

# Thermal Engineering

## Part-3

chapters includes →

- (1) Refrigeration
- (2) Air conditioning
- (3) Psychrometry
- (4) Vapour compression system
- (5) Vapour absorption system
- (6) Refrigerant

Prepared by →

Engineering Solutions

At/P.O - Bhainsa

Dist - Balangir

Phone - 9439424511

whatsapp - 9439424511

# Refrigeration

Refrigeration is the science of producing and maintaining temperature below that of surrounding temperature.

It means removal of heat from a substance that is to be cooled, and cooling or removal of heat takes place inside the system. This can be produced by →

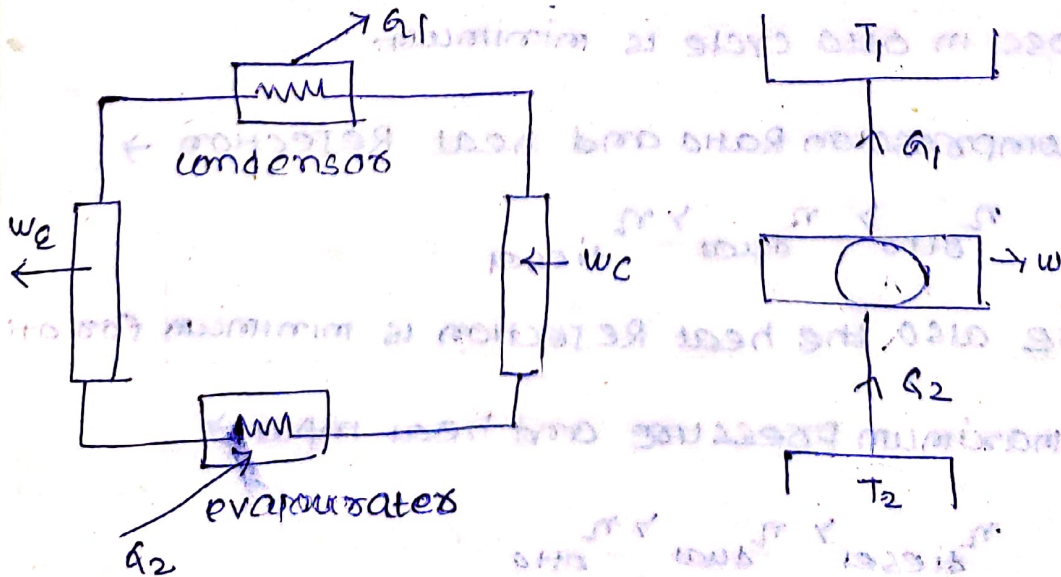
- (1) By melting of solid
- (2) By sublimation of solid
- (3) By evaporation of solid

## Element In Refrigeration

- (1) A lower temperature sink to which heat will flow from the space to be cooled.
- (2) Means of extracting energy from the sink, to raising the temp level
- (3) A receiver to which heat will transfer from high pressure refrigerant

$$C.O.P) = \frac{R_m}{W} = \frac{\text{Net Refrigeration effect}}{\text{work expanded}}$$

## Reversed Carnot Cycle



This is receiving heat from a lower temperature region and discharging heat to a higher temperature region and Receiving a net heat flow work under such condition it is called a Refrigeration cycle.

$$(C.O.P)_{H.P} = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

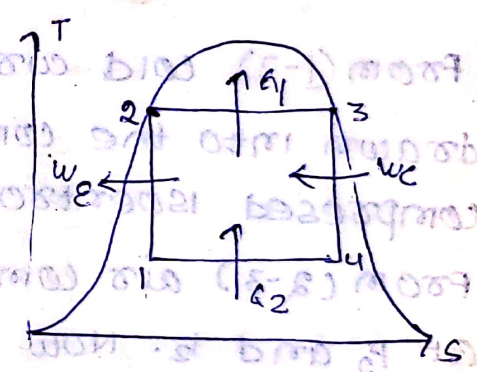
$$(C.O.P)_{Ref} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

The working fluid in the Refrigerator is known as Refrigerant and in this cycle the Refrigerant composed Reversibly and adiabatically in the process 1-2 where the work input is  $w_c$  and in the process 2-3 the heat rejection is  $Q_1$ . Then the Refrigerant expands Reversibly from 3-4 and work output is  $w_e$  and finally absorbs heat  $Q_2$  by the process 4-1.

$$Q_1 = T_1 (s_2 - s_3)$$

$$Q_2 = T_2 (s_1 - s_4)$$

$$w_{net} = Q_1 - Q_2 = (T_1 - T_2) (s_1 - s_4)$$



$$(C.O.P)_{Ref} = \frac{Q_2}{w_{net}} = \frac{T_2}{T_1 - T_2} \quad (C.O.P)_{H.P} = \frac{T_1}{T_1 - T_2}$$

$$(C.O.P)_{H.P} = (C.O.P)_{Ref} + 1$$

from here we observe that the  $(C.O.P)_{H.P}$  is always greater than that of Refrigerator. and we

know that  $(C.O.P)_R = \frac{T_1}{T_2 - T_1}$   $T_1 = \text{lower temp}$   
 $T_2 = \text{higher temp}$

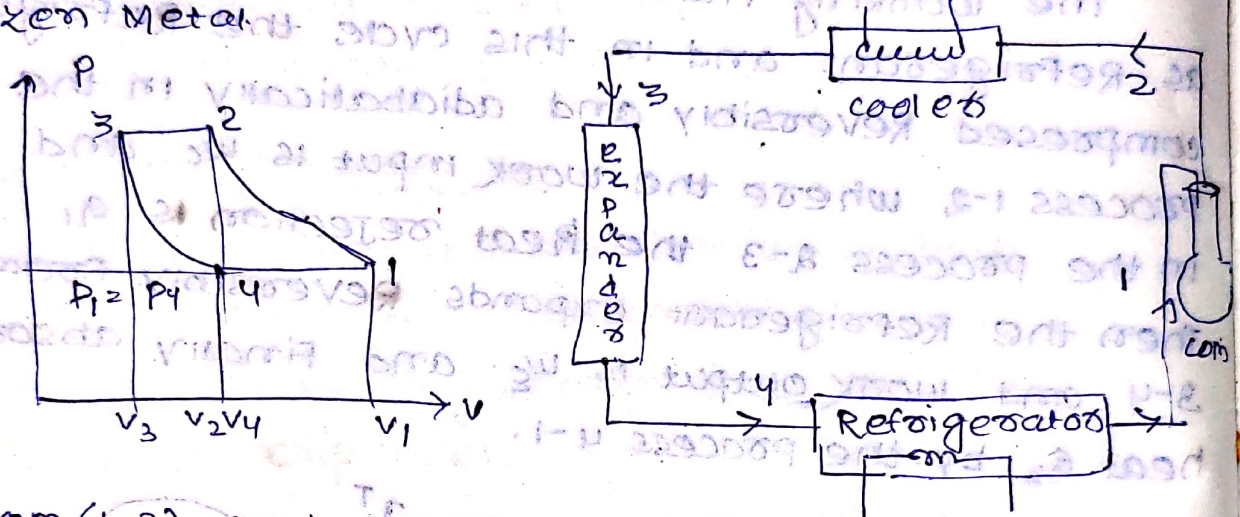
This C.O.P can be improved by the following method

- (1) by decreasing the higher temperature  $T_2$
- (2) by increasing the lower temperature  $T_1$

The COP of the Reversed Carnot cycle is maximum possible when it is operated bet<sup>n</sup> two fixed temperature limits.

