LEARNING MATERIAL OF

REFRIGERATION & AIRCONDITIONING

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RAC

Refrigeration → Means a continued Extractions of heat from a body whose temp is already below the temp of atmospheric surroundings.

or It may be defiend as the process of removing heat from a substance under controlled condtion.

→ It also Includes the process of reducing and maintaning the temp. of the body below general temp of the surrounding.

→ It works upon the 2nd law of T.D. about the direction of heat transfer.

→ Removing of heat Transfer.

→ The Removal of heat from one place and depositing it to another using Intermediate. (vapour compression ; Refrigeration system).

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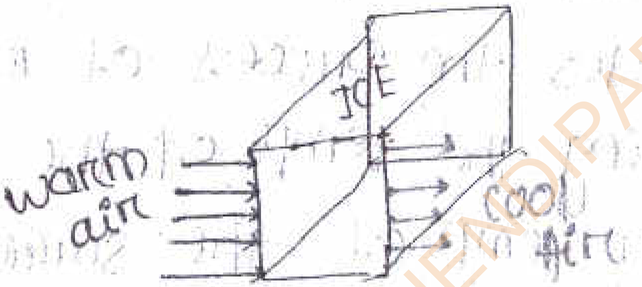
* Refrigeration Effect :-

The amount of heat absorbed by the refrigeration system from the space to be cooled in a given time is called Refrigeration Effect.

→ unit :- kJ/min

Units of Refrigeration →



(1 tonn of Ice)

→ The practical unit of Refrigeration is tonn of Refrigeration.

→ A tonne of refrigeration is defiend as the amount of Refrigeration Effect Produce by the uniform melting of 1 tonne (1000 kg) of Ice from and at 0°C in 24 hours.

→ Latent heat of Ice 335 kJ/kg.

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1 TOR (Tonne of Refrigeration) = 335 × 1000
(in 24 hour

$$1\ TOR = 335000$$

$$1\ Hour = \frac{335000}{24} = 13958.3$$

$$1\ min = \frac{335000}{24 \times 60} = 232.6\ kJ/mi$$

$$= 232.6\ kJ/min$$

$$1\ sec = \frac{232.6}{60}$$

$$= 3.87\ kJ/sec\ (3.5)$$

$$\boxed{kJ/sec = kWatt}$$

→ In actual practice 1 TR is taken as 210 kJ/min. which is equivalent to 3.5 kW.

$$\boxed{1\ TOR = 210\ kJ/min = 3.5\ kW}$$

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co-efficient of performance of refrigerator (COP)

→ Ratio of heat extracted to the workdone

$$\boxed{COP = \frac{Q}{W}}$$

Q = amount of heat extracted in the Refrigerator

W = Amount of workdone

Problem :-

Find the COP of a refrigeration system if the work input is 80 kJ/kg and refrigeration effect produce is 160 kJ/kg.

Given data →

$W = 80 \text{ kJ/kg}$

$Q = 160 \text{ kJ/kg}$

$$COP = \frac{Q}{W} = \frac{160}{80} = 2$$

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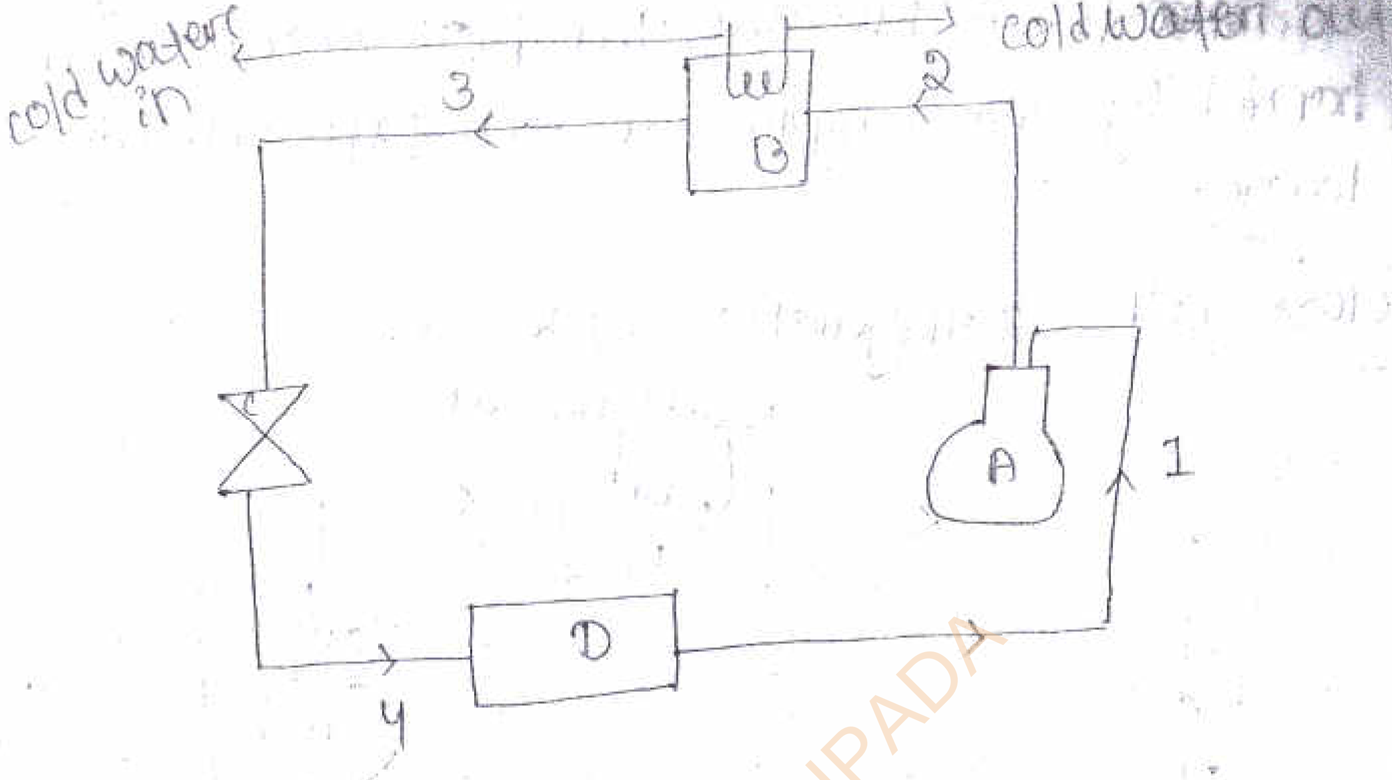
open air refrigeration cycle →



A → compressor (1-2)

B → Heat. Exchanger (2-3)

C → Expander (3-4)

D → Refrigerator (4-1)

→ In open air refrigeration cycle, the air is directly led to the space / surrounding to be cooled. (i.e Refrigerator) allowed to circulate through the cooler and then return to compressor to the start the another cycle.

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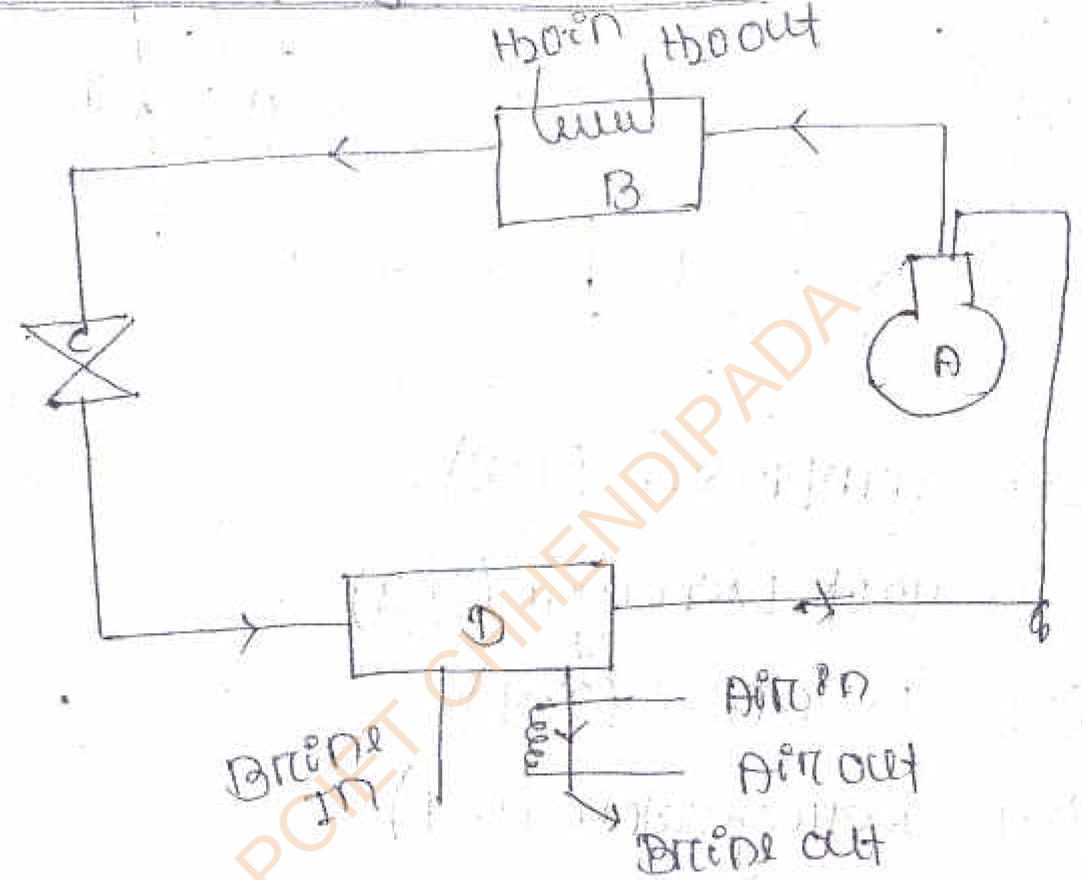
→ Since the air is supplied to the refrigeration at atmospheric pressure therefore volume air handel by the compressor and Expander is large.

close air refrigeration cycle →



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- A → compressor
- B → cooler
- C → Expander
- D → Refrigerator

Brine :-

Acquas solution of sodium chloride (Nacl) is called brine.

* The water that contain salt is called brine.

→ In close/ dense air refrigeration cycle the air pass through the pipes and components parts of the system all time.

This air in the system is used for absorbing heat from the other fluid i.e brine and this cool brine is circulated into this space to be cooled.

→ The air in the closed system dosenot come in contact directly with the space to be cooled.

Advantages →

→ Since it can work at a suction pressure higher than atmospheric pressure therefore the volume of air is handel by compressor and Expander are smaller as compared to open air cycle.

→ The operating pressure ratio can be reduced which a result higher cop.

