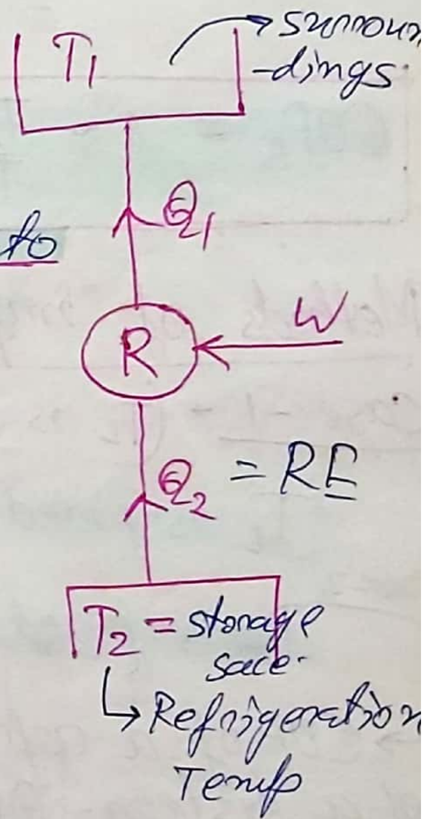
Refrigeration – It is the process of producing lower temp compair to surrounding. To produce lower temp continuously the system should run in a cycle.

Refrigerant – These are the substances which are used for producing lower temp.

Ex → Air, CO_2, water, Amonia, Freon etc.

Refrigeration effect → (RE)

It is the amt. of heat extracted from storage space inorder to maintain lower temperature.



unit of Refrigeration – (TR)

TR → Ton of refrigeration.

It is defined as the amount of heat reqd to convert 1 ton of water ~~into~~ at 0°C into ice at 0°C in 24 hrs.

$$1\,TR = 3.5\ kJ/sec = 3.5\ kW = 210\ kJ/min$$

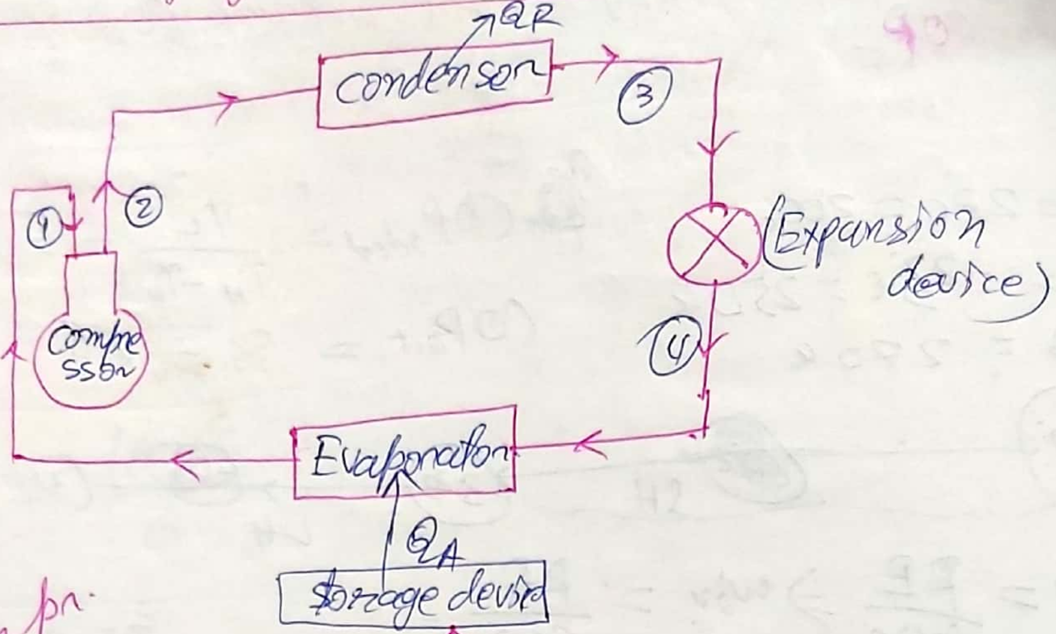
"when the capacity of plant is given in TR it means that "RE" is given."

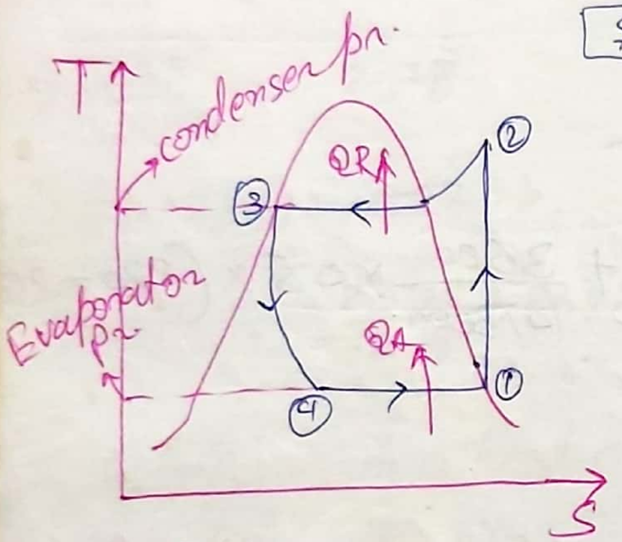
Coefficient of performance

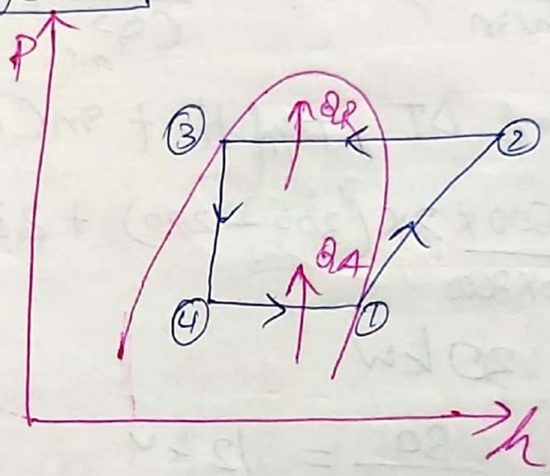
$$COP_R = \frac{\text{Desired effect}}{W} = \frac{RE}{W}$$

~~Ideal~~

Vapour compression Refrigeration cycle (VC cycle)







The processes are

1-2 → isentropic compression
2-3 → const. pr. heat rejection
3-4 → isenthalpic expansion (Throttling)
4 → 1 → const. pr. heat absorption.

The principle component of a VC system are compressor, condenser, Expansion device & Evaporator. The flow of refrigerant is compressor → condenser → expansion device → Evaporator.

Energy eqn for various component in VC system →

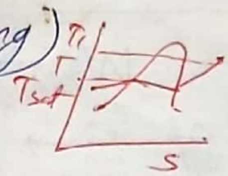
① compressor → $W_{in} = h_2 - h_1$

② condenser → $h_2 + \frac{c_2^2}{2} + gz_2 + q = h_3 + \frac{c_3^2}{2} + gz_3 + w$ → SFEE

$\Rightarrow Q_R = h_2 - h_3$

heat rejected in condenser = $h_2 - h_3 = Q_R$

(3) Expansion device → $h_3 = h_4$ (∵ process is throttling)



(4) Evaporator → $Q_A = h_1 - h_4$

H

$h_1 = h_g + C_{P_{vap}}(T_1 - T_{sat})$ (superheated)

$s_1 = s_g + C_{P_{vap}} \ln\left(\frac{T_1}{T_{sat}}\right)$

subcooled

$h_1 = h_f - C_{P_{liq}}(T_{sat} - T_1)$

$s_1 = s_f - C_{P_{liq}} \ln(T_1/T_{sat})$

COP of VC cycle –

$$COP = \frac{\text{Refrigeration effect}}{\text{work input}}$$

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

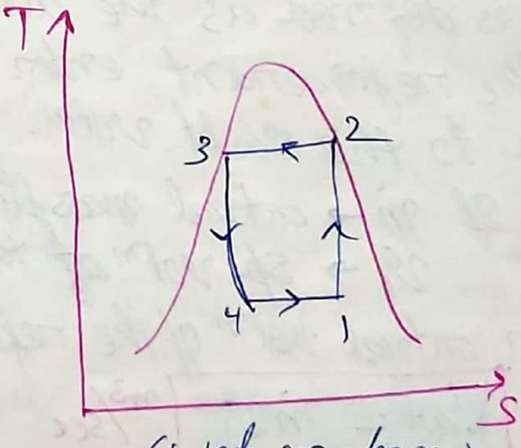
$$= \frac{h_1 - h_3}{h_2 - h_1} \quad (\because h_3 = h_4)$$

$$COP_{VC} = \frac{h_1 - h_3}{h_2 - h_1}$$

Wet compression VC cycle –

Throttling

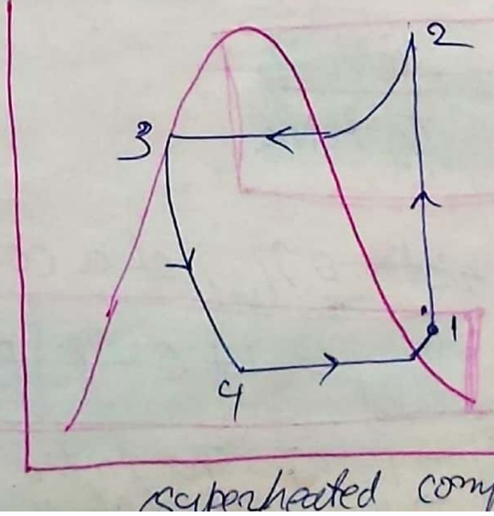
1. It is an irreversible process
2. No heat transfer
3. No work "
4. It is an isenthalpic process.



(wet compression)

Superheated compression cycle.

Ideal gas eqn can be applied in superheated region.



(superheated compression)

Power input to the compressor –

$W_{in} = (h_2 - h_1)$ kJ/kg

If $\dot{m}$ → mass flow rate of the refrigerant (kg/sec)

∴ Power input $= \dot{W} = \dot{m}(h_2 - h_1)$ kW

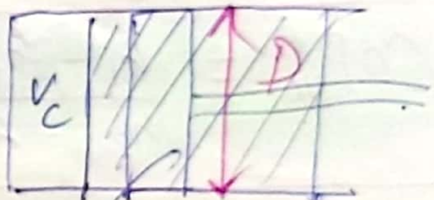
Refrigeration capacity (RC) →

$RE = (h_1 - h_4)$ kJ/kg

$RC = \dot{m}(h_1 - h_4)$ kW

Volumetric efficiency of Reciprocating compressor →

$$\eta_{vol} = \frac{\text{Act vol}}{\text{swept vol}}$$



$v_s = \frac{\pi}{4} D^2 L$

It is defined as the actual volume of the refrigerant enter into the compressor to the swept vol^m.

If $\dot{m}$ → actual mass flow rate of refrigerant &
v_1 → sp. vol^m of the inlet to the comp.

then actual vol^m of the refrigerant inlet to the compressor is

$V_{act} = \dot{m} v_1$ m³/sec

Swept vol^m $= \frac{\pi}{4} D^2 L N k$

where D → bore dia
L → stroke length
N → rpm (speed)
k → no. of cylinders

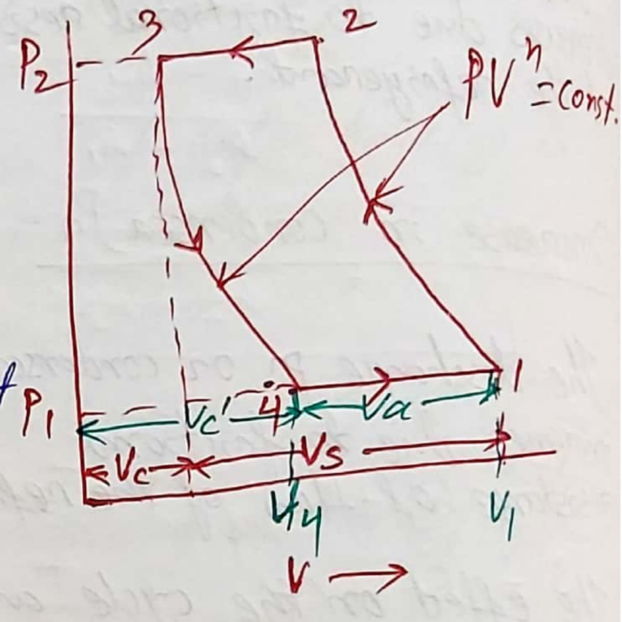
$$\eta_{vol} = \frac{\dot{m} v_1}{\frac{\pi}{4} D^2 L N k}$$

NOTE The ~~vol^m~~ η_{vol} of a compressor is given by

$\eta_{vol} = 1 + C - C\left[\frac{P_2}{P_1}\right]^{1/n}$ → $C = \frac{V_c}{V_s}$

Volumetric efficiency of Reciprocating Refrigerant ...

In a reciprocating compressor, when the piston reaches the end of it's compression stroke, a portion of refrigerant always remains in & is not discharged from the cylinder. The space in the cylinder occupied by the refrigerant at the end of discharge stroke is known as the clearance volume & it is usually expressed as the %age of the stroke displacement volume.



Let
P_2 = Delivery pressure
P_1 = Suction pressure of comp^r
V_s = stroke volume of comp.
V_a = Actual Volume of refrigerant taken in
V_c = clearance volume
n = Index of comp & exp^n.

η_{vol} =
It is the ratio of actual volume of the refrigerant taken into the swept volume.

$$\eta_{vol} = \frac{\text{Actual vol}}{\text{Swept vol}}$$

If $\dot{m}$ = actual mass flow rate of refrigerant
v_1 = Sp. vol^m at the inlet to the comp.

Then the actual vol^m flow rate = $\dot{m}\, v_1$

So
$$\eta_{vol} = \frac{\dot{m}\, v_1}{\frac{\pi}{4} D^2 L N k}$$

where D = Dia of piston
L = Length of stroke
N = speed of piston rpm
k = no. of cylinder.

$$\eta_{vol} = \frac{\text{Actual Volume}}{\text{Swept volume}}$$

$$= \frac{V_1 - V_4}{V_1 - V_c} = \frac{V_1 - V_4 + V_c - V_c}{V_1 - V_c} = \frac{V_1 - V_c - V_4 + V_c}{V_1 - V_c}$$

$$= \frac{(V_1 - V_c) - (V_4 - V_c)}{V_1 - V_c}$$

$$= \frac{V_1 - V_c}{V_1 - V_c} - \frac{V_4 - V_c}{V_1 - V_c}$$

$$= 1 - \frac{V_4 - V_c}{V_1 - V_c}$$

$$= 1 - \frac{V_c\left(\frac{V_4}{V_c} - 1\right)}{V_1 - V_c}$$

(where $\frac{V_c}{V_1 - V_c} = \frac{V_c}{V_s} = c$)

$$= 1 - c\left(\frac{V_4}{V_c} - 1\right)$$

$$= 1 - c\left(\frac{V_4}{V_c} - 1\right)$$

~~= 1 + c − c(V₄~~

~~= 1 − c(~~

$$= 1 - c\left(\frac{V_4}{V_c}\right) + c$$

$$= 1 + c - c\left(\frac{V_4}{V_c}\right)$$

In 3-4 process

($\because PV^n = C$

$\Rightarrow P_2 V_c^n = P_1 V_4^n$

$\Rightarrow \frac{V_4^n}{V_c^n} = \frac{P_2}{P_1}$

$\Rightarrow \left(\frac{V_4}{V_c}\right)^n = \frac{P_2}{P_1}$

$\Rightarrow \frac{V_4}{V_c} = \left(\frac{P_2}{P_1}\right)^{1/n}$)

$$\boxed{\eta_{vol} = 1 + c - c\left(\frac{P_2}{P_1}\right)^{1/n}}$$

$\dot{m} v_1 = \frac{\pi}{4} D^2 L N k$

$\Rightarrow 0.0451 \times 0.4351 = \frac{\pi}{4} D^2 \times 1.2D \times \frac{1000}{60} \times 1$

$\Rightarrow D = 0.1076\ m$

$= 10.77\ cm$

$L = 1.2 \times 10.77 = 12.92\ cm$

Refrigerants :-

They are the substances used for producing lower temperatures.

