UNIT-2: Vapour Compression Refrigeration

Vapour compression refrigeration

Working principle and essential components of the plant

Simple Vapour compression refrigeration cycle

COP

Representation of cycle on T-S and p-h charts

Effect of sub cooling and super heating

Cycle analysis

Actual cycle Influence of various parameters on system performance

Use of p-h charts

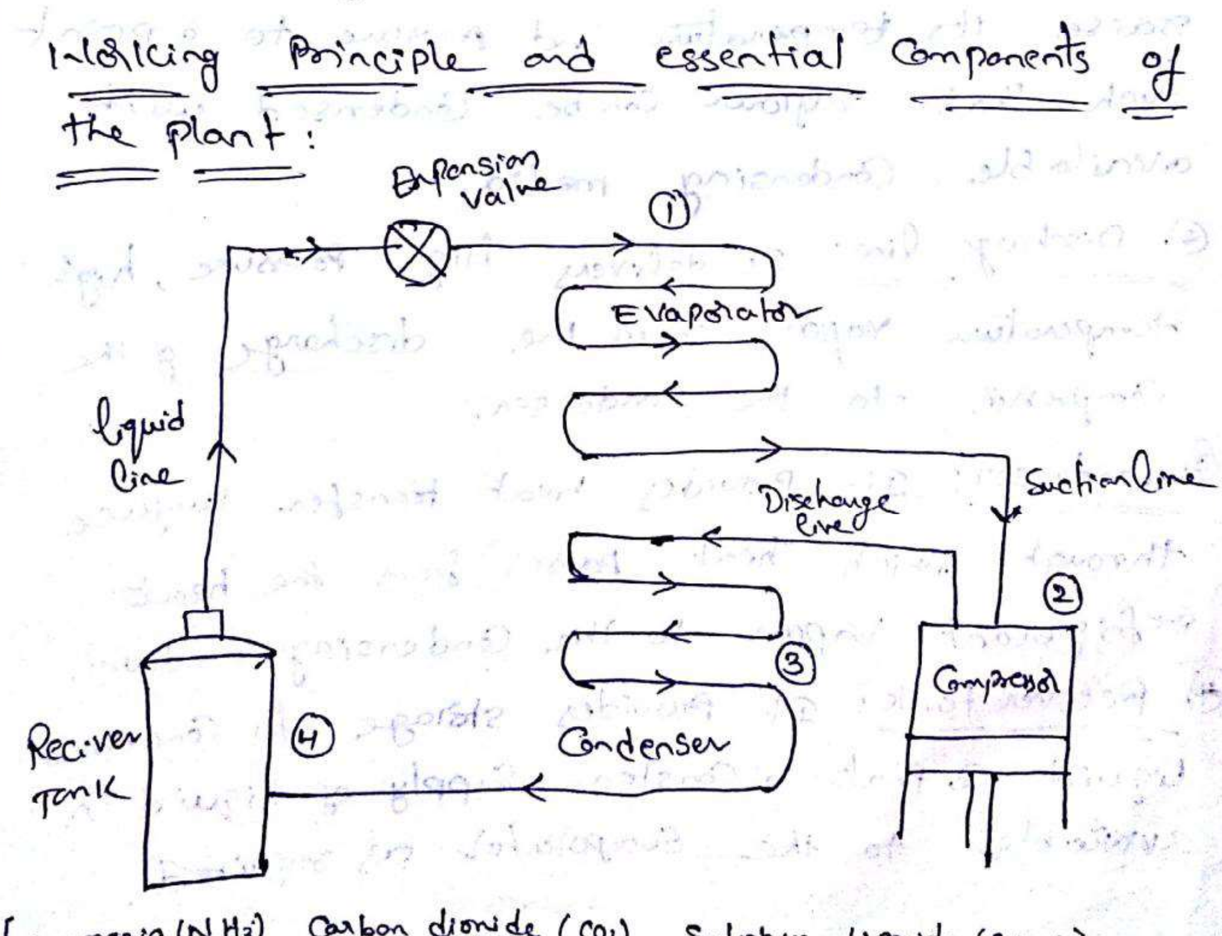
Numerical Problems.

UNIT-2

Vapour Compression Refrigeration:

Introduction: The vapour Compression system is the most important system in all refrigeration systems. In this system, the working fluid is a vapour. It changes between the vapour and liquid phases without leaving the refrigerating plant. During evaporation it absorbs latent heat from cold body and convert from liquid to vapour. During condensation, it rejects heat to enternal body, creating cooling effeect in working fluid. This refrigeration System acts as a latent heat pump since it pumps latent heat from cold body and rejects it to cooling medium.

Working Principle and essential Components of the plant:



[Ammonia (NH_3), Carbon dioxide (CO_2), Sulphur dioxide (SO_2)]

The vapour at low temperature and pressure enters the compressor where it is compressed isentropically its temperature and pressure increases. This vapour after leaving the compressor enters the condenser where it is condensed into high pressure liquid and is colleted in a receiver tank. Than it passes through the expansion valve, where it is throttle down to a lower pressure and temperature. It finally passes through evaporator, where it extracts heat from the surroundings or space being refrigerated and vapourised to low pressure vapour.

Essential Components:

① **Compressor:** It removed vapour from evaporator raise its temperature and pressure to a point such that vapour can be condensed with available condensing media.

② **Discharge line:** It delivery high pressure, high temperature vapour from the discharge of the compressor to the condenser.

③ **Condenser:** It provides heat transfer surface through which heat passes from the heat refrigerant vapour to the condensing medium.

④ **Receiver tank:** It provides storage for condensed liquid so that a constant supply of liquid is available to the evaporator as required.

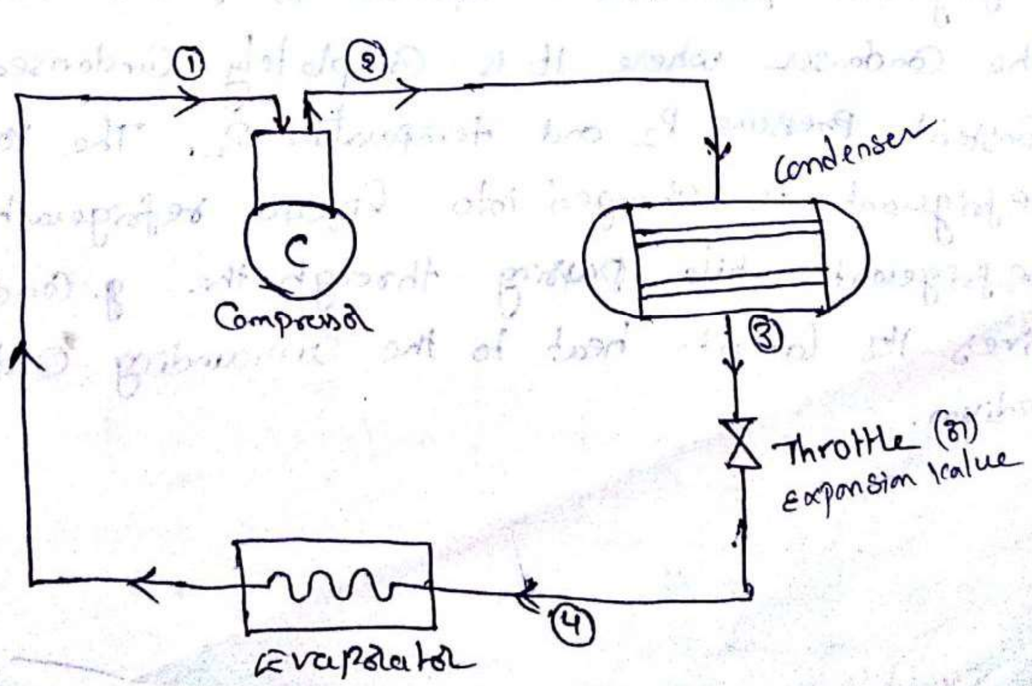
⑤ **liquid line:** It Carries the liquid refrigerant from the receiver tank to the refrigerant flow Control.