### Bell Coleman / Reversed Joule Cycle

A Bell-Coleman air Refrigeration was developed by bell-coleman and light foot by Reversing the Joule's air cycle. It is one of the earliest types of Refrigeration and was used in ships carrying frozen Metal.



From (1-2) cold air from the Refrigerator is drawn into the compressor cylinder where it is compressed isentropically  $s_1 = s_2$ ,  $q_{1-2} = 0$

From (2-3) air coming from the compressor is at  $P_2$  and  $T_2$ . Now this is passed to the cooler at  $T_3$  but constant pressure  $P_2 = P_3$

$$q_{2-3} = c_p (T_2 - T_3) = \frac{R \times v}{\gamma - 1} = \frac{\gamma}{\gamma - 1} (P_2 v_2 - P_3 v_3)$$

From (3-4) the air from the cooler is drawn into the expander cylinder isentropically  $P_2 = P_3$  temp during expansion is  $T_3$  to  $T_4$ .

$$q_{3-4} = 0$$

From (4-1) The work take place inside the Refrigerator. The cold air from the expanded absorb heat at constant pressure.

$$q_{4-1} = c_p (T_1 - T_4)$$

c.o.p

$$\int W = \int Q_2 \frac{v \times g}{1-v} = (p(T_2 - T_3)) =$$

$$W = (Q_{2-3} - Q_{4-1}) = (p(T_2 - T_3) - (p(T_1 - T_4))) = Q.O.P$$

$$(C.O.P) = \frac{c_p(T_1 - T_4)}{(p(T_2 - T_3) - c_p(T_1 - T_4))} = \frac{T_1 - T_4}{T_2 - T_3 - c(T_1 - T_4)}$$

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

for isentropic compression (1-2)

$$\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad \frac{T_3}{T_4} = \left( \frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}}$$

we know  $P_3 = P_2$  and  $P_1 = P_4$

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

$$C.O.P = \frac{T_4 \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}{T_3 \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] - T_4 \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

$$C.O.P = \frac{1}{(\sigma_p)^{\frac{\gamma-1}{\gamma}} - 1} \quad \sigma_p = \text{compression ratio} = \frac{P_3}{P_4} = \frac{P_2}{P_1}$$

case-1 (compression and expansion  $pV^n = \text{constant}$ )

$$W_c = \frac{n}{n-1} (P_2 V_2 - P_1 V_1) = \frac{n}{n-1} (R \times T_2 - R \times T_1)$$

$$W_e = \frac{n}{n-1} (P_3 V_3 - P_4 V_4) = \frac{n}{n-1} (R \times T_3 - R \times T_4)$$

$$\text{Net work input} = W_c - W_e$$

$$= \frac{n}{n-1} \times R \left[ (T_2 - T_1) - (T_3 - T_4) \right]$$

Heat absorbed during constant pressure ( $w_1$ )

$$= (p (T_1 - T_4)) = \frac{R \gamma}{\gamma - 1} (T_1 - T_4) \cdot w$$

$$c.o.p = \frac{\text{Heat absorbed}}{w \cdot D} = \frac{R \gamma}{\gamma - 1} (T_1 - T_4) = w$$

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{and} \quad \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

Case-2 when compression and expansion

$$P V^{\eta_1} = c \quad \text{and} \quad P V^{\eta_2} = c$$

$$w_c = \frac{\eta_1}{\eta_1 - 1} R (T_2 - T_1) = w_e = \frac{\eta_2}{\eta_2 - 1} R (T_3 - T_4)$$

$$W = w_c - w_T = \left[ \frac{\eta_1}{\eta_1 - 1} (T_2 - T_1) - \frac{\eta_2}{\eta_2 - 1} (T_3 - T_4) \right] R$$

$$\text{heat absorbed} = (p (T_1 - T_4)) = \frac{R \gamma}{\gamma - 1} (T_1 - T_4)$$

$$c.o.p = \frac{\gamma}{\gamma - 1} (T_1 - T_4)$$

$$\frac{\eta_1}{\eta_1 - 1} (T_2 - T_1) - \frac{\eta_2}{\eta_2 - 1} (T_3 - T_4)$$

here we write  $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\eta_1 - 1}{\eta_1}}$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\eta_2 - 1}{\eta_2}}$$

Case-3 (when isentropic efficiency of turbine

and compressor is not 100%)

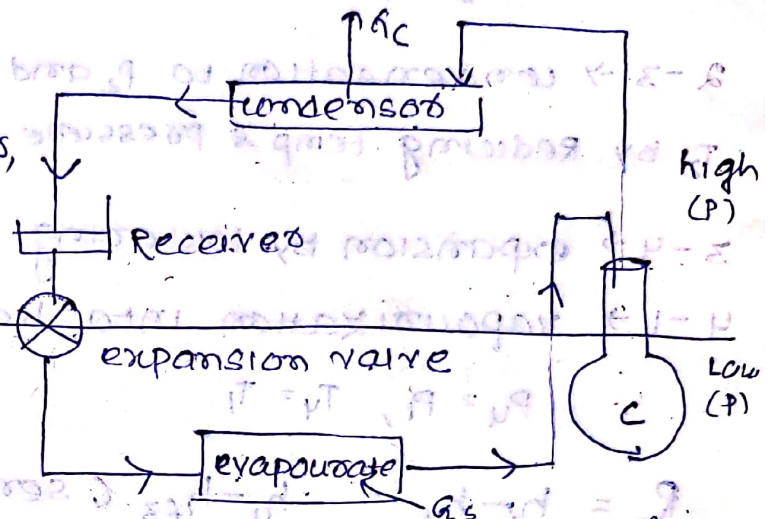
$$\eta_c = \frac{T_2 - T_1}{T_2' - T_1} \quad \eta_T = \frac{T_3 - T_4}{T_3' - T_4}$$

$$c.o.p = \frac{(T_1 - T_4')}{(T_2' - T_1) - (T_3 - T_4')}$$

# Vapour Compression System

It is a kind of Refrigeration system in which the vapours like Ammonia, carbon-dioxide, sulphur dioxide are used as working fluid. Since the low temp vapour refrigerant is compressed into high temp vapour refrigerant it is known as vapour compression system.