Refrigerant :-

It is a heat carrying medium in which heat absorb from space by evaporating/ Latent heat at low temprature, and reject heat to atmosphere by condensing at high temp

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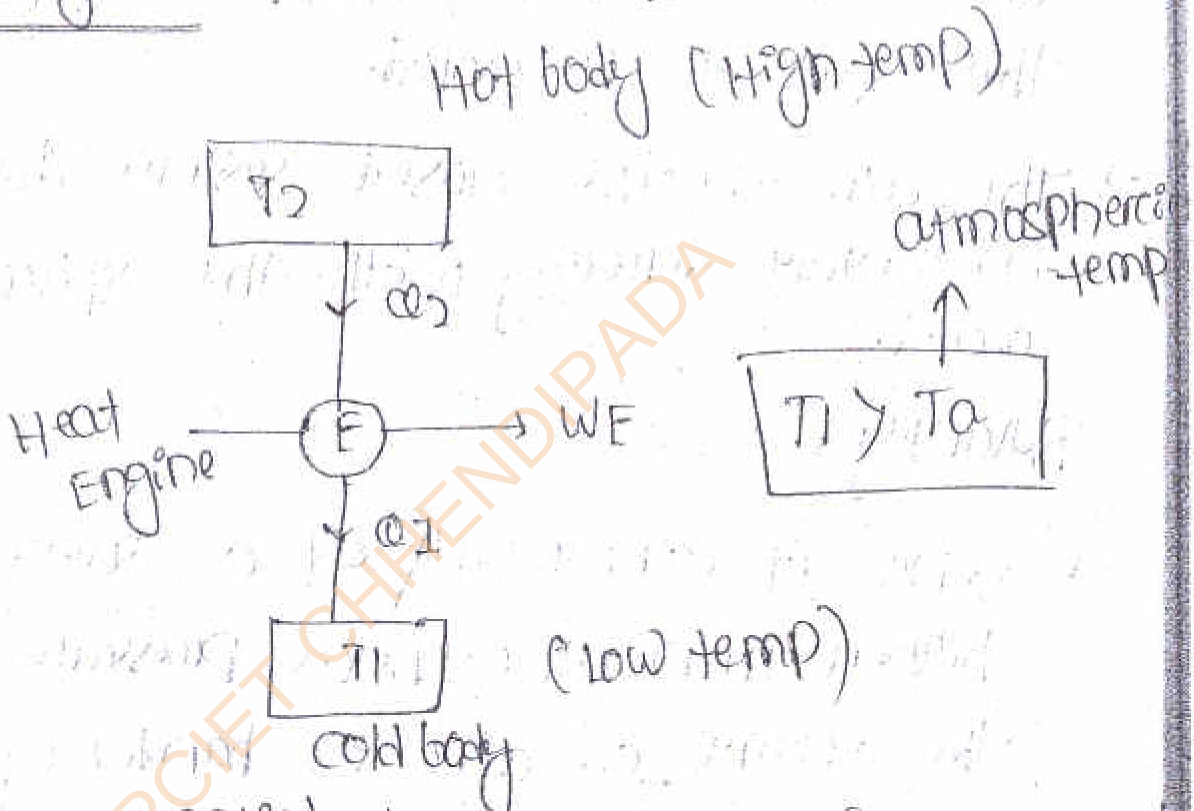
→ It consist of Evaporation & condensation which absorb heat & produce cooling.

Diffrence b/w Heat Engine, Refrigerator and heat pump →

Heat Engine →



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→ The heat supplied to the Engine is converted into useful work. If Q_2 is the heat supplied to the Engine and Q_1 is the heat rejected from the Engine.

Now workdone by the Engine,

$$\boxed{W_E = Q_2 - Q_1}$$

$$\boxed{Q_2 = W_E + Q_1}$$

The performance of Engine is expressed by Efficiency or COP of Engine.

$$\eta_E / (COP)_E = \frac{\text{workdone}}{\text{Heat supplied}}$$

$$= \frac{W_E}{Q_2}$$

$$\boxed{\frac{W_E}{Q_2} = \frac{Q_2 - Q_1}{Q_2}}$$

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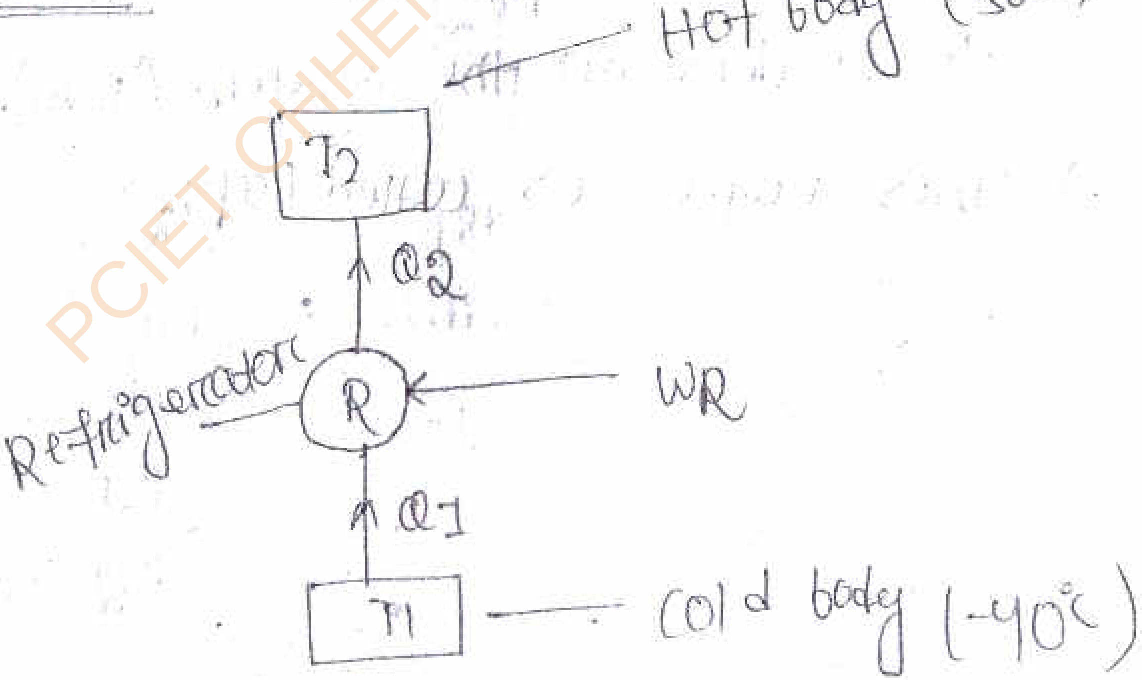
Refrigerator :



→ A Refrigerator is Reversed heat Engine which Either cool or maintain the temp of a body T1 Lower than atmospheric temp (Ta).

This is done by Extracting heat (Q_1) from the cold body and deposit it into a hot body (Q_2).

Workdone by Refrigerator,

$$W_R = Q_2 - Q_1$$

(1st law of T.D.)

→ The performance of a refrigerator is Expressed by the ratio of heat taken from the cold body (Q_1). to the amount of work required to be done on the system (W_R).

→ This ratio is called $(COP)_R$

$$= \frac{Q_1}{W_R}$$

$$= \frac{Q_1}{Q_2 - Q_1}$$

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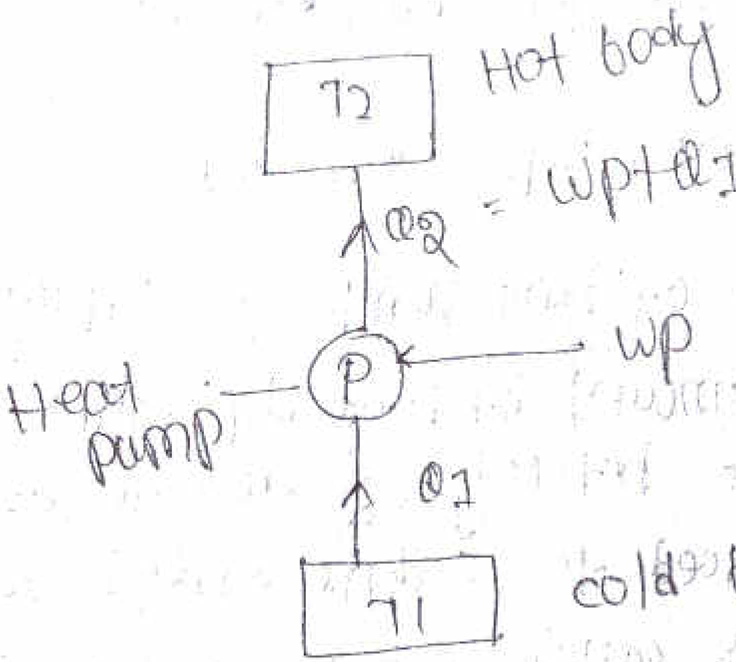
Heat pump :



→ Any refrigeration system is a heat pump which Extract heat(Q_1) from a cold body and deliver it into a hot body.

→ Thus their is no diffrence b/w the cycle operation of a heat pump & a refrigerator.

→ The Main diffrence b/w these two is in their operating tempreatures.

→ A Refrigerator works b/w the cold body tempT_1 and atmospheric temp (T_a). where as a heat pump operates b/w the hot body temp(T_2) and the atmospheric temp (T_a).

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→ A refrigerator used for cooling in summer & heat pump used for heating in winter.

workdone, $wp = Q_2 - Q_1$

→ The performance of heat pump is expressed by the ratio of amount of heat deposited or delivery to the hot body Q_2 to the amount of work required to be done on the system (wp) this is called cop of pump or E.P.R (Energy performance ratio)

$$= \frac{Q_2}{wp} = \frac{Q_2}{Q_2 - Q_1}$$

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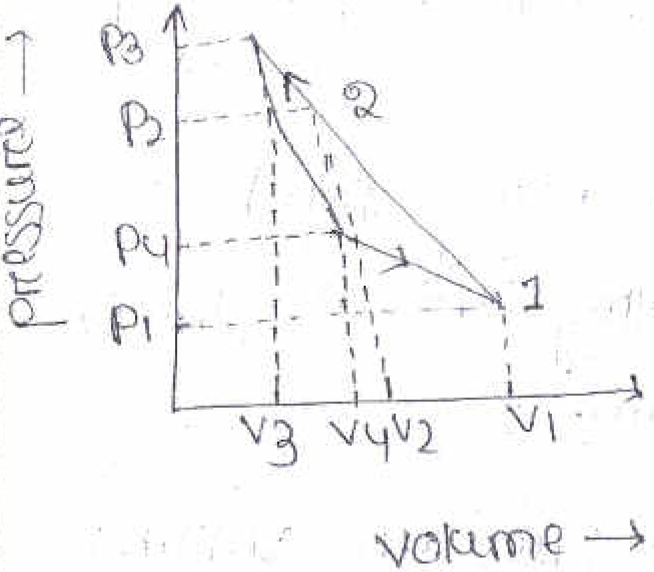
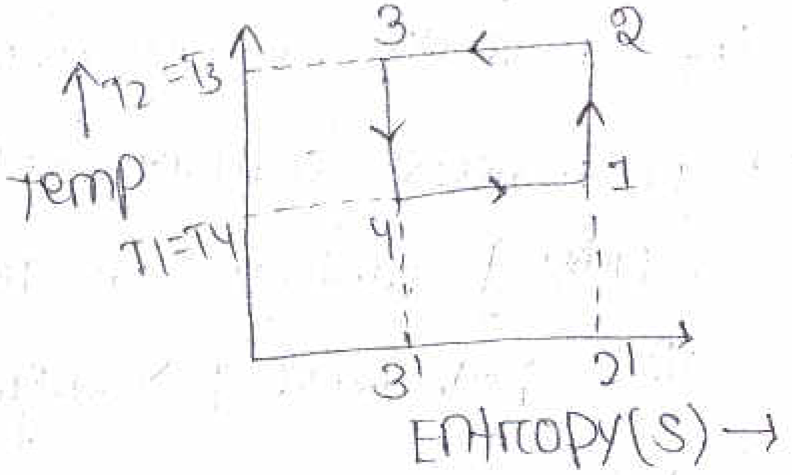
Air refrigerator working on Reversed carnot cycle →



(P-V. digram)



(T-S digram)

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process; 1-2 → Isentropic compression process
2-3 → Isothermal compression process
3-4 → Isentropic Expantion process
4-1 → Isothermal Expansion.

→ In refrigeration system the carnot cycle is considered as Reversed carnot cycle. we know that a heat Engine working in carnot cycle has the max^{m} Efficiency. Lightly a refrigerating system working on Reverse carnot cycle will have the maximum possible cop. but we know that It is not possible to make an Engine working on carnot cycle:

carnot cycle simillarly it is also not possible to make a refrigerating m/c working on the reverse carnot cycle.

→ A reverse carnot cycle using (Air) as working medium or refrigerant as shown the p-v and T-s digram.

Let, P_1, V_1, T_1 be the pressure, volume and temp. of air.

process (1-2) [S=c]

→ The air is compressed isentropically as shown by the curve p-v & T-S digram.

→ during this process the pressure of air Increases, specific volume decreases from V_1 to V_2. and temp Increases from temp (T_1) to temp (T_2).

→ we know that in this process no heat is absorb or rejected by the air.

process (2-3)

The air is now compressed Isothermally i.e constant temp ($T_2 = T_3$) as shown by 2-3 on p-v and T-S digram.

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→ During this process the pressure of air increases from P_2 to P_3 and specific volume decreases from V_2 to V_3.

