coolers etc.)

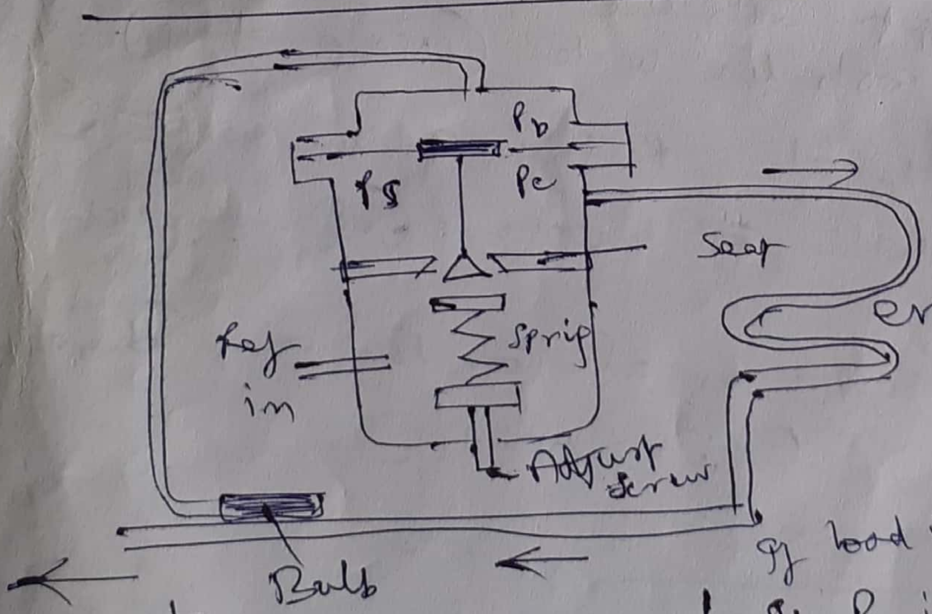
Automatic expn Valve



P_s = spring tension
P_e = evaporator press.

If Pe falls valve opens more and increases the flow of refrgt.

Thermostatic expn valve with diaphragm



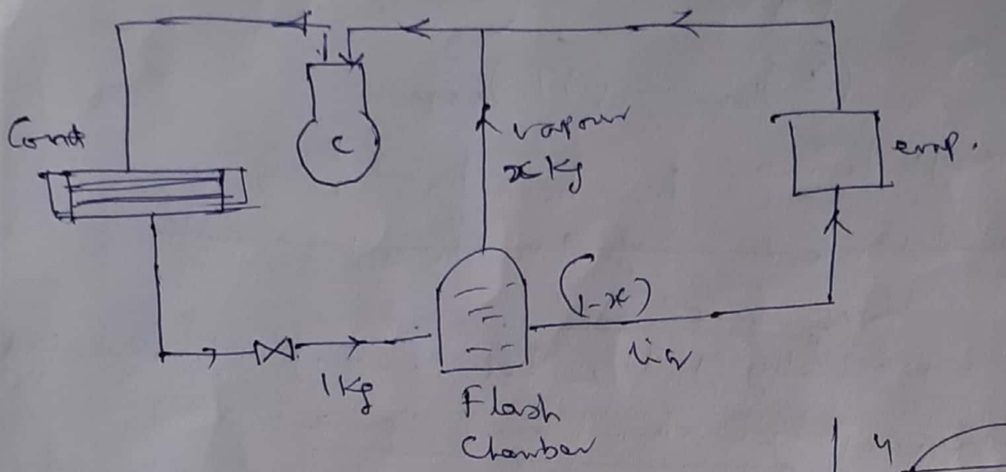
P_b = Pr in bulb
P_s = sprig Tension
P_e = Pr in evap.

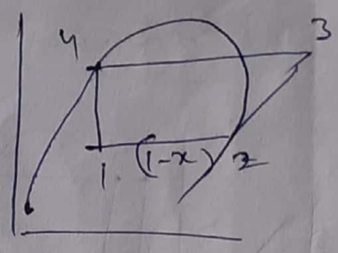
$$P_b = P_s + P_e$$

If load is more, pb increases.
If P_b is more, more qty of ref. flows to evap.
reverse when load is less.

Methods of improving C.O.P.

(1) Flash chamber.