It consists of compressor, condenser, Receiver, expansion valve, evaporator

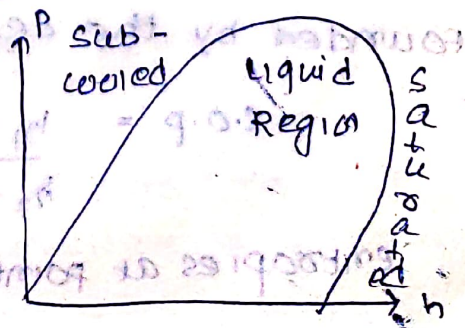
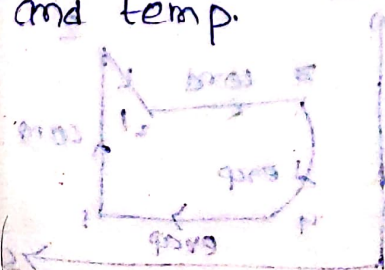


compressor → The low pressure and temp refrigerant is converted to high temp and high pressure.  
 condenser → It consists of coils of pipes in which high pressure and high temp refrigerant is cooled and condensed.

Receiver → Only liquid refrigerant from the condenser stored inside the Receiver

expansion valve → Allow the liquid refrigerant to pass through a controlled rate after reducing the temp and pressure.

evaporator → It consists of coils of pipe in which the low pres<sup>n</sup> and temp refrigerant is evaporated and change into vapour refrigerant at low pres<sup>n</sup> and temp.



# Theoretical Vapour Compression Cycle

Case-1 (Dry saturated vapour after compression)

1-2 → comp<sup>n</sup> from low temp and pressure to high temp & press

$$W = h_2 - h_1$$

2-3 → condensation to  $P_2$  and  $T_2$  by Reducing temp & pressure

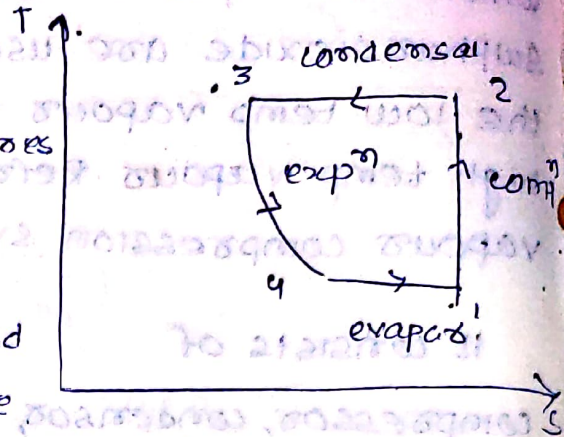
3-4 → expansion by lowering temp  $P_4 = P_1, T_4 = T_1$

4-1 → vapourization into liquid refrigerant

$$P_4 = P_1, T_4 = T_1$$

$$R_E = h_1 - h_4 = h_1 - h_{f3} \text{ (sensible heat at } T_3)$$

$$(C.O.P) = \frac{h_1 - h_4}{h_2 - h_1} = \left( \frac{R_E}{W} \right)$$

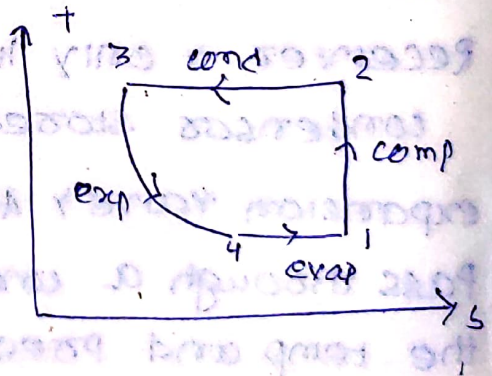


Case-2 (Wet vapour after compression)

enthalpy at point 2 is

found out by dryness fraction

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1}$$



Case-3

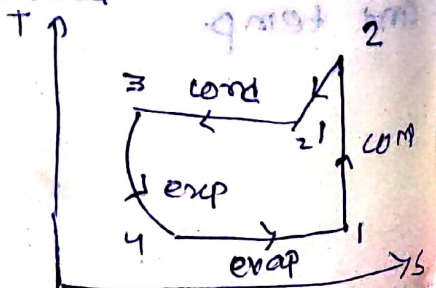
(superheated vapour after compression)

here the enthalpy at point 2 is

found by the degree of superheat.

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

entropies at point 1 and 2.

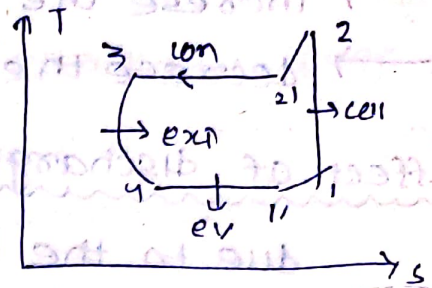


case-4

(Superheated vapour before compression)

here evaporation starts at point 4 and continued upto 1 when it is dry saturated.

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

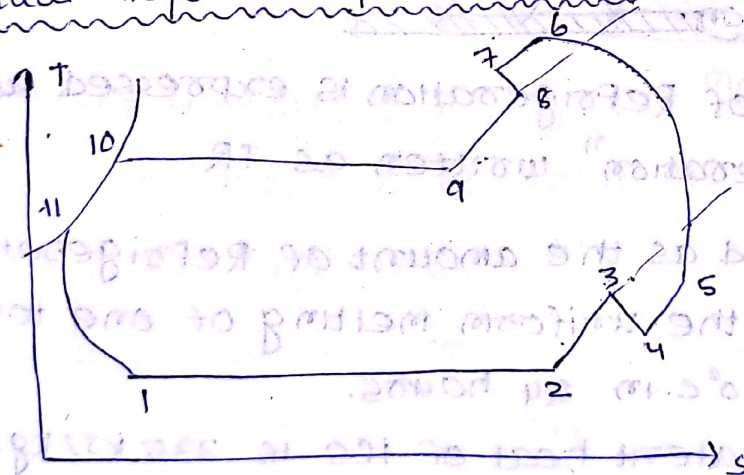


case-5

(undercooling - subcooling of Refrigerant) +  
sometimes the Refrigerant after condensation process 2'-3' cooled below the saturation temp ( $T_3$ ) before expansion such process is called sub-cooling or under-cooling.

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1} \quad h_{f3} = h_{f31} - c_p \times \text{Degree of under-}$$

Actual Vapour Compression Cycle



Process (1-2-3) Flow of Refrigerant in evaporator  
Process (3-4-5-6-7-8) Flow of Refrigerant in compressor  
when it enters through  $P_3$  pressure falls to  $P_4$ .  
Process (8-9-10-11) Flow of Refrigerant in condenser.  
Condenser: (8-9) - cooling of Refrigerant (9-10) Removal of latent heat  
Process (11-1) expansion of sub-cooled liquid Refr by throttling from condenser pressure to evaporator pressure.