⑥ **Expansion Valve:-** It meter the proper amount of refrigerant to the evaporator and to reduce the pressure of liquid entering the evaporator. so that liquid will vapourise in the evaporator at the desired low temperature and take out sufficient amount of heat.

⑦ **Evaporator:** It provides a heat transfer surface through which heat can pass from the refrigerated space in to the vapourizing refrigerant.

⑧ **Suction line:-** It Conveys the low pressure vapour from the Evaporator to the Suction inlet of the Compressor.

Simple Vapour Compression refrigeration Cycle:



The possible Process in this Cycle

Process 1-2 : Compression

Process 2-3 : Condensation

Process 3-4 : Throttling or Expansion Process

Process 4-1 : Refrigeration and Cooling. or Vaporising Process.

Process 1-2 : Compression Process,

The Vapour refrigerant at low pressure P_1 and temperature T_1 is Compressed isentropically and rises from P_1 to P_2 and T_1 to T_2 respectively.

The workdone during isentropic $\overset{\text{Comp}}{}$ process per kg of refrigerant is given by $W = h_2 - h_1$

where h_1 = Enthalphy of vapour refrigerant at temp T_1 i.e. at suction of the Compressor.

h_2 = Enthalphy of the vapour refrigerant at temp T_2 i.e discharge of the Compressor.

Process 2-3: Condensing Process:

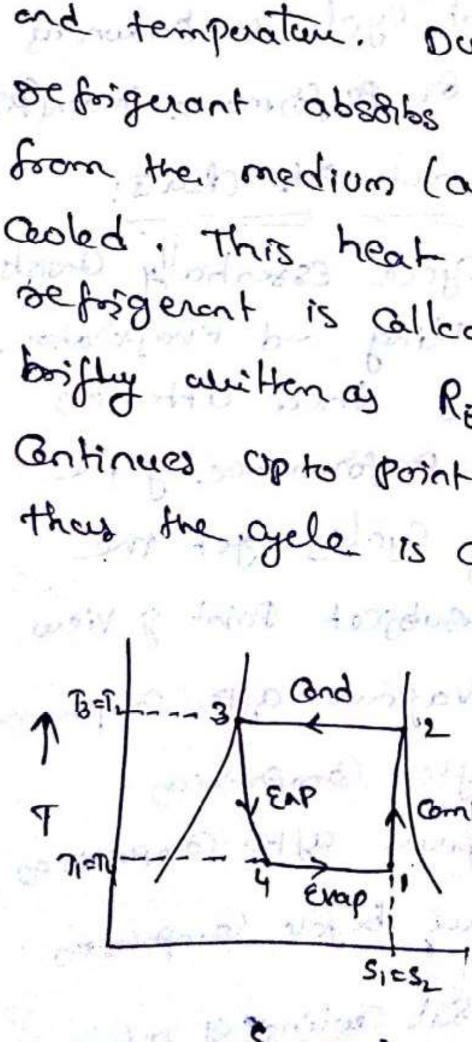
The high pressure and temperature Vapour refrigerant from the Compressor is passed through the Condenser where it is Completely Condensed at Constant Pressure P_2 and temperature T_2. The vapour refrigerant is Changed into liquid refrigerant. The refrigerant while passing through the ~~g~~ Condenser gives its latent heat to the surrounding Condensing medium.

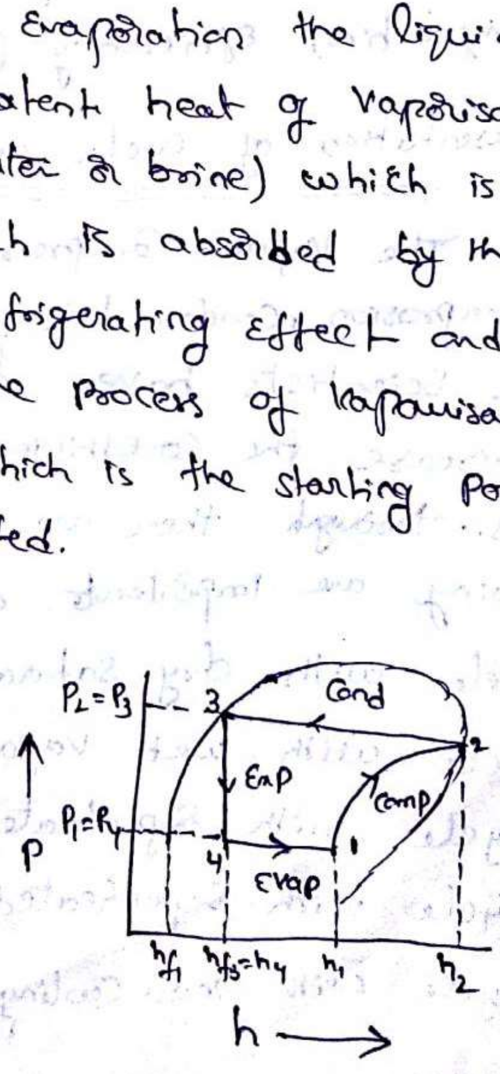
Process 3-4: Expansion Process.

The liquid refrigerant at pressure $P_3 = P_2$ and temperature $T_3 = T_2$ is expanded by throttling process (Irreversible Process) through the Expansion Valve to a low pressure $P_4 = P_1$ and $T_4 = T_1$. In this process No heat is obsorbed or rejected by the liquid refrigerant.

Process 4-1: Vaporising Process.

The liquid - vapour mixture of the refrigerant at pressure $P_4 = P_1$ and $\overset{temp}{T_4} = T_1$ is evaporated and changed into vapour refrigerant at constant pressure and temperature. During evaporation the liquid - vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled. This heat which is absorbed by the refrigerant is called refrigerating effect and it is brifly written as R_E. The process of vapourisation continues up to point 1. which is the starting point and thus the cycle is completed.





We know that Refrigerating Effect or heat absorbed or Extracted by the liquid vapour refrigerant during evaporation per kg of refrigerant is given by

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

where h_{f3} = Sensible heat at temperature T_3.
i.e., Enthalpy of liquid refrigerant leaving the Condenser.

∴ Coefficient of Performance = $\frac{\text{Refrigerating Effect}}{\text{work done}}$

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

Note:- The ratio of C.O.P of Vapour Compression Cycle to the C.O.P of Carnot cycle is known as refrigeration efficiency (η_R) or performance index (P.I)

Representation of cycle on T-S and P-h Charts:

The Vapour Compression Cycle essentially consists of Compression, Condensation, throttling and Evaporation. Many Scientists have focused their attention to increase the Co-efficient of performance of the cycles. ~~though~~ there are many cycles yet the following are importance from the subject point of view.

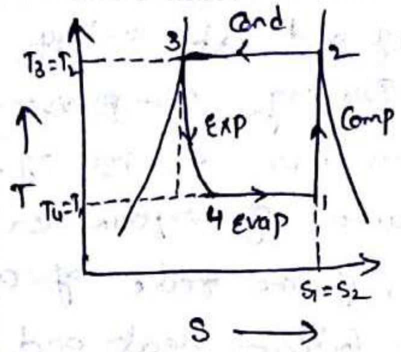
1. Cycle with dry saturated vapour after Compression
2. Cycle with wet vapour after Compression
3. Cycle with Superheated Vapour after Compression
4. Cycle with Superheated Vapour before Compression
5. Cycle with Under Cooling or Sub cooling of refrigerant.