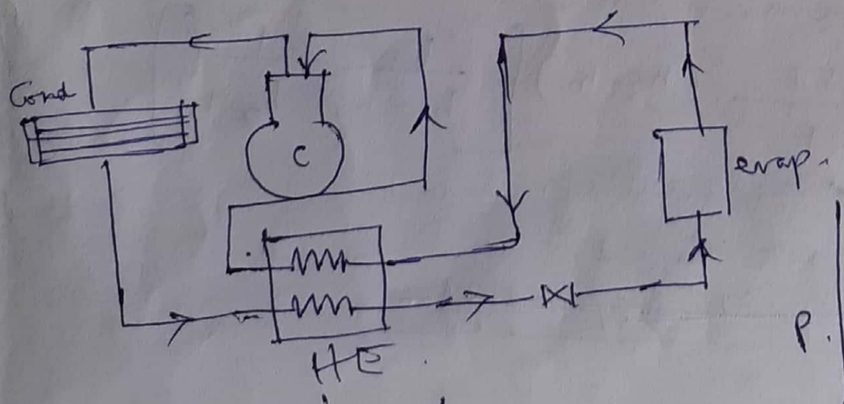
Flash is the mass of vapourised refrigerant per kg after leaving the throttle valve. This vapour does not take part in RE as compared with liq. This vap can be bypassed & sent directly to compr.

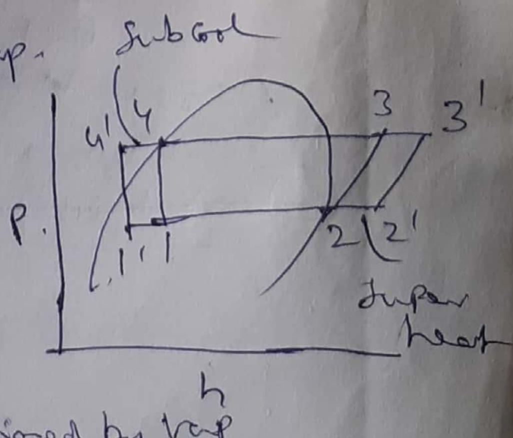
Theoretically there is no effect on thermodynamic cycle.

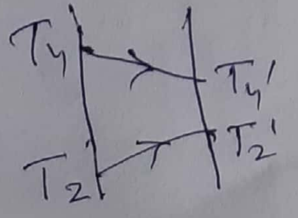
Evap size can be reduced

Power & C.O.P will remain as simple sat cycle (theoretically)

2) Sub cooling of liq refrigerant by using vapour refrigerant







Heat gained by vap = Heat lost by liq.

6

$$Cp_l \cdot m_l \cdot (T_4 - T_4') = Cp_v \, m_v \cdot (T_2' - T_2)$$

l = liq, v = vap, Cp = sp ht.

$m_l = m_v$ & $Cp_l > Cp_v$.

$$(T_4 - T_4') < (T_2' - T_2)$$

$$(\Delta T)_{liq} < (\Delta T)_{vap}$$

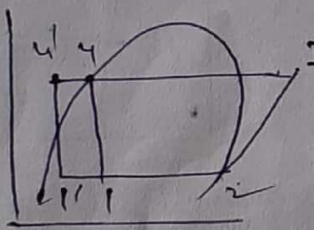
By energy balance $h_2' - h_2 = h_4 - h_4'$.

~~Under Ideal Conditions of heat Transfer in HE~~

~~$T_4' = T_2'$~~.

This is practically good, but C.O.P. gets reduced.

3) **Sub Cooling by external Cooling source:**



load = T Ton.

$$\text{mass } m = \frac{3.5\,T}{h_2 - h_1}$$

$$\text{Power} = \frac{m \cdot (h_3 - h_2)}{1} = \frac{3.5\,T}{(h_2 - h_1)} \cdot \frac{(h_3 - h_2)}{1}$$