Classifications of Refrigerants

1. Primary ~~second~~ Refrigerants
2. Secondary Refrigerants.

Primary refrigerants are the substances which absorb heat directly from the storage space by running in a cycle. They absorb Latent heat of vaporisation.

Ex R-11, R-12, NH_3 etc.

Secondary refrigerants are the substances which are 1st cooled by primary refrigerant & then are used for cooling at the reqd. place. It only takes sensible heat.

Ex – Glycol, air, water, Brine.

Designation of a Refrigerant (Refrigerant nomenclature)

Case-1 → If the refrigerant is a saturated hydrocarbon of the general formulae is $C_m H_n F_p Cl_q$ (single bond) where n, m, p & q represents no. of atoms of carbon hydrogen, fluorine, & chlorine respectively. Then such refrigerant are designated as $R-(m-1)(n+1)p$

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

Ex: If the refrigerant is designated as R-12 then find the chemical formula.

R-012

$R-(m-1)(n+1)p$

$m-1=0 \Rightarrow m=1$

$n+1=1 \Rightarrow n=0$

$p=2$

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

$\Rightarrow 0+2+q = 2\times1+2$

$\Rightarrow 2+q=4$

$\Rightarrow q=2$

R-21 → R-021

$R-(m-1)(n+1)p$

$m-1=0 \Rightarrow m=1$

$n+1=2 \Rightarrow n=1$

$p=1$

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

$\Rightarrow 1+1+q = 2\times1+2$

$\Rightarrow 2+q=4$

$\Rightarrow q=2$

$C_1H_1F_1Cl_2 = CHFCl_2$ monochlorodifluro methane

∴ The chemical formular is $CH_0F_2Cl_2 = CF_2Cl_2$

dichlorodifluro methane.

NOTE

Earlier R-12 is used as a refrigerator in domestic Refrigera

Ex-2

For R-11 -

R-011

$R-(m-1)(n+1)p$

$m-1=0 \Rightarrow m=1$

$n+1=1 \Rightarrow n=0$

$p=1$

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

$\Rightarrow 0+1+q=2+2$

$\Rightarrow q=3$

$C_mH_nF_pCl_q = CFCl_3$

Trichloro mono Fluoro meth

Ex3 Write the chemical formula for R22

R-022

R-(m-1)(n+1)P

$m-1=0 \Rightarrow m=1$

$n+1=2 \Rightarrow n=1$

$P=2$

$C_m H_n F_p Cl_q$

CHF_2Cl_1

↓

Chloro difluoro methane.

$n+P+q=2m+2$

$\Rightarrow 1+2+q=2+2$

$\Rightarrow q=1$

Ex4 If the chemical formula for is $C_2H_2F_4$ then write it's designation.

$C_2H_2F_4Cl_0$

$n+P+q=2m+2$

$\Rightarrow 2+4+0=2\times2+2$

$\Rightarrow 6=6$

$m=2 \quad n=2 \quad P=4 \quad q=0$

R-(m-1)(n+1)P

R-134 → Tetrafluoro ethane. → Eco friendly refrigerant.

NOTE → R-134a is used now a days as a refrigerant in domestic refrigerator.

Isomer →

Isomers are the compound with same chemical formula but different molecular structure. The letter 'a' in R-134a represents that it is an isomer of $C_2H_2F_4$ (R-134)

R-134a → $CHF_3 - CH_2F$

Ex-5 R-13

R - 013

$R - (m-1)(n+1)P$

$m-1 = 0 \Rightarrow m = 1$

$n+1 = 1 \Rightarrow n = 0$

$P = 3$

$n+P+q = 2m+2$

$\Rightarrow q = 2m+2-(n+P) = 2\times1+2-3$

$= 4-3 = 1$

$C_m H_n F_p Cl_q$

$CH_0 F_3 Cl \rightarrow CF_3Cl \rightarrow$ Chlorotrifluoromethane

—o—

Case-2 If the refrigerant is unsaturated hydrocarbon →

$C_m H_n F_p Cl_q$

$R\text{-}1(m-1)(n+1)P$

$n+P+q = 2m$

NOTE → It's starts from 1 thousand.

Ex write the designation for C_2H_4

$m = 2$, $n = 4$, $P = 0$, $q = 0$

~~R-1(m~~ $R\text{-}1(m-1)(n+1)P$

R-1150

$n+P+q = 2m$

$\Rightarrow 4+0+0 = 2\times2$

$\Rightarrow 4 = 4$

Case-3 If the refrigerant is inorganic compound →

~~Deg~~ Designation is = R - 700 + molecular wt.

Ex NH_3

$14 + 3\times1 = 17$

R-717

Ex CO_2

$12+2\times16 = 44$

R-744

Ex - SO_2

$32+2\times16 = 64$

R-764

Ex
water
H_2O
$1 \times 2 + 16 = 18$
R-718

Ex
Air
mol wt = 29
R-729

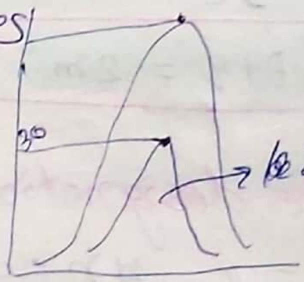
case-4

Azeotropes →

Mixture of refrigerants is known as Azeotropes. ~~It's~~ The designations of these refrigerants starts with R-500 series. Ex - R-502

Desirable properties of Refrigerants (selection of a Refrigerant)

The properties of refrigerant can be studied under 3 heads -
1. Thermodynamic properties
2. chemical properties
3. Physical properties



① Thermodynamic properties

① critical temperature -

The critical temp of the ~~temp~~ refrigerant should be as high as possible. The critical temp of CO_2 & C_2H_2 are almost undesirable because the critical temp is below ambient summer condition in India -

Refrigerant	critical temp °C
H_2O	371.5
SO_2	156.5
NH_3	132.4
R-12	111.5

R-134	101.2
CO_2	31
C_2H_2	10.6

condensible

② **Specific heat** - $\frac{ds}{dT} = T/c_p$

We know that $c_p = T\left(\frac{ds}{dT}\right)$

for liquid refrigerant during throttling the irreversibility must be small & hence 'ds' should be small & hence c_p of liquid as low as possible.

For vapour refrigerant the degree of superheat 'dT' must be small because greater superheat results in higher temp. to the inlet to the comp & more work is reqd. ~~& hence~~ There fore for minm value of 'dT' the sp. heat of vapour refrigerant must be large.

③ **Enthalpy of Vaporisation** -

Enthalpy of vaporisation must be as large as possible because large enthalpy of vaporisation means smaller mass flow rate for a given capacity.

Refrigerant	enthalpy of vaporisation
H_2O	2261
NH_3	1369
R-22	234.7
R-12	165.7
R134a	197.3

→ not a common refrigerant because it's freezing pt is 0°C

Out of the ~~five~~ common refrigerant given above table it can be seen that NH_3 has large enthalpy of vaporisation.

④ Condenser & Evaporator pr — Imp

We know that with reduction in saturation pr the saturation temp also decreases & hence for lower refrigeration temp the evaporator pr. are generally low. If the evaporator pr. is lower than atm pr. Then atm air leaks into the refrigeration system. To avoid this the evaporator pr must be as close to atm pr. as possible. The condenser must be moderate. If it is more then W_{in} is more.

⑤ Compression pressure ratio →

Larger compression ratios results in larger work input to the compressor & also at higher compression ratio the η_{vol} of a reciprocating comp. decrease & hence the comp. ratio must be low.

⑥ Freezing pt. of refrigerant –

The freezing pt. of the refrigerant must be as low as possible. because when need of ~~-15°C~~ evaporative temp low it's becomes ice so it

Ref	freezing pt
R-22 →	-160.5
R-12 →	-157.4
NH3 →	-77.3
R-134a →	-101.2

The freezing pt of water is very high so it is not used as common Refrigerant.

7) Sp. Vol^m of the inlet to the compressor

Sp. vol^m of refrigerant at the inlet to the compressor (v_1) must be small because larger sp. vol^m means larger cylinder dimension. R-11 & R-113 are used centrifugal compresso.

8) COP →

COP indicates the running cost of Refrigerator so higer COP is desirable. & the running cost is low.

NOTE

The COP of all the common refrigerant is almost same in a given temp range. Though NH_3 has larger latent heat of vaporisation it does not help any way in the improvement of COP because incase NH_3 compresser the Win is very large because of higher value of ($r = 1$..

9) Compressor discharge Temp –

A rise in temp causes heating of cylinder walls of the compresser. The cylinder has to be cooled to avoid loss of strength of compresser material. It is seen the the comp. temp ~~is much~~ of NH_3 is much larger than R-12 & R-22 & hence NH_3 compressor are always water cooled where as R-11, R-12 & R-22 compressers are air cooled.

Ref	comp discharge temp °C
R-11	52
R-12	48
R-22	71
R-717 (← NH_3)	120

(11) Conductivity -

For faster heat transfer conductivity of Refrigerant must be high.

Chemical properties -

(1) Toxicity - Refrigerant must be non-Toxic.

NOTE NH_3 is toxic & CFCs are non toxic.

(2) Flammability - Refrigerant must be non-flammable & non-explosive.

NOTE
→ NH_3 is explosive.
→ Despite it's chilpness NH_3 is not used as refrigerant in domestic refrigerator due to it's toxic & explosive nature.

(3) Action with oil → (Imp)

In compressor some oil is carried by high temp refrigerant to the condenser & finally to the evaporator. In the evaporator the refrigerant evaporates & oil separates from the refrigerant & a build of oil in the evaporater would result in reduced heat transfer coefficient & oil chocking in evaporator.

Refrigerants that are not miscible with oil such as NH_3 & CO_2 does not present any problem because oil separator is install at the exit of the compressor & separated oil is brought back to the comp.

Refrigerants that are completely miscible with oil such as R-11 & R-12 also do not present any problem because the oil which reaches the evaporator returns to the comp. along with the refrigerant.

Refrigerant that are partially miscible with oil such as R-22 creates problem. & hence synthetic oil is used instead of mineral oils.

④ Action with material of construction -

NH_3 attacks Cu (copper) & hence when NH_3 used as refrigerant "Cu" material is not used instead wrought iron or steel material is used. Similarly Freons attack Aluminium (Al) & hence Cu (copper) is used as material of construction.

Physical properties -

① Cost - it should be cheep.

② Viscosity - it should be low.

③ Leak detection -

The refrigerant should not leak from the system. If at all leaks the detection is simple

→ Freon ~~dete~~ leaks are detect by means of Halid-torch method

In presence of freon colour of the light changes from Blue to Blueish green.

→ NH_3 leaks are detected by means of sulphur stick method. In presence of NH_3 white fumes of ammonium sulphite is form.

Recent Trends in Refrigerants -

The ozone layer which is situated in stratosp-
-ears absorbs harmful UV radiations & protect.
the earth surface. The chlorine (Cl) which is present
in the refrigerant attacks ozone & hence depletes
(reduction) it's thickness. Therefore Cl element
must be eliminated from the Refrigerant & hence
the suitable substitudes are ① HC → Hydro carbons
② FC → Fluoro carbons
③ HFC → Hydro fluoro carbons.

The ~~environ~~ eco-friendly refrigerant used in
domestic refrigerator is R-134a

-o-

R-11 ⟶ $CFCl_3$
R-12 ⟶ CCl_2F_2
R-13 ⟶ CF_3Cl
R-22 ⟶ CHF_2Cl

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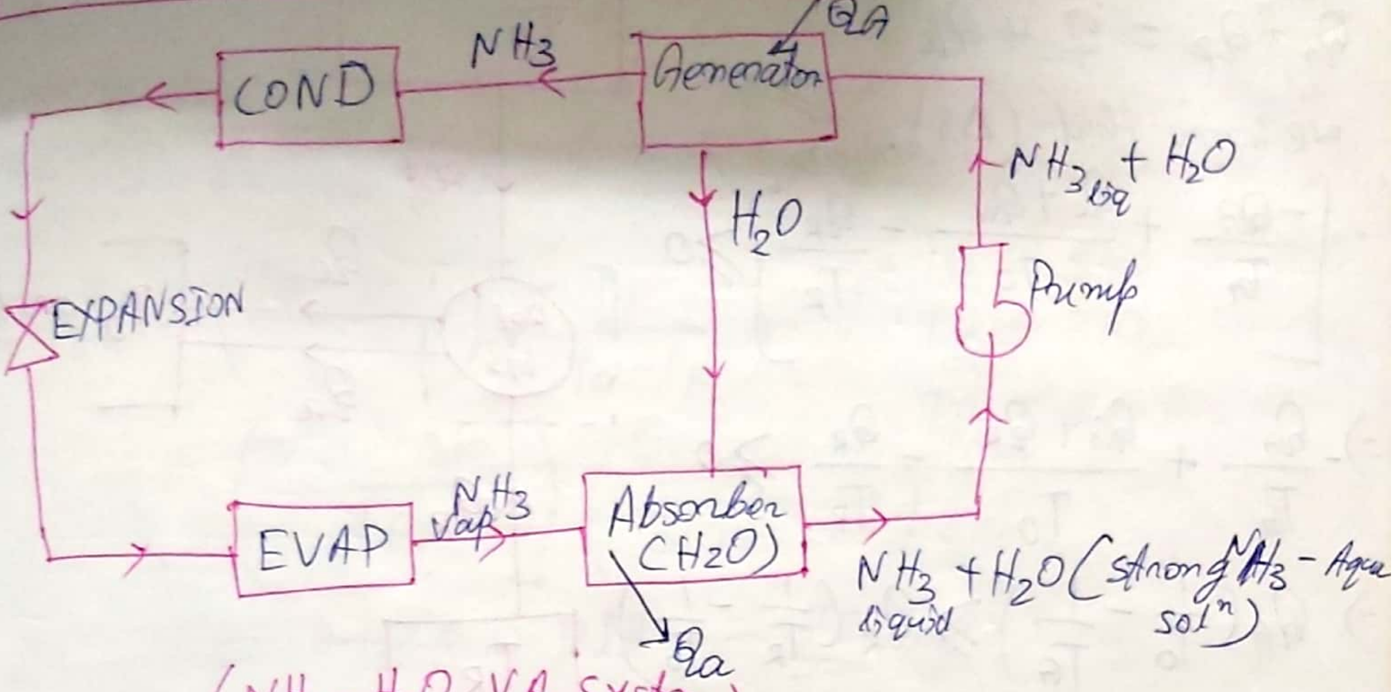
Vapour Absorption Refrigeration system ← (Heat operated devices)



($NH_3 - H_2O$ VA System)

In vapour absorption refrigeration system 2 fluids are used i.e. refrigerant & absorbant. The most popular VA system is Amonia-water system. In this NH_3 is used as refrigerant & H_2O is used as absorbant.