## Effect of suction pressure

due to the decrease in suction pressure

- decrease the Refrigeration effect
- increase the work required for compression
- decrease the C.O.P

## Effect of discharge pressure

due to the increase in discharge pressure

- decrease in Refrigeration effect
- increase in work required for compression

$$\eta_{vol} = \frac{\text{Actual volume drawn}}{\text{Piston displacement}}$$

$$= \frac{m \times v_1}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times \eta}$$

## Unit of Refrigeration

The unit of Refrigeration is expressed as "tonnes of Refrigeration" written as TR.

It is defined as the amount of Refrigeration effect produce by the uniform melting of one tonne of ice from  $0^\circ\text{C}$  in 24 hours.

Since the latent heat of ice is  $335 \text{ kJ/kg}$ .

$$1 \text{ TR} = \frac{1000 \times 335}{24 \times 60} = 232.6 \text{ kJ/min}$$

but due to practical purpose  $1 \text{ TR} = 3.5 \text{ kW}$

if  $1000 \text{ kg}$  then  $1 \text{ TR} = 3.88 \text{ kW}$

# PSYCHROMETRY

The science which deals with the study of behaviour of air and water vapour mixture is known as psychrometry.

Dry air  $\rightarrow$  mixture of  $N_2, O_2$ , water vapour, other gas

Moist air  $\rightarrow$  mixture of dry air and water vapour

Moisture  $\rightarrow$  water vapour present in the air.

Dry bulb temp  $\rightarrow$  The temp of air measured by an ordinary thermometer of air.

Wet bulb temp  $\rightarrow$  The temp of air measured by a thermometer when its bulb is covered with wet cloth exposed to current of air.

Dew point temp  $\rightarrow$  It is defined as the temperature at which the moisture present in air begin to condensed when the air is cooled.

Specific humidity  $\rightarrow (w) = \frac{\text{mass of water vapour}}{\text{mass of dry air}}$

Absolute humidity  $\rightarrow$  The mass of water vapour present in  $1 m^3$  of air.

Degree of saturation  $\rightarrow$

$\frac{\text{mass of water vapour in unit mass}}{\text{mass of dry air in unit mass}}$

at same temperature.

Relative humidity ( $\phi$ )  $\rightarrow \frac{w_v}{w_s} = \frac{\text{weight of water vapour in given}}{\text{weight of water vapour at saturated temperature}}$

## Relations in psychrometry

(1) Dalton's law of partial pressure

It state that the total pressure of

Of a mixture of gases is equal to the sum of the partial pressure exerted by each gas when it occupies the mixture volume at mixture temp

$$P_T = P_{N_2} + P_{O_2}$$

(ii) humidity ratio of specific humidity (w)

$$\text{Specific humidity} = \frac{\text{mass of water vapour}}{\text{mass of dry air}}$$

Assuming the both as ideal gas we write

$$\text{water vapour } P_v V_v = m_v R_v T_v$$

$$\text{dry air } P_a V_a = m_a R_a T_a$$

According to the Dalton's law of partial pressure

$$V_v = V_a \quad T_v = T_a = T_d$$

$$\frac{P_v V_v}{P_a V_a} = \frac{m_v R_v T_v}{m_a R_a T_a} \Rightarrow \frac{P_v}{P_a} = \frac{m_v R_v}{m_a R_a}$$

$$\Rightarrow \frac{m_v}{m_a} = \frac{P_v}{P_a} \times \frac{R_a}{R_v} = \frac{P_v}{P_a} \times \frac{29.27}{46.8} = \frac{m_v}{m_a} = 0.662 \times \frac{P_v}{P_a}$$

$$\boxed{\text{specific humidity (w)} = \frac{m_v}{m_a} = 0.662 \times \frac{P_v}{P_a}}$$

$$\text{we know } P_b = P_v + P_a \Rightarrow P_a = P_b - P_v$$

$$w = 0.662 \times \frac{P_v}{P_b - P_v}$$

Let the partial pressure of water vapour is  $P_s$

$$\boxed{w = 0.662 \times \frac{P_s}{P_b - P_s}}$$

$$\text{Degree of saturation } (u) = \frac{w}{w_s} = 0.662 \times \frac{P_v}{P_b - P_v}$$

$$u = \frac{P_v}{P_s} \times \left( \frac{P_b - P_s}{P_b - P_v} \right)$$

Relative humidity ( $\phi$ )

$$(\phi) = \frac{w_v}{w_s} \quad \text{According to Dalton's law}$$

$$P_s V_s = m_s R_s T_s$$

$$P_v V_v = m_v R_v T_v$$

$$V_v = V_s$$

$$T_v = T_s$$

$$R_v = R_s = 49.8$$

$$(\phi) = \frac{P_v}{P_s} = \frac{m_v}{m_s}$$

$$\text{we know } u = \frac{P_v}{P_s} \left( \frac{1 - \frac{P_s}{P_b}}{1 - \frac{P_v}{P_b}} \right) = \frac{\left(1 - \frac{P_s}{P_b}\right)}{\left(1 - \frac{P_v}{P_b} \times \frac{P_s}{P_b}\right)} \times \phi$$

$$\Rightarrow \phi = \frac{u}{1 - (1-u) \times \frac{P_s}{P_b}}$$

PSYCHROMETER

It is a device for measuring the dry bulb, wet bulb temperature. It consists of two thermometers that is dry bulb thermometer and wet bulb thermometer side by side in a protected case and a handle is attached to the end with a swivel connection that makes it to rotate. The dry bulb thermometer directly measures it and exposed to air while the wet bulb temp<sup>n</sup> is covered with a wet cloth that coated by distilled water in a wet bulb thermometer water evaporates and become saturated

then measure the temperature. When the psychrometer is heated in the air for several minutes to get the readings of both the thermometers.

(1) Pressure of water vapour

$$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{15.45 - 1.44 \times t_w}$$

$P_v$  = partial pressure of water vapour

$P_w$  = saturation pressure of wet bulb

$t_d$  = dry bulb temperature

$t_w$  = wet bulb temperature

(2) Vapour density or absolute humidity

mass of water vapour  $m_v = v_v \times \rho_v$

mass of dry air  $m_a = v_a \times \rho_a$

Now  $\frac{m_v}{m_a} = \frac{v_v \times \rho_v}{v_a \times \rho_a} \Rightarrow w = \frac{m_v}{m_a} = \frac{P_v}{P_a}$

$\Rightarrow P_v = w \times P_a$

We also know that  $P_a v_a = m_a R_a T_d$

$\Rightarrow v_a = \frac{1}{\rho_a}$  and  $m_a = 1 \text{ kg}$

$\Rightarrow P_a \times \frac{1}{\rho_a} = R_a \times T_d \Rightarrow \rho_a = \frac{P_a}{R_a \times T_d}$