If Sub Cooling is used, mass of refrgnt reqd is

$$m_1 = \frac{3.5\,T}{h_2 - h_1'}$$

$$\text{Power} = m_1 (h_3 - h_2) = \frac{3.5\,T}{h_2 - h_1'} (h_3 - h_2)$$

Net reduction in Power

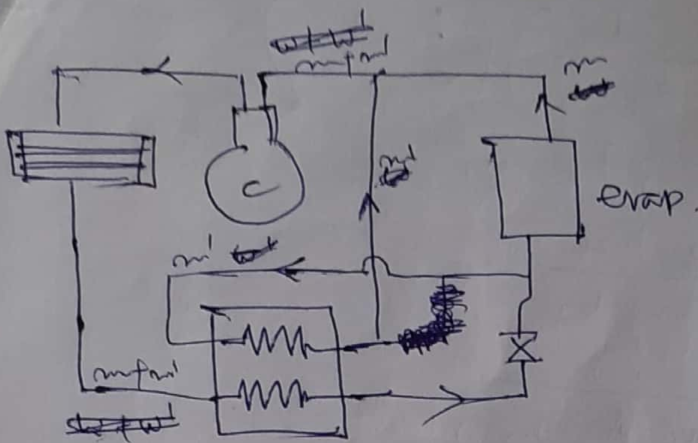
$$\frac{3.5\,T}{1} \cdot (h_3 - h_2) \left[\frac{1}{h_2 - h_1} - \frac{1}{h_2 - h_1'} \right]$$

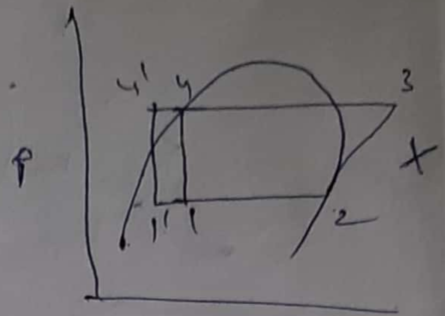
As Power required is reduced

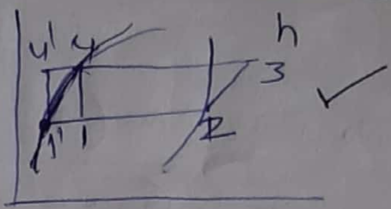
C.O.P. is increased.

~~(4) Sub Cooling with liq refrgnt~~

(4) Sub Cooling with liq refrigerant







Temp of liq refrgnt coming out of expn valve is less than temp of liq coming out of condr.

Energy balance at HE

Heat lost by hot liq = Heat gained by cold liq

$$(m+m')(h_4 - h_4') = m'(h_2 - h_1')$$

It is assumed that cold fluid entering the HE as saturated liq & coming out as sat vapour

$$(m+m')(h_4 - h_4') = m'(h_2 - h_4') \qquad h_4' = h_1',\ h_4 = h_1$$

$$m(h_4 - h_4') = m'(h_2 - h_4') - m'(h_4 - h_4')$$

$$m(h_4 - h_4') = m'(h_2 - h_4)$$

$$m' = \frac{m(h_4 - h_4')}{h_2 - h_4}$$

Power $= (m+m')(h_3 - h_2)$ kW.

Substituting

$$= \left[m + \frac{m(h_4 - h_4')}{h_2 - h_4}\right](h_3 - h_2)$$

$$= m\left[1 + \frac{h_4 - h_4'}{h_2 - h_4}\right](h_3 - h_2)$$

$$= m\left[\frac{h_2 - h_4'}{h_2 - h_4}\right](h_3 - h_2)$$

6b

$T =$ load

$m = \frac{3.5T}{h_2 - h_1'}$ Substitute

$P = \frac{3.5}{(h_2 - h_1')}\left(\frac{h_2 - h_4'}{h_2 - h_4}\right)\left(\frac{h_3 - h_2}{1}\right)$

$h_4' = h_1', \; h_4 = h_1$

$= 3.5 \cdot \frac{h_3 - h_2}{h_2 - h_4}$.

$C.O.P = \frac{m(h_2 - h_1')}{(m + \text{fund})(h_3 - h_2)}$

$= \frac{m(h_2 - h_1')}{m\left[\frac{h_2 - h_4'}{h_2 - h_4}\right]\left[\frac{h_3 - h_2}{1}\right]}$

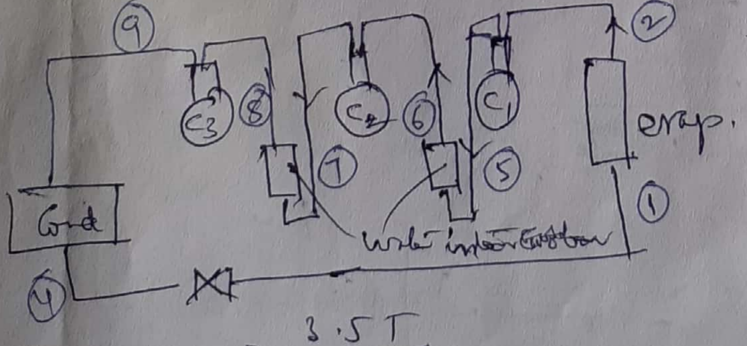
$= \frac{h_2 - h_4}{h_3 - h_2} = \frac{h_2 - h_1}{h_3 - h_2}$