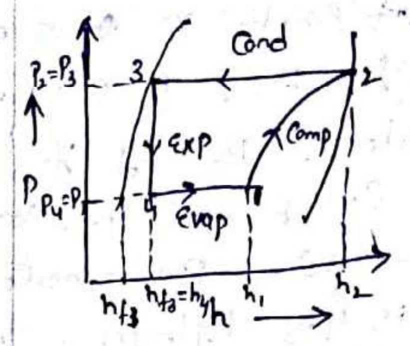
Cycle

T-S

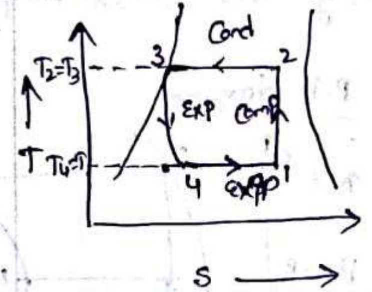
p-h

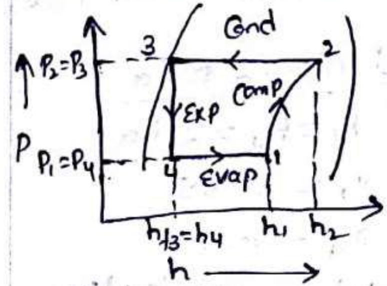
1. Cycle with dry Saturated vapour after Compression



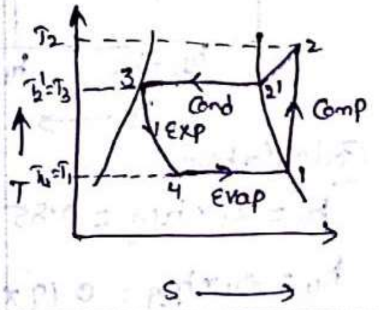


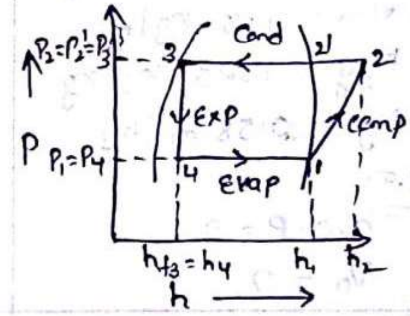
2. Cycle with wet vapour after Compression



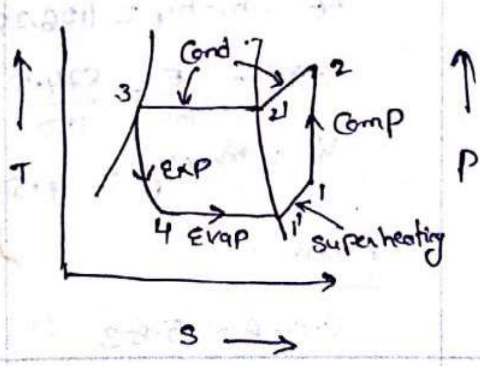


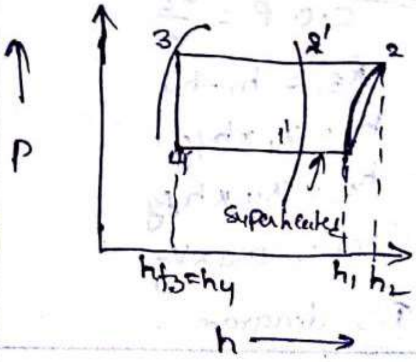
3. Cycle with Superheated vapour after Compression



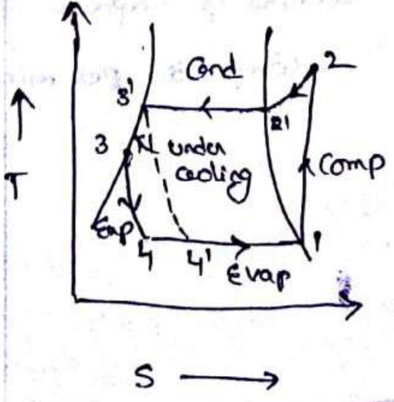


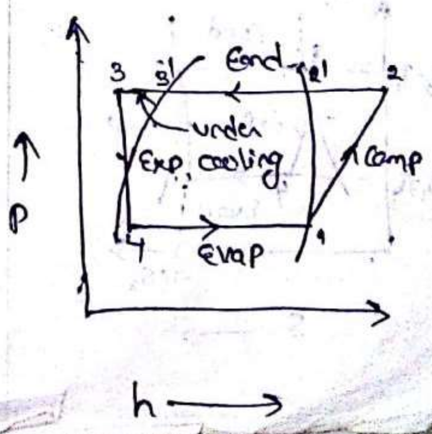
4. Cycle with superheated vapour before Compression





6. Cycle with under cooling or sub cooling of Refrigerant





⇒ In an ammonia Vapour Compression System, the pressure in the evaporator is 2 bar. Ammonia at exit is 0.85 dry and at entry its dryness fraction is 0.19. During Compression the work done per kg of ammonia is 150 kJ. Calculate the C.O.P and the volume of vapour entering the Compressor per minute, if the rate of ammonia circulation is 4.5 kg/min. The latent heat and specific volume at 2 bar are 1325 kJ/kg and 0.58 m3/kg respectively.

Sol: Given Data:

$P_1 = P_4 = 2$ bar

$x_1 = 0.85$

$x_4 = 0.19$

$W = 150$ kJ/kg

$m_a = 4.5$ kg/min

$h_{fg} = 1325$ kJ/kg

$v_g = 0.58$ m³/kg

R.T:

$C.O.P = ?$

$V_a = ?$

F.U:

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

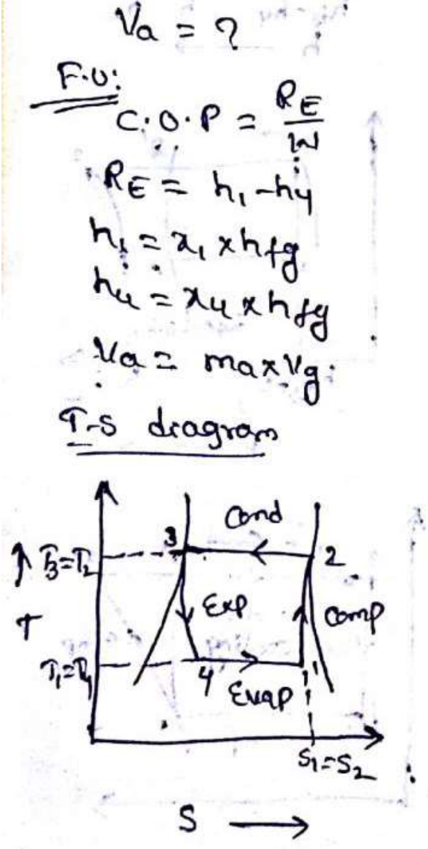
$R_E = h_1 - h_4$

$h_1 = x_1 \times h_{fg}$

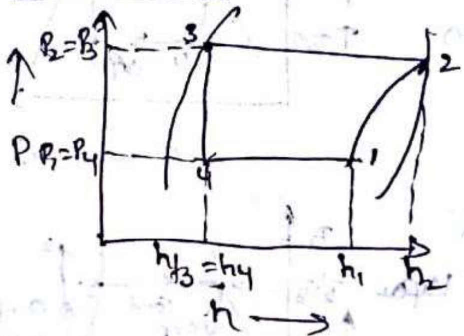
$h_4 = x_4 \times h_{fg}$

$V_a = m_a \times v_g$

T-S diagram



P-h diagram



Calculations:

$h_1 = x_1 \times h_{fg} = 0.85 \times 1325 = 1126.25$ kJ/kg

$h_4 = x_4 \times h_{fg} = 0.19 \times 1325 = 251.75$ kJ/kg

$R_E = h_1 - h_4 = 1126.25 - 251.75 = 874.5$ kJ/kg

$C.O.P = \frac{R_E}{W} = \frac{874.5}{150} = 5.83$

$V_a = m_a \times v_g = 4.5 \times 0.58 = 261$ m³/min

Answers:

$C.O.P = 5.83$

Volume of vapour entering the Compressor per minute $= 2.61$ m³/min

⇒ An ammonia refrigerating machine fitted with an expansion valve works between the temperature limits of -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 C.O.P as 60% of the theoretical, calculate the kilograms of ice produced per kW hour at 0°c from water at 10°c. Latent heat of ice is 335 kJ/kg. Ammonia has the following properties.