We know that the heat rejected by the air during isothermal compression per kg of air.

q_r = heat rejection

$q_r = q_{2-3}$ = Area $2-3-3'-2'$

$$q_r = T_3(S_2 - S_3) \quad [\because T_2 = T_3]$$

$$= T_2(S_2 - S_3)$$

Process (3-4)

The air is expanded isentropically as shown by the curve 3-4 on p-V & T-S digram.

→ The pressure of air decreases from P_3 to P_4, specific volume increases from vol. V_3 to V_4 and the temp decreases from (3-4).

In this process no heat is absorb or reject by the air.

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process (4-1)

The air is now Expanded Isothermally i.e at constant temp $T_4 = T_1$ as shown by the curve 4-1 on p-v & T-S digram.

→ The pressure of air decreases from 4-1 & specific volume Increases from volume v_4 to v_1.

Here Heat absorb by the air or Heat rejected / Extracted from the cold body during Isothermal Expantion.

$$q_A = q_{4-1} = \text{Area } 4-1-2'-3'$$

$$q_A = T_4 (S_2 - S_3) \quad [\because T_4 = T_1]$$

$$= T_1 (S_2 - S_3)$$

work done during the cycle per kg of air

$$\text{workdone } (W_R) = q_R - q_A$$

$$= q_{2-3} - q_{4-1}$$

$$= (T_2 - T_1)(S_2 - S_3)$$

$$(COP)_R = \frac{\text{Heat absorb}}{W_R} = \frac{T_1 (S_2 - S_3)}{(T_2 - T_1)(S_2 - S_3)}$$

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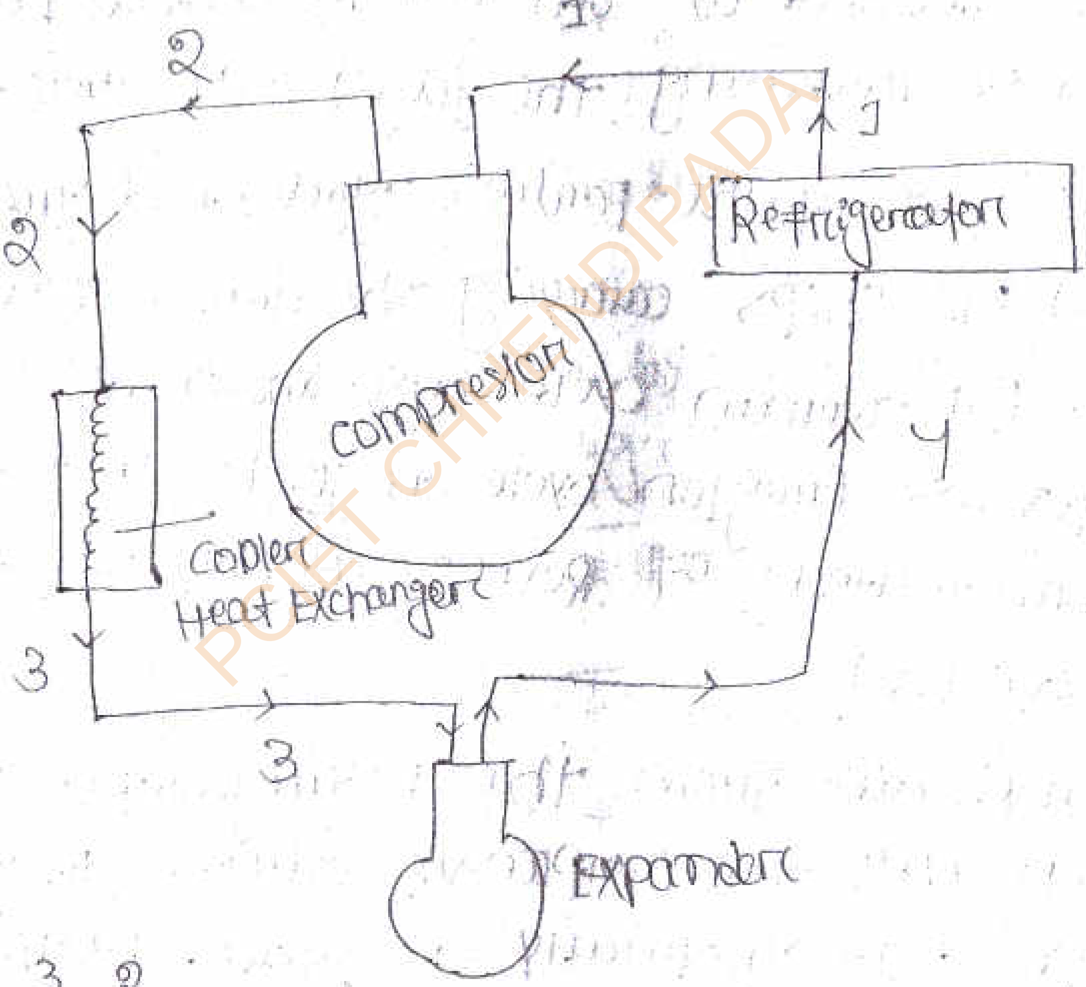
2) $$\frac{q_A}{W_R} = \frac{T_1}{T_2 - T_1}$$

Calculation of COP of Bell-coleman cycle / Reversed Brayton cycle / Joule cycle →



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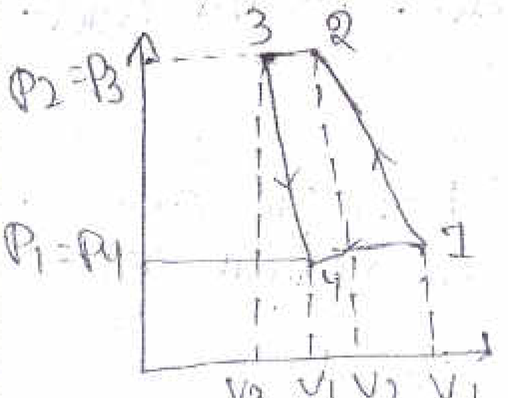
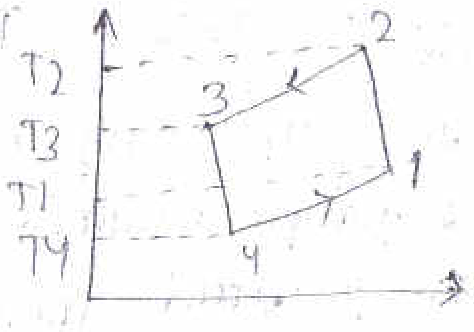


(P-V digram)



(T-S digram)

Process,

1-2 → Isentropic compression process

2-3 → constant pressure cooling process.

3-4 → Isentropic Expantion process

4-1 → constant pressure Expantion process.

→ A Bell cole man air refrigeration m/c was devloped by bell cole man and Light fot by reversing the joules air cycle.

→ It is one of the Earliest types of Refrigerator used in ships carrying the frozen meet. The bell coleman cycle also known as. Reverse brayton cycle or joule cycle is a modification of Reverse carnot cycle.

Process (1-2)

The cold air from the refrigerator is drawn into the compressor cylinder where it is compress isentropically as shown by the curve 1-2 on P-V & T-S digram.

→ During the compression stroke both pressure and temp. Increases and specific volume of air delivered from compressor reduce from V_1 to V_2.

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→ During the isentropic process no heat absorb or reject by the air.

2-3 process

The warm air from the compressor is now pass into the cooler where it is cooled at constant pressure ($P_3 = P_2$) Reducing the temp from T_2 to T_3 (the temp of cooling water) as shown by the curve 2-3 on p-v & T-s digram.

This specific volume also reduced from V_2 to V_3.

We know that heat rejected by the air during constant pressure per kg of air

$$\boxed{q_R = Q_{2-3} = c_p(T_2 - T_3)}$$

Process 3-4

The air from the cooler is now drawn into the expander cylinder where it is expanded isentropically from pressure P_3 to P_4 (Refrigerator pressure) which is equal to the atmospheric pressure.

The temp of air during expansion fall from T_3 to T_4 (i.e. the temp much below the temp of cooling water)

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→ The Expantion process is shown by the curve 3-4 on P-V & T-S digram.

The specific volume of air at Entry to the refrigerator increases from V_3 to V_4.

we know that during isentropic Expansion of air no heat is absorb or reject by the air.

process (4-1)

→ The cold air from the Expander is now pass to the refrigerator where it is Expanded at constant pressure ($P_4 = P_1$).

→ The temprature of air increases from T_4 to T_1 this process is shown by the curve 4-1 on the P-V & T-S digram.

→ Due to the heat from the refrigerator the specific volume of the air changes from V_4 to V_1.

→ we know that the heat absorb by the air or (heat Extracted from the refrigerator or refrigerating Effect produce) during constant pressure Expansion per kg of air.

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

workdone during the cycle per kg of air →

$$= \text{Heat rejected} - \text{Heat absorbed}$$

$$= q_R - q_A$$

$$= c_p(T_2 - T_3) - c_p(T_4 - T_1)$$

co-efficient of performance (COP)

$$COP = \frac{\text{Heat absorbed}}{\text{workdone}} = \frac{q_A}{q_R}$$

$$= \frac{c_p(T_4 - T_1)}{c_p(T_2 - T_3) - c_p(T_4 - T_1)}$$

$$= \frac{c_p(T_1 - T_4)}{c_p(T_2 - T_3) - c_p(T_1 - T_4)}$$

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

now taking common,

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

→ for isentropic compression process 1-2

ratio of specific heat

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \text{ ——— } ii)$$

similarly for Isentropic Expansion process 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \text{ ——— } iii)$$

since $P_2 = P_3$ and $P_1 = P_4$ therefore

from the eqn 2 & 3

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \text{ or } \frac{T_2}{T_3} = \frac{T_1}{T_4}$$

Now substituting this value in eqn i)

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

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

$$\boxed{COP = \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}-1}}$$

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Problem -

In a refrigeration plant working on a bell-coleman cycle, air is compressed to 5 bar from 1 bar. Its initial temp is 10°c After compression the air is cooled upto at 20°c. In a cooler before Expanding back to a pressure of 1 bar.

Determine the cop of the plant and net refrigerating Effect.

take $c_p = 1.005$ kJ/kg

$c_v = 0.718$ kJ/kg

Given data :-

$P_2 = P_3 = 5\text{bar}$

$P_1 = P_4 = 1\text{ bar}$

$T_1 = 10°c = 10 + 273 = 283K$

$T_3 = 20°c \Rightarrow 293K$

$c_p = 1.005$ kJ/kg

$c_v = 0.718$ kJ/kg

$\gamma = \frac{c_p}{c_v} = 1.39$

Isentropic index for compression and Expantion process, $\gamma = \frac{c_p}{c_v} = 1.39$

for Isentropic compression (1-2)

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

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{5}{1}\right)^{\frac{1.39-1}{1.39}} = (5)^{0.28} = 1.57$$

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for Isentropic Expantion (3-4)

$$\frac{T_3}{T_4} = \left(\frac{5}{1}\right)^{\frac{1.39-1}{1.39}}$$

$$= 1.57 \qquad \left[\because \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

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

$$\boxed{\begin{array}{l} T_3 = T_2 \\ T_1 = T_4 \end{array}}$$

$$\Rightarrow T_4 = \frac{T_3}{1.57} = \frac{293}{1.57} = 186\,K$$

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

COP of the plants, $= \dfrac{\text{Heat absorb}}{\text{workdone}}$

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

$$= \frac{186}{293 - 186} = 1.73$$

Net refrigerating Effect, = Heat absorb during constant pressure (4-1)

$$= c_p (T_1 - T_4)$$

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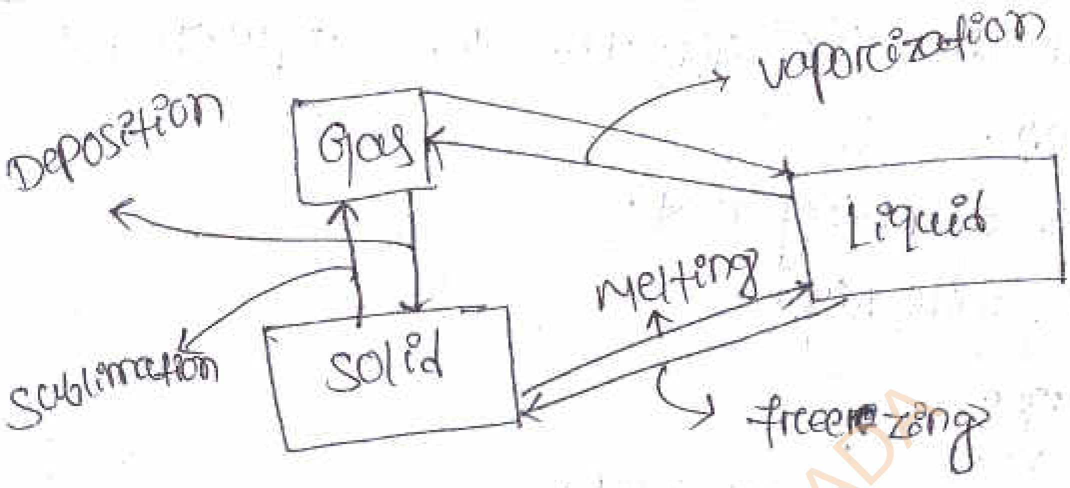
$= 1.005 (283-186)$

$= 97.48$ kJ/kg

simple vapour compression Refrigeration system →



(Refrigeration & Phase change dig.)