VA system is used where the cost of electricity is very high.

→ Solar refrigeration system based on VA refrigeration system.

VA system uses low grade energy as the input. The compressor which is used in VC system is replaced with absorber, pump & generator.

$$COP = \frac{RE}{W_{in}}$$

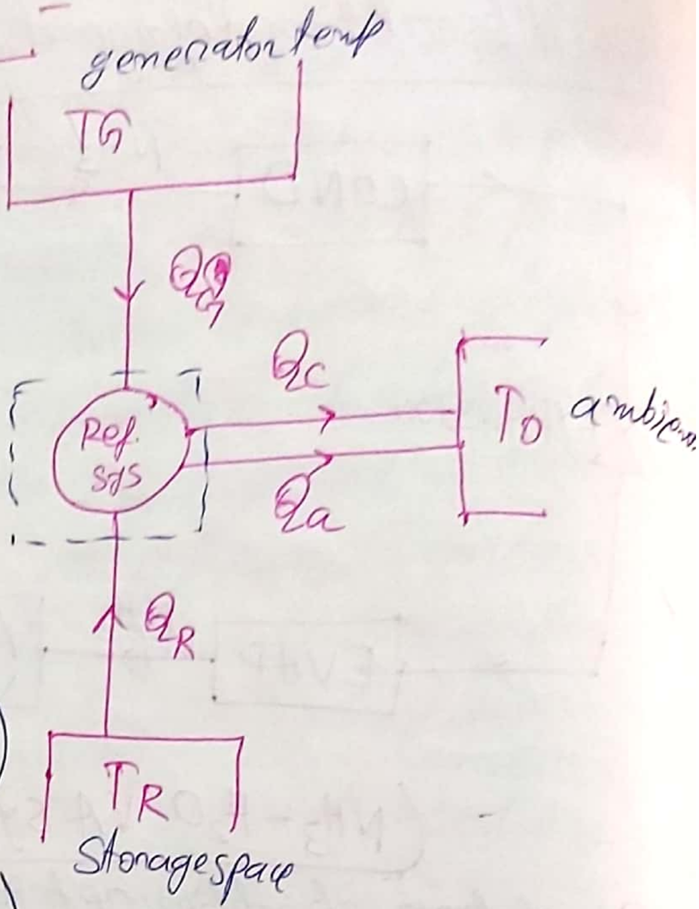
As VA system is a heat operated system therefore

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

(where W_p = Pump work & it is very small & hence it can be neglected)

$$\Rightarrow COP = \frac{Q_R}{Q_G}$$

Equ^n for COP of VA system -



$$Q_G + Q_R = Q_c + Q_a$$

we know that $(\Delta S)_{universe} \geq 0$

$$\therefore \left[\frac{-Q_G}{T_G} + \frac{Q_c + Q_a}{T_0} - \frac{Q_R}{T_R} \right] \geq 0$$

$$\Rightarrow -\frac{Q_G}{T_G} + \frac{Q_G + Q_R}{T_0} - \frac{Q_R}{T_R} \geq 0$$

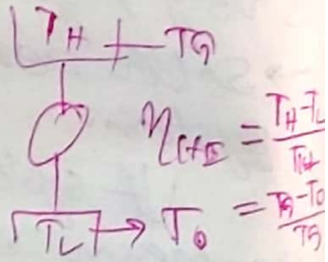
$$\Rightarrow Q_G\left(\frac{1}{T_0} - \frac{1}{T_G}\right) \geq Q_R\left(\frac{1}{T_R} - \frac{1}{T_0}\right)$$

$$\Rightarrow Q_G\left(\frac{T_G - T_0}{T_0 T_G}\right) \geq Q_R\left(\frac{T_0 - T_R}{T_0 T_R}\right)$$

$$\Rightarrow \left(\frac{T_G - T_0}{T_G}\right)\left(\frac{T_R}{T_0 - T_R}\right) \geq \frac{Q_R}{Q_G}$$

$$\Rightarrow \left(\frac{T_G - T_0}{T_G}\right)\left(\frac{T_R}{T_0 - T_R}\right) \geq COP$$

$$\Rightarrow COP \leq \left(\frac{T_G - T_0}{T_G}\right)\left(\frac{T_R}{T_0 - T_R}\right)$$



$$\Rightarrow COP_{max} = \left(\frac{T_G - T_0}{T_G}\right)\left(\frac{T_R}{T_0 - T_R}\right) = \eta_{opr\ HE} \times COP_{carnot\ refrigerator}$$

where T_G = Generator temp.
T_0 = ambient temp
T_R = Refrigeration temp.

AIR CONDITIONING

PSYCHROMETRY →

Air conditioning the simultaneous control of temp, humidity, air velocity & purity of air.

→ It is the study of properties of moist air.

Psychrometry terms -

① Sp. humidity or Humidity Ratio (w) →

It is the ratio of mass of vapour to the mass of dry air in a certain moist air.

$$w = \frac{m_v}{m_a} \quad kg/kg \text{ of dry air.}$$

vapour

$PV = mRT$

$\Rightarrow P_v V_v = m_v R_v T_v$

$\Rightarrow P_v V = m_v R_v T$ — ①

dry air

$PV = mRT$

$\Rightarrow P_a V_a = m_a R_a T_a$

$\Rightarrow P_a V = m_a R_a T$ — ②

$$\frac{\text{eqn } ①}{\text{eqn } ②} = \frac{P_v V}{P_a V} = \frac{m_v R_v T}{m_a R_a T}$$

$$\Rightarrow \frac{P_v}{P_a} = \frac{m_v R_v}{m_a R_a}$$

$$\Rightarrow \frac{m_v}{m_a} = \frac{R_a P_v}{R_v P_a}$$

characteristic gas const; universal gas const $= 8.314$ kJ/kgmol K; molecular mass

$$R_a = \frac{\bar{R}}{M_a} = \frac{\bar{R}}{29}, \quad R_v = \frac{\bar{R}}{M_v} = \frac{\bar{R}}{18}$$

$$w = \frac{\bar{R}/29}{\bar{R}/18} \times \frac{P_v}{P_a} = \frac{18}{29} \cdot \frac{P_v}{P_a} = 0.622 \frac{P_v}{P_a}$$

$$\therefore w = 0.622 \frac{P_v}{P_a}$$

$P_t = P_a + P_v$ where P_t = Total atm pr.
P_a = Partial pr. of dry air
$\Rightarrow P_a = P_t - P_v$ P_v = " " " vapour

$$\therefore \omega = 0.622\left(\frac{P_v}{P_t - P_v}\right)$$

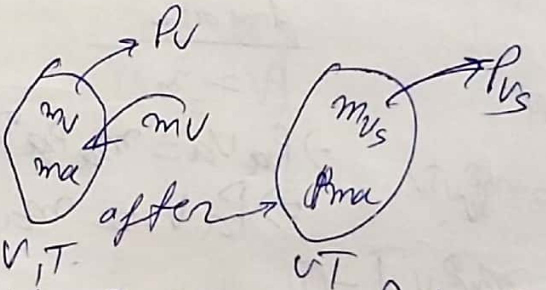
$$\omega = f(P_v)$$

We know that atmp pr. is more or less const. & hence "ω" is funⁿ of partial pr. of vapour only.

② Relative humidity - (φ)

It is defined as the ratio of mass of vapour to the mass of vapour under saturation conditions. in the same volᵐ & the same temp.

$$\phi = \frac{m_v}{m_{v_{sat}}}$$



$P_v V = m_v R_v T$ $P_{v_{sat}} V = m_{v_s} R_v T$

$$\therefore \frac{P_v V}{P_{v_{sat}} V} = \frac{m_v R_v T}{m_{v_s} R_v T}$$

$$\Rightarrow \frac{m_v}{m_{v_{sat}}} = \frac{P_v}{P_{v_{sat}}} \Rightarrow \phi = \frac{P_v}{P_{v_{sat}}}$$

→ Relative humidity is generally expressed in %age.
→ Relative humidity of Sat. air is 100% or 1

%.

NOTE: Sp. humidity gives the actual quantity of water vapour present in air. whereas Relative humidity indicates the moisture absorbing capacity of air.

③ Dry bulb temperature (DBT) →

The normal atmospheric temp. is known as dry bulb temp. (DBT)

④ Wet bulb Temperature (WBT) →

It is the temp measured by a thermometer whose bulb covered with a wet cloth. Wet bulb temp indicated moisture present in the air. When Air is saturated DBT = WBT

under unsaturated condn DBT > WBT

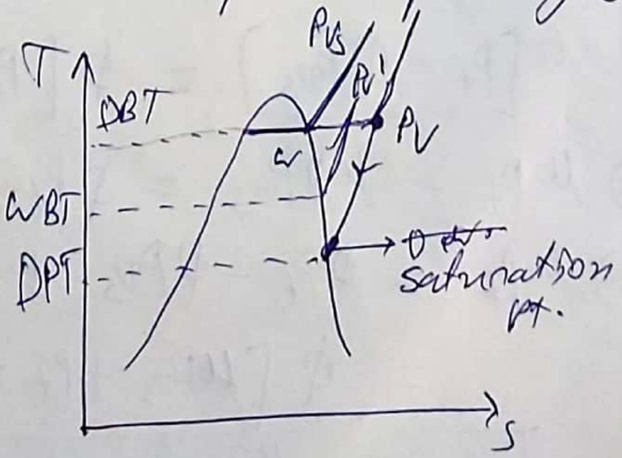
wet bulb depression –

WBD = DBT – WBT

under saturation condn WBD = 0

⑤ Dew point temp (DPT) →

It is the temp at which water vapour present in air start condensation. It is the saturation temp corresponding to partial pr of vapour.



NOTE

Under saturation condn WBT = DPL

for unsaturated condn

DBT > WBT > DPT

PLANK 60

Degree of saturation - (μ)

It is the ratio of actual sp. ~~heat~~ humidity (ω) to the sp. humidity under ~~as = sat~~ saturation condition (ω_s) i.e. $\mu = \omega/\omega_s$

$$\mu = \frac{\omega}{\omega_s} = \frac{0.622\left(\frac{P_v}{P_t - P_v}\right)}{0.622\left(\frac{P_{vs}}{P_t - P_{vs}}\right)}$$

$$= \left(\frac{P_v}{P_t - P_v}\right) \Big/ \left(\frac{P_{vs}}{P_t - P_{vs}}\right)$$

$$\Rightarrow \left(\frac{P_v}{P_{vs}}\right)\left(\frac{P_t - P_{vs}}{P_t - P_v}\right)$$

$$\Rightarrow \phi \left[\frac{P_t - P_{vs}}{P_t - P_v}\right]$$

$$\Rightarrow \phi \left[\frac{P_t - P_{vs}}{P_t - \phi P_{vs}}\right] \quad \left(\because \phi = \frac{P_v}{P_{vs}}\right)$$

$$\Rightarrow \mu\left[P_t - \phi P_{vs}\right] = \phi\left[P_t - P_{vs}\right]$$

$$\Rightarrow \mu P_t - \mu\phi P_{vs} = \phi P_t - \phi P_{vs}$$

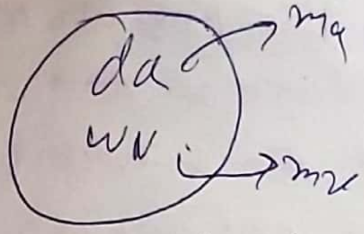
$$\Rightarrow \mu P_t = \phi P_t - \phi P_{vs} + \mu\phi P_{vs}$$

$$= \phi\left[\mu P_{vs} + P_t - P_{vs}\right]$$

$$\Rightarrow \phi = \frac{\mu P_t}{\mu P_{vs} + P_t - P_{vs}}$$

*** gate 2009

Enthalpy of Moist air -



$$H_{Total} = H_a + H_v$$

$$H_{Total} = m_a h_a + m_v h_v$$

$t_a = t_v = t$

h_a

The enthalpy of dry air at 0°C = 0 so therefore $h_a = C_{pa}(t - 0)$

$$\Rightarrow \boxed{h_a = C_{pa}\, t}$$ where 't' is DBT in °C

$C_{pa} = 1.005$ kJ/kg K

h_v

enthalpy of satd. water at 0°C is taken a 0.

$$h_v = 2500 + C_{p_v}(t - 0)$$

$$\boxed{h_v = (2500 + C_{p_v} t)}$$ kJ/kg v where $C_{pv} = 1.88$ kJ/kg K.

$$\therefore H_{Total} = m_a h_a + m_v h_v$$

$$\Rightarrow \frac{H}{m_a} = \frac{m_a h_a + m_v h_v}{m_a}$$

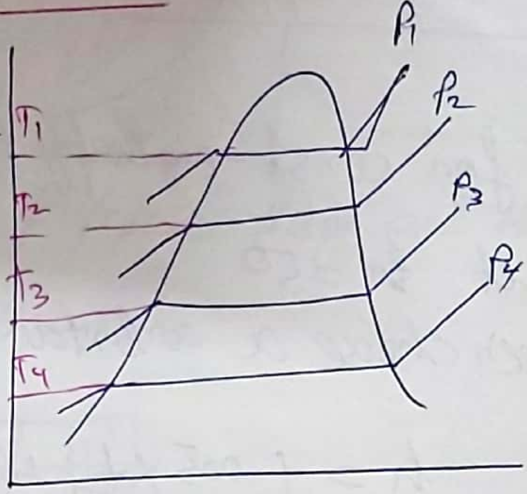
$$\Rightarrow \frac{H_{total}}{m_a} = h_a + \left(\frac{m_v}{m_a}\right) h_v$$

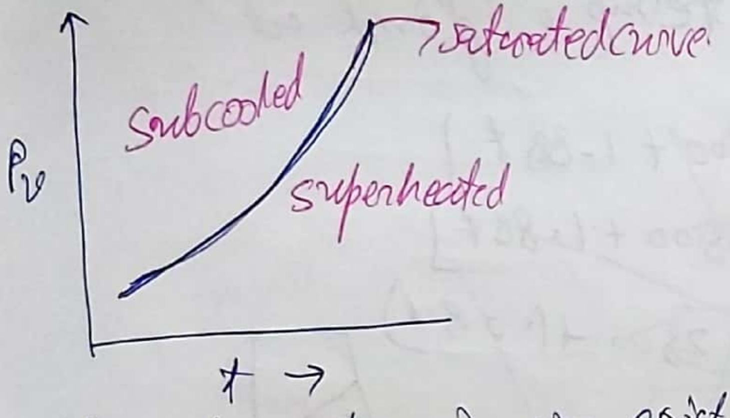
$$= h_a + \omega h_v$$

$$\Rightarrow \boxed{h_{total} = h_a + \omega h_v}$$ kJ/kg d.a.