Temperature °c	Liquid heat (h_f) kJ/kg	Latent heat (h_{fg}) kJ/kg	Liquid entropy (S_f)	Total entropy of dry saturated vapour
2,3 30	323.08	1145.80	1.2037	4.9842
1,4 -10	135.37	1297.68	0.5443	5.4770

Given Data:

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

$T_2 = T_3 = 30°c = 30 + 273 = 303\,k$.

$x_2 = 0.95$, $h_{f3} = h_{f2} = 323.08$ kJ/kg, $h_{fg_2} = 1145.80$ kJ/kg

$h_{f1} = h_{f4} = 135.37$ kJ/kg, $h_{fg_1} = 1297.68$ kJ/kg

$s_{f2} = 1.2037$ kJ/kg K, $S_{f1} = 0.5443$ kJ/kg K

$S_2' = 4.9842$ kJ/kg K, $S_1' = 5.4770$ kJ/kg K

Actual C.O.P = 0.6 × Theoretical C.O.P

Latent heat of Ice $h_{fg} = 335$ kJ/kg

R.T:

Produced Ice = ? kg/kW hour.

R.U

Theoretical C.O.P = $\frac{h_1 - h_{f3}}{h_2 - h_1}$, $S_1 = S_{f1} + \frac{x_1 h_{fg1}}{T_1}$

$h_1 = h_{f1} + x_1 h_{fg1}$, $S_2 = S_{f2} + \frac{x_2 h_{fg2}}{T_2}$

$h_2 = h_{f2} + x_2 h_{fg2}$, $S_1 = S_2$

Produced Ice = $\frac{\text{Actual Heat Extracted}}{\text{Heat Extracted formation of Ice}}$

Actual Heat Extracted = Workdone × Actual C.O.P

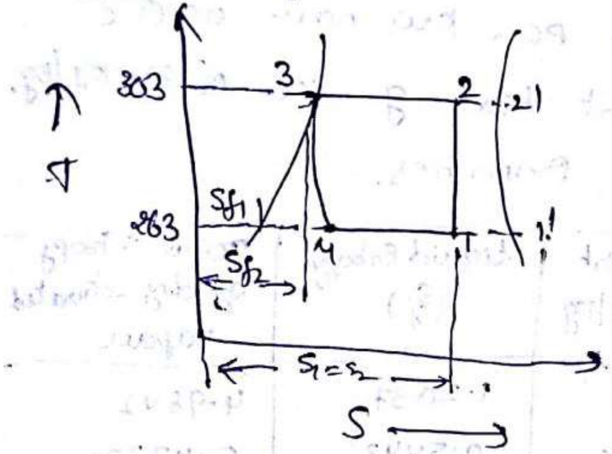
Work done W = 1 kw hour = 3600 kJ/kw hour

Actual C.O.P = 0.6 Theoretical C.O.P

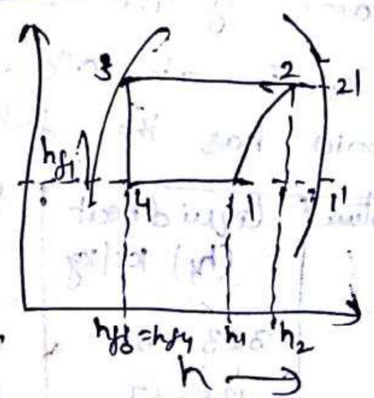
Heat Extracted from 1kg of water at 10°C for the formation of 1kg of Ice at 0°C $= 1\times 4.187\times 10 + 335$

$= 376.87$ kJ/kg

T-S diagram



P-h diagram



Calculations:

$$S_1 = S_{f1} + \frac{x_1 h_{fg1}}{T_1} = 0.5443 + \frac{x_1 \times 1297.68}{263} = 0.5443 + 4.934x_1$$

$$S_2 = S_{f2} + \frac{x_2 h_{fg2}}{T_2} = 1.2037 + \frac{0.95 \times 1145.8}{303} = 4.796$$

$S_1 = S_2$

$0.5443 + 4.934x_1 = 4.796 \Rightarrow x_1 = 0.86$

$h_1 = h_{f1} + x_1 h_{fg1} = 135.37 + 0.86 \times 1297.68 = 1251.4$ kJ/kg

$h_2 = h_{f2} + x_2 h_{fg2} = 323.08 + 0.95 \times 1145.8 = 1411.6$ kJ/kg

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{1251.4 - 323.08}{1411.6 - 1251.4} = 5.8$$

Actual C.O.P = $0.6 \times 5.8 = 3.48$

Actual Heat Extracted = $3600 \times 3.48 = 12528$ kJ/kw hour

Amount of Ice produced = $\frac{\text{Actual Heat Extracted}}{\text{Heat extracted formation of Ice}}$

$= \frac{12528}{376.87} = 33.2$ kg/kw hour.

Answer:

Amount of Ice Produced = 33.2 kg/kw hour.

⇒ A simple refrigerant 134a (tetrafluroethane) heat pump for space heating, operates between temperature limits of 15°C and 50°C. The heat required to be pumped is 100 MJ/h. Determine: 1. The dryness fraction of refrigerant entering the evaporator. 2. The discharge temperature assuming the specific heat of vapour as 0.996 kJ/kg K: 3. The theoretical piston displacement of the compressor 4. the theoretical power of the compressor: and 5. the C.O.P.

The specific volume of refrigerant 134a saturated vapour at 15°C is 0.04185 m³/kg. The other relevant properties of R-134a are given below

Saturation temperature (°C)	Pressure (bar)	Specific enthalpy (kJ/kg)		Specific Entropy kJ/kg K	
		Liquid	Vapour	Liquid	Vapour
15	4.887	220.26	413.6	1.0729	1.7439
50	13.18	271.97	430.4	1.2410	1.7312

G.D $T_1 = T_4 = 15°C = 15+273 = 288\,K$; $h_{f3} = h_4 = 271.97\ kJ/kg$

$T_2' = T_3 = 50°C = 50+273 = 323\,K$ $h_1 = 413.6\ kJ/kg$

$Q = 100\,MJ/h = 100\times10^3\ kJ/h$ $h_2' = 430.4\ kJ/kg$

$C_p = 0.996\ kJ/kgK$ $s_{f1} = 1.0729\ kJ/kgK$

$v_1 = 0.04185\ m^3/kg$ $s_1 = s_2 = 1.7439\ kJ/kg.K$

$h_{f1} = 220.26\ kJ/kg$ $s_{f3} = 1.2410\ kJ/kgK$

$s_2' = 1.7312\ kJ/kgK$

R.T

$x_4 = ?$

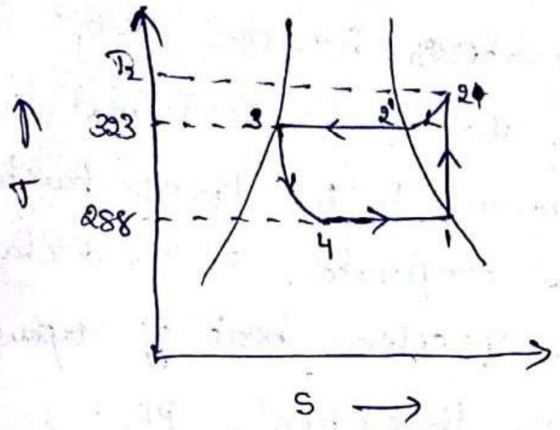
$T_2 = ?$

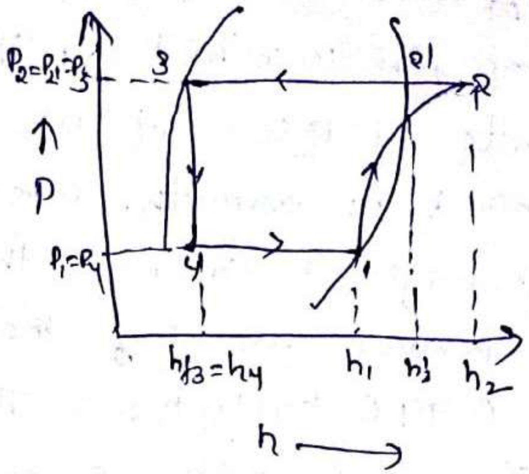
Displacement = ?