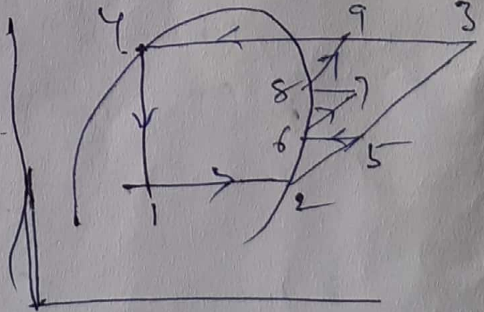
No change in C.O.P.

This arrangement is thermodynamically identical.

Single load Systems

① Compound Compn with water intercooler & Single expn Valve.





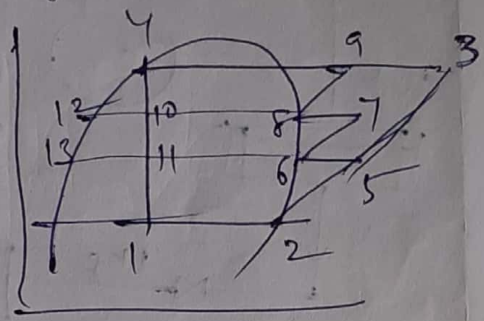
$m_r = \frac{3.5T}{h_2 - h_1}$

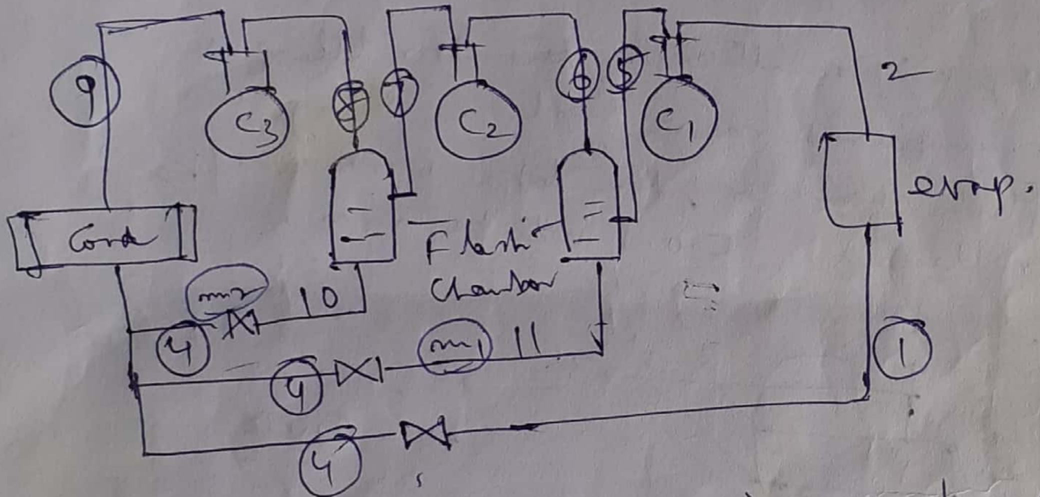
$P = \frac{m_r(h_3 - h_2)}{1} = \frac{3.5T(h_3 - h_2)}{h_2 - h_1}$ for Single Cycle

$$P_1 = \frac{3.5T}{h_2 - h_1}\left[\frac{(h_5 - h_2) + (h_7 - h_6) + (h_9 - h_8)}{1}\right]$$

Power will be reduced with this.

② Compound compr with flash intercooling & single expan valve along the flow line to evap.