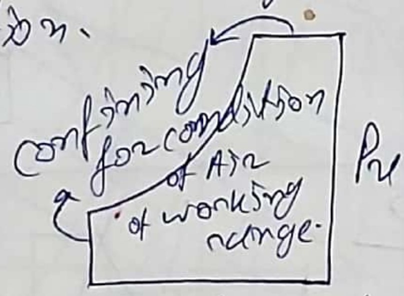
Development of Psychrometric chart -

We know that the increase in satⁿ temp the satⁿ pr. also increases & hence if we plot satⁿ (P_v) v/s ~~DBT (t)~~ satⁿ temp (t) we have

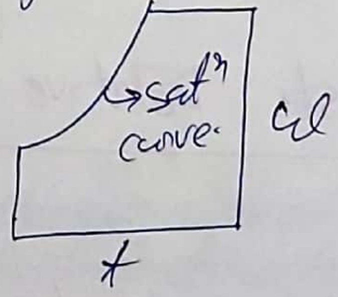




As water vapour in air exist in superheated state, the region which is towards right of satⁿ curve is taken into consideration.



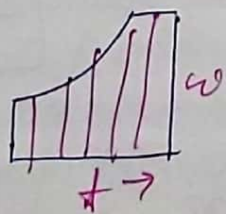
But in A/C process removal of moisture & addition of moisture occurs regularly & hence P_v is replaced with ω since ω = funⁿ of (P_v). Therefore the final skeleton psychrometric chart is



Various line in psychrometric chart

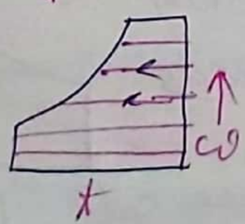
① Const DBT lines -

vertical line



② const 'ω' lines

horizontal lines



③ Const enthalpy lines -

$h = C_{pa} t + \omega [2500 + 1.88 t]$

for const-enthalpy line h = same (arbitarily choose)

let h = 50

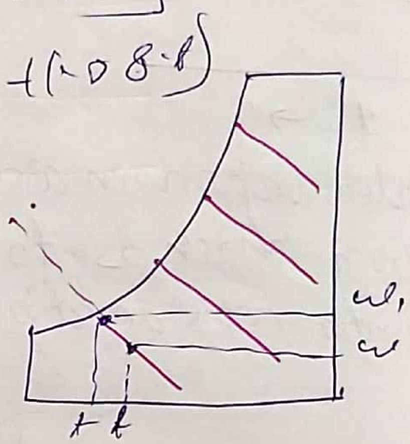
then choose a arbitarily temp & find 'ω'?

$h = 1.005 \times t + \omega [2500 + 1.88 t]$

$\Rightarrow 50 = 1.005 \times 10 + \omega [2500 + 1.88 t]$

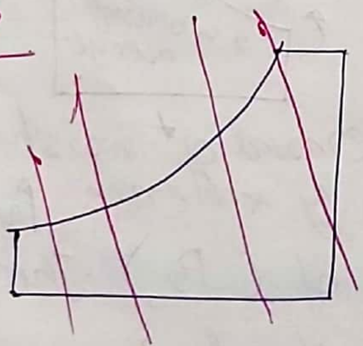
change temp

$\Rightarrow 50 = 1.005 \times 15 + \omega [2500 + 1.08.8]$

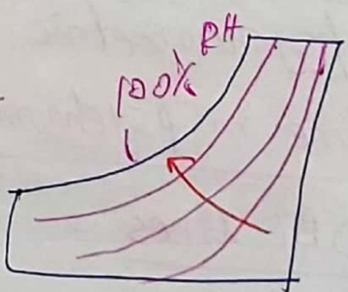


④ Const sp-volm lines

Repeat same process.

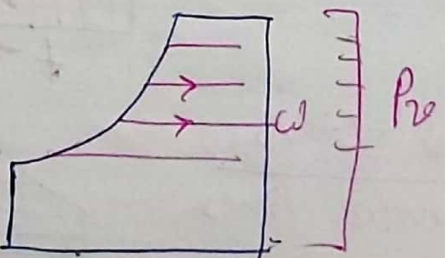


⑤ Const Relative humidity lines



⑥ Const Dew pt. temp lines -

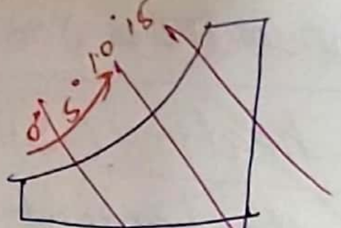
horizantal line & starts from saturation line & towards ω axis.

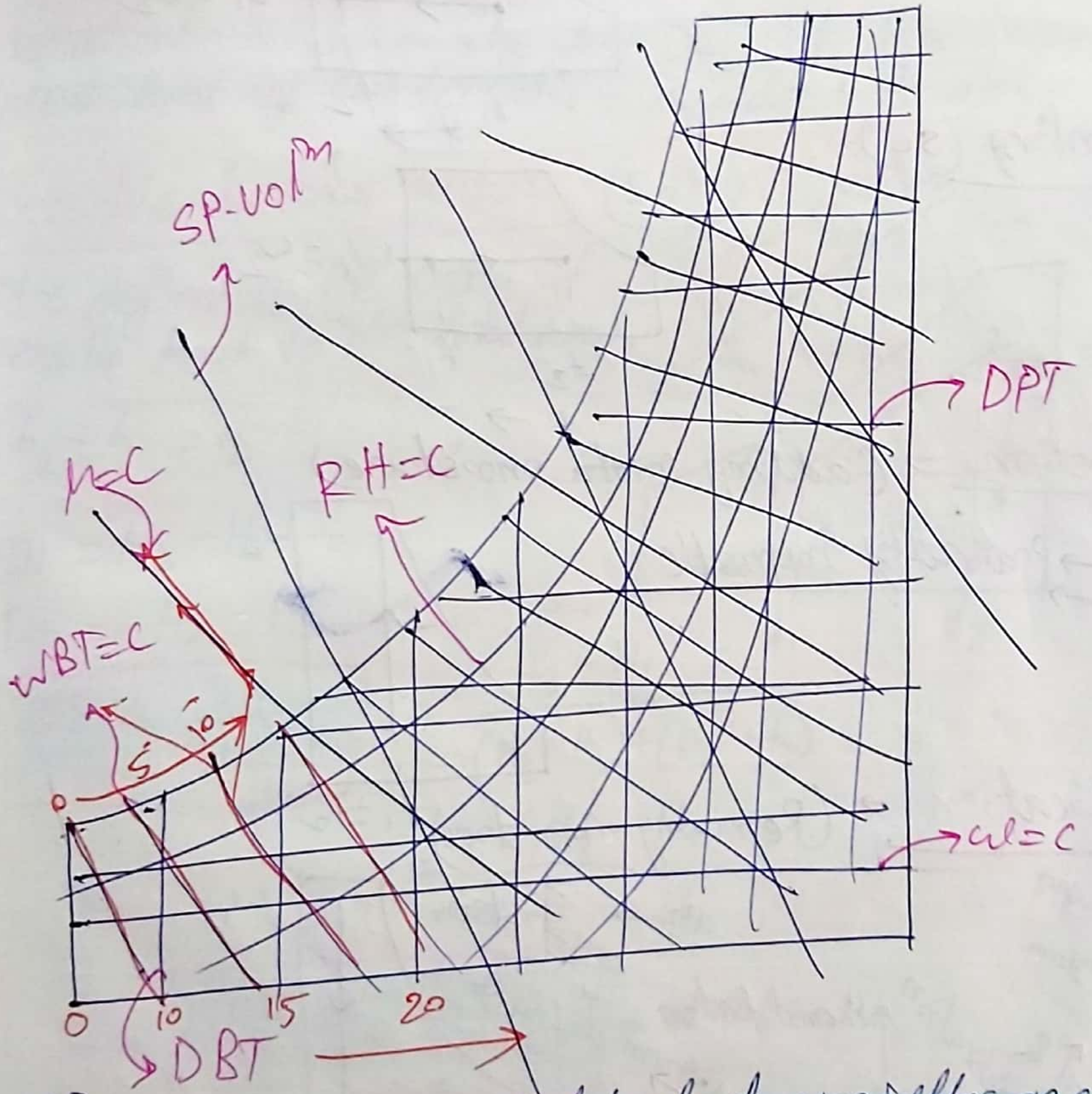


NOTE As dew pt. temp is satn temp corresponding to Pv these lines emerge from satn curve.

Const WBT lines

Though there is still a slight deviation betn const WBT & const enthalpy lines for calculation purposes they are assumed to be same.





NOTE For moist air 3 independent variables are reqd to fix the state of moist air. But on psychrometric chart only 2 variables are reqd. because the chart is drawn for a fixed pr. i.e. 3rd property is fixed

i.e. $P+F=C+2$ water vapour & dry air.

$1+F=2+2$

$\Rightarrow F=3$

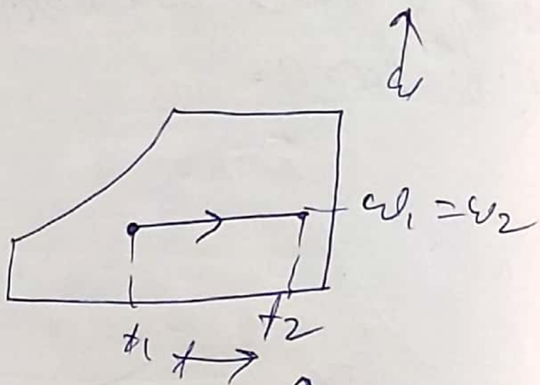
Basic Psychrometric processes –

$P + F = C + 2$
$\Rightarrow 1 + F = 2 + 2$
$\Rightarrow F = 4 - 1 = 3$
water vapour + dry air

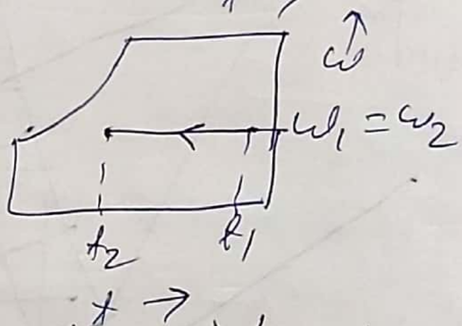
① Sensible heating (SH)

It is the process of heating air at const sp. humidity

$T_2 > T_1$

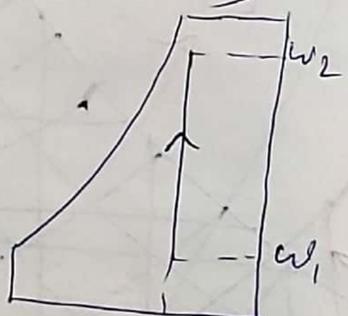


② Sensible cooling (SC)

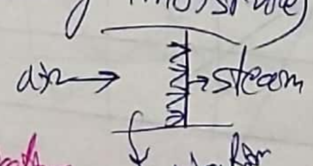


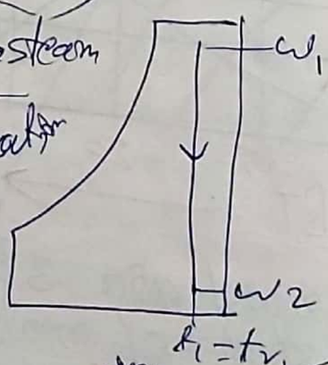
③ Humidification → (adding ~~moisture~~ moisture)

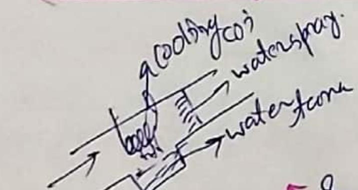
↳ practically impossible

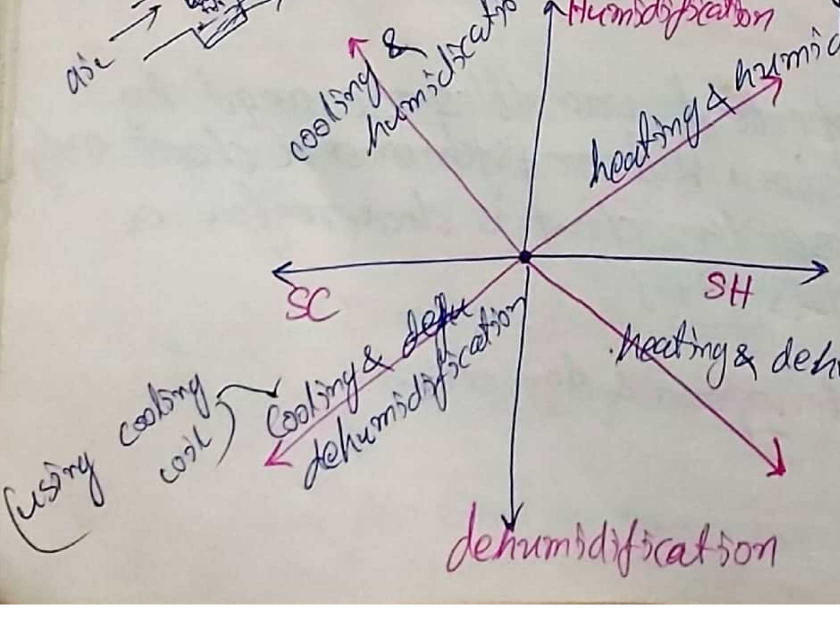


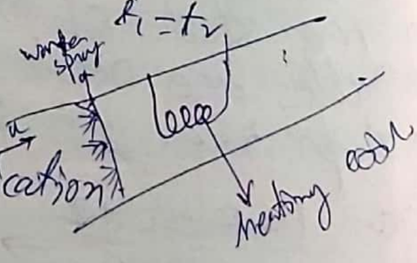
④ Dehumidification → (Removing moisture)





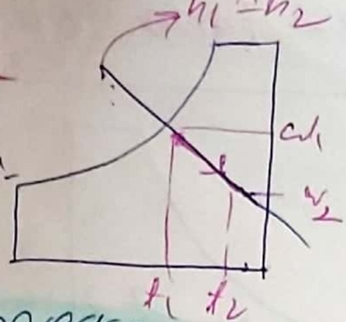






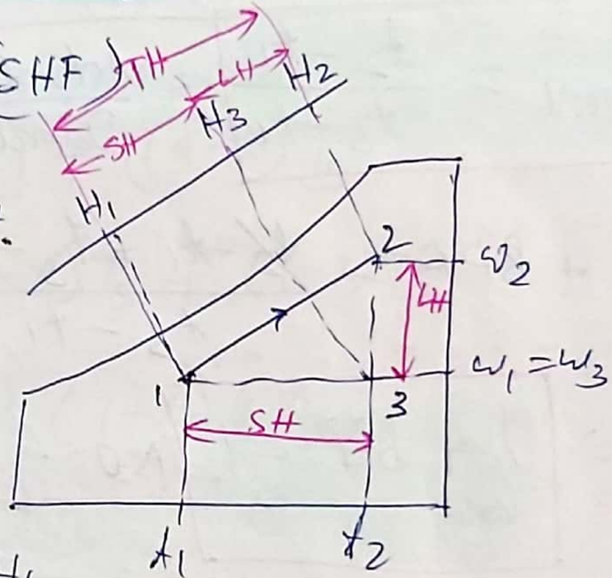
Special cases →

Adiabatic chemical dehumidification -



In adiabatic chemical dehumidification process enthalpy remains const (from SFEE) & sp. humidity decreases. certain chemical like silica gel & Alumina (Al_2O_3) are used to absorb moisture. The DBT of air increases because latent heat of condensation is added to air.

Sensible heating factor - (SHF)



It is defined as the ratio of sensible heat to the total heat.