Power = ?

C.O.P = ?

~~Calculations~~: Formulas used





$$x_4 = \frac{h_4 - h_{f_1}}{h_1 - h_{f_1}}$$

$$s_2 = s_{2'} + 2.3\, c_p \log\left(\frac{T_2}{T_{2'}}\right)$$

$$h_2 = h_{2'} + c_p (T_2 - T_{2'}) \; ; \; m_R = \frac{Q}{h_2 - h_{f_3}}$$

Piston displacement = $m_R \times v_1$

$$\text{Power} = \frac{m_R (h_2 - h_1)}{60} \text{ kW}$$

$$\text{C.O.P} = \frac{h_1 - h_{f_3}}{h_2 - h_1}$$

Calculations:

$$x_4 = \frac{h_4 - h_{f_1}}{h_1 - h_{f_1}} = \frac{271.97 - 220.26}{413.6 - 220.26} = \frac{51.71}{193.34} = 0.2675$$

$$s_2 = s_{2'} + 2.3\, c_p \log\left(\frac{T_2}{T_{2'}}\right)$$

$$1.7439 = 1.7312 + 2.3 \times 0.996 \log\left(\frac{T_2}{T_{2'}}\right)$$

$$\frac{T_2}{T_{2'}} = 1.0128 \Rightarrow T_2 = 323 \times 1.0128 = 327.13K$$

$$\boxed{T_2 = 54.13^\circ C}$$

$$h_2 = h_{2'} + c_p (T_2 - T_{2'})$$

$$= 430.4 + 0.996(327.13 - 323) = 434.5 \text{ kJ/kg}$$

$$m_R = \frac{Q}{h_2 - h_{f_3}} = \frac{100 \times 10^3}{434.5 - 271.97} = 615.3 \text{ kg/h} = 10.254 \text{ kg/min}$$

Piston displacement = $m_R \times v_1$

$$= 10.254 \times 0.4185 = 4.29 \text{ m}^3/\text{min}$$

Workdone = $m_R(h_2-h_1)$

$= 10.254(434.5-413.6) = 214.3$ KJ/min

Power of the compressor = $\frac{214.3}{60} = 3.57$ KJ/s or kW

$$C.O.P. = \frac{h_1-h_{f3}}{h_2-h_1} = \frac{413.6-271.97}{434.5-413.6} = \frac{141.63}{20.9} = 6.8$$

— o —

⇒ A Vapour Compression refrigeration plant works between pressure limits of 5.3 bar and 2.1 bar. The vapour is superheated at the end of compression, its temperature being 37°C. The vapour is superheated by 5°C before entering the compressor. If the specific heat of superheated vapour is 0.63 KJ/Kg K, find the coefficient of performance of the plant. Use the data given below

Pressure bar	saturation temp °C	Liquid heat KJ/Kg	Latent heat KJ/kg
5.3	15.5	56.15	144.9
2.1	−14.0	25.12	158.7

Sol: $P_2 = 5.3$ bar

$P_1 = 2.1$ bar

$T_2 = 37°C = 37+273 = 310K$

$T_1 - T_1' = 5°C$

$C_p = 0.63$ KJ/kgK

$T_2' = 15.5°C = 15.5+273 = 288.5K$

$T_1' = -14°C = -14+273 = 259K$

$h_{f3} = h_{f2'} = 56.15$ KJ/kg

$h_{f1'} = 25.12$ KJ/kg

$h_{fg2'} = 144.9$ KJ/kg

$h_{fg1'} = 158.7$ KJ/kg

R.T

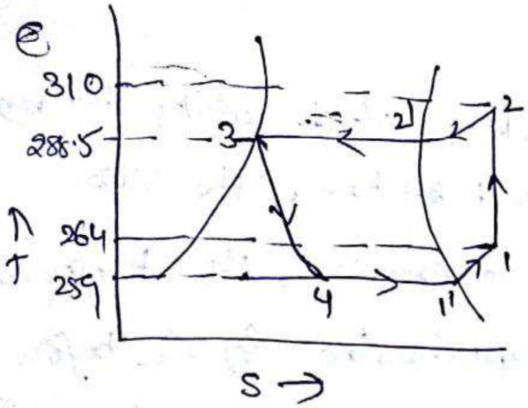
C.O.P = ?

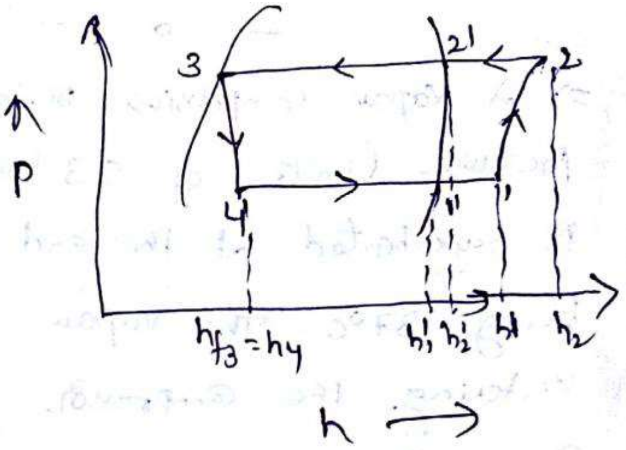
F.O

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

$$h_1 = h_1' + C_p(T_1 - T_1') = (h_{f1}' + h_{fg1}') + C_p(T_1 - T_1')$$

$$h_2 = h_2' + C_p(T_2 - T_2') = (h_{f2}' + h_{fg2}') + C_p(T_2 - T_2')$$





Calculations

$$h_1 = h_{f1}' + h_{fg1}' + C_p(T_1 - T_1')$$

$$= (25.12 + 158.7) + 0.63 \times 5 = 186.97 \text{ kJ/kg}$$

$$h_2 = (h_{f2}' + h_{fg2}') + C_p(T_2 - T_2')$$

$$= (56.15 + 144.9) + 0.63 \times (310 - 288.5) = 214.6 \text{ kJ/kg}$$

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{186.97 - 56.15}{214.6 - 186.97} = 4.735$$

⇒ A Saturated ammonia at 2.5 bar enters a 160mm × 150 mm (bore × stroke) twin Cylinder, single acting Compressor whose volumetric Efficiency is 79% and speed is 250 r.p.m. The head pressure is 12 bar. The subcooled liquid ammonia at 22°C enters the expansion valve. For a standard refrigeration cycle, Find

1. The ammonia circulated in kg/min
2. The refrigeration in TR
3. The C.O.P of the refrigeration cycle.

Refer to the following table for the properties of ammonia.

pressure bar	saturation temp °C	Specific volume m³/kg	Specific enthalpy kJ/kg		Specific entropy kJ/kgK	
			Liquid	Vapour	Liquid	Vapour
2.5	−15	0.5098	112.4	1426.58	0.4572	5.5497
12	30	0.1107	323.08	1468.87	1.2037	4.9842

Assume specific heat at constant pressure for liquid ammonia as 4.606 kJ/kg K and for superheated ammonia vapour as 2.763 kJ/kg K.

G.D:

$P_1 = P_4 = 2.5\,bar$

$D = 160\,mm = 0.16\,m$

$L = 150\,mm = 0.15\,m$

No. of. cylinders = 2

$\eta_v = 79\% = 0.79$

$N = 250$ r.p.m.

$P_2 = P_3 = 12\,bar$

$T_3 = 22°C = 22+273 = 295K$

$T_1 = T_4 = -15°C = -15+273 = 258K$

$T_2' = T_3' = 30°C = 30+273 = 303K$

$v_1 = 0.5098\,m^3/kg$, $v_2' = 0.1107\,m^3/kg$

$h_{f1} = 112.4\,kJ/kg$; $h_{f3}' = 323.08\,kJ/kg$

$h_1 = 1426.58\,kJ/kg$; $h_2' = 1468.87\,kJ/kg$

$s_{f1} = 0.4572\,kJ/kgK$; $s_{f3} = 1.2037\,kJ/kgK$

$s_1 = s_2 = 5.5497\,kJ/kgK$;

$s_2' = 4.9842\,kJ/kgK$

$c_{pl} = 4.606\,kJ/kgK$; $c_{pv} = 2.763\,kJ/$

P.T

(1) $m_R = ?$

(2) Refrigeration = ?