Flow of refgnt is diff in each branch

$$m_r = \frac{3.5T}{h_2 - h_1}$$

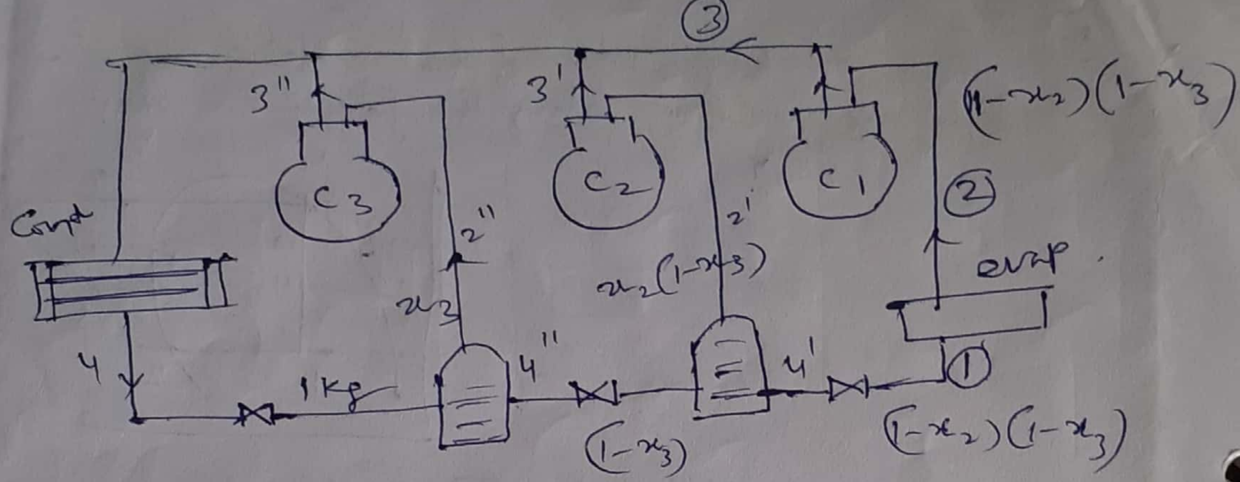
m_r = refgnt passing through evap.

$$m_1 = \frac{m_r(h_5 - h_6)}{(h_6 - h_{13})}$$

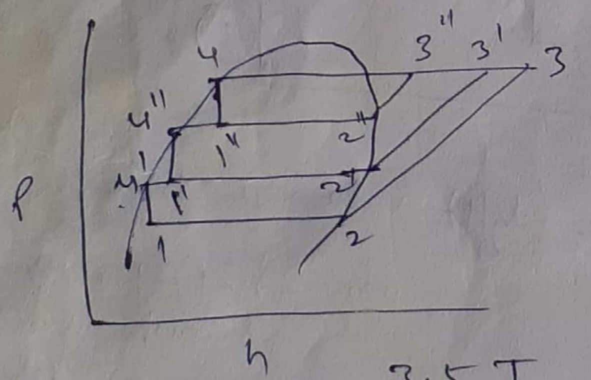
$$m_2 = \frac{(m_r + m_1)(h_7 - h_8)}{h_8 - h_{12}}$$

$$P = m_r(h_5 - h_2) + (m_r + m_1)(h_7 - h_6) + (m_r + m_1 + m_2)(h_9 - h_8) \quad kW$$

(3) Single evaporator with multi expansion valves & flash chambers



By using multi expn, the throttling is maintained near liq line & by using flash chamber, the total work done/kg is reduced. C.O.P will be more.