$h_2 - h_1 = Q$

$SH = H_3 - H_1$

$LH = H_2 - H_3$

$$SHF = \frac{SH}{SH + LH} = \frac{H_3 - H_1}{(H_3 - H_1) + (H_2 - H_3)}$$

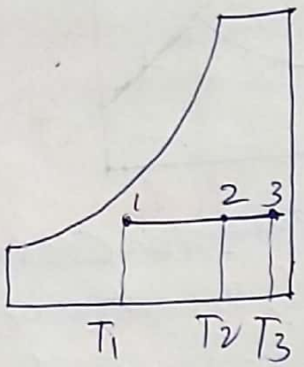
$$= \frac{H_3 - H_1}{H_2 - H_1}$$

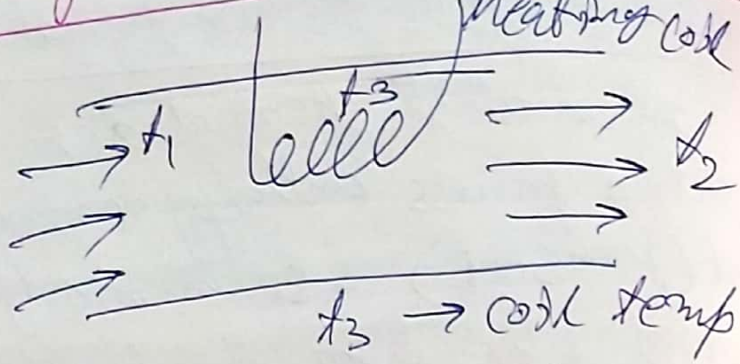
$$SHF = \frac{H_3 - H_1}{H_2 - H_1}$$ ***

Sensible heat for various cond^n are ① for

1. For residence & private offices SHF = 0.9
2. For restaurant & busy offices SHF = 0.8
3. For Auditorium & cinemahall SHF = 0.7

Bypass Factor of a ~~cooling~~ coil (BPF) ~~of~~ (Uncontacted fac...)





$t_3 \rightarrow$ coil temp

$$BPF_{Heat} = \frac{t_3 - t_2}{t_3 - t_1} = \frac{\text{loss}}{\text{Ideal total}}$$

$$\eta_{cooling\ coil} = \frac{t_2 - t_1}{t_3 - t_1} = \frac{\text{Actual}}{\text{Ideal}}$$

$$\therefore \eta + BPF = \frac{t_2 - t_1 + t_3 - t_2}{t_3 - t_1} = 1$$

$$BPF_{cooling} = \frac{T_2 - T_3}{T_1 - T_3}$$

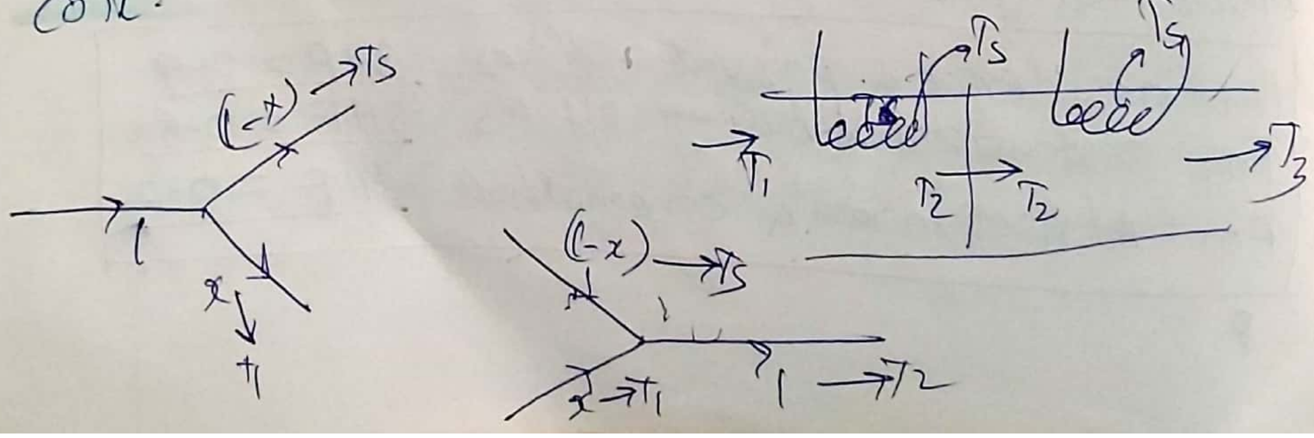
$$\therefore \eta_{cooling\ coil} + BPF = 1$$ AS O

→ Low value of Bypass factor ~~of the~~ is desire.

→ ~~Ideal~~ By pass factor for ideal coil is '0'.

By pass factor of a coil H more than 1 row of coil

Let both the coils be similar & the By factor of both the coiles be 'x'. & ~~let~~ T_s be the temp of both coil.



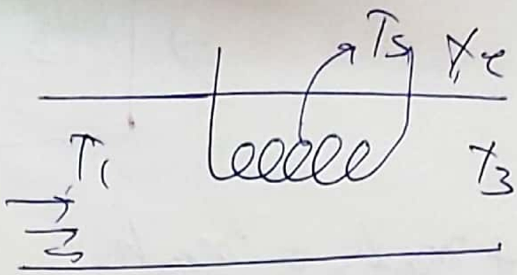
$(1-x) C_p T_s + x C_p T_1 = 1 C_p T_2$

$$\Rightarrow \boxed{T_2 = x T_1 + (1-x) T_s}$$

Similarly for 2nd coil.

$T_3 = x T_2 + (1-x) T_s$

$\therefore T_3 = x_e T_1 + (1-x_e) T_s \longrightarrow (1)$



~~$\therefore x T_2 + (1-x) T_s = x_e T_1 +$~~

$\therefore T_3 = x[x T_1 + (1-x) T_s] + (1-x) T_s$

$= x^2 T_1 + x(1-x) T_s + (1-x) T_s$

$= x^2 T_1 + (1+x)(1-x) T_s$

$= x^2 T_1 + (1-x^2) T_s \longrightarrow (2)$

comparing (1) & (2) we have $x_e = x^2$

similarly $\boxed{x_e = x^n}$ * * *

all coils are same kind

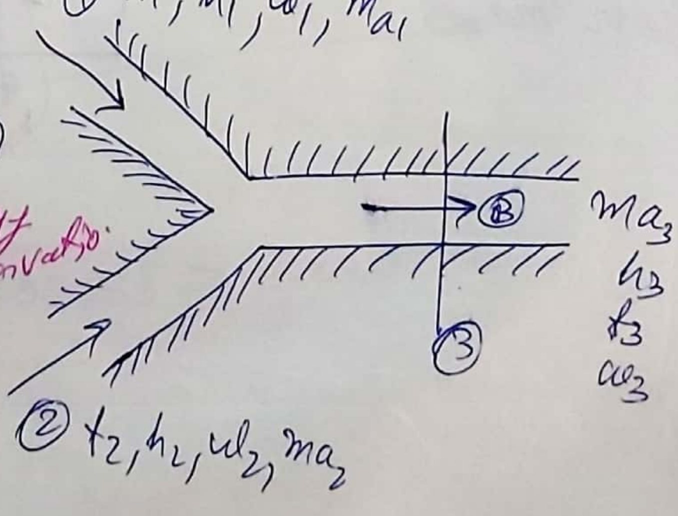
Mixing of Air streams -

$\boxed{m_{a3} = m_{a1} + m_{a2}} \longrightarrow (1)$ → mass conservation

$m_{a1} h_1 + m_{a2} h_2 = m_{a3} h_3 \longrightarrow (2)$ → energy conservation

$\Rightarrow h_3 = \dfrac{m_{a1} h_1 + m_{a2} h_2}{m_{a3}}$

$$\Rightarrow \boxed{h_3 = \frac{m_{a1} h_1 + m_{a2} h_2}{m_{a1} + m_{a2}}}$$

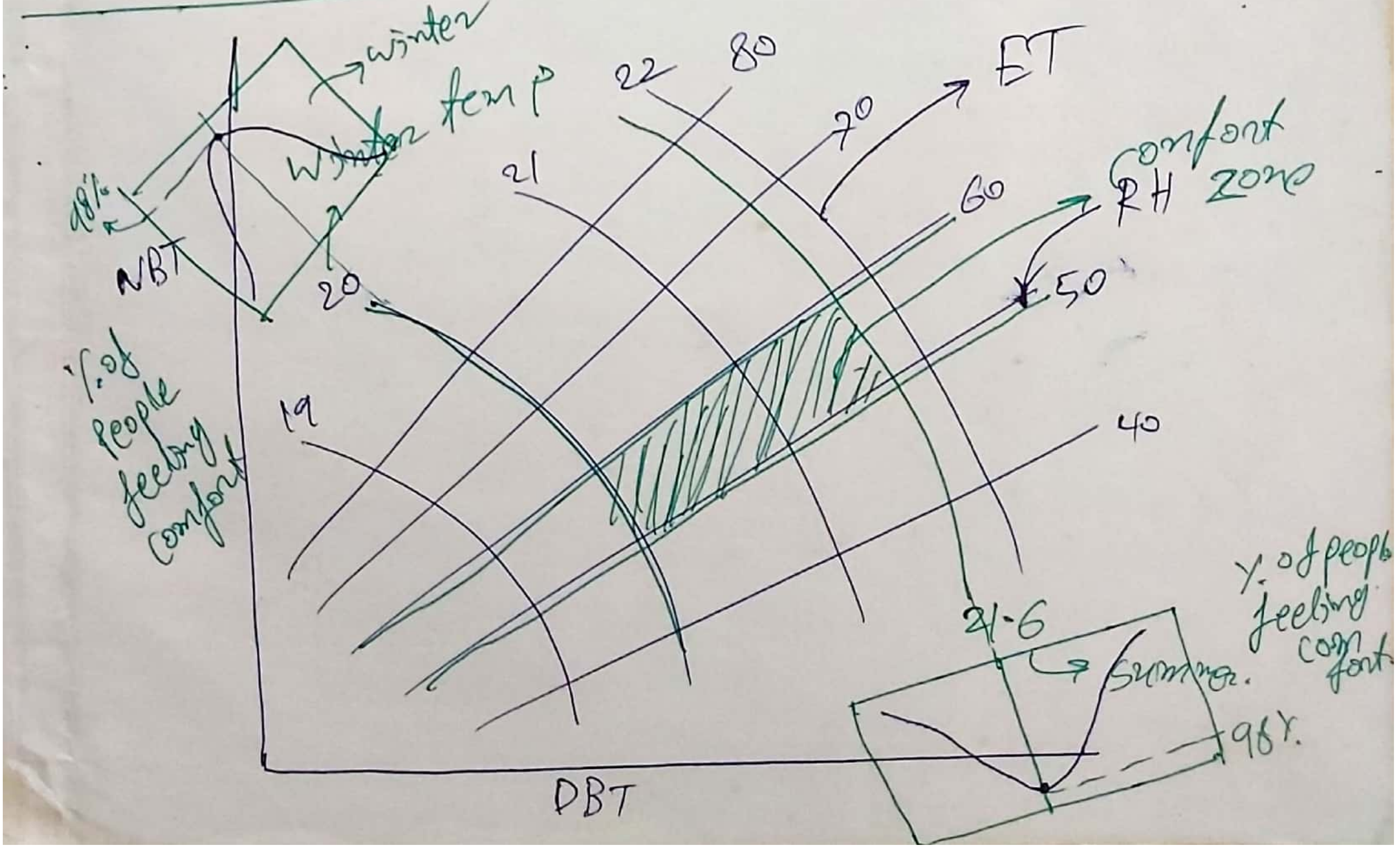


Effective Temperature (ET)

It is the temp of saturated air at which a person would experience same ~~felli~~ ~~filli~~ feeling of ~~of~~ comfort as a unsaturated condⁿ. Effective temp includes temp, humidity & air velocity. The general air velocities are 5-8 m/min.

Effective temp depends on climatic & seasonal condⁿ i.e. people staying in ~~older~~ colder climates reqd. lower effective temp compared to people ~~lea~~ living ~~in~~ hotter climate. It also depends on age & sex, women of all ages reqd ~~ma~~ a slightly higher temp ~~a~~ as compared to men. Maternity halls are generally kept at 2-3° ~~degree~~ higher ~~te~~ effective temp. ET also depends on the type of activity & density of occupant.

COMFORT CHART



This chart is the result of research made on different kind of people subjected to wide range of environmental temps. On comfort charts the DBT taken on X axis & WBT on Y-axis. The RH lines are plotted from psychrometric chart.

when the RH is below 50% the skin surface becomes too dry for comfort & on the other hand if the RH is more there is a tendency for sticky sensation to developed. It is found that in winter 98% of people felt comfortable at an ~~eff~~ ET of 20°C where is in summer this temp is above 21.6°C.

— o —

13.1 COMPRESSORS

The Compressor is considered as the heart of refrigeration system, because it pumps the refrigerant through the system similar to the heart which pumps the bloodthrough the body.

13.1.1 Reciprocating Compressor

The reciprocating compressor sucks the low pressure and low temperature refrigerant from evaporator during its suction stroke and delivers it at high pressure and high temperature to the condenser. The reciprocating compressors are built in sizes ranging from a fraction of horse power to several hundred horse power. These are used for refrigerating plant ranging in sizes from 0.25 ton to 1000 tons capacity per unit. The reciprocating compressors are satisfactorily used with the refrigerants as NH_3, SO_2, CH_3Cl and most of the freons. This is preferable for high compression ratio and low specific volume refrigerants.

The head and cylinder of the high capacity compressors are cooled by means of water jackets. Low capacitycompressors are cooled just by providing the fins on the cylinder head. This type of cooling is more effective and sufficient for low capacity compressors when F_{-12} is used as refrigerant because of the low temperature of gas at high perssure.

The are two different types of compressors in general use.

(*a*) Single acting vertical compressors.

(*b*) Double acting horizontal compressors.

There is one delivery of high pressure refrigerant for every revolution for single actign compressor and two deliveries from both sides of the pistons for each revolution for double acting compressor.

The single acting compressors are further classified according to the conditions considered below :

(*a*) Number of cylinders

(*b*) Arrangement of cylinders

(*c*) Speed of cylinder

(*d*) Staging of the cylinder.

The double acting horizontal cylinders require more space compared with vertical cylinder. As both the sides of the pistons are exposed to rapid temperature and pressure changes, there is greater possibility of leakages. More consideration in design of stuffing box is required as it is subjected to high and low temperature alternately because stuffing box contractsand expands alternately and provides more chances of leakage. Considerably long stuffing box is used to prevent the leakage.

Hermetically Sealed Compressor. In ordinary compressor, the crank shaft extends through the compressor housing and it is connected to the driving motor. A seal must be provided at the place where the shaft comes out through the compressor housing. This is necessary to prevent the leakage of refrigerant otuside or leakage of air inside. With best type of seals, the leak develops with the working of the compressor. To avoid the complete leakage of the refrigerant, the compressor and motor are enclosed in one housing which is known as hermetically sealed compressor. The motor in the housing is exposed to the low vapour refrigerant which helps for cooling also. The only connections to this type of compressor are the suction and discharge connections to the housing and electrical connections to the motor. The dehydration of the unit before charging is essential as the moisture in the system may damage the motor. This compressor has many advantages over ordinary type of compressor as listed below :

(a) The leakage of refrigerant is completely avoided.