(3) C.O.P = ?

F.U:

$\cancel{m_R} = \frac{\text{Suction volume}}{\text{Piston displacement per min}}$

Suction volume = Piston Area × R.P.M × Stroke × No. of Cycles

Piston displacement per min = $m_R \times v_1 \times \frac{1}{m_v}$

$$\text{Refrigeration} = \frac{m_R (h_1 - h_{f3})}{210} \text{ TR}$$

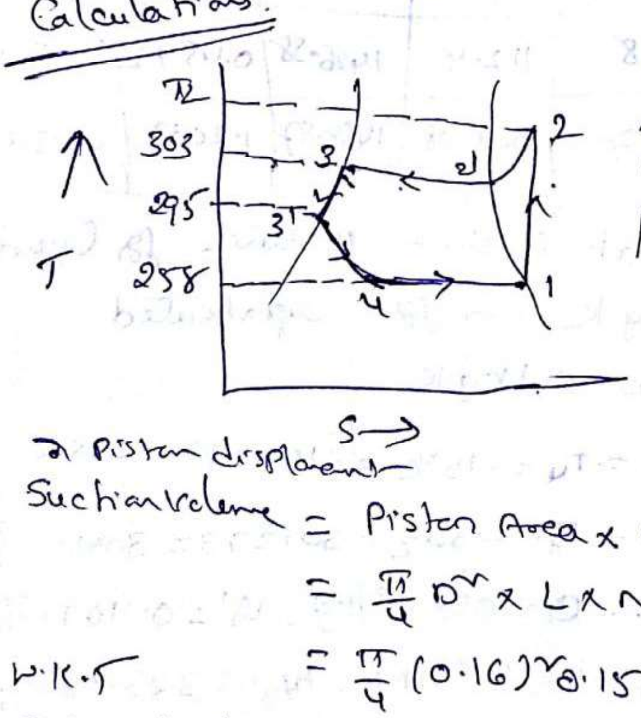
$$h_{f3} = h_{f3'} = C_{pL} (T_{3'} - T_3)$$

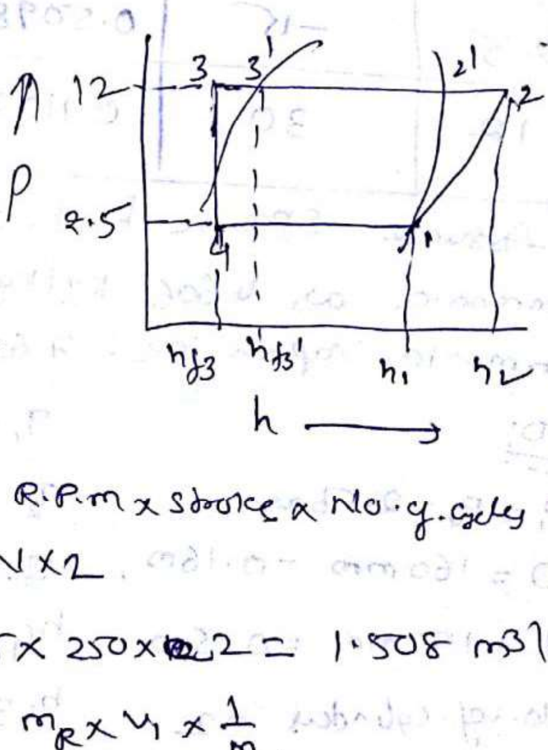
$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

$$s_2 = s_{2'} + 2.3\, C_{pv} \log\left(\frac{T_2}{T_{2'}}\right)$$

$$h_2 = h_{2'} + C_{pv}(T_2 - T_{2'})$$

Calculations:





→ Piston displacement

Suction volume = Piston Area × R.P.m × stroke × No. of cycles

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

W.K.T $= \frac{\pi}{4} (0.16)^2 \, 0.15 \times 250 \times 2 = 1.508 \text{ m}^3/\text{min}$

Piston displacement per min = $m_R \times v_1 \times \frac{1}{m_v}$

$= m_R \times 0.5098 \times \frac{1}{0.79} = 0.6453\, m_R$

$m_R\, 0.6453 = 1.508$

$m_R = \frac{1.508}{0.6453}$ = 2.3[illegible] kg/min

$h_{f_3} = h_{f_3'} - C_{pl}(T_{3'} - T_3)$

$= 323.08 - 4.606(303 - 295) = 286.23$ KJ/kg

Refrigeration or capacity of the system

$$= \frac{m_R(h_1 - h_{f_3})}{210}$$

$$= \frac{2.34(1426.58 - 286.23)}{210} = \frac{2668.4}{210} = 12.7 \text{ TR}$$

$S_2 = S_{2'} + 2.3\, C_{pv} \log\left(\frac{T_2}{T_{2'}}\right)$

$5.5497 = 4.9842 + 2.3 \times 2.763 \log\left(\frac{T_2}{T_{2'}}\right)$

$\frac{T_2}{T_{2'}} = 1.227 \Rightarrow T_2 = 371.78\text{K} = 98.78°\text{C}$

$h_2 = h_{2'} + C_{pv}(T_2 - T_{2'})$

$= 1468.87 + 2.763(371.78 - 303) = 1658.9$ KJ/kg

$$\text{C.O.P} = \frac{h_1 - h_{f_3}}{h_2 - h_1} = \frac{1426.58 - 286.23}{1658.9 - 1426.58} = \frac{1140.5}{232.32} = 4.91$$

— o —

⇒ A Vapour Compression refrigerator uses methyl Chloride (R-40) and operates between pressure limits of 177.4 KPa and 967.5 KPa. At entry to the Compressor the methyl chloride is dry saturated and after Compression has a temperature of 102°C. The Compressor has a bore and Stroke of 75mm and runs at 8 rev/s with a Volumetric Efficiency of 80%. The temperature of the liquid refrigerant as it leaves the Condenser is 35°C and its specific heat capacity is 1.624 KJ/kg K. The Specific heat capacity of superheated vapour may be assumed to be constant. Determine 1. refrigerator COP 2. mass flow rate of refrigerant and 3. Cooling water required by the Condenser if its temperature rise is limited to 12°C. Specific heat capacity of water = 4.187 kJ/kgK. The relavent properties of methyl Chloride are as follows.

sat temp °C	Pressure kPa	Specific volume m3/kg		specific enthalpy kJ/kg		specific Entropy kJ/kg K	
		Liquid	vapour	Liquid	Vapour	Liquid	Vapour
-10	177.4	0.00102	0.233	45.38	460.76	0.183	1.762
45	967.5	0.00115	0.046	132.98	483.6	0.485	1.587