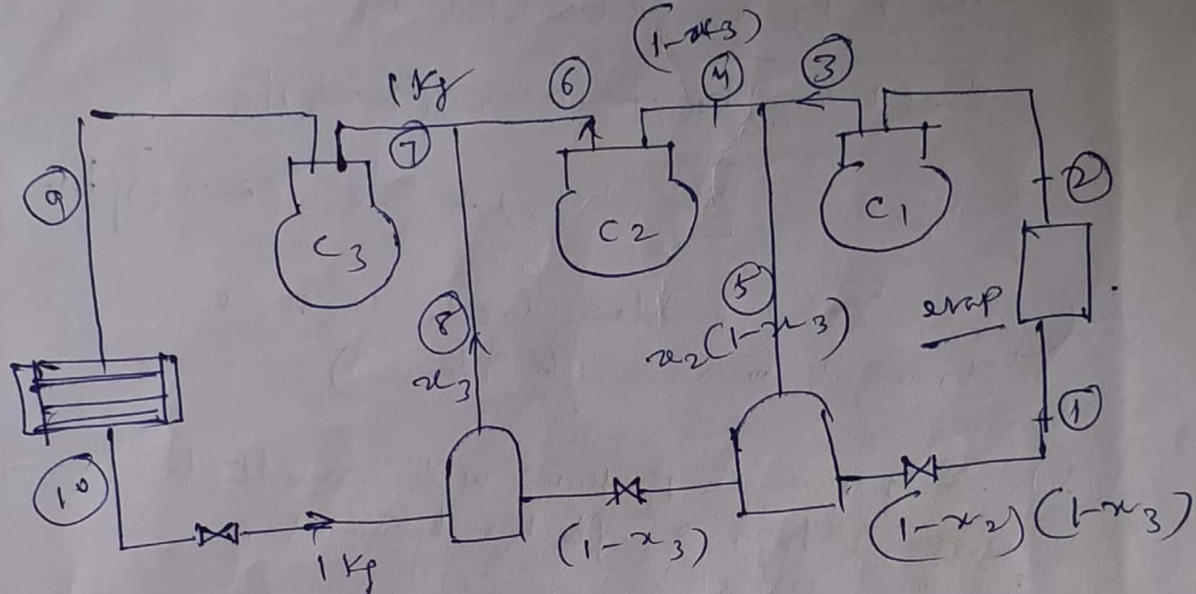


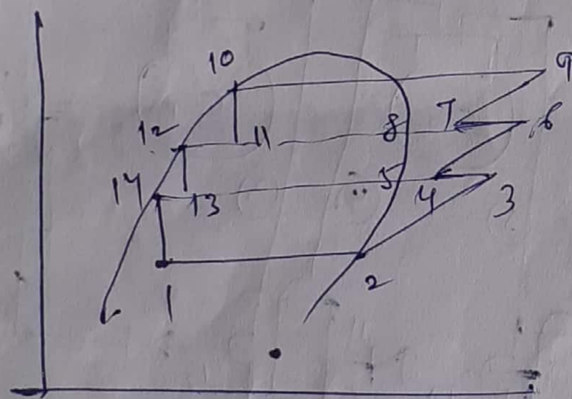
$$m_r = \text{mass of ref} = \frac{3.5\,T}{(1-x_2)(1-x_3)(h_2-h_1)} \text{ kg/sec}$$

$$\text{Power} = m_r\left[(1-x_2)(1-x_3)(h_3-h_2) + x_2(1-x_3)(h_3'-h_2') + x_3(h_3''-h_2'')\right] \text{ kW}$$

$$\text{C.O.P} = \frac{(1-x_2)(1-x_3)(h_2-h_1)}{(1-x_2)(1-x_3)(h_3-h_2) + x_2(1-x_3)(h_3'-h_2') + x_3(h_3''-h_2'')}$$

(4) Compound Compression with multiple expansion valves in series with flash chamber ~~and~~ but no intercooling.





For 1 kg comes from C_3, then Compr C_1 compresses $(1-x_2)(1-x_3)$

Mass Compressed by C_2

$$= (1-x_2)(1-x_3) + x_2(1-x_3)$$

$$\Rightarrow 1-x_3)$$

Mass of refrgnt Compressed by C_1

$$= (1-x_3) + x_3 = 1\text{ Kg}$$

$$m = \frac{3.5\,T}{(1-x_2)(1-x_3)(h_2-h_1)}.$$

7°

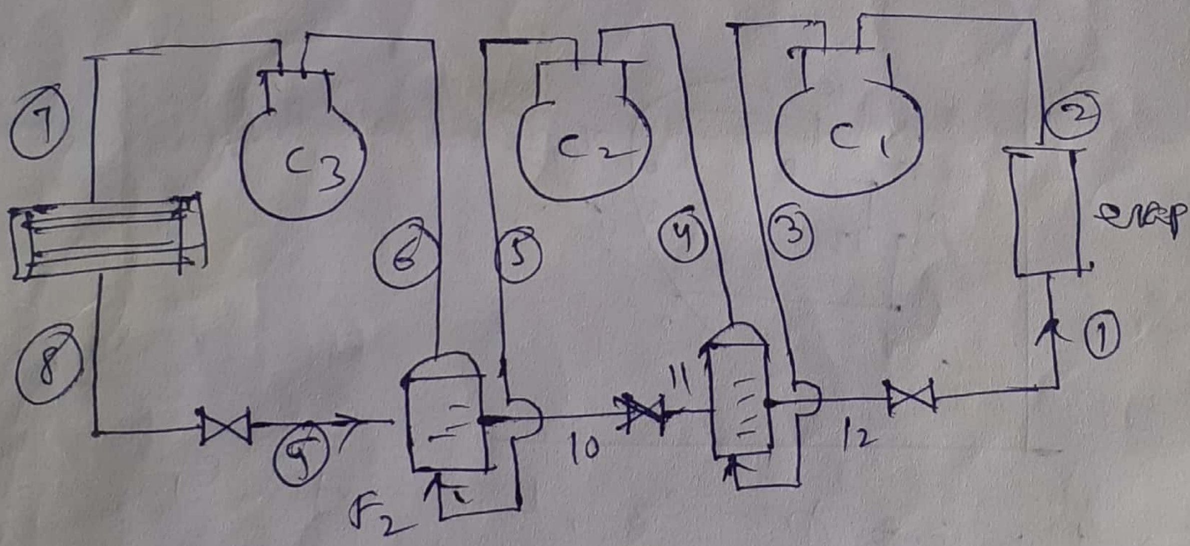
$$\text{Power} = m_r\left[(1-x_2)(1-x_3)(h_3-h_2) + (1-x_3)(h_6-h_4) + 1\,(h_8-h_7)\right]$$