(b) It is less noisy than the ordinary systems.

(c) Being more compact requires small space.

This type of construction is generally used for small capacity refrigerating systems as household refrigerator or small capacity coolers.

13.1.2 Volumetric Efficiency of Reciprocating Compressor

In a reciprocating compressor, when the piston reaches the end of its compression stroke, a portion of gas always remains in and is not discharged from the cylinder. The -pace in the cylinder occupied by the gas at the end of discharge stroke is known as the clearance volume and it is usually expressed as the percentage of the stroke displacement volume.

Some clearance is always necessary and desirable to provide cushioning and to prevent piston slap on the cylinder head. Clearance is objectionable becuase the capacity of two similar compressors each having the same piston displacement will be smaller for the machine having greater clearance.

The volume v_c of gas in the clearance space of a compressor is at discharge pressure p_2 and as the piston moves out on its suction stroke, this entrapped gas in the clearance re-expands, finally reaching vlume v_c', when the cylinder pressure has dropped to the system suction pressure p_1. The valve on the compressor operates by differential pressure and therefore cannot openuntil the pressure in the cylinder is less than the perssure in the suction line from the evaporator. Thus a fresh charge of gas cannot enter until the piston has swept out the volume $(v_c' - v_c)$. The effective piston stroke displacement remaining for new charge is thus only v_a as shown in Fig. 13.1 instead of full displacement v_s, which would be available if no clearance existed.

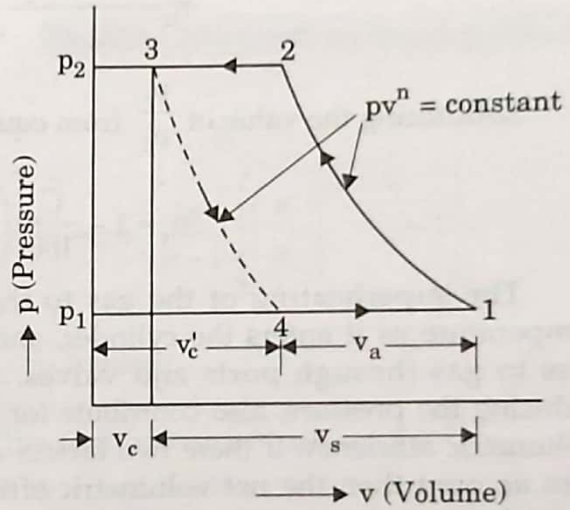


Fig. 13.1 Pressure volume diagram of a compressor

p_1 = Suction pressure of compressor,

p_2 = Delivery pressure of compressor

v_s = Stroke volume of the compressor,

v_a = Actual volume of gas taken in,

v_c = Clearance volume,

v_c' = Volume of gas after re-expansion,

n = Index of compression and expansion.

The clearance voume v_c is always presented in terms of stroke volume, so that the percentage clearance (C) is given by

$$C = \frac{v_c}{v_s} \times 100. \qquad ...(13.1)$$

The volumetric efficiency of the compressor is defined as the ratio of actual volume taken in per stroke divided by the stroke volume.

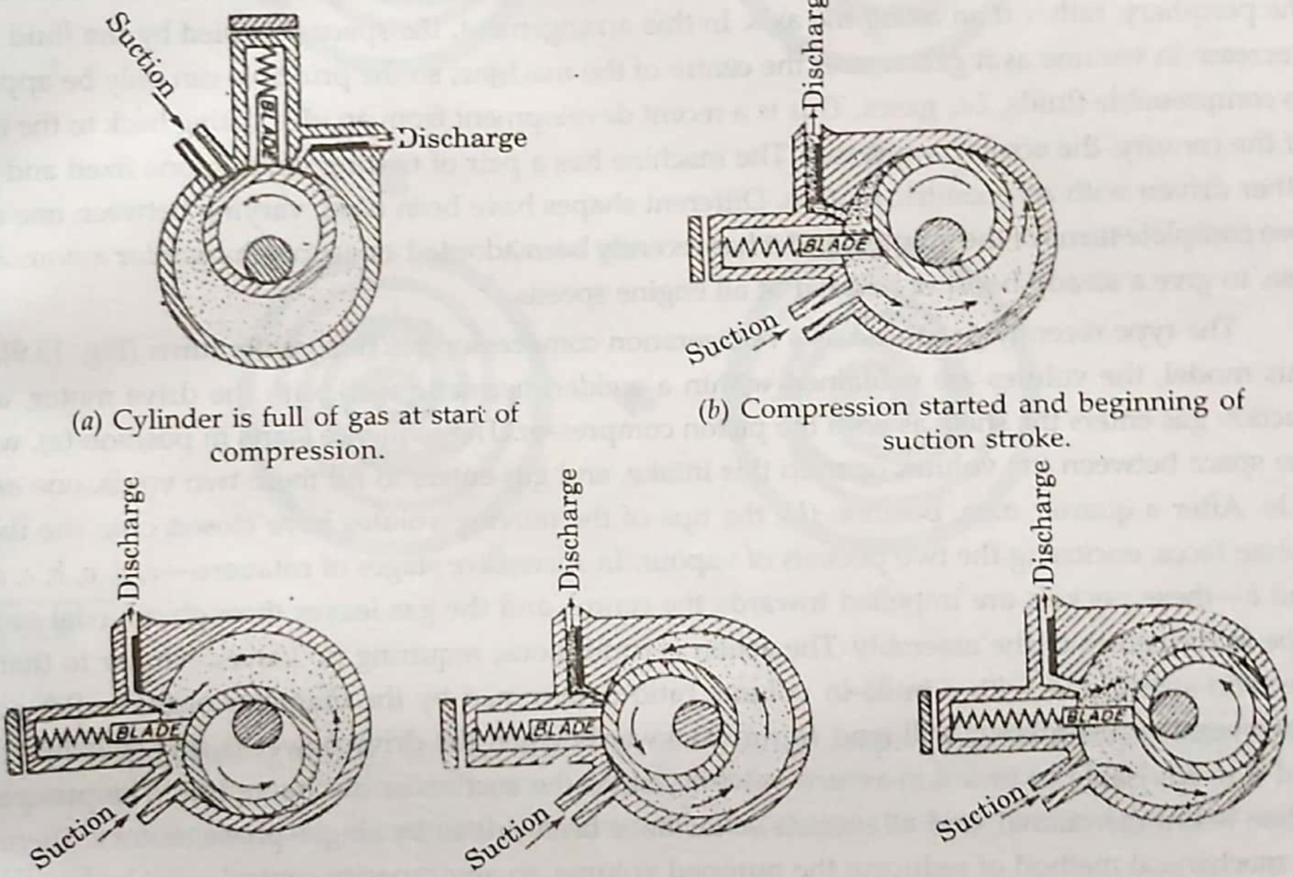
13.1.6 Rotary Compressors

There are mainly two types of rotary compressors :

1. Rotary compressors with one stationary sealing blade and eccentric rotor.
2. Rotary compressors with sealing blade which rotate with eccentric shaft.

These compressors are generally preferred with fractional tonnage refrigeration applications.

In single blade rotary compressor, a cylindrical roller rotates on an eccentric shaft and shaft is mounted concentrically in the cylinder. The rollar touches the cylinder wall at a point of minimum clearance as the roller is eccentric with the cylinder. The roller always touches the cylinder wall as it rotates on the shaft. A spring loaded blade mounted in the slot of the cylinder as shown in Fig. 13.7 moves in and out of the slot to follow the rotor as the rotor rotates. The compression process of this compressor is illustrated in Fig. 13.7 showing different positions of the rotor.



(*a*) Cylinder is full of gas at start of compression.

(*b*) Compression started and beginning of suction stroke.

(*c*) Discharge and suction stroke half completed.

(*d*) Discharge and suction are near completion.

(*e*) Discharge and suction strokes are completed.

Fig. 13.7. Rotary compressor with fixed blade.

The construction of another type of rotary compressor is shown in Fig. 13.8. 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. The blades move outward against the cylinder due to centrifugal action during the rotation of the rotor. These blades follows the contour of the cylinder wall as the rotor is eccentric with the cylinder.

The suction vapour is entrapped between the adjacent blades as shown in the figure. The vapour is compressed as the vanes rotate from the point of maximum rotor clearance

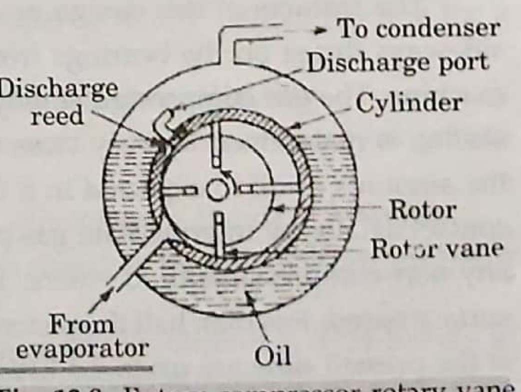


Fig. 13.8. Rotary compressor rotary vane type.

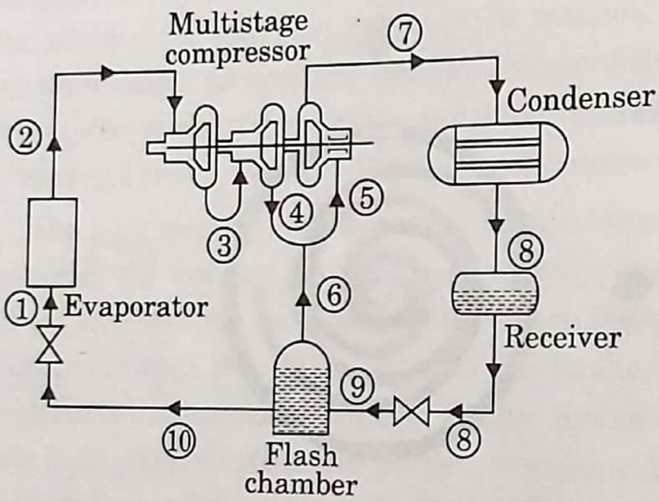
13.1.8 Centrifugal Compressors

The use of centrifugal compressor for refrigeration applications was made by Dr. Willis Carrier in 1920.

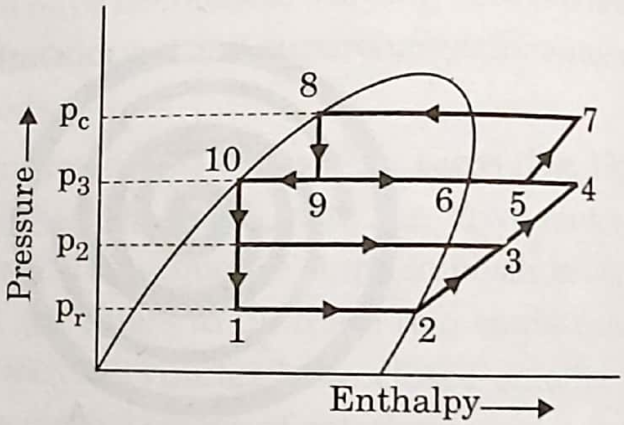
The refrigerant vapour is drawn into the compressor and it is discharged with a considerable high velocity at the outside edge of the impeller. This high velocity head is further converted into pressure head by passing through the diffuser. The rise in pressure per stage of centrifugal compressor is considerably smaller compared with single stage reciprocating compressor, therefore, when high compression ratio is required with centrifugal compressor, a multistage system is used. A three-stage system with flash chamber is shown in Fig. 13.10 (*a*) and its *P-h* diagram is shown in Fig. 13.10 (*b*).

The following points must be noted with centrifugal compressor refrigeration systems.

(*a*) The baffles must be provided in the suction path of refrigerant to prevent the flow of liquid droplets with vapour which may damage the compressor impeller.



(*a*) Refrigeration system with centrifugal compressor.



(*b*) *p-h* diagram.

Fig. 13.10.

(*b*) The power requirement of the compressor drastically increases with an increase in pressure of the system. The pressure increase may be due to the leakage of air or non-condensible gases into the system. Some method for removing the air and non-condensible gases must be used.

Design Considerations. The energy given by the impeller to the vapour is used to increase the static as well as velocity head of the vapour.

The total head developed by a single impeller is given by

$$H = \frac{V^2}{2g}$$

where H = Total head in metres

and V = Peripheral velocity of wheel in m/sec

and

$$p \text{ (pressure head)} = \rho H = \frac{\rho . V^2}{2g} \quad ...(13.13)$$

where p = Pressure in bar

ρ = Density of refrigerant vapou...

All the lubricating oils contain more or less wax and paraffins. These contents will start precipitating if the temperature of oil is reduced below a particular temperature. The temperature at which this precipitation starts is known as a clog point. Low clog-point (below the evaporator temperature) lubricating oils are preferred. High clog point oils create the difficulty in heat transfer in evaporator forming a wax layer on the evaporator surface and in flow by clogging the tubes carrying the low temperature refrigerant to the evaporator.

The floc-point is the temperature of the oil at which the wax will start precipitating from a mixture of 90% F_{-13} and 10% oil by volume. The oil soluble refrigerant lowers the viscosity of the oil as well as pour point also. The floc point property is very important for oil miscible refrigerants.

13.1.14 Methods of Lubrication

The methods of lubrication used for refrigeration system are divided into two main groups : (*a*) Splash lubrication. (*b*) Forced Feed Lubrication.

In splash lubrication system, the crank case acts as a sump for lubricating oil. The crank-shaft and connecting rod dip into the oil sump. Each revolution of the crank-shaft splashes the oil on the rubbing surfaces and lubricates. This system is preferred for the compressors below 10 kW capacity.

In the forced feed method, the oil is forced under pressure with the help of pump through the system and the oil comes back under gravity after performing the lubricating function into the sump located in the crank case. This system is used for high capacity compressors.

13.2 CONDENSERS AND COOLING TOWER

This is alnother important component of the refrigeration system which needs more consideration in design and construction. The condenser removes the heat from refrigerant carried from evaporator and added by comprcssor and converts the vapour refrigerant into liquid refrigerant.

It is an heat exchanger in which heat transter takes place from high temperature vapour to low temperature air or water which is used as cooling medium. Two considerations are necessary in design for effective functioning of the condenser as given below :

(*a*) Effective temperature differential. (*b*) High heat transfer coefficient.

There are different types of condensers and selection of condenser depends upon the capacity of the system, refrigerant used and medium of cooling available.

13.2.1 Types of Cooling Medium

The cooling mediums provided by nature are air and water. Both can be used as cooling medium either separately or combinedly as per the availability and requirement.

Air-cooled condensers are designed for condensing temperatures of 15°C to 20°C above the temperature of the entering air and 6°C to 12°C above if water is used as cooling medium. The condensing temperatures adopted with air as cooling medium is 55°C to 60°C where with water it is 31°C to 37°C. The temperature of condensing with water also depends upon the purity of water. The temperature adopted may be 2 to 4°C above the temperature used with clean water if the available water is dirty. Whenever the temperature of atmospheric air is 40°C, water is often available at 25°C, therefore the choice also depends upon the temperature of the available source.

Few more factors considered with air or water cooled condensers are listed below :

1. Quantity of Cooling Medium. The quantity of air required in air-cooled condenser is 30 to 35 cu. m./mim./Ton of refrigeration, whereas quantity of water is 7 to 20 litres/min./Ton depends upon the source of water (well or city main).