Sol:-

G.D

$P_1 = P_4 = 177.4$ kPa

$P_2 = P_3 = 967.5$ kPa

$T_2 = 102°C = 102+273 = 375$ K

$D = L = 75$ mm $= 0.075$ m

$N = 8$ r.p.s $= 480$ r.p.m

$\eta_v = 80\% = 0.8$

$T_3 = 35°C = 35+273 = 308$ K

$C_{pL} = C_{pv} = 1.624$ kJ/kg K

$C_{pw} = 4.187$ kJ/kg K

temp rise limit $= 12°C$

$T_1 = T_4 = -10°C = -10+273 = 263$ K

$T_{2'} = T_{3'} = 45°C = 45+273 = 318$ K

$v_1 = 0.233$ m3/kg

$v_{2'} = 0.046$ m3/kg

$h_{f1} = 45.38$ kJ/kg

$h_{f3'} = 132.98$ kJ/kg

$h_1 = 460.76$ kJ/kg

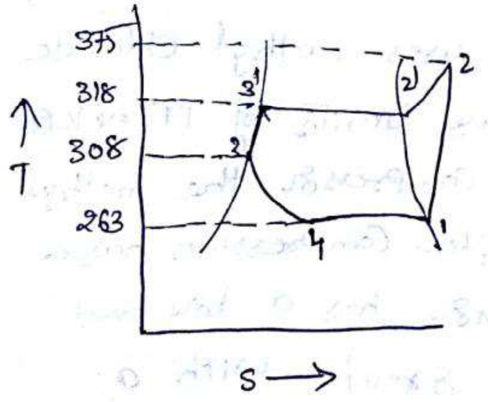
$h_{2'} = 483.6$ kJ/kg

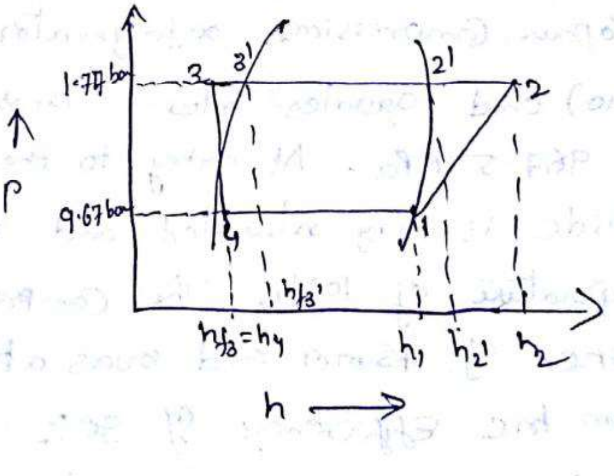
$S_{f1} = 0.183$ kJ/kg K

$S_{f3} = 0.485$ kJ/kg K

$S_1 = S_2 = 1.762$ kJ/kg K

$S_{2'} = 1.587$ kJ/kg K





R.T:

1. C.O.P = ?
2. m_R = ?
3. m_w = ?

F.O $C.O.P = \dfrac{h_1 - h_{f3}}{h_2 - h_1}$; $h_2 = h_{2'} + C_{pv}(T_2 - T_{2'})$; $h_{f3} = h_{f3'} - C_{pL}(T_{3'} - T_3)$

suction volume (or) Piston Displacement = Piston Area × stroke × RPM $= m_R \times v_1 \times \frac{1}{\eta_v}$

Heat given out by the refrigerant in the Condenser = heat taken by ~~water~~ in the Condenser

$m_R(h_2 - h_{f3}) = m_w \times C_{pw} \times$ Rise in temp

Calculations.

$$h_2 = h_{2'} + C_{pv}(T_2 - T_{2'}) = 483.6 + 1.624(375 - 318) = 576.2 \text{ kJ/kg}$$

$$h_{f3} = h_{f3'} - C_{pl}(T_{3'} - T_3) = 132.98 - 1.624(318 - 308) = 116.74 \text{ kJ/kg}$$

$$C.O.P = \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{460.76 - 116.74}{576.2 - 460.76} = 2.98$$

(ii) Piston Area × Stroke × R.P.M = $m_R \times V_1 \times \frac{1}{\eta_v}$

$$\frac{\pi}{4}(0.075)^2 \times 0.075 \times 480 = m_R \times 0.233 \times \frac{1}{0.8}$$

$$0.16 = 0.29\, m_R$$

$$m_R = \frac{0.16}{0.29} = 0.55 \text{ kg/min}$$

(iii) $m_R \times (h_2 - h_{f3}) = m_w \times C_{pw} \times$ Rise in temp

$$0.55(576.2 - 116.74) = m_w \times 4.187 \times 12$$

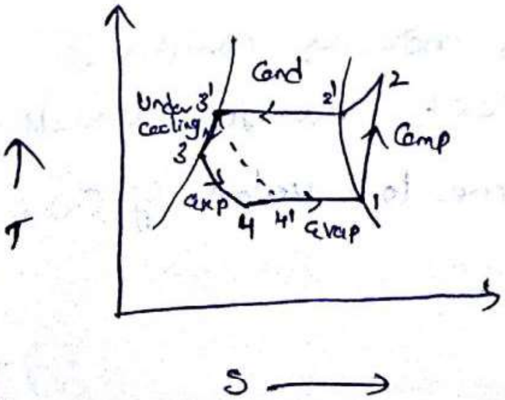
$$252.7 = 50.244\, m_w$$

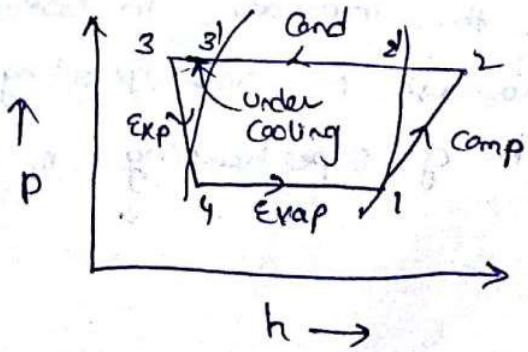
$$m_w = \frac{252.7}{50.244} = 5.03 \text{ kg/min}$$

* * *

Effect of Subcooling and Super heating :

Effect of Subcooling of Liquid: Subcooling is the process of cooling the liquid refrigerant below the condensing temperature for a given pressure.





⇒ The Effect of subcooling is to increase the refrigerating effect. thus increase in C.O.P, provided that no further energy has to be spent to obtain the extra cold coolant required.

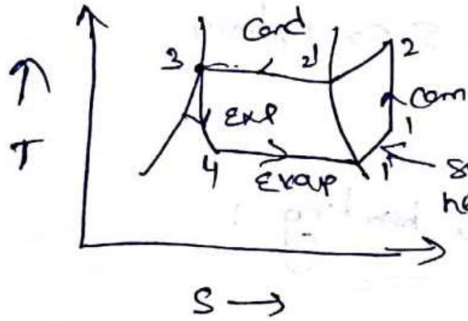
The sub cooling or under cooling is obtained by

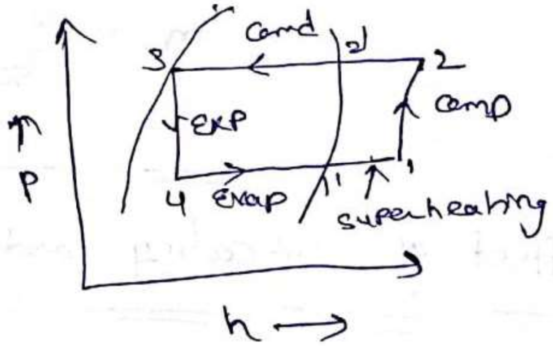
(i) Inserting a special coil between condenser & Expension device

(ii) Circulating greater quantity of cooling water through the condenser

(iii) Using water cooler than main circulating water,

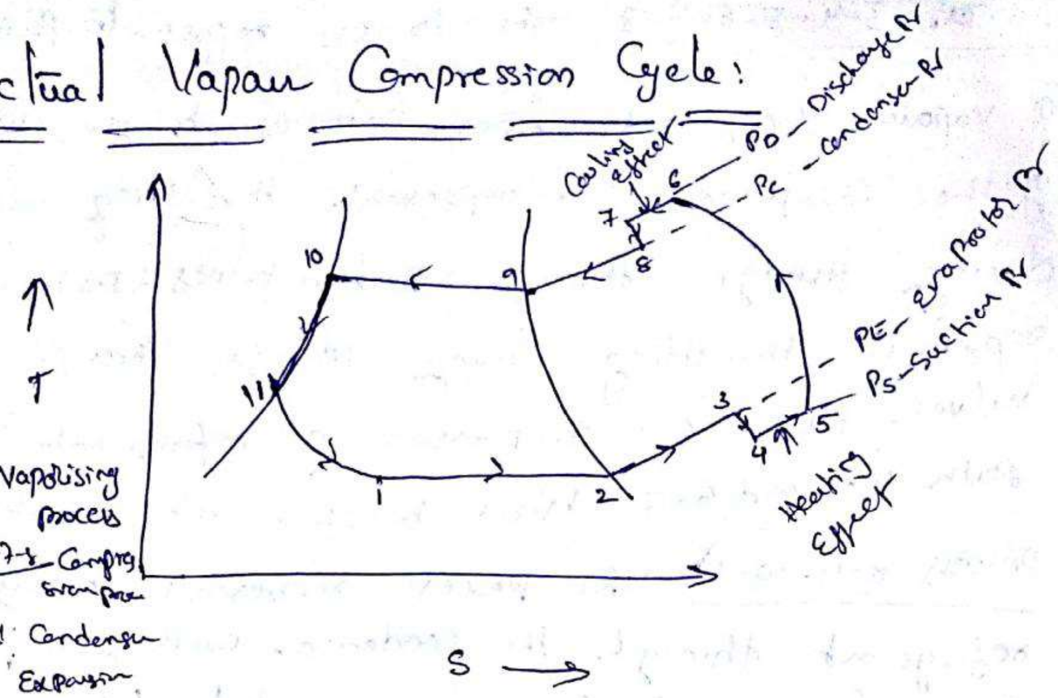
Effect of super heating:





