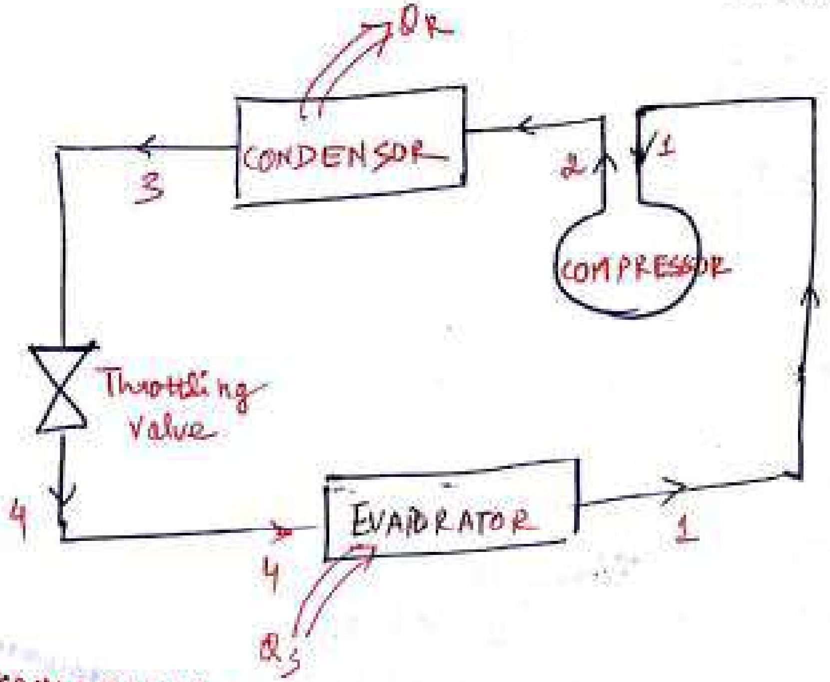
Vapour compression Ref. system

Notes by Vaibhav Sir



Compressor

It is used to inc. both pressure & temp.

Condensor :- It is a type of heat exchanger in which heat is rejected at constt pressure.

Throttling valve : Flow thru a restricted passage, partially opened valve is known as throttling.

NOTE

1) Throttling is also known as isenthalpic proce
2) Throttling is an irreversible adiabatic process.
3) Throttling always results a decrease in pres

Evaporator :- It is also a form of heat exchanger i which heat is supplied at constt. pressure

Assumptions

1) Entry to the compressor or exit of evapora (state - 1) is saturated vapour.
2) Exit of condensor or entry of enthrottling (state-3) is saturated liquid.

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T-S diagram

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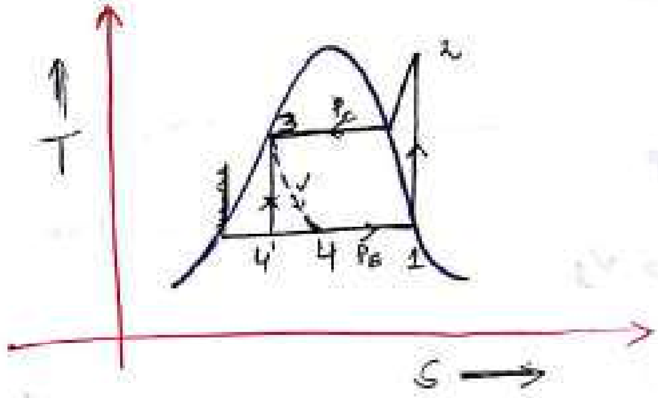


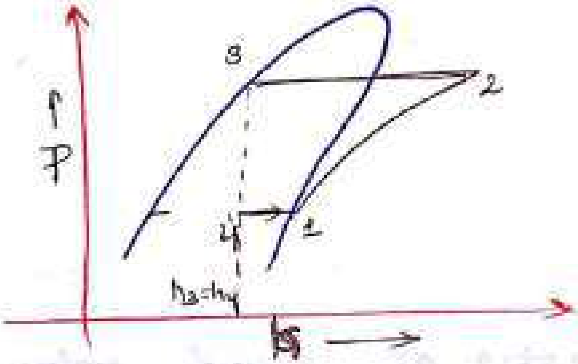
(1-2)
→ Rev. adiabatic or isentropic compression.

(2-3)
→ Heat rejection at constt. pressure.

(3-4)
→ Isenthalpic process.

(4-1)
→ constt press heat add^n.

$$\boxed{COP = \frac{RE}{W_{I/P}} = \frac{h_1 - h_4}{h_2 - h_1}}$$



$$(RE)_{h_3 = h_4} = h_1 - h_4$$

$$\uparrow (RE)_{s_3 = s_4'} = h_1 - h_4'$$

$$\uparrow COP = \frac{RE}{W_{I/P}} = \frac{RE}{W_C - W_E}$$

Q) why Isentropic exp^n is not used in V.C.R.S ?

A1:- The state of the refrigerant at the entry of expander is saturated liquid and its work is provided by $w = -\int v_f \, dp$

where, v → sp. volume of saturated liq which is neg. as compared to sp. vol. of saturated vapour handled by the compressor.

Therefore with the use of isentropic exp^n for the negligible work in comparison to the comp. the cost of the expander is not justified hence isenthalpic exp^n is preferable.

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$\downarrow W_m = W_c - (W_E)\uparrow$

$\rightarrow s_3 = s_4' = 0 \quad ds = 0$ — valve

$\rightarrow h_3 = h_4 \rightarrow ds > 0$

$\rightarrow$ Cap. tube

$W_c \rightarrow \int v_g\, dp \qquad W_E \rightarrow \int v_f\, dp$

$v_g >>>> v_f$

$$\boxed{W = -\int v_f \cdot dp}$$

NOTE

1) $RE = (h_1 - h_4)$ KJ/Kg

2) $RC = \dot{m} \times RE$ KW

$\frac{Kg}{s} \times \frac{KJ}{Kg}$

$W_{\tau/p} = (h_2 - h_1) \cdot$ KJ/Kg

$P_{in} = \dot{m} \times W_{\tau/p}$.

Volumetric efficiency OF a Reciprocating Compressor

It is defined as the ratio OF actual volume OF the working fluid entering the compressor to the theoritical swept volume.

$$\boxed{\eta_v = \frac{\dot{m} \cdot v_{entry}}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times K}}$$

$\dot{m}$ → mass flow rate taken in (Kg/s)

v → Sp. volume at the entry OF compressor (m^3/Kg)

D → dia. or Bore. (m)

L → Stroke length (m).

N → Speed in RPM.

K → no. of cylinders ($K=1$ if not given).

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Q) Prove the Volumetric eff. is provided by the expression.

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