Now putting the value in the above equation

$$P_v = w \times \frac{P_a}{R_a \times T_d} = w \times \frac{(P_b - P_v)}{R_a \times T_d}$$

$P_a$  = pressure of air

$R_a = 0.287$

### (3) Enthalpy or total heat of moist air

The enthalpy of moist air is numerically is equal to the enthalpy of dry air plus the enthalpy of water vapour associated with dry air.

$$H_a = C_p \times t_d \quad H_v = W \times H_g$$

The moist air is superheated =  $W \times C_{ps} \times (t_d - t_{dp})$

The total enthalpy (H) =

$$= C_p \times t_d + W \times H_g + W \times C_{ps} \times (t_d - t_{dp})$$

$$= C_p \times t_d + W [h_{dp} + h_{fdp} + C_{ps} (t_d - t_{dp})]$$

$$= C_p \times t_d + W [t_{dp} + h \times f_{fdp} + C_{ps} (t_d - t_{dp})]$$

$$= 1.002 \times t_d + W [h_{fdp} + 2.3 \times t_{dp}] \text{ kJ}$$

### PSYCHROMETRIC CHART

(1) Dry bulb temp  $\rightarrow$  lines are vertical, parallel to ordinate

(2) Specific humidity  $\rightarrow$  lines are horizontal, parallel to abscissa

(3) Dew point temp  $\rightarrow$

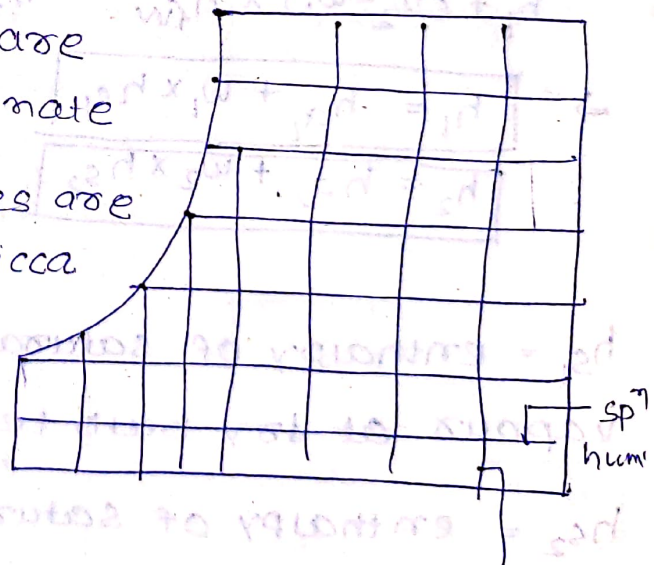
Temp lines are horizontal, parallel to abscissa

(4) wet bulb temp  $\rightarrow$  lines are inclined straight line

(5) enthalpy  $\rightarrow$  lines are inclined straight line and parallel to wet bulb temp

(6) specific volume  $\rightarrow$  lines are inclined straight.

(7) vapour pressure lines  $\rightarrow$  horizontal lines



(8) Relative humidity  $\rightarrow$  curved lines and given by Percentage

Dew point temperature

When the air is gradually cooled at constant pressure, the temp at which the condensation of water vapour start is called dew point temperature

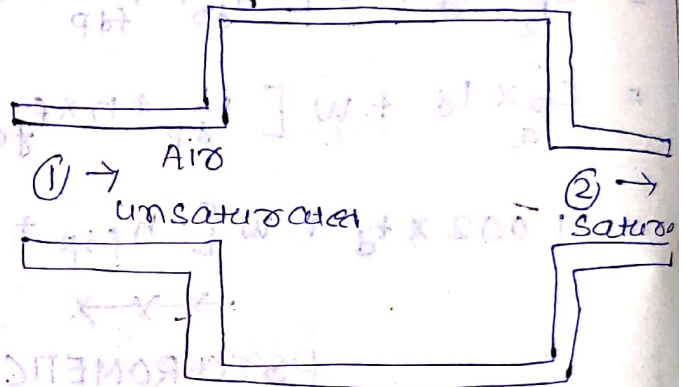
It is the saturation temperature corresponding to the partial pressure of water vapour.

Thermodynamic wet bulb temperature on adiabatic saturation temperature

$h_1, w_1 =$  section 1

$h_2, w_2 =$  section 2

$h_{fw} =$  sensible heat of water at saturation temp



$$h_1 + c \cdot (w_2 - w_1) \times h_{fw} = h_2$$

$$\Rightarrow \boxed{h_1 = h_{a1} + w_1 \times h_{s1}}$$

$$\boxed{h_2 = h_{a2} + w_2 \times h_{s2}}$$

$h_{a1} =$  enthalpy of 1 kg at dry bulb temp

$h_{a2} =$  enthalpy of

$h_{s1} =$  enthalpy of saturated 1 kg of air at wet bulb vapour - at dry bulb temp

$h_{s2} =$  enthalpy of saturated vapour at wet bulb

$$\Rightarrow h_{a1} + w_1 \times h_{s1} - w_1 \times h_{fw} = h_{a2} + w_2 \times h_{s2} - w_2 \times h_{fw}$$

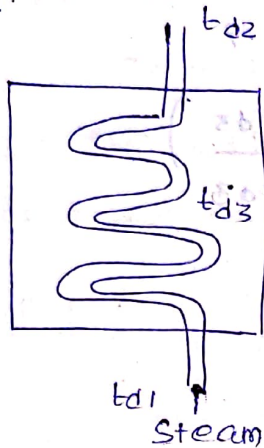
$$\Rightarrow w_1 = \frac{w_2 (h_{s2} - h_{fw}) + h_{a2} - h_{a1}}{h_{s1} - h_{fw}}$$

# Psychrometric Process

## (1) sensible heating

The heating of air without changing its specific humidity is known as sensible heating.

Let the air temperature  $t_{d1}$  passes over a heating coil of temp  $t_{d3}$  less air heating and leaving coil  $t_{d2}$ .



this can be obtained from the psychrometric chart

$$Q = h_2 - h_1$$

$$= C_{pa} \times t_{d2} + w (h_s + C_{ps} (t_{d2} - t_{d1}))$$

$$- [C_{pa} \times t_{d1} + w (h_s + C_{ps} (t_{d2} - t_{d1}))]$$

$$= C_{pa} (t_{d2} - t_{d1}) + w \times C_{ps} (t_{d2} - t_{d1})$$

$$= C_{pm} (t_{d2} - t_{d1}) = 1.002 (t_{d2} - t_{d1}) \text{ KJ/kg}$$

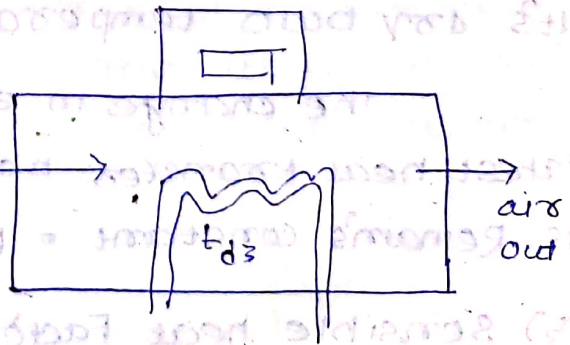
## (2) sensible cooling

The cooling of air without changing its specific humidity is called sensible cooling.