⇒ The Effect of super heating is to increase the refrigerating Effect but this increase in refrigerating Effect is at the cost of increase in amount of work spent to obtain the upper Pressure limit since the increase in work is more as compared to increase in refrigerating Effect, therefore overall Effect of superheating is to give low value of C.O.P

Actual Vapour Compression Cycle:



1-2-3: Vaporising process

3-4-5-6-7-8 Compression process

8-9-10-11 Condenser

11-1 – Expansion

The actual cycle differs from theoritical cycle in several ways.

(i) Compression assumed to be isentropic, may actually neither isentropic nor polytropic.

(ii) The liquid refrigerant is subcooled before it is allowed to enter the expansion valve and gas leaving the evaporator is superheated a few degrees before it enters the compressor.

(iii) Pressure drop in long suction and liquid line piping.

(iv) Actual suction pressure inside the compressor to be slightly below that of evaporator and the discharge pressure to be above that of condenser.

Process 1-2-3: The process represents passage of refrigerant through the evaporator with 1-2 indicate gain of latent heat of vapourisation and 2-3 gain of superheat before entrance to compressor.

Process 3-4-5-6-7-8: The process represents passage of vapour refrigerant from entrance to the discharge of the compressor. 3-4 represent throttling action during passage through suction valves. Path 7-8 represent throttling during passage through exhaust valves. Path 5-6 : Compression of refrigerant. Path 4-5 and 6-7 : Heat transfer at constant pressure.

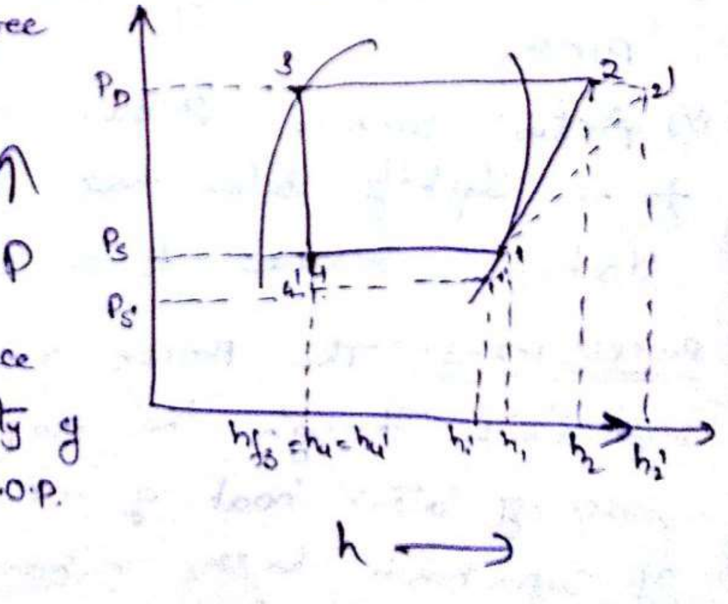
Process 8-9-10-11: The process represents passage of refrigerant through the condenser with 8-9 indicate removal of superheat, 9-10 removal of latent heat, 10-11 removal of heat of liquid or subcooling.

Process 11-1: The process represent passage of refrigerant through expansion valve, adiabatic process.

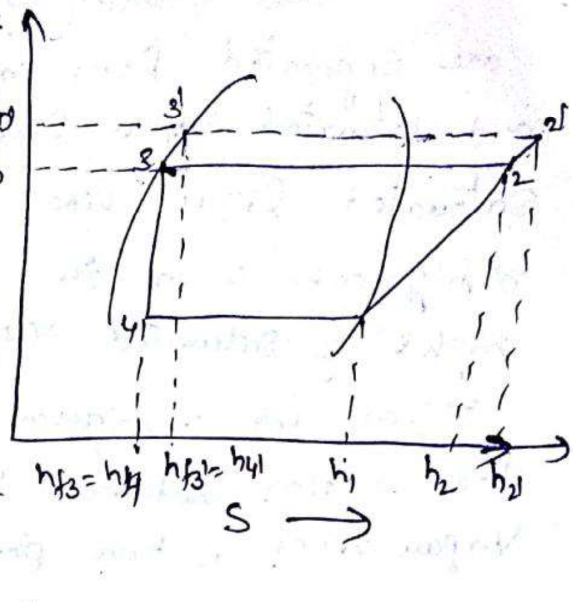
Influence of Various Parameters on System Performance:

① Effect of Suction Pressure:

The effect of degree in suction pressure is refrigerating effect is decreased and work required is increased. The net effect is to reduce the refrigerating capacity of the system and the C.O.P.



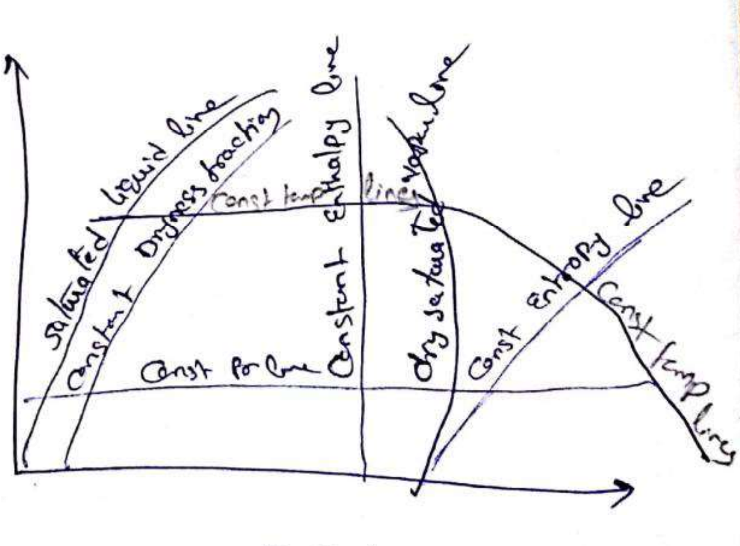
② Effect of Delivery Pressure:-



The Effect of Increase in delivery Pressure is ↑ Similar to effect of decreasing the suction pressure. The only difference is that the Effect of decreasing the Suction pressure is more Predominant than the effect of increasing the discharge pressure. The increase in discharge pressure is necessary for high Condensing temperature and decrease in Suction pressure is necessary to maintain low temperature in the evaporator.

Use of P-h charts:-

The analysis of ↑ refrigerating pressure Cycle are done by P-h charts.



The Condition of the refrigeration in any thermo-dynamic state can be represented as a point on the P-h. chart, point is located if any two properties of the refrigerant for that state are known the other properties of the refrigerant for that state can be determined directly from the chart for studying the performence of the machines.

The Chart is dividing into 3 areas that are separated from each other by the saturated liquid and saturated vapour lines. The region on the left of saturated liquid line is called sub cooled region, refrigerant is in the liquid phase. The area to the right of saturated vapour line is called superheated region and refrigerant is a superheated vapour. The section between saturated liquid and saturated vapour lines is two phase region is wet vapour region.