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→ A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance termed as Refrigerant is used.

→ The refrigerant is usually used for this pupose are amonia (NH_3), carbon dioxide(CO_2) sulfer dioxide(SO_2),

→ The refrigerant used doesnot leave the system but circulated throughout the cycle.

→ The first vapour compression system was devloped in 1834 by Jacob perkins.

Advantages and disadvantages of vapour compression Refrigeration system over air refrigeration system →

Advantages :

→ It has simellar size for the given capacity of Refrigeration.

→ It has less running cost.

→ The cop is wide high.

Disadvantages

→ The intial cost is very high.

→ The prevention of Likage of refrigerant is the major problem in vapour compression system.

* Mechanism of a simple vapour compression Refrigeration system →

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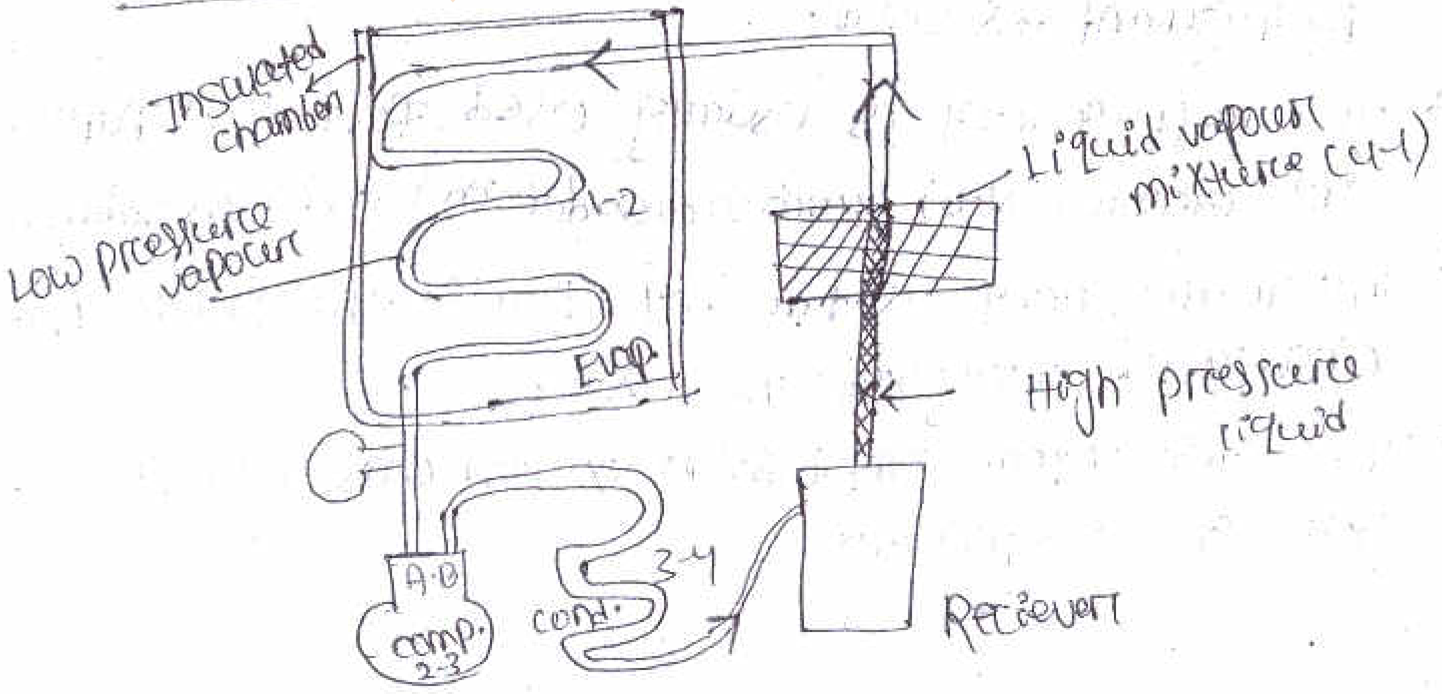

Evaporator :-

An Evaporator consist of coils of pipe in which the liquid vapour refrigerant at low pressure and temp is Evaporated and change into vapour refrigeran at low pressure and temp.

→ In Evaporating the liquid vapour refrigerant absorbed its latent heat of vaporization. from the medium (Air, water, brime) which is to be cooled.

compressor :-

→ The low pressure and temp vapour refrigerant from Evaporator is drawn into the compressor through the Inlet and suction valve A-B where it is compress to a high pressure and temp.

→ This high pressure and temp vapour refrigerant is discharge into the condenser through the discharge valve.

condenser :-

→ condenser is used to cool the vapour and the vapour will converted into Liquid.

→ the condenser or cooler consist of coils of pipe in which the high pressure and temp vapour refrigerant is condense.

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→ The Refrigerant while passing through the condenser give up its latent heat to the surrounding.

Receiver :

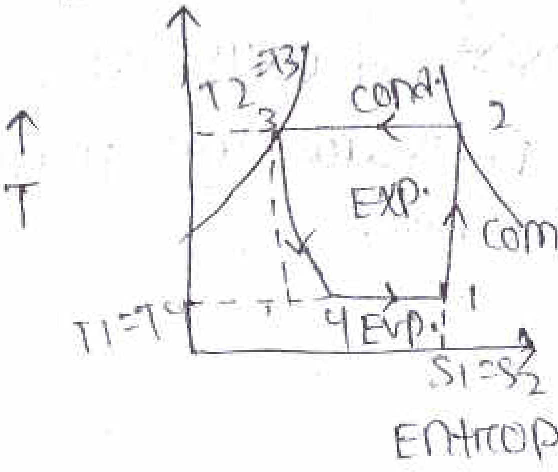
→ The Receiver is a storage tank which store the liquid refrigerant.

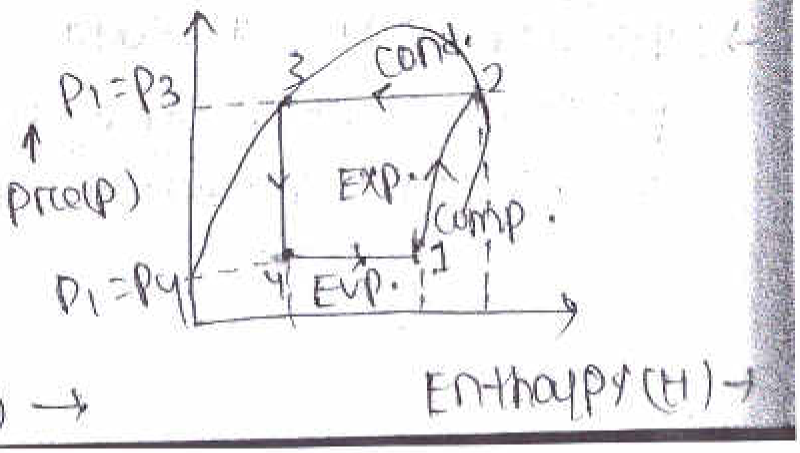
→ The condense liquid refrigerant from the condenser is stored in a vessel known as receiver, from where it is supplied to the Evaporatore through the Expantion valve or Throttle valve / control valve.

Types of vapour compression cycle →

i) cycle with dry saturated vapour after compression.
ii) cycle with wet vapour after compression.
iii) cycle with superheated vapour after compression.
iv) cycle with superheated vapour before compression.
v) cycle with under cooling or sub cooling of refrigerant.

i) cycle with dry saturated vapour after compression





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→ A vapour compression cycle with dry saturated vapour after compression is shown by the T-S & P-H digram.

→ At point 1 let T1, P1 & S1 be the temp pressure & Entropy of the vapour refrigerant respectively.

Process (1-2) [compression process]

→ the vapour refrigerant at low pressure (P1) and temp (T1) is compressed isentropically to dry saturated vapour as show by the vertical line 1-2 on T-S digram and by the curve 1-2 on P-H digram.

→ the pressure & temp raise from P1 to P2 and temp T1 to T2.

workdone during isentropic compression per kg of refrigerant.

$$\boxed{W = h_2 - h_1}$$

where,

h_1 = Enthalpy of vapour refrigerant at temp T1 (suction of the compression)

h_2 = Enthalpy of vapour refrigerant at temp T2 (discharge of the compressor)

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process (2-3) [condensing process]

→ The high pressure & temp vapour refrigerant from the compressor is pass through the condenser where it is completoly condensed at constant pressure P_2 and temp T_2 as show by the horizontal line 2-3 on T-S & P-H digram.

→ The vapour refrigerant is converted into liquid. refrigerant while passing through the condenser gives its latent heat to the surrounding condensing medium.

Expantion process (3-4) →

→ The liquid refrigerant at pressure $(P_3 = P_2)$ and temp $(T_2 = T_3)$ is Expanded by throttling process through the Expantion valve at low pressure $P_1 = P_4$ & Temp $(T_1 = T_4)$ as shown by the curve 3-4 on P-H & T-S digram.

→ The liquid refrigerant Evaporates as it passes through the Expansion valve, but the greater portion is vaporized in the Evaporator.

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[illegible] process (4-1) / Evaporating process →

→ The Liquid vapour mixture of the refrigerant at pressure $p_1 = p_4$ and temp $T_4 = T_1$ is evaporated and change into vapour refrigerant at constant pressure and temp as show by the horizontal line 4-1 on T-S & p-H digram.

→ During Evaporation the liquid vapour refrigerant absorbs its latent heat of vapourisation from the medium. (air, water brine solution)

→ Refrigerating Effect (RE) =

Heat absorbed / Extracted – refrigerant Evaporating per kg of refrigerant.

$$\boxed{RE = h_1 - h_4}$$

$$h_4 = h_{f3}$$

↑ sensible heat at temp T_3.
(i.e. Enthalpy of liquid refrigerant leaving the condenser.)

$$COP = \frac{\text{Refrigerating Effect (RE)}}{\text{workdone}}$$

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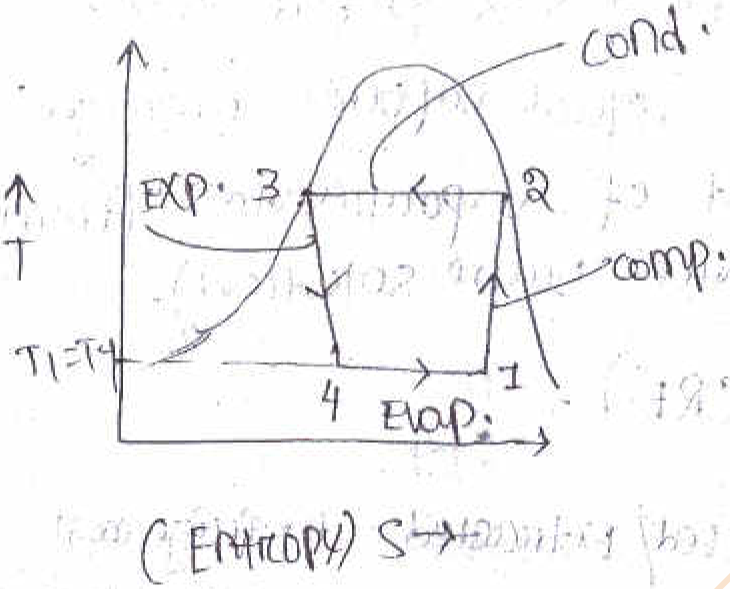
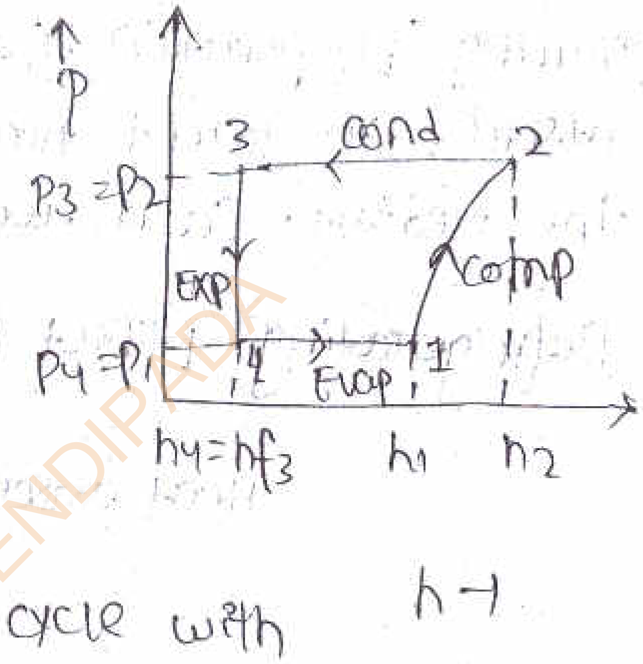
$$COP = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

ii) cycle with wet vapour after compression →





→ A vapour compression cycle with wet vapour after compression is shown by the curve on T-S & p-H digram.