$$Q = 1.022 (t_{d1} - t_{d2})$$

## (3) By-pass Factor

Let 1 kg of air at temperature  $t_{d1}$  passes over having surface temperature  $t_{d3}$ . The amount of air that bypass is known as by-pass factor. It's depend upon the



- (1) velocity of flow air
- (2) no. of rows in a coil
- (3) no. of fins provided in unit length

due to enthalpy balance we write

$$x \times c_{pm} \times t_{d1} + (1-x) \times c_{pm} \times t_{d3} = 1 \times c_{pm} \times t_{d2}$$

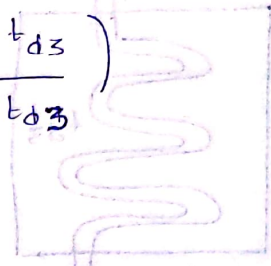
$$\Rightarrow x \times t_{d1} + (1-x) \times t_{d3} = t_{d2}$$

$$\Rightarrow x = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}} = \frac{\text{Last two difference}}{\text{First and last difference}}$$

efficiency of heating or cooling coil  $\rightarrow$

$$\eta_{H.C} = 1 - B.P.F = 1 - \left( \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}} \right)$$

$$= \frac{t_{d2} - t_{d1}}{t_{d3} - t_{d1}}$$



$$\eta_{\text{cooling coil}} = 1 - B.P.F \times \text{cooling}$$

$$= 1 - \left( \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}} \right) = \frac{t_{d1} - t_{d2}}{t_{d1} - t_{d3}}$$

#### (4) Humidification & de-humidification

Addition of water vapour into the air without changing its dry bulb temperature is known as humidification. Similarly removal of water vapour from the air without changing its dry bulb temperature is known as de-humidification.

The change in enthalpy is known as the latent heat transfer because the dry bulb temp is remain's constant  $= h_2 - h_1 = h_{fg} (w_2 - w_1)$

#### (5) Sensible heat Factor

$$(S.H.F) = \frac{\text{sensible heat}}{\text{Total heat}}$$

$$= \frac{S.H}{S.H + L.H}$$

## (6) cooling and de-humidification

Cooling process is generally used in the summer air conditioning system where the weather is hot and humidity. The air is passed through a cooling coil or through cold water system; in this process both dry bulb temperature and specific humidity of air decreases.

The de-humidification of air is possible only when the effective surface temperature of cooling coil is less than D.B.T.

$$B.P.F = \frac{t_{d2} - t_{d4}}{t_{d1} - t_{d4}} = \frac{t_{d2} - A.D.P}{t_{d1} - A.D.P} = \frac{h_2 - h_4}{h_1 - h_2}$$

## (7) cooling with Adiabatic humidification

When the air is passed through an insular temperature where spray of water is done. The water absorbs its latent heat from the air so temp of air decreases and humidification is obtained.

$$\eta_{\text{humidifict}} = \frac{t_{d1} - t_{d2}}{t_{d1} - t_{d3}} = \frac{w_2 - w_1}{w_3 - w_1}$$

## (8) cooling and humidification by water injection

The above process can be possible only when supply sprays water to the air coming into the chamber. When water is sprayed into the air it absorbs its latent heat.

$$h_2 = h_1 + \frac{m_w}{m_a} \times h_{fw}$$
$$= h_1 + (w_2 - w_1) \times h_{fw}$$

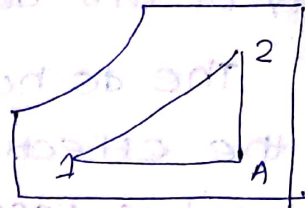
$$h_2 = h_1 + (w_2 - w_1) \times h_{fw}$$

$$w_2 = w_1 + \frac{m_w}{m_a}$$

### (9) heating and humidification

This process is generally used in winter air conditioning system. so we have to warm and humidify the air when the air is passed through humidifier having spray water temperature higher than the D.B.T of entering air.

$$S.H.F = \frac{h_2 - h_1}{h_2 - h_1}$$



### (10) heating and humidification by steam injection

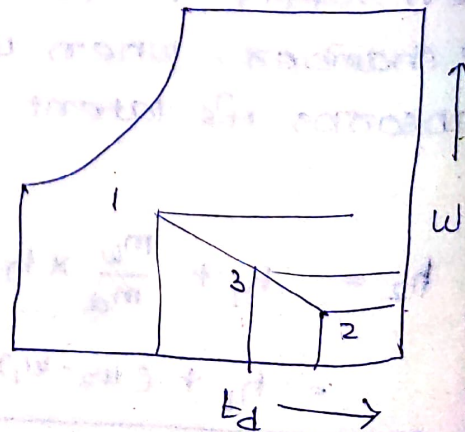
The steam is normally injected into the air to increase its specific humidity.

$$w_2 = w_1 + \frac{m_s}{m_a} \Rightarrow h_2 = h_1 + (w_2 - w_1) \times h_s$$

### (11) heating and de-humidification

This process is widely used in the industrial air conditioning, where the air must pass through some chemicals which have an affinity for moisture. As the air comes in contact with these chemicals the moisture gets condensed and gives up latent heat.

$$\eta_H = \frac{t_{d3} - t_{d1}}{t_{d2} - t_{d1}}$$



### (12) Adiabatic mixing of two air-streams

## Refrigerant

It is a heat carrying medium which during the cycle in the refrigeration system absorbs heat from a lower temperature and discards heat to a high temperature system. The natural ice and mixture of ice were the first Refrigerant. There is no ideal Refrigerant. It's depend upon it's application where it is used.

## Properties

- (1) Low boiling point
- (2) high critical temperature
- (3) high latent heat of vapourisation
- (4) Low specific heat
- (5) Low specific volume
- (6) NON-toxic, Low cost
- (7) NON-Flamable, NON-explosive
- (8) Mixed well with oil

## Classification

(I) Primary  $\rightarrow$  which directly take part in the Refrigeration process

(II) Secondary  $\rightarrow$  which are first cool by primary refrigerant and then used for the cooling purpose.

## Primary Refrigerants

(I) Halo-carbon  $\rightarrow$

R-11 ( $\text{CCl}_3\text{F}$ )  $\rightarrow$  stable, NON-Flamable, low pressure due to this it is used in large centrifugal compressor.