2. **Amount of Condensing Surface.** Lower heat transfer ... provided with heat transfer surface coefficients and greater temperature differential between the cooling and condensing gas. The area required with air-cooled condensers is 4 to 5 times greater than water cooled condensers. Water-cooled condensers require 0.5 to 1 m² area per ton of refrig... capacity.

3. **Velocity of Cooling Medium.** The heit transfer rates increase with an increase in ... of the cooling medium. The recommended velocities for air-cooled condensers are 270 m... m/min. and with water cooled condensers are 120 to 180 m/min.

4. **Type of Refrigerant.** The heat transfer coefficient of condensing side mostly depend... the properties of the refrigerant as density, conductivity, viscosity and latent heat. More about this are given in chapter 15. As these properties are different for different refrigerants, heat transfer coefficients are also considerably different. The condensing surface requi... chlorinated refrigerants is much greater than ammonia due to poor physical properties as me... above.

5. **Purity of the Refrigerant.** The heat transfer coefficient also depends upon the purit... refrigerant as free from oil and air because oil presence with the refrigerant gives more re... for heat transfer. This factor is more noticeable with chlorinated refrigerants. The presenc... also reduces the rate of heat transfer rapidly and reduction depends upon the percentag... present.

The condensers are classified on the basis of the cooling medium used. (*a*) Air-cooled cond... (*b*) Water-cooled condensers, (*c*) Evaporative condensers.

13.2.2 Air-cooled Condensers

The air was not considered as an economical coolant before the introduction o... refrigerants. This is because the condensing temperature of NH_3 was limited to 30°C due to i... condensing pressure and air temperature often exceeded above 30°C in many of the count...

The use of freons as refrigerants allowed to use air as coolant for condensing tempe... above 30°C under normal condensing pressures. Nowadays air-cooled condensers are com... used for domestic refrigerators, freezers and room air-conditioners.

The circulation of air may be by natural convection or force convection. The area requi... the natural convection is considerably large compared with forced convection due to its lo... transfer coefficient. Natural convection condensers are used for small capacity purpos... domestic refrigerators, water coolers and room air-conditioners.

In case of forced convection condensers, the air is circulated through the condenser b... blower. The force convection condensers are further divided into two groups : (*a*) Chassis mo... condenser, (*b*) Remote air-cooled condenser.

The chasis mounted condensers are mounted on the same base of compressor and mot... small units, the compressor is belt driven from the monitor and blower required to force th... through the condenser is mounted on the sahft of motor. The use of this compressor for indoor... is limited up to 3 kW capacity motor only because the length and height exceed the door ope... dimensions.

The remote air-cooled condensers may be of forced type or of free convection type. I... natral convection type, the condensing tubes are arranged on a large floor with an inclinatio... 7°C with horizontal. These condenser, the noise of the fan can be avoided and running power... of the blower can be eliminated. Forced type air-condensers for big unit require 0.1 to 0.2 kW to... the blower per ton of refrigerating capacity of the plant. These types of condensers are used... refrigeration system from 0.5 ton to 500 tons capacity of the plant.

The arrangement of natural and force convection condensers is shown in Figs. 13.20 (*a*) and (*b*).

The forced air cooled condensers are designated as **draw through** or **blow through** air flow as shown in Fig. (13.19). With a draw through design, the face velocity across the coil is more uniform and the coil is more effectively used. But hot discharged air from the coil flows over the fan * motor so they should be designed to withstand higher air temp. In blow through desing the fan & motor has ambient air flowing over them, but the face velocity across the coil is less uniform than the draw through design.

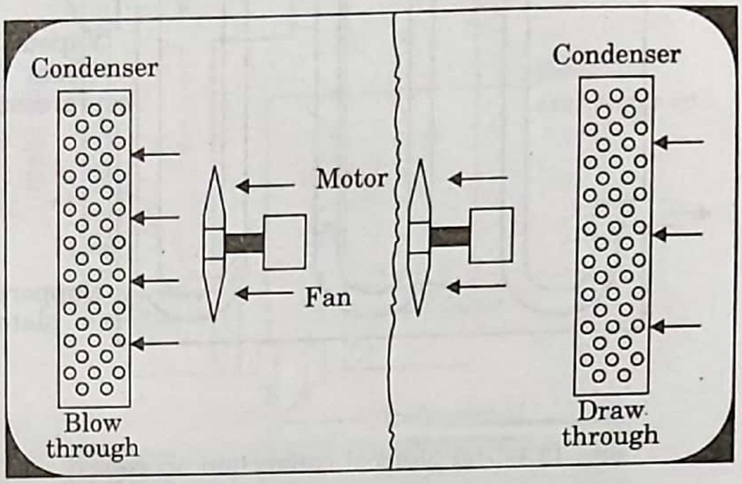


Fig. 13.19

Static Condensers. Small units like domestic refrigerantors, water coolers, freezers use static condensers where the heat carried away by natural convention (heat rejection) is limited to 300W.

It comprises a copper tube which may have wire fins brazed to it and located outside the refrigerator. The present trend is to embed it on the isside wall of the refrigerator or freezer so that the entire cabient wall acts as one large fin. It also keeps the cabient wall warm and free from condensation.

Rating of Condenser. Condeners are rated in terms of total heat rejection (THR) which is the heat absorbed in the refrigerator and work input to the compressor $Q_r + W = m_r (h_o - h_i)$ where m_r is the mass of refrigerant passing through condenser and h_i and h_o are the enthalpies of refrigerant entering and leaving the condenser.

In condenser, the refrigerant looser heat by desuperheating, condensing and sub-cooling. The desuperheating and subcooling occupies 15%, surface area where as condensing is carried out in 85% of the surface area of condenser.

Advantages and Disadvantages of Air-Cooled Condensers over Water-Cooled Condensers

1. Simplicity of construction.
2. No handling problems.
3. Piping arrangement for carrying the air is not required.
4. There is no problem of disposal of used air.
5. Fouling effects are very less compared with water.
6. Installation and maintenance costs are considerably less.
7. High flexibility.

The disadvantages are listed below :

1. Poor heat carrying capacity.
2. It requires very large quantity of air as 300 m^3 per ton of refrigeration per hour.
3. These condensers are seldom used for refrigeration units over 5 tons capacity because power required to drive the fan becomes excessive and fans noise becomes objectionable.
4. The major disadvantage associated with this type of condenser is that the condenser gives lowest capacity when the outside air temperature is highest and this is usually the time when greatest capacity is required.
5. Air-cooled condenser operates at a greater condensing temp therefore, the refrigeration system delivers 15 to 20% lower capacity.

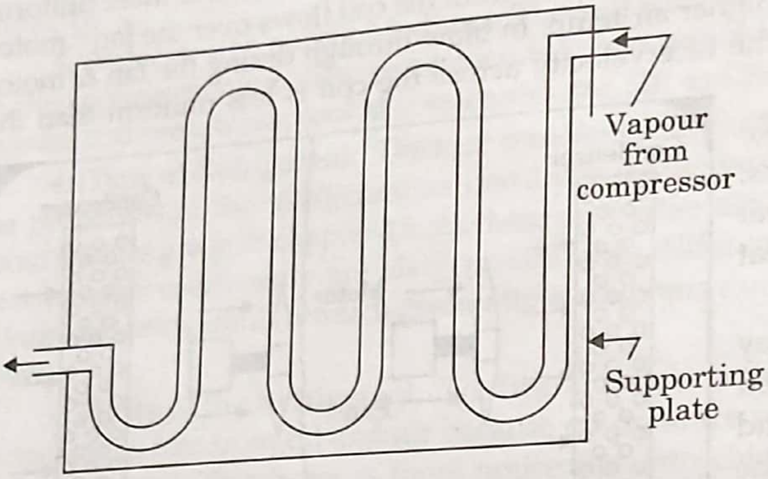


Fig. 13.19. (*a*) Normal convection air-cooled condenser.

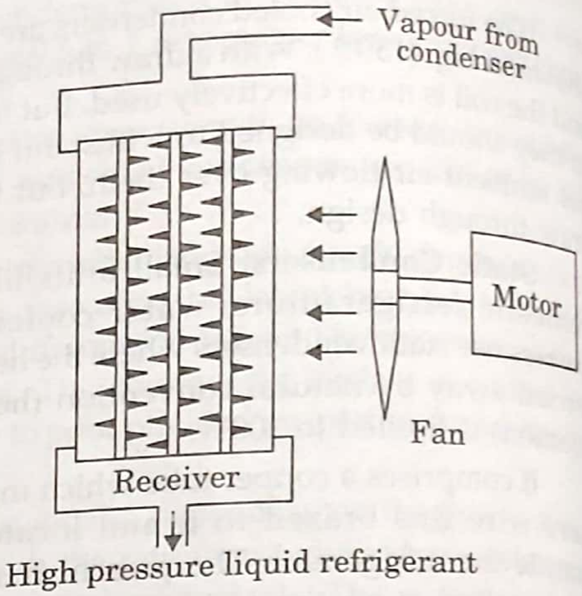


Fig. 13.19. (*b*) Forced convection air-cooled condenser.

The air-cooled condensers are preferred under the following circumstances :

1. Minimum corrosion is the major requirement.
2. Inadequate supply of cooling water.
3. Expensive means of water disposal.

13.2.3 Water-Cooled Condensers

Water-cooled condensers are always preferred where adequate supply of clean and inexpensive means of water disposal are available.

In air-conditioning plants, it is possible to harness the exhaust air with integrated heating and refrigeration. Switchable systems for heating in winter and cooling in summer are particularly economical. Because by fitting the condenser in the exhaust air duct, *it is possible to lower the condensation pressure during cooling operation and hence the input to the compresor.* When heating cycle is used, the evaporation temperature can be raised by mixing exhaust air from ventilation and air-conditioning systems to the outdoor air, especially where the exhaust air comes from rooms with high internal cooling load. This narrows the span between evaporation and condensing temperatures increasing the C.O.P. of the system.

The heat from evaporator absorbed by refrigerant and heat of compression is dissipated to atmosphere by air-cooled condenser. The considerable amount of energy lost in this way can now be recovered by directing the hot refrigerant through a water-cooled heat exchanger which can produce large quantities of warm water at 50 to 62°C for domestic, commercial or industrial uses at no extra running cost.

The heat from an air-cooled condenser is lost to atmosphere and cannot be used for any other purpose. The considerable amount of energy lost in this way can be recovered by passing the hot refrigerant through and water-cooled heat exchanger which can produce large quantities of hot water at 50 to 60°C for domestic, commercial or industrial uses at no extra running cost.

Such type of condenser is designed by AlfaLeval Company, West Germany and its features are shown in Fig. 13.20 (*c*).

Similar type is also designed by Doucette Industries, New York, U.S.A. titled as *desuperheater*. The device is available for residential or industrial systems using all refrigerants as NH_3, solar fluid and chlorinated water. it also features the protection of vented double walls and mechanically cleanable water tubes. The company also offers a free computer program to ensure correct sizing for the most economical condenser with the lowest possible cost and payback period.

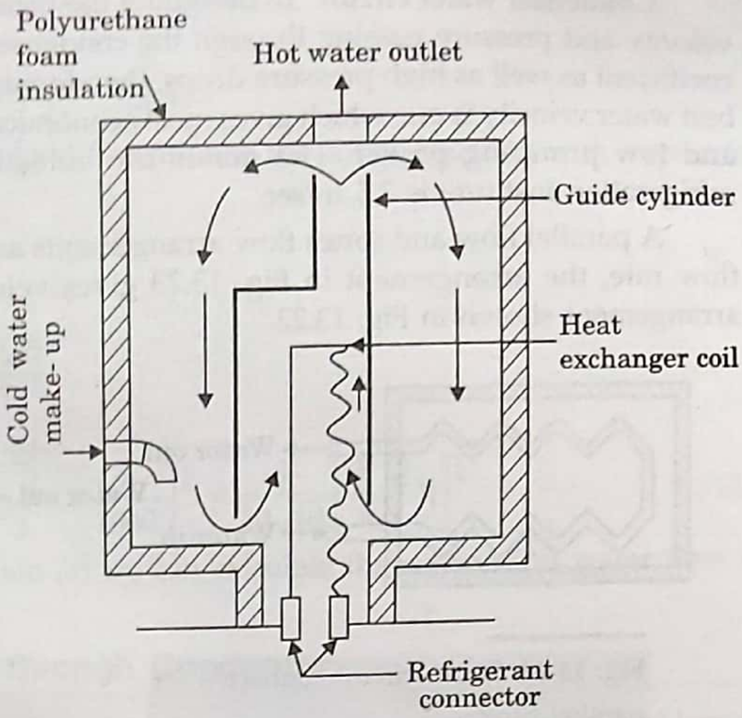


Fig. 13.20. (*c*) Alfatherm refrigerant condenser designed by Alfa Leval, West germany.

This category of condenser is divided into two groups :

(*a*) Water waste system.

(*b*) Reciculated system.

When ample supply of inexpensive water is available, then the water is taken from the supply, circulated in the condenser and disposed to the sewer. This system is known as water waste system.

When inadequate and expensive supply of water is available then the water used in the condenser is recooled and used again and again in the condenser similar to the steam power plants. This system is known as recirculated system. generally the water supply rate through this type of condenser is 15 litres/min/ton of refrigerating capacity of the system which provides the most economical balance between the compressor power and Pump power.

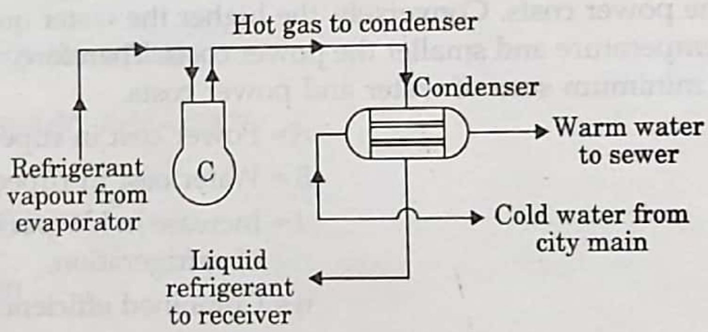


Fig. 13.21 (*a*) Waste water system for condenser.

The two above described systems of coolig are shown in Fig. 13.21 (*c*) and (*b*).

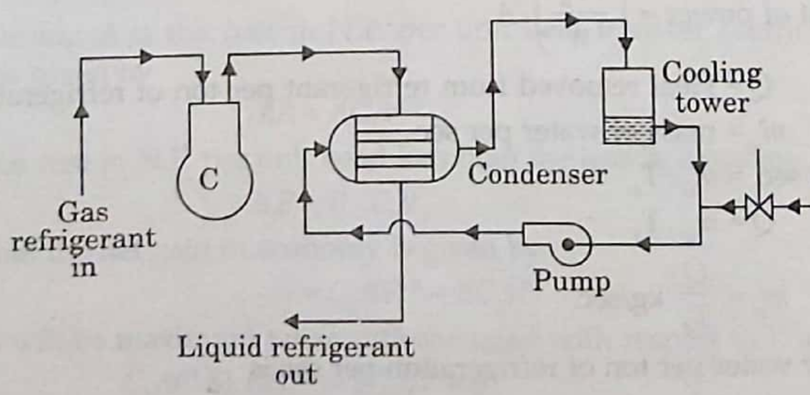


Fig. 13.21 (*b*) Recirculating water system for condenser.