→ In this cycle the Enthalpy at point 2 is findout with the help of dryness fraction at this point.

→ The dryness fraction at point 1 & 2 may be obtained by Equating Entropy at point 1 & 2

$$COP = \frac{\text{Refrigerating Effect}}{\text{work done}}$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

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problem →

In an amonia (NH_3) vapour compression system the pressure in the Evaporator is 2 bar. NH_3 at Exist is 0·85 dry and at Entry its dryness fraction is 0·19. during compression the workdone per kg of NH_3 is 150 kJ. calculate the cop and the volume of vapour Entering the compression per minute, If the rate of NH_3 circulation is 4·5 kg/min The latent heat & specific volume at 2 bar are 1325 kJ/kg and 0·58 m3/kg.

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Given data :

$P_1 = P_4 = 2$ bar (Pre. at Evap.)

NH_3 Exist $(x_1) = 0·85$

(Entry) $x_4 = 0·19$

workdone = 150 kJ/kg

(Mass of Rfg.) $m_a = 4·5$ kg/min

Sp. volume, = 0·58 m3/kg

Latent heat = 1325 kJ/kg

Dryness fraction →

$$* \boxed{x = \frac{m_s}{m_s + m_w}}$$

m_s → mass of dry steam

m_w → mass of water vapour

Dig

→ Since the NH_3 vapour at Entry to the Evaporator (i.e at point 4) has dryness fraction (x_4) = 0·19, Therefore the Enthalpy at point 4 is

$$\boxed{h_4 = x_4 \times h_{fg}}$$

Enthalpy = dryness fraction × latent heat

$$h_4 = 251 \cdot 74 \text{ kJ/kg}$$

Enthalpy of amonia vapour dryness fraction,

$$h_1 = x_1 \times h_{fg}$$
$$= 0 \cdot 85 \times 1325$$
$$= 1126 \cdot 25 \text{ kJ/kg}$$

Heat Extracted from the Evaporator refrigerating Effect, $R_E = h_1 - h_4 = 874 \cdot 5 \text{ kJ/kg}$

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Work during compression, $W = 150$ kJ/kg

$$COP = \frac{RE}{W}$$

$$= \frac{874.5}{150} = 5.83$$

Volume of vapour entering the compression per minute. = mass of refrigerant × SP volume

$$m_a \times v_g$$

$$= 4.5 \times 0.58$$

$$= 2.61\, m^3/min$$

Problem :-

The temp limit of NH_3 refrigerating system are 25°C and -10°C. If the gas is dry at the end of compression.

Calculate the cop of the cycle assuming no under cooling of the liquid NH_3.

Use the following table for properties of NH_3.

Temp °C	liquid heat kJ/kg	latent heat	liquid Entropy
25	298.9	1166.94	1.1242
-10	133.37	1297.68	0.5443

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Given data:-

$T_2 = T_3 = 25°C \Rightarrow 25 + 273 = 298K$

$T_1 = T_4 = -10°C \rightarrow -10 + 273 = 263K$

$h_4 = hf_3 = 298.9$ kJ/kg (liquid heat)

$hfg_2 = 1166.94$ kJ/kg. (latent heat)

$sf_2 = 1.1242$ kJ/kg

$hf_1 = 135.37$ kJ/kg (liquid heat)

$hfg_1 = 1297.68$ kJ/kg

$sf_1 = 0.54$ kJ/kg

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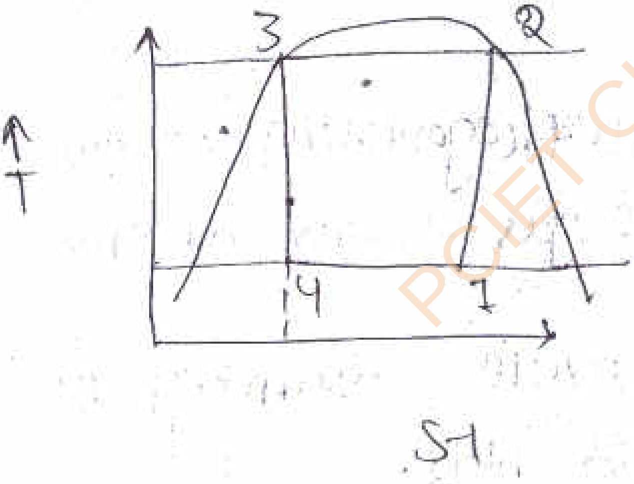

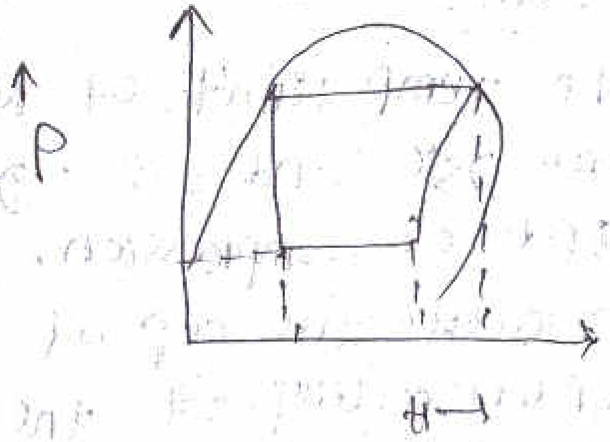

Let, x_1 = dryness fraction at point 1

so Entropy at point 1

$$S_1 = \frac{sf_1 + x_1 \times hfg_1}{T_1}$$

$$S_1 = \frac{0.54 + x_1 \times 297.68}{263}$$

$S_1 = 0{\cdot}54 + 4{\cdot}93x_1$

$S_1 = 0{\cdot}54 + 4{\cdot}93x_1$ ——— i)

Similarly, $S_2 = \dfrac{sf_2 + hfg_2}{T_2}$

$= \dfrac{1{\cdot}1242 + 1166{\cdot}94}{298}$

$S_2 = 5{\cdot}04$

Since Entropy at point 1 = Entropy at point 2

So equating 1 & 2

$S_1 = S_2$

$\Rightarrow 0{\cdot}54 + 4{\cdot}93x_1 = 5{\cdot}04$

$x_1 = 0{\cdot}92$

Enthalpy at point 1 on (P-H)

$$\boxed{h_1 = hf_1 + x_1 \times hfg_1}$$

$h_1 = 1316{\cdot}26$ kJ/kg

$h_2 = hf_2 + hfg_2$

$= 1166{\cdot}94 + 1{\cdot}1242$

$= 1168{\cdot}06$ kJ/kg

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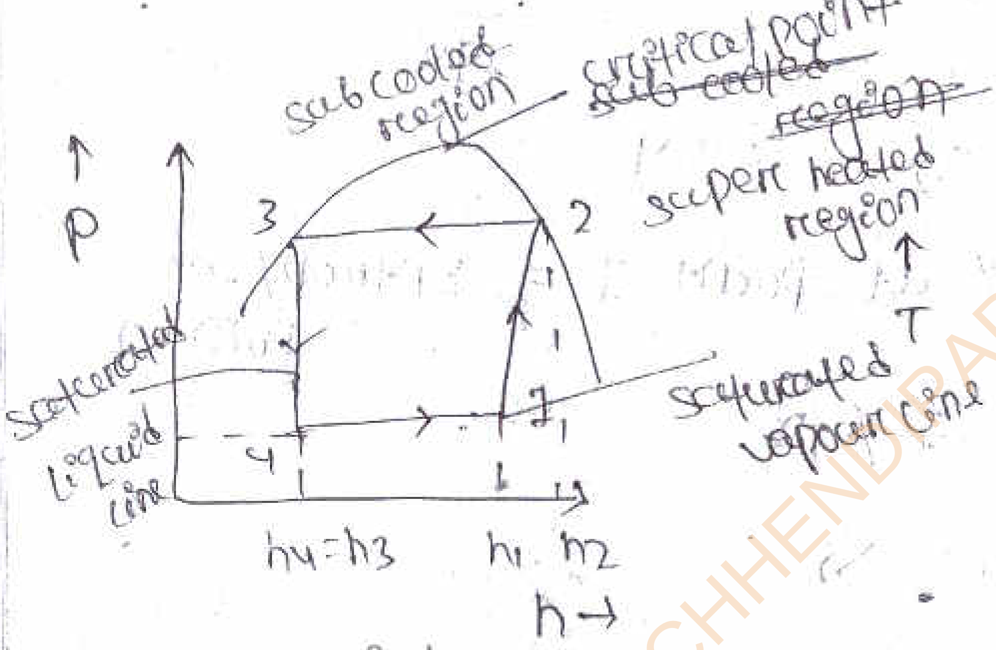
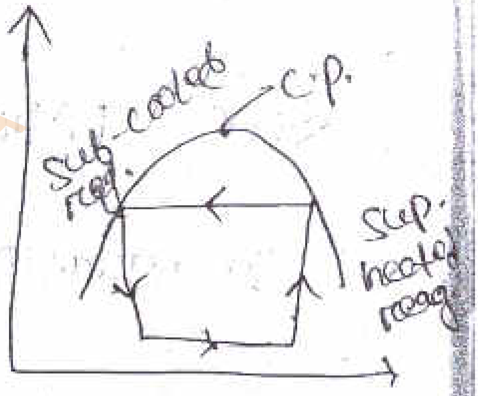
$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1} \quad (\because h_4 = h_{f3})$$

$$= -6.31$$





S-T

critical point →

critical point is the point of saturated liquid line on left hand side and saturated vapour line on right hand side.

$h_4 = h_{f3}$

→ It easier to find the Enthalpy of those point which are in saturation curve so h_4 would be replaced by h_3 or h_{f3}.