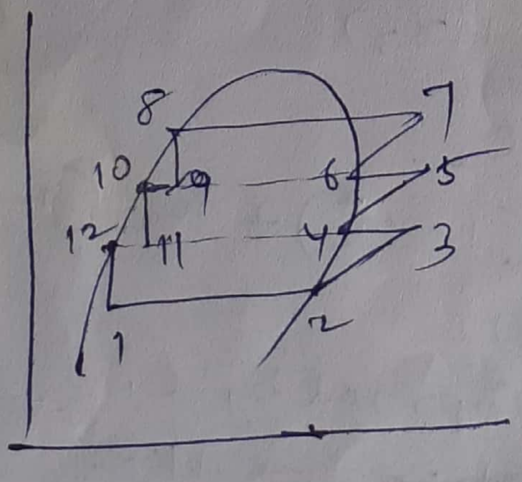
h_4 & h_7 are calculated by

$$x_2(1-x_3)h_5 + (1-x_2)(1-x_3)h_3 = \left[x_2(1-x_3) + (1-x_2)(1-x_3)\right]h_4$$

(In actual problem locate 4, 7 & draw 4 to 6 & 7 to 9 lines.)

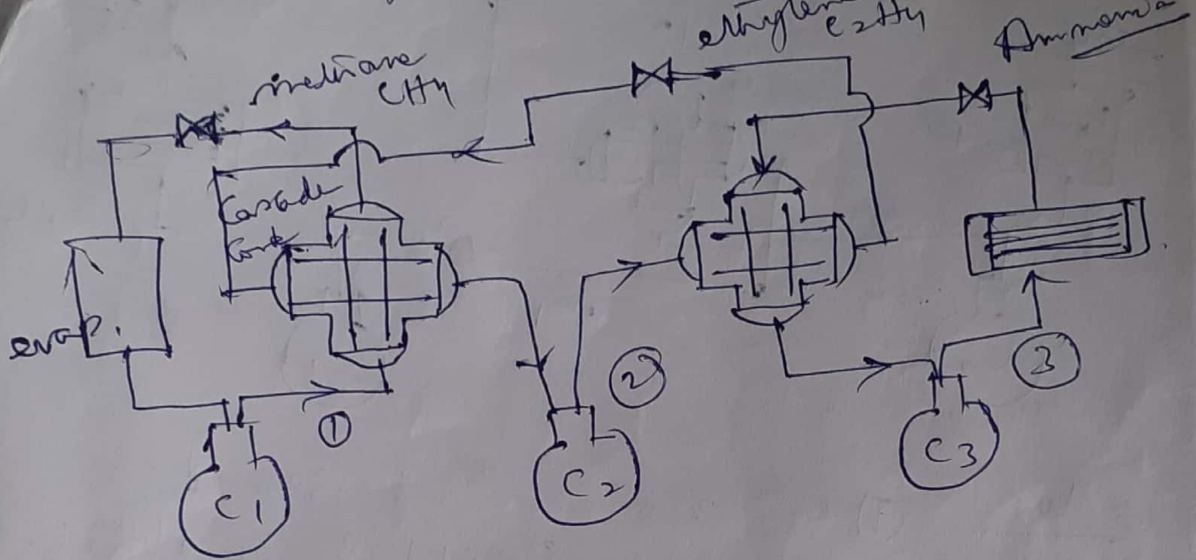
(5) Compound compression with multiple expn valves & flash intercooling.