Fig. 13.49.

13.3.5 Shell and Tube Evaporator

The construction of shell and tube evaporator is similar to the construction of shell and tube condenser which is shown in Fig. 13.50. In this evaporator, the refrigerant is expanded into the tube and chilled water is circulated through shell. If the evaporator is operated flooded then the water is circulated through the tubes and liquid refrigerant is passed through the shell. The height of the liquid refrigerant in the shell is controlled by float valve not shown.

Many times, the liquid refrigerant is sprayed through the nozzles into the shell and the water is circulated through the tubes. The liquid refrigerant collected at the bottom of the shell is again recirculated with the help of pump. The arrangement gives high heat transfer coefficients and requires a small units compared with other arrangement for the given duty.

Dry expansion shell and tube evaporators are used for the units of 2 tons to 250 tons capacity and flooded evaporators are used for the units of 10 tons of 5000 tons capacity.

13.3.6 Shell and Coil Evaporator

These types of evaporators are generally dry-expansion type. The arrangement of the evaporator is just similar to the shell and tube condenser which is already described. These evaporators are desired when the temperature of the outcoming water is above 5°C which prevents the possibility of freezing.

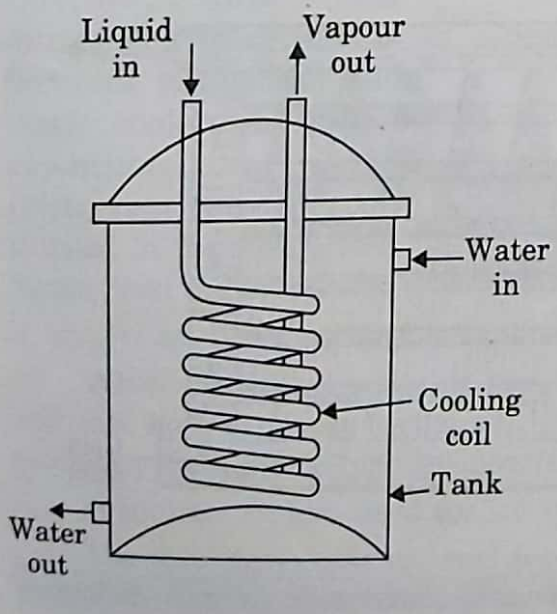


Fig. 13.50.

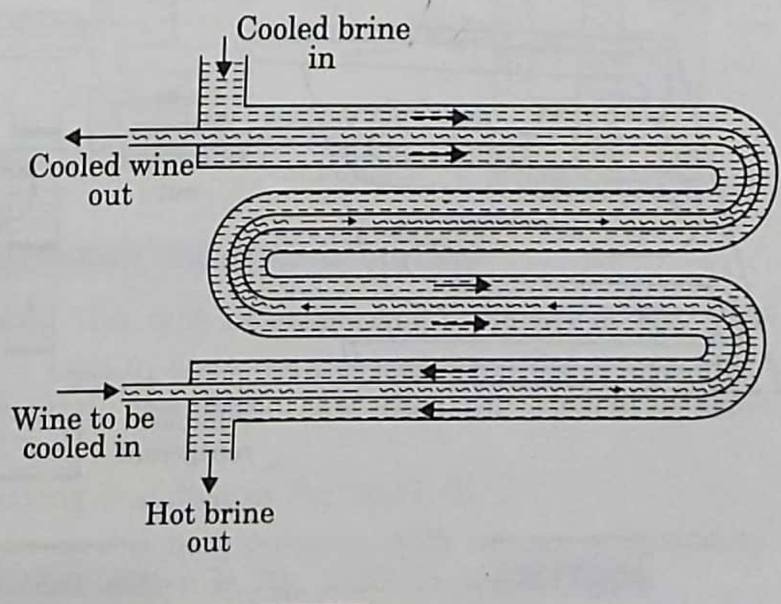


Fig. 13.51. Double-pipe evaporator.

13.4 EXPANSION DEVICES

This is one of the basic components of the refrigeration system. The functions performed by the expansion device are listed below :

1. It must reduce the pressure of the refrigerant coming from the condenser and temperature also as per the requirement of the system.

2. It must regulate the flow of the refrigerant as per the load on the evaporator.

The different devices which are used to perform the above functions are listed below :

1. Capillary Tube.
2. Pressure Control or Automatic Expansive Valve.
3. Thermostatic Expansion Valve.
4. High-side Float Valve.
5. Low-side Float valve.
6. Solenoid Valve.

13.4.1 Capillary Tube

A capillary tube is universally used as a refrigerant control devices in refrigerating systems which use hermetic compressor because of its simplicity, reliability, and cost saving advantages. Great care must be exercised in the selection of the capillary tube and the design of a system to accept it.

Its resistance to flow permits the capillary to be used as a pressure reducing device to meter the flow of refrigerant given to the evaporator. The selection of the capillary depends upon the application and anticipated range of operating conditions. A refrigerating system may be said to be operating at the condition of capacity balance when the flow resistance of the capillary is just sufficient to maintain a liquid refrigerant seal at the capillary inlet without excess liquid excess liquid backing up in the condenser. At this condition, the capillary will be operating at maximum efficiency (100%). Only one such point exists for any given discharge pressure. A curve through the capacity balance points for a range of compressor discharge pressure is called the capacity balance characteristic of the system.

This device is only used for small capacity units like doemestic refrigerators, water coolers and small commercial freezes. It is small diameter tube connected between condenser and evaporator. The required pressure drop (pressure difference condenser and evaporator pressures) is caused due to heavy frictional resistance offered by a small diameter tube. The resistance is directly proportional to the length and inversely proportional to the diameter. Different length and diameter combinations are recommended for the required pressure drop and flow quantity.

The rate of flow for a selected capillary tube is the function of the pressure differential between the condenser and evaporator. As the load increases in summer, the tube supplies more quantity of refrigerant flow as an effect of increased condenser pressure (or pressure difference) with air-cold condensers used on domestic units. Similarly when the load on the unit is reduced in winter, the flow through the tube decreases as an effect of decreased condenser pressure. The capillary is a self-compensating device over a limited range of pressure difference.

The relationship between the load, diameter and length is given in the table below.

kW of Motor	*Load in kcal/hr*	*Suction Temperature °C*	*Tube Diameter mm*	*Tube Length in cms*
0.25	700	– 3.33	1	90
0.25	700	– 3.33	1.25	150
0.20	540	– 3.33	1	120
0.20	540	– 3.33	1.25	195
0.15	400	– 3.33	1	180
0.15	400	– 3.33	1.25	285

The use os this expansion device is limited to small units of maximum capacity of 1 ton.

Advantages and Disadvantages of this Device

1. It is simple in construction and no maintenance is required.

2. When the compressor steps, the refrigerant continues to flow from high pressure side to low pressure side until the pressure is equalised. This requires less starting torque to start the compressor so a low starting torque motor (low cost motor) can be used with these units.

3. System using this device does not require receiver.

4. Its cost is also considerably low compared with other devices.

The disadvantages associated with this device, the refrigerant must be free from moisture and dirt otherwise it will choke the tube and stop the flow of refrigerant. It cannot be used with high fluctuating load conditions.

13.4.2 Automatic Expansion Valve

Automatic (constant pressure) expansion valve works in response to the pressure changes in the evaporator due to increase in load (pressure increases) or due to decrease in load (pressure decreases). This valve maintains a constant pressure throughout the varying load operation on the evaporator controlling the quantity of refrigerating flowing into evaporator.

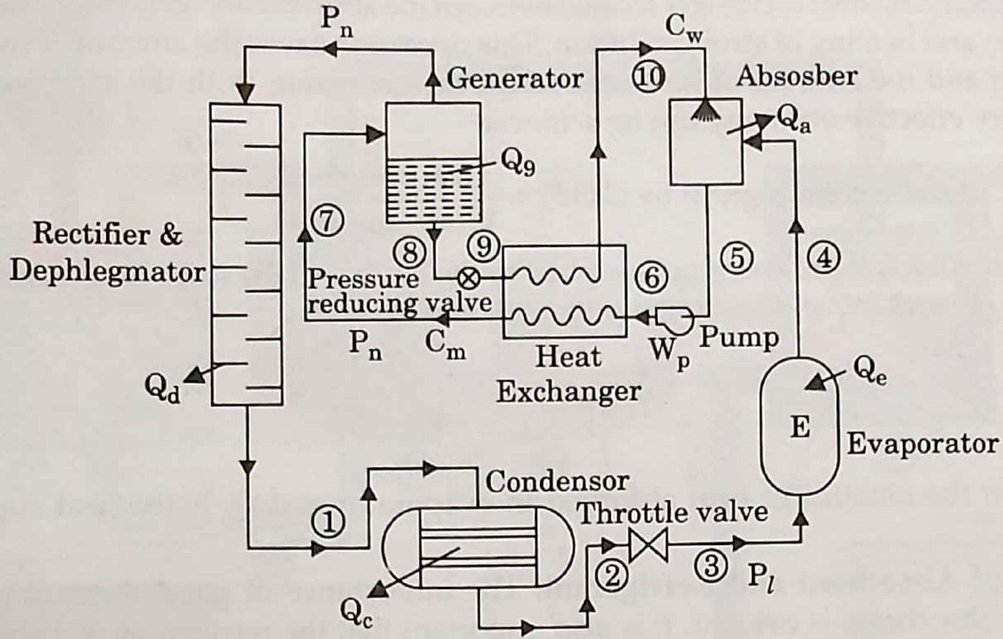


Fig. 6.1

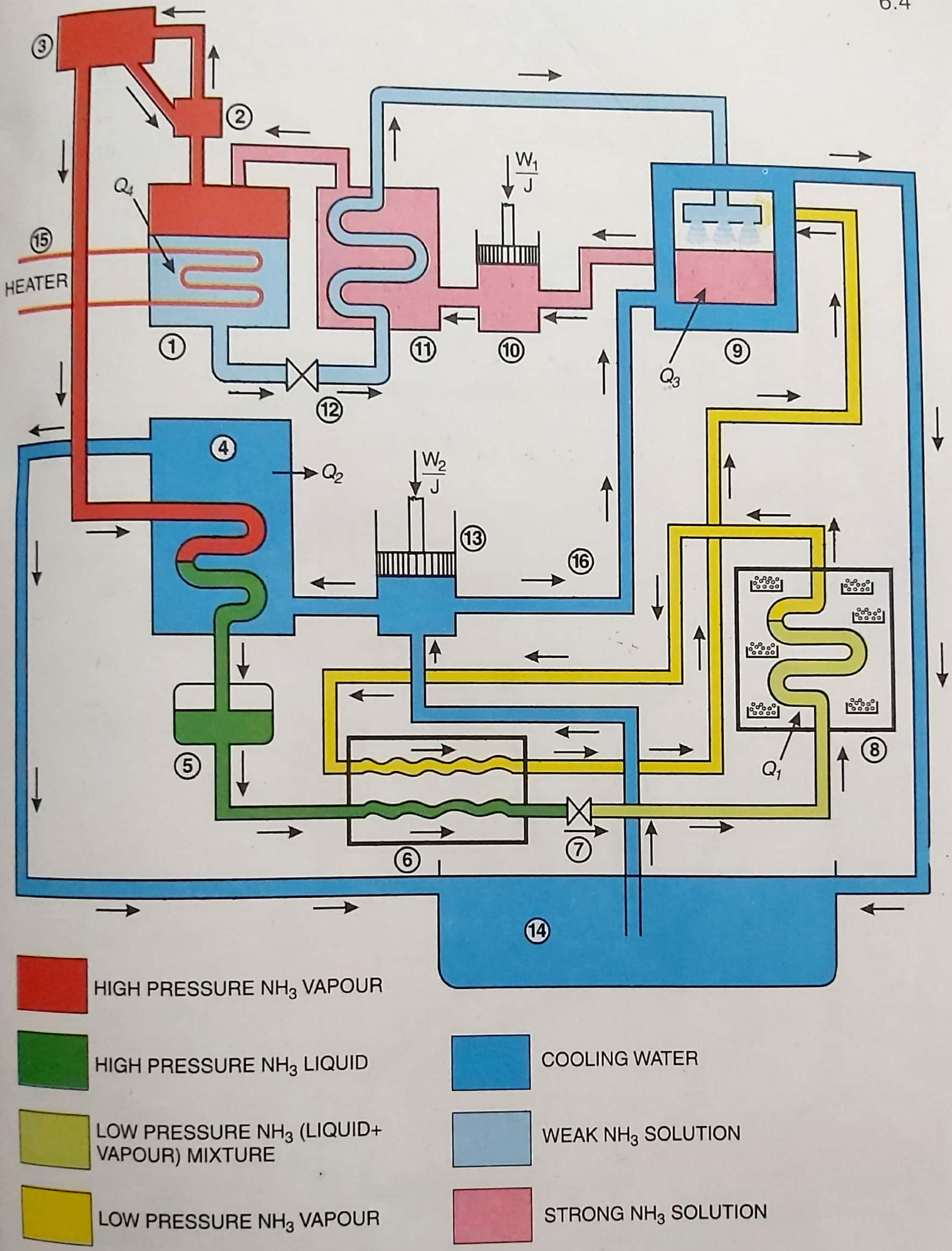
6.3 PRACTICAL AMMONIA ABSORPTION SYSTEM

The basic components of practical NH_3 absorption system are listed below and numbered on plate-I.

(1) Generator. (2) Analyser. (3) Rectifier. (4) Condenser. (5) Receiver. (6) Heat-exchanger (HE_1) or liquid sub-cooler. (7) Expansion valve (EV_1). (8) Evaporator. (9) Water-jacked absorber. (10) Pump (P_1). (11) Heat-exchanger (HE_2) (Aqua ammonia Heat Exchanger). (12) Expansion valve (EV_2). (13) Pump (P_2). (14) Pond containing cooling water. (15) Heating coil.

The system described in the last article is not very economical. However, by the addition of certain auxiliary equipments, the economy can be sufficiently improved to make the system practical. The basic auxiliaries included are an analyzer, a rectifier and two heat exchangers as shown in plate-I.

The vapour which rises from the solution in the generator consists of ammonia vapour along with small quantities of water vapour. Unless major part of this water-vapour is removed before the vapour enters the condenser, this water-vapour may enter the expansion valve and freeze there. As this mixture of ammonia vapour and water vapour is cooled, the water vapour condenses out first. The analyzer performs the function of dehydration by bringing the vapour into contact with the aqua richest in ammonia and by cooling the vapour with this aqua. If the dehydration is not complete enough in the analyser, an added water cooled vessel called a rectifier may be used to complete the process for sending anhydrous dry ammonia to the condenser. In the heat exchanger HE_1, liquid refrigerant is sub-cooled by using low temperature ammonia vapour. This sub-cooled liquid is passed through the expansion valve to the evaporator. The mixture absorbs heat in evaporator and enters into the water jacked absorber. Water jacketing to the absorber is provided to cool the hot weak ammonia solution to increase the absorbity of the weak solution, then the strong ammonia solution from the absorber is passed through the pump and aqua ammonia heat exchanger to the generator. The weak hot solution from generator is passed to the absorber in the form of spray through aqua ammonia heat exchanger. The weak liquid absorbs vapour coming from evaporator and becomes strong in ammonia.



Practical Ammonia Water Absorption Refrigeration System