R-12 ( $\text{CCl}_2\text{F}_2$ )  $\rightarrow$  colourless, it is having low latent heat value so it is used in small refrigeration system used in Refrigerator, water-cooler

R-13 ( $\text{CClF}_3$ ) low temp cascade, it is used in Reciprocating compressor

R-14 ( $\text{CF}_4$ ) ultra low-temp refrigerant

R-21 ( $\text{CHCl}_2\text{F}$ ) high temp  $\rightarrow$  Reciprocating comp

R-22 ( $\text{CHClF}_2$ ) It is used in fast freezing, Man-made, low evaporating temp. used in air-conditioning and household

R-30 ( $\text{CH}_2\text{Cl}_2$ ) It is having high boiling point It is stored in closed cans. It is used in the air conditioning of theaters, Auditorium buildings

R-40 ( $\text{CH}_3\text{Cl}$ ) It is flammable and toxic also so it is not used in all types of applications

R-100 ( $\text{C}_2\text{H}_5\text{Cl}$ ) low operating pressure It is toxic and flammable

R-113 ( $\text{C}_2\text{Cl}_3\text{F}_3$ ) commercial as well as industrial application.

R-114 ( $\text{C}_2\text{Cl}_2\text{F}_4$ ) drinking water coolers and household Refrigeration

### Azeotrope Refrigerant

It is a stable mixture of Refrigerant whose vapour and liquid phase retain identical composition over a wide range of temperature

#### R-500

mixture of 73.8% R-12 ( $\text{CCl}_2\text{F}_2$ ) and 26.2% of R-152 ( $\text{CH}_3\text{CHF}_2$ ). It is non-flammable, non-toxic and non-corrosive. It is used in industrial as well as commercial application but it is only used in the Reciprocating compressor, colour is yellow.

#### R-502

mixture of 48.8% of R-22 ( $\text{CHClF}_2$ ) and 51.2% of R-115 ( $\text{CClF}_2\text{CF}_3$ ). It is non-flammable non-toxic, it is a good Refrigerant which can be operated as low or medium temperature

It is used in food lockers, food processing plant, Refrigeration household system.

It is also used only with Reciprocating air compressor. It also increases the life of the compressor and valve. colour code is orchid.

R-503

mixture of 40.1% R-23 ( $\text{CHF}_3$ ) and 59.9%

of R-13. This is a lower temperature Refrigerant good for the use of lower temperature cascade system. The leak generally can be detected by using the soap solution. colour code is Aqua-marine.

R-504

48.2% of R-32 ( $\text{CH}_2\text{F}_2$ ) and 51.8% of R-115

As with the lower temperature Refrigerant there are various difficulty arises. with the addition of 2-5% R-170 it can be used.

The leaks may be easily detected by using soap solution, a halide torch or electronic leak detector. colour code is tan.

### Inorganic Refrigerants

(1) Ammonia (R-717)  $\rightarrow \text{NH}_3$   $\rightarrow$  It is used in large commercial application and it is also widely used in the absorption system. It is a colourless gas. due to its low boiling point it is suitable to use this at  $0^\circ\text{C}$ . The leak to the Refrigerant may be easily found by burning sulphur candle. It is widely used in cold storage, warehouse plants, food freezing plants etc.

(2) R-729 ( $\text{Ar}$ )  $\rightarrow$  dry air used in air-craft

(3) R-744 ( $\text{CO}_2$ )  $\rightarrow$  It is non-toxic, non-flammable, non-irradiating. due to its high operating pressure the compressor of  $\text{CO}_2$  unit is very small even for large plant also. due to poor efficiency it is seldom used in household unit.

(4) R-764 ( $\text{SO}_2$ )  $\rightarrow$  It is a very stable refrigerant with high critical temperature and it is also non-flammable, non-toxic. It is used in small unit but as the preservation of foods. leak may be easily detected by using soap solution.

(5) R-118 (water)  $\rightarrow$  It is widely used as ice. It is used in vapour absorption system with steam jet compressor.

### Hydro Carbon Refrigerants

These are widely used in industrial and commercial application. but are highly flammable and explosive.

R-170 (Ethane) ( $\text{C}_2\text{H}_6$ )

R-290 (Propane) ( $\text{C}_3\text{H}_8$ )

R-600 (Butane) ( $\text{C}_4\text{H}_{10}$ )

R-600a (Isobutane) ( $\text{C}_4\text{H}_{10}$ )

R-1120 (Trichloroethylene) ( $\text{C}_2\text{H}_4\text{Cl}_3$ )

R-1130 (Dichloroethylene) ( $\text{C}_2\text{H}_4\text{Cl}_2$ )

R-1150 (Ethylene) ( $\text{C}_2\text{H}_4$ )

R-1270 (Propylene) ( $\text{C}_3\text{H}_6$ )

# Designation system of Refrigerant

R Followed by

Two digit indicates  $\rightarrow$  methane base

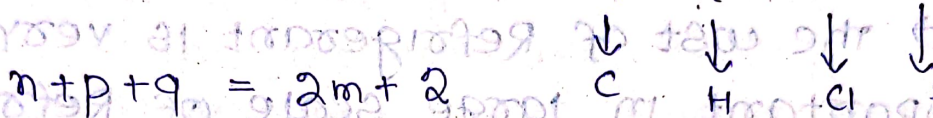
three " "  $\rightarrow$  Ethane base

First digit on Right hand  $\rightarrow$  Fluorine

2nd " "  $\rightarrow$  Hydrogen

" "  $\rightarrow$  Carbon

general formula is  $C_m H_n Cl_p F_q$



The number is given by  $R(m-1)(n+1)q$

example  $\rightarrow$

(1) Dichloro-tetrafluoro-ethane

$$Cl = 2 = p$$

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

$$F = 4 = q$$

$$\Rightarrow m = 2$$

$$H = 0 = n$$

$$R(2-1)(0+1)4 \rightarrow R-114$$

## Physical Properties

(1) stability  $\rightarrow$  An ideal Refrigerant should not decompose at any temperature. It should not form higher boiling liquid. There may be vapour lock occurs due to this inert must be taken. Feron group of Refrigerant it becomes stable.

(2) Corrosive property  $\rightarrow$  It must be taken into consideration. Among all Feron group of Refrigerant are not providing corrosive prop

(3) viscosity  $\rightarrow$  low viscosity is Required bcz of pressure drop in passing through the liquid suction are small.

(4) Thermal conductivity  $\rightarrow$  It must have high  $k$ . It is used to find heat transfer coefficient.

(5) Dielectric strength  $\rightarrow$  The dielectric strength is hermetically sealed unit.

(6) Leakage tendency  $\rightarrow$  It must be low. If there is leakage it must be detectable. It occurs due to opening or flaws of material.

(7) Cost  $\rightarrow$  The cost of Refrigerant is very much important in large scale of Refrigeration. Chemical properties

(1) Flammability  $\rightarrow$  All hydrocarbon Refrigerants are highly flammable. But halo carbon are non flammable.

(2) Toxicity  $\rightarrow$  Fluorocarbon Refrigerant when mixes with air becomes toxic.