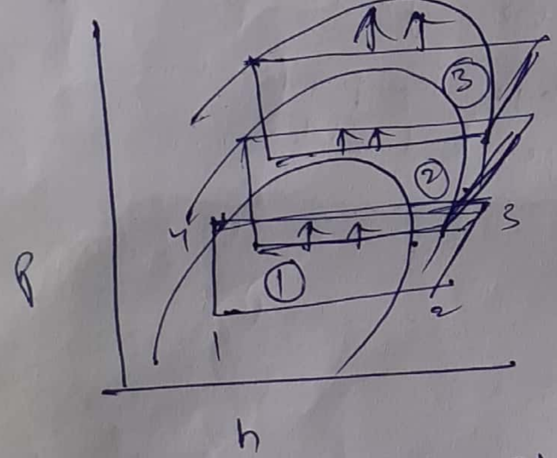




Cascade System

To obtain low temp -80°C & below Cascade system are used.





3 stage Cascade system with ph diagram.

2 stage :- m_2 = Mass of refgnt through low temp evap.

T_2 = load in Tons on low temp evap.

$$m_2 = \frac{3.5\,T_2}{h_2-h_1}$$

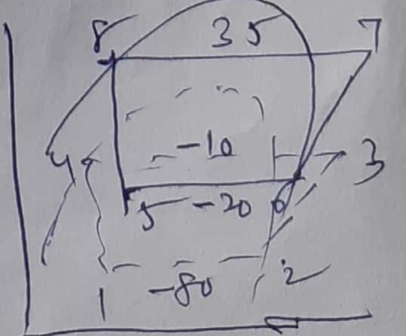
Mass of refgnt in high temp circuit is given by

$$m_2(h_3-h_4) = m_1(h_6-h_5)$$

$$m_1 = \frac{m_2(h_3-h_4)}{h_6-h_5}$$

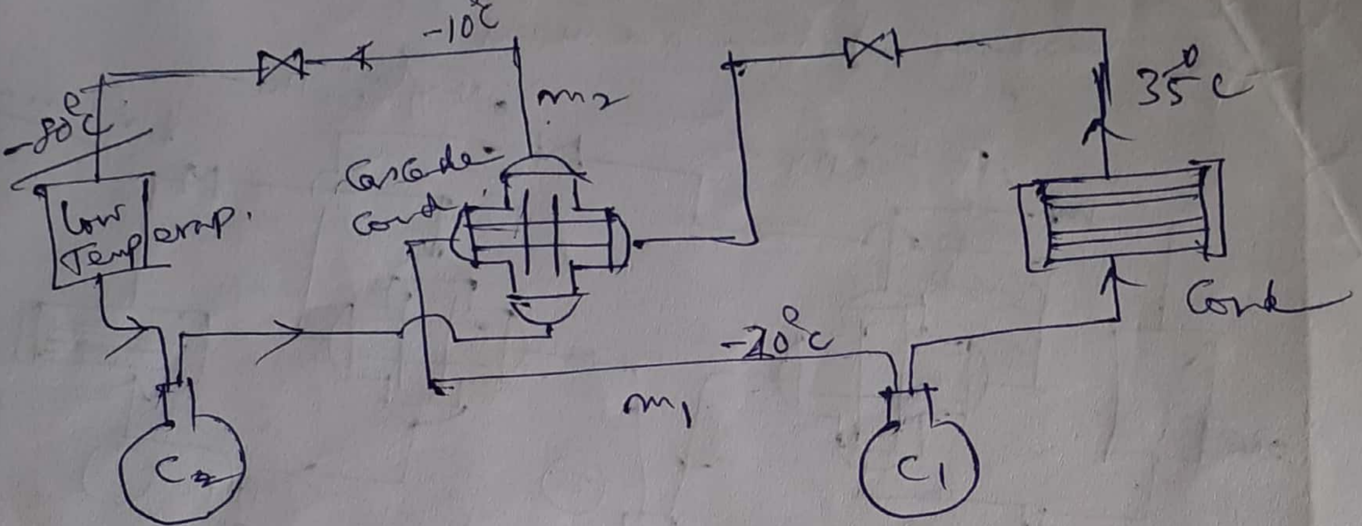
$$P = m_2(h_3-h_2) + m_1(h_7-h_6)$$

$$C.O.P = \frac{3.5\,T_2}{m_2(h_3-h_2)+m_1(h_7-h_6)}$$



72

210



Adv :- ① 2 or more refrigerant circuits are used. So ckt is simplified.

② Each refrigerant chosen for the conditions.

③ optimum interstage Temp is chosen by heat Exchanger calculations.