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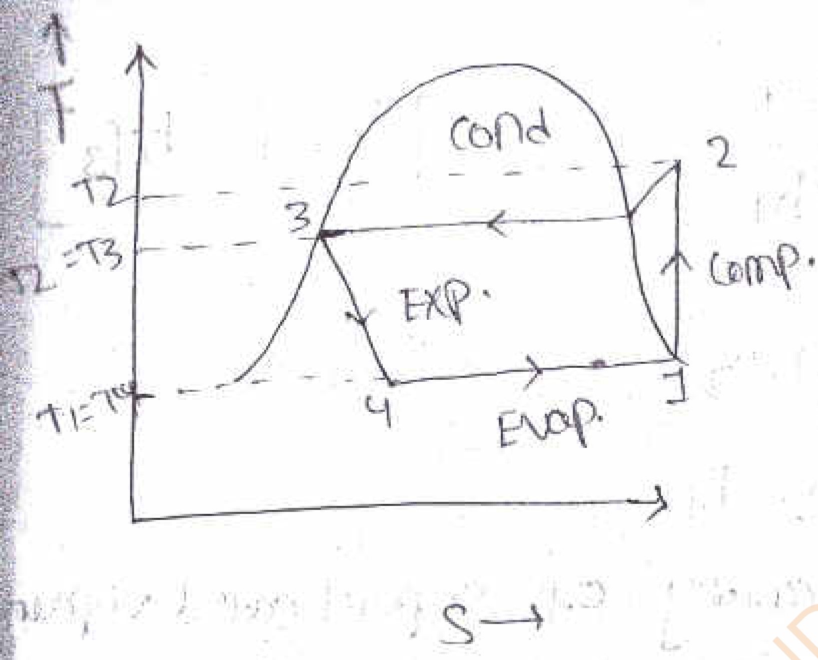
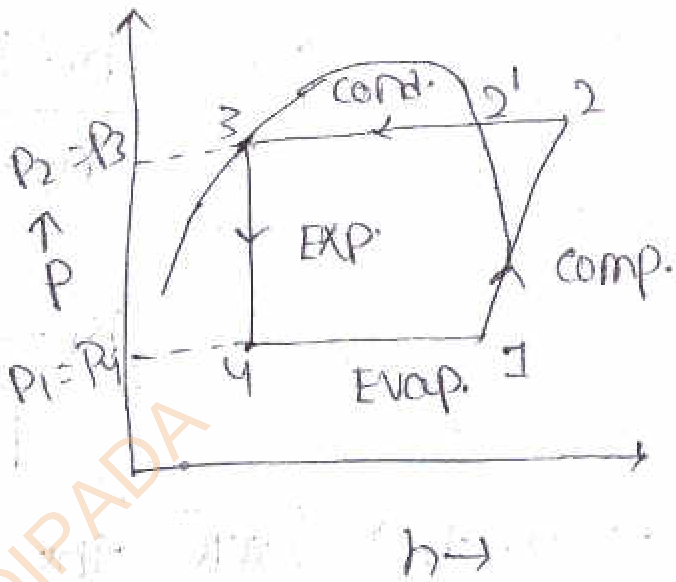
Vapour compression cycle with superheated vapour after compression :-



(T-S digram)



(P-h digram)

→ Superheated vapour is a vapour at a temp higher than its vaporizing point at the absolute pressure where the temp is measure.

→ A vapour compression cycle ~~oh~~ with a superheated vapour after compression is show on the above fig on T-S & P-H digram.

→ In this cycle the enthalpy at point 2 is found out with the help of degree of superheat.

→ The degree of superheat may be found out by equating the entropy at point 1 & 2 on compression process.

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→ Now,

$$COP = \frac{\text{Refrigerating Effect}}{\text{workdone}}$$

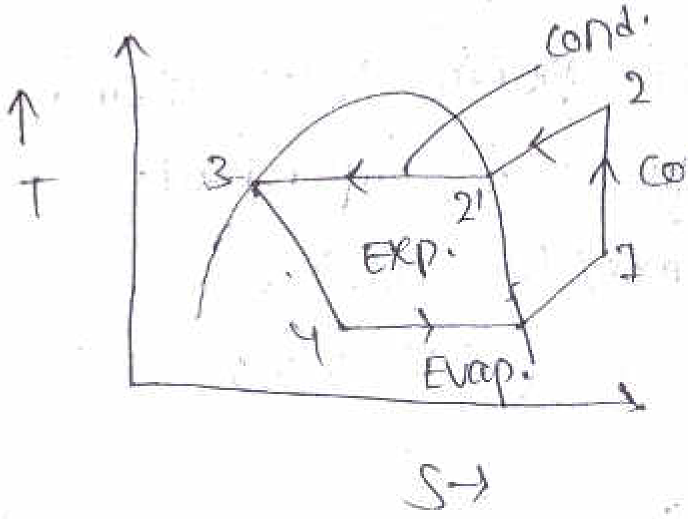
$$= \frac{h_1 - h_4}{h_2 - h_1} \quad [\because h_4 = h_{f3}]$$

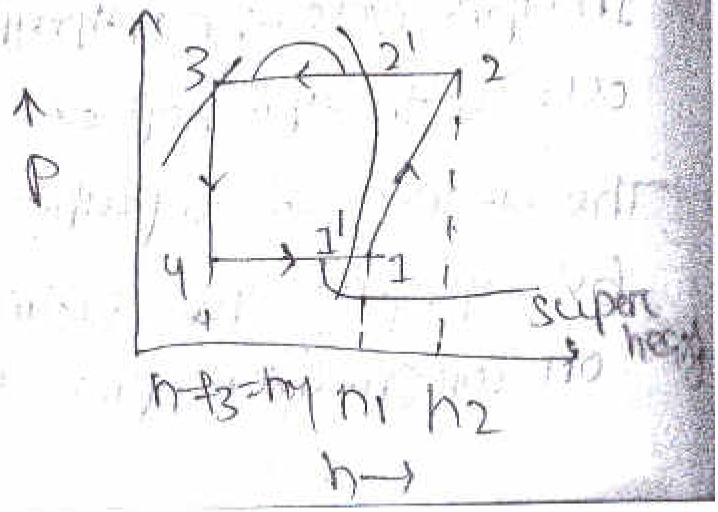
$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

→ In this cycle the cooling of superheated vapour will take place in two stage.

→ firstly it will be condense to dry saturated stage at constant pressure by the graph 2 to 2' and secondly it will be condense at constant temp by graph 2' to 3.

iv) vapour compression cycle with superheated vapour before compression →





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A vapour compression cycle with superheated vapour before compression is show by the above curve, T-S & P-H digram.

In this cycle the Evaporation start at point 4 and continue upto 1', when it is dry saturated. The vapour is now superheated before Entering the compressor upto the point 1.

The COP,

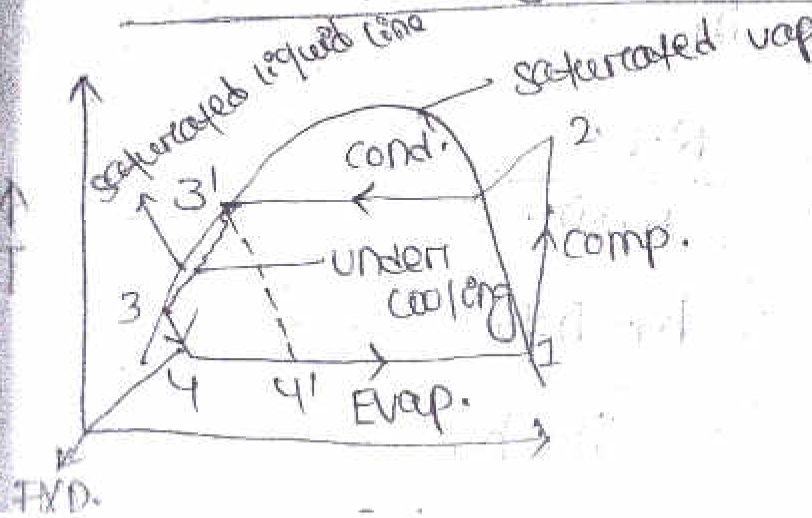
$$COP = \frac{R.E.}{W.D.}$$

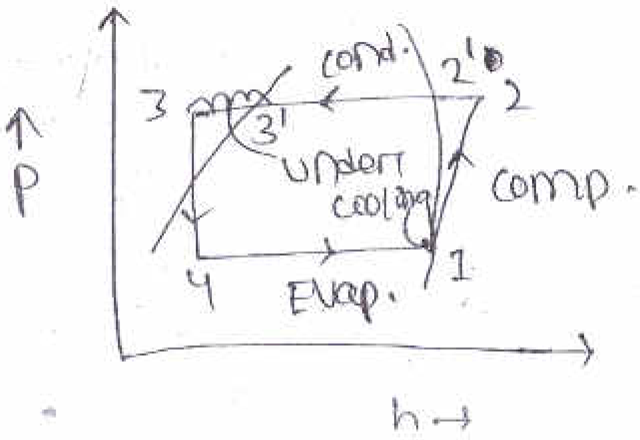
$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

NOTE

In this cycle the heat is absorbed or Extracted in two stage firstly from point 4 to point 1' and secondly from point 1' to 1.

V) vapour compression cycle with under cooling or sub-cooling of refrigerant →





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→ some time The refrigerant after condensation process 2' to 3' is cooled below the saturation temp (T_3') before expantion by throttling.

→ such a process is called under cooling or sub-colling of the refrigerant.

→ The sub cooling of the refrigerant is generally done along the liquid line as show on the above digram, Here refrigerant Effect is increase.

→ The ultimate effect of the under cooling is to increase the value of cop under the same set of condition.

→ The process of undercooling is generally brought about by circulating more quantity of cooling water through the condenser.

→ Some times This process is also brought about by adding a heating a heat Exchanger.

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$$R.E. = h_1 - h_4 \qquad [\because h_4 = h_{f3}]$$

$$\text{workdone} = h_2 - h_1$$

$$\text{cop} = \frac{R.E.}{W.D.}$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

NOTE :-

$$\boxed{h_{f3} = h_{f3}' - c_p \times \text{Degree of under cooling}}$$

* h_f = specific Enthalpy of saturated liquid

h_g : specific Enthalpy of saturated gas

h_{fg} : Represent Enthalpy diffrence b/w gas and liquid. and tells how much heat is needed to change 1 kg of boiling water to steam.

or h_{fg} = latent heat of Evap. (Energy required to transfer saturated water into dry saturated steam)

$$\boxed{h_{fg} = h_g - h_f}$$

→ Diffrence b/w specific Enthalpy value of the substance.

Problem →

A vapour compression refrigerator works b/w the pressure limit of 60 bar and 25 bar. The working fluid is just dry at the end of compression and there is no under cooling of the liquid before the Expansion valve. Determine

1) COP of the cycle
2) capacity of the Refrigerator if the fluid flow is at rate of 5 kg/min.

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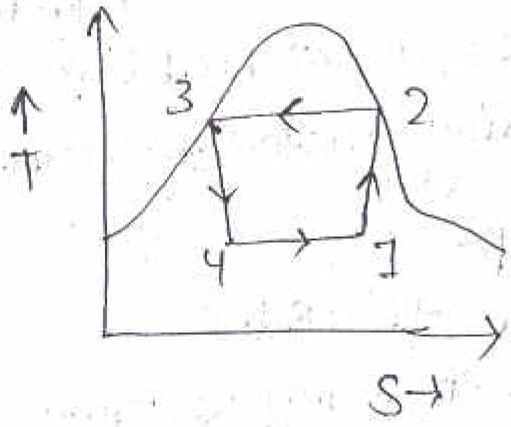
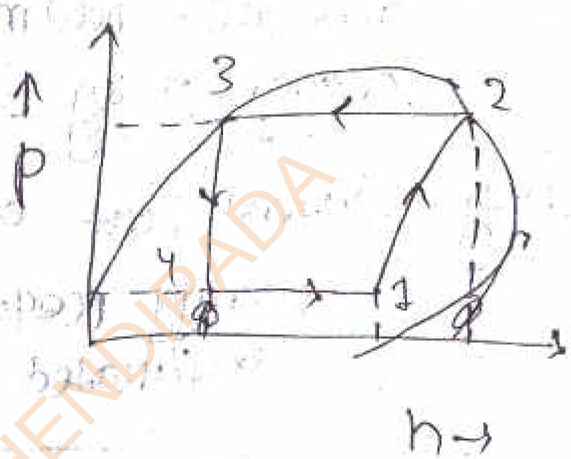
pressure (bar)	Saturation temp (K)	Enthalpy liquid	Enthalpy vapour	Entropy liquid	Entropy vpr
60	295	151.96	293.29	0.554	1.033
25	261	56.32	322.58	0.226	1.246

Given data:





pressure, $P_2 = P_3 = 60$ bar

$P_1 = P_4 = 25$ bar

temperature, $T_2 = T_3 = 295K$

$T_1 = T_4 = 261K$

$H_4 = H_{f_3} = 151.96$ kJ/kg

$h_{f_1} = 56.32$ kJ/kg

$h_2 = h_{g_2} = 293.29$

$h_{g_1} = 322.58$ kJ/kg

$S_{f_1} = 0.226$ $s_{g_1} = 0.226$

$S_{f_2} = 0.554$

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$s_{g_2} = s_2 = 1.0332$ kJ/kg-K

let, x_1 = dryness fraction of the vapour refrigerant enter to the compression at point 1.

S_1 = Entropy at point 1.

$$S_1 = S_{f1} + x_1 (S_{fg1})$$

$$= S_{f1} + x_1 (S_{g1} - S_{f1})$$

$$S_1 = S_{f1} + x_1 S_{fg1}$$

$$= S_{f1} + x_1 (S_{g1} - S_{f1})$$

$$[\because S_{g1} = S_{f1} + S_{fg1}]$$

$$= 0.226 + x_1 (1.12464 - 0.226]$$

$$S_1 = 0.226 + 1.024 x_1 = 1.0332 \longrightarrow i)$$

$$S_2 = S_{g2} = 1.0332 \text{ kJ/kg-K} \longrightarrow ii)$$

Since Entropy at point equal to the Entropy at point 2 Therefore equating eqⁿ i) & ii)

$$x_1 = 0.79$$

Now Enthalpy 1.

$$h_1 = h_{f1} + x_1 h_{fg1}$$

$$= h_{f1} + x_1 (h_{g1} - h_{f1})$$

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$h_1 = 266.66$ kJ/kg [$\because hg_1 = hf_1 + hg_1$

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

$$= \frac{266.66 - 151.96}{293.29 - 266.66}$$

$$= 4.30$$

capacity of refrigerator,

Heat Extracted or refrigerating Effect produce per kg of refrigerant = $h_1 - hf_3$

$$= 266.66 - 151.96$$

$$= 114.7 \text{ kJ/kg-k}$$

since the fluid flow at the rate of 5 kg per minute so total heat Extracted equal to 5×114.7

$$= 573.5 \text{ kJ/min}$$

capacity of refrigerator,

$$\frac{573.5}{210} = 2.73$$

$$\boxed{1 \text{ TOR} = 210 \text{ kJ/min}}$$

PCIET CHHENDIPADA

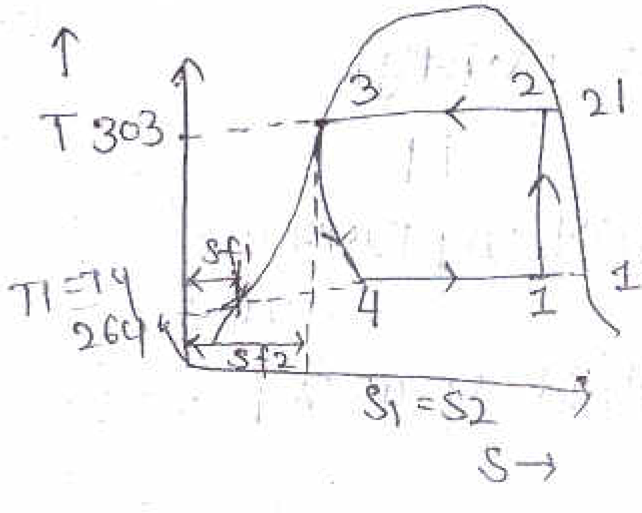
Problem →

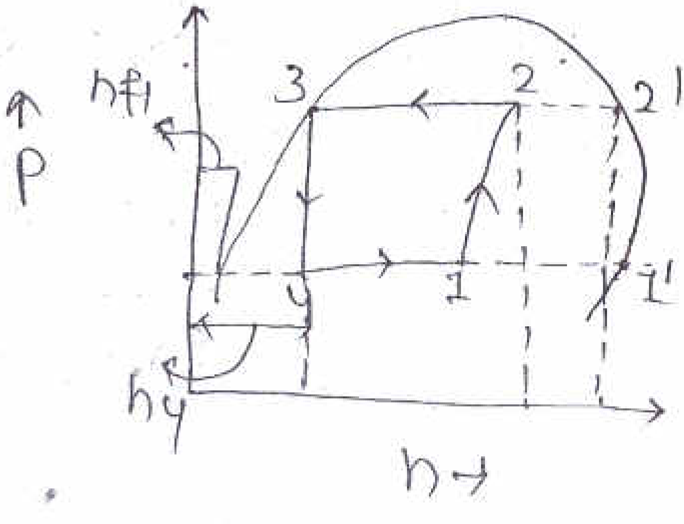
Dt :- 11.Dec.21

An ammonia refrigerating m/c fitted with an Expantion valve work b/w the temperature lemit −10°C and 30°C. The vapour is 95% dry at the end of Isentropic compression and the fluid leaving the condenser is at 30°C assuming actual cop as 60% of the theoretical calculate the kilogram of Ice produce per kw hour at 0°C from water at 10°C latent heat of Ice is 335 kJ/kg. Ammonia has following properties.

Temp °C	liquid heat hf kJ/kg	Latent heat hfg (kJ/kg)	liquid Entropy (Sf)	Total S of dry sat vap
30	323.08	1145.80	1.2037	4.984
−10	135.37	1297.68	0.5443	5.477

Given data :-





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Temp, $T1 = T4 = -10^\circ C \Rightarrow 263K$

$T2 = T3 = 30^\circ C \Rightarrow 303K$

~~hf1=~~ $x_2 = 95\% = 0.95$

$hf_3 = hf_2 = 323.08$, $hf_1 = hf_4 = 135.37$

$hfg_1 = 1297.68$ kJ/kg

$hfg_2 = 1145.80$ kJ/kg

$sf_1 = 0.5443$

$sf_2 = 1.2037$

Total Entropy of dry saturated vapour,

$S_2' = 4.9842$

$S_1' = 5.4770$

Let x_1 = dryness fraction at point 1.

$$S_2 = Sf_2 + \frac{hfg_2 \times x_2}{T2}$$

$$S_1 = Sf_1 + \frac{x_1 hfg_1}{T1}$$

$$S_1 = 0.5443 + x_1 \frac{1297.68}{263}$$

$$S_1 = 0.5443 + 4.93 x_1 \longrightarrow i)$$

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$$S_2 = S_{f2} + x_2 \frac{h_{fg2}}{T_2}$$

$$S_2 = 1{\cdot}2037 + 3{\cdot}78 \times x_2$$

$$S_2 = 1{\cdot}2037 + 3{\cdot}78 \times 0{\cdot}95$$

$$S_2 = 4{\cdot}79 \text{ —— } ii)$$

Since it is an Isentropic process,

so $S_1 = S_2$

$\Rightarrow 0{\cdot}5443 + 4{\cdot}93 x_1 = 4{\cdot}79$

$\Rightarrow 4{\cdot}93 x_1 = 4{\cdot}79 - 0{\cdot}5443$

$x_1 = 0{\cdot}86$

Enthalpy at point 1

$h_1 = h_{f1} + x_1 h_{fg1}$

$=$ ~~$h_{f1} + x_1(h_{g1} - h_{f1})$~~

$h_1 = 1251{\cdot}37$

$h_2 = h_{f2} + x_2 h_{fg2}$

$= 323{\cdot}08 + 0{\cdot}95 \times 1145{\cdot}8$

$h_2 = 1411{\cdot}59$

$$cop = \frac{h_1 - h_4}{h_2 - h_1} \qquad [\because h_4 = h_{f3}]$$

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$$\text{cop} = \frac{1251.37 - 323.08}{1411.59 - 1251.37}$$

$$= 5.79$$

Dt:- 13 dec 21

Actual cop = 60% = 0.6

$0.6 \times 5.79 = 3.47$

$\boxed{1\,\text{kW in hr} = 3600\,\text{kJ}} = W$

Actual heat extracted or refrigerating effect produce in per kw hour

$= \boxed{W \times \text{Actual cop}}$

PCIET CHHENDIPADA

Vapour absorption Refrigeration system

Q. What is vapour absorption?

A) In this system an absorber, a pump a generator and a pressure reducing valve replace the compressor.

→ The low pressure ammonia vapour leaving the Evaporator Enters the absorber where it is absorb by the cold water in the absorber.

* The vapour absorption refrigeration system include all processes in a vapour compression refrigeration system such as absorber, heat pump, pressure reducing valve, generator, condenser, Expantion and Evaporation.

→ Here refrigerant use or working fluid use in vapour absorption amonia (NH_3) water (H_2O) Lithium Bromide(LiBr)

Q) Where is vapour absorption refrigeration system is used.

A) vapour absorption refrigeration system is based for place where heat Energy is easily available at a low cost.

→ This process is based for steam power plant.

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steam power plant can easily run this refrigeration system using the waste of heat produce in the power plant.

Q) why water is used in vapour refrigeration system?

A) The water use as the absorbent in the solution is unsaturated and it has the capacity to absorb more amonia gas. As amonia from evaporator enters the absorber it is partially absorbed by water and the strong solution ~~solution~~ of Amonia water is form. ($NH_3 - H_2O$)

Q) which energy is used in vapoure absorption Refrigeration system :→ Heat energy

A) The vapour absorption system used heat Energy instead of Mechanical Energy as in vapour compression system in order to change the condition of refrigerant required for the operation of refrigerating cycle.

Q) why amonia is used in vapour absorption system?

A) Strong sol^n.

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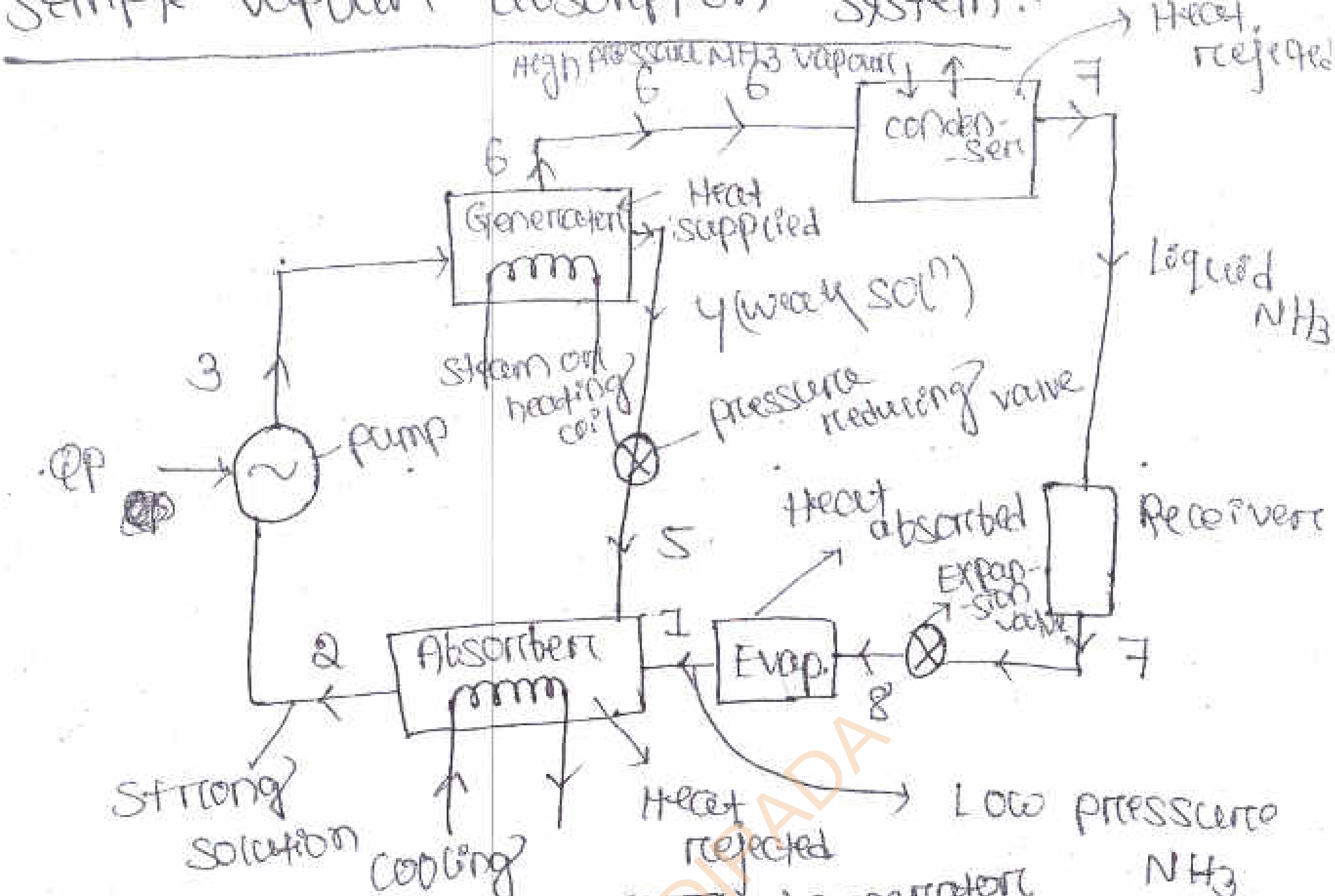
* Simple vapour absorption system :-



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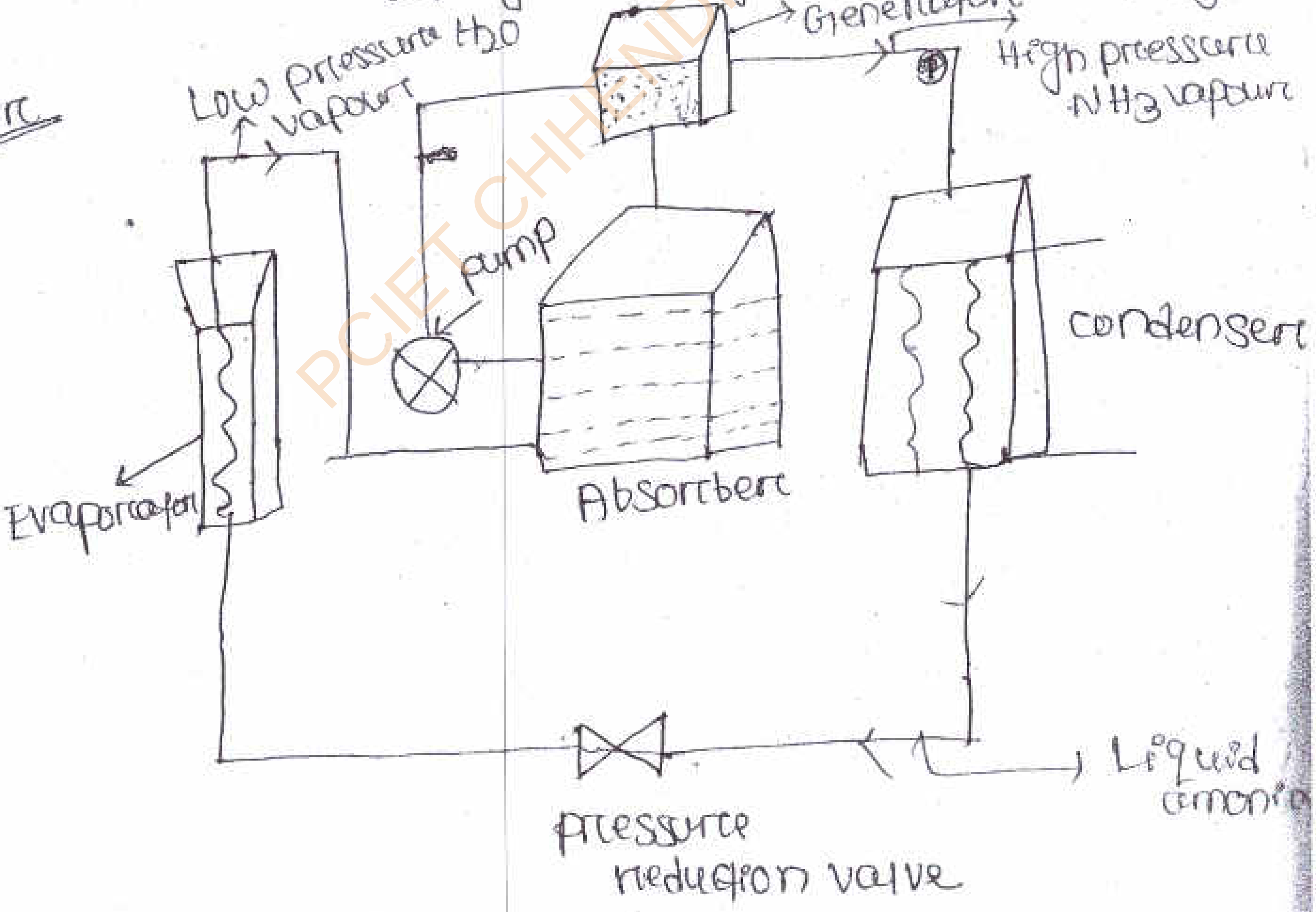

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→ The simple vapour absorption system consist of an absorber, A pump, a generator and a pressure reducing value to replace the vapour compression system.

→ The other components of the system are condenser, receiver, expantion valve and evaporator as in the vapour compression system.

→ In this system low pressure ammonia leaving the Evaporator Enters the absorber where It is absorb by the cold water in the absorber.

→ The water has the ability to absorb very large quantity of Ammonia vapour and the solution those ~~form~~ is known as aqua-amonia.

→ The absorption of ammonia vapour in water lowers the pressure in the absorber which in ~~term~~ turns draws more amonia vapour from the evaporator and this rise the temp of the solution.

→ Here some of cooling arrangment water is Employed in the absorber to remove the heat of the sol^n present there.

→ This is necessary Inorder to Increase the absorption capacity of water because at high temp. waters absorb less amonia vapour.

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The strong solution formed in the absorber is pumped to the generator by liquid pump. The pump increases the pressure of the sol^n up to 10 bar.

The strong sol^n of amonia in the generator is heated by some external source such as steam. During the heating process the ammonia vapour is drivener off the sol^n at high pressure leaving behind the hot ~~with~~ weak ammonia solution in the generator.

→ This weak amonia sol^n flow back to the absorber at low pressure after passing through a pressure reducing value.

→ The high pressure ammonia vapour from the generator is condense in the condenser to a high pressure liqued amonia.

→ This liquid amonia is pass to the Expantion value through the reciver and then go to the Evaporator.

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Dt:- 15 Dec 21

comparision of vapour compression & absorption system.

vapour compression	vapour Absorption system
1) The system as more wear & tear and produce more noise due to the moving part of the compressor.	1) only moving part in the system is an aqua pump (water pump). Hence the quiter in operation an less wear & tear.
2) Electric power is needed to drive the system.	2) waste low grade, solar power can be used; no need of Electric power.
3) cop is max^{m} or more.	3) Less cop or min^{n} cop.
4) Mechanical Energy is supplied through a compressor.	4) Heat energy is used.
5) charging of Refrigerant to the system is easier.	5) charging of refrigerant is defficult.

* Practical vapour Absorption system →

→ The simple vapour absorption is not very economical. In order to make the system more practical an analyser, a rectifier and two heat Exchanger ~~heated in~~ fitted In this operation.

→ This accessories help to improve the performance & working of the plant.

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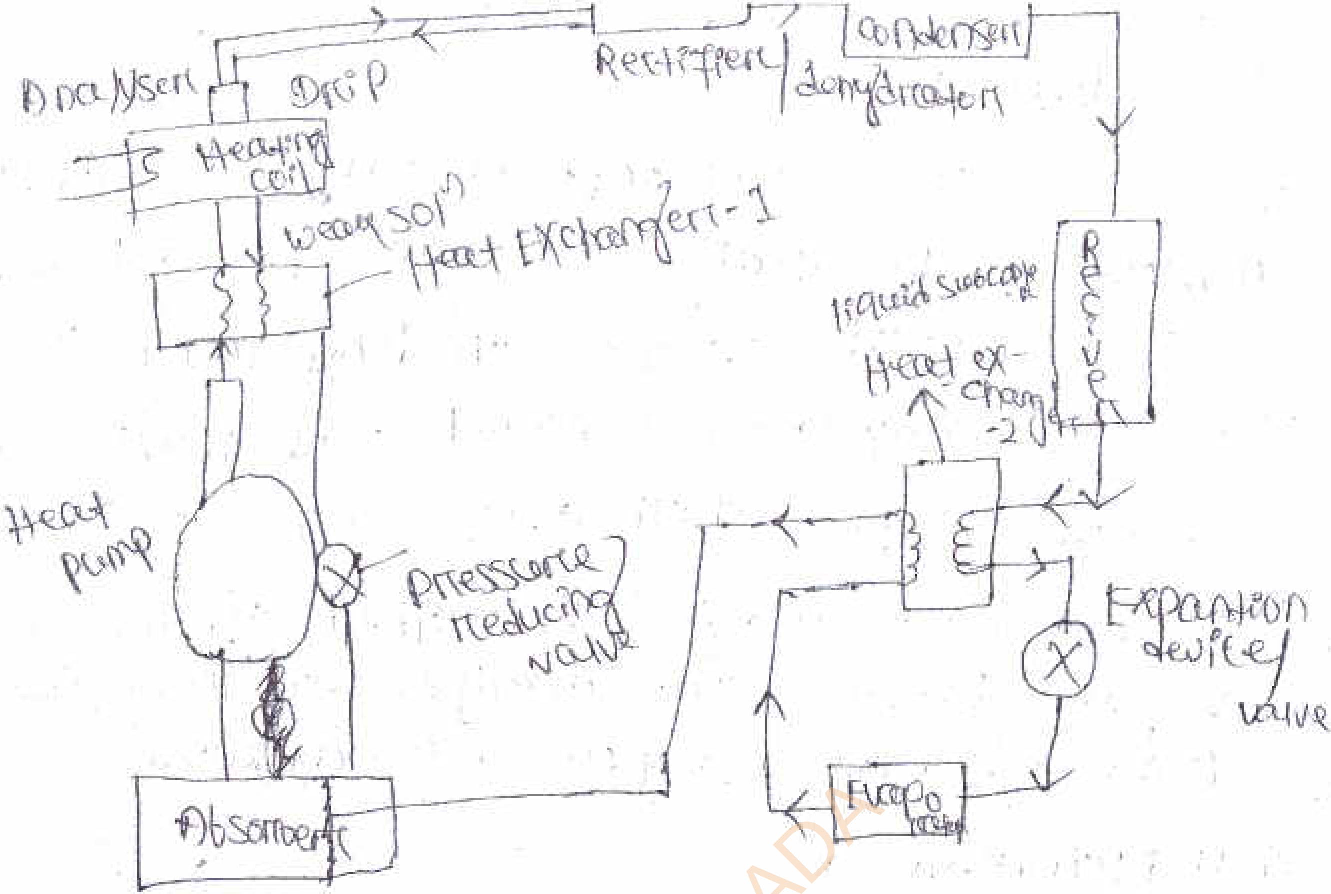

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Analyser →

when ammonia is vaporise in the generator, some water is also vaporised and will flow into the condenser along with ammonia vapours in this simple system.

→ If this unwanted water particle are not removed before enter into the condenser they will enter into the expantion valve where they freeze and chock the pipe line.

→ The analyser may be built as an integrical part ~~particles flowing to the condenser,~~ ~~an analyser is use~~. of the generator or maid as a separate piece of equipment.

~~→ the analyser consist of a series~~ of

Rectifier →

In case of the water vapour are not completly remove in the analyser a close type of vapour cooler called rectifier or dehydrator is used.

→ It is generally water cooled and maybe of the double pipe shell and tube type.

→ Its function is to cooled further the ammonia vapour leaving the analyser so that the remaning water vapour are condensed.

Heat Exchanger →

→ The heat Exchanger provide b/w the pump and the generator is use to cool the weak hot solution returning from the generator to absorber.

→ The heat remove from the weak sol^n rises the temp of strong solution leave the pump and going to the analyser & generator.

→ This operation reduce the heat supplied to the generator & the ammount of cooling required for the absorber.

Heat Exchanger-2

→ The heat exchanger provide b/w condenser & Evaporator may be called liquid sub-cooler.

PCIET CHHENDIPADA

In this heat Exchanger. the liqued refrigerant leaving the condenser is sub-cooled by the low temp ammonia vapour from the Evaporator.

This sub-cooled liquid is now pass to the Expantion valve next to the Evaporator.

PCIET CHHENDIPADA