(3) Solubility of water  $\rightarrow$  Water is only soluble in R-12 at  $-18^\circ\text{C}$ . R-22 and R-12 are miscible in nature.

(4) Miscibility  $\rightarrow$  The ability of Refrigerant to mix with oil. The degree of miscibility depends upon the temperature of the oil and pressure of Refrigerant vapour.

(5) Effect on perishable material  $\rightarrow$  The Refrigerant should be such that if leakage occurs it should not have any effect on the materials. Ferrous group of Refrigerant have not any effect on the materials.

## Thermodynamic Properties

(1) **Boiling Temperature** → The boiling temperature of the Refrigerant at the atmospheric pressure is as low. If the boiling temperature is high at atm pressure then compressor should be operated at high vacuum.

(2) **Freezing Temperature** → The freezing temperature of the Refrigerant should be below the operating evaporator temperature. Most of the Refrigerant having freezing temperature  $-35^{\circ}\text{C}$ . It is also taken to be low temperature.

(3) **Evaporator & Condenser Pressure** → The Both evaporator and condenser pressure must be positive at the atmospheric pressure. The positive pressure is necessary to prevent leakage of air & moisture into the Refrigerant system.

(4) **Critical Temperature & Pressure** → The critical temperature of the Refrigerant is the highest temperature at which it condensed into liquid. It should be above the highest condensing temperature. If the critical temperature is too near the desired condensing temperature excessive power consumption result.

(5) **c.o.p & Power Requirement** → For an ideal Refrigerant operating bet<sup>n</sup>  $-15^{\circ}\text{C}$  evaporator temp and  $30^{\circ}\text{C}$  of condenser temp the c.o.p is 5.74. Among all R-11 gives c.o.p = 5.09.

(6) **Latent heat of vapourisation** → A Refrigerant must having high latent heat of vapourisation at the evaporator temperature.

high latent heat of vapourisation gives  
high Refrigerant effect.

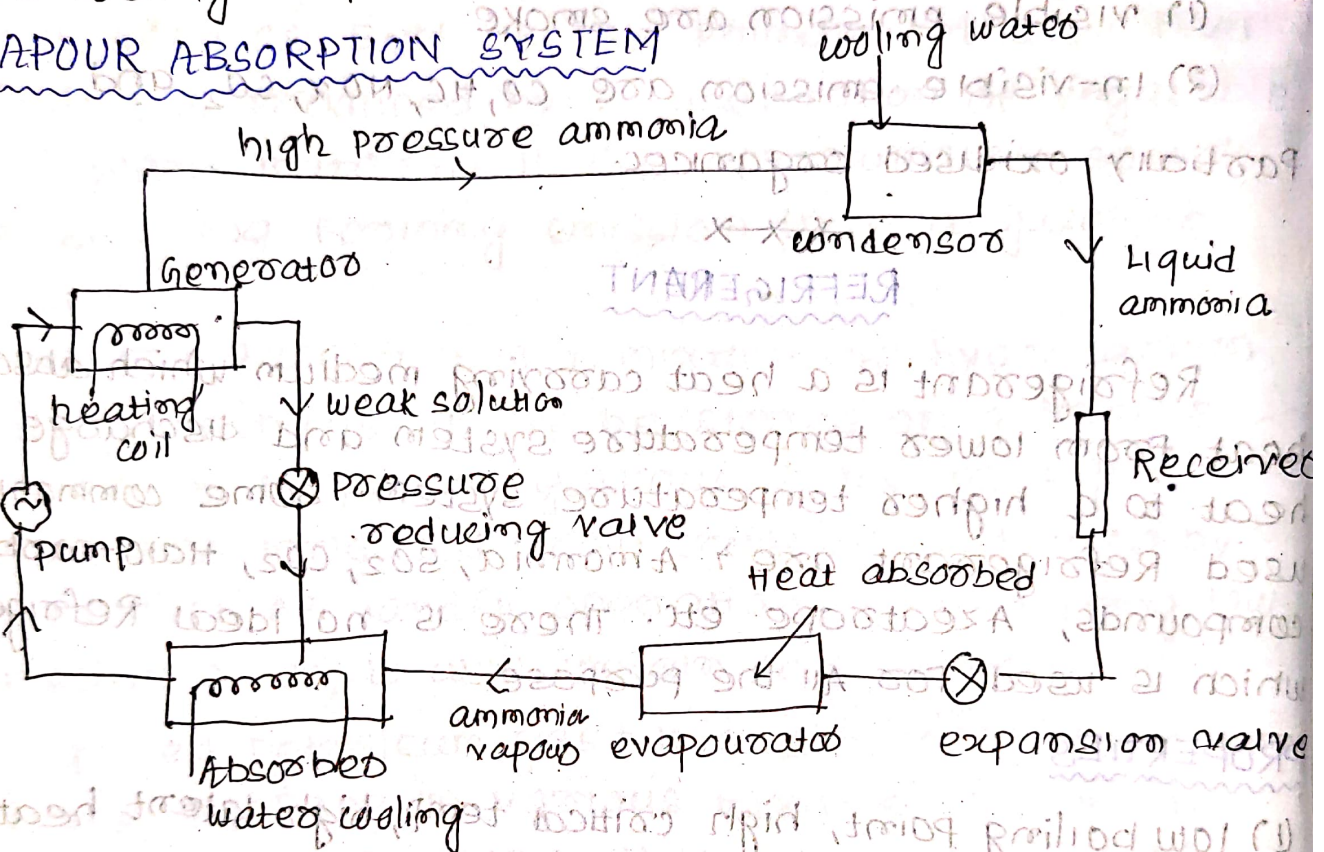
(7) **specific volume** → The specific volume of a Refrigerant vapour at evaporator temperature indicates the theoretical displacement of the compressor. It is used as low.

## CLASSIFICATION

(1) Primary Refrigerant → The refrigerant which directly take part in the refrigeration system are called as primary Refrigerant.

(2) Secondary Refrigerant → The Refrigerant is first cooled by primary Refrigerant and then used for cooling purpose is called secondary Refrigerant.

## VAPOUR ABSORPTION SYSTEM



It is consisting of a absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour absorber system. The other compon are same as in vapour comp<sup>n</sup> system like condensers, evaporators, Receiver and expansion valve.

The low pressure ammonia vapour leaving the evaporator enters to the absorber where it is absorbed by cold water solution. The water has the ability absorb very large quantity of ammonia vapour thus the solution called aqua-ammonia. Some form of cooling arrangement generally water cooling system is employed in absorber. Now the strong solution thus formed pumped to the generator by means of liquid pump.

The strong solution of ammonia in the generator is heated by some external agent. During the heating process the ammonia vapour is driven off the solution leaving the hot weak ammonia solution in the generator which is flow back again to the absorber by pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to high pressure liquid ammonia which is passed to the expansion valve through Receiver.

—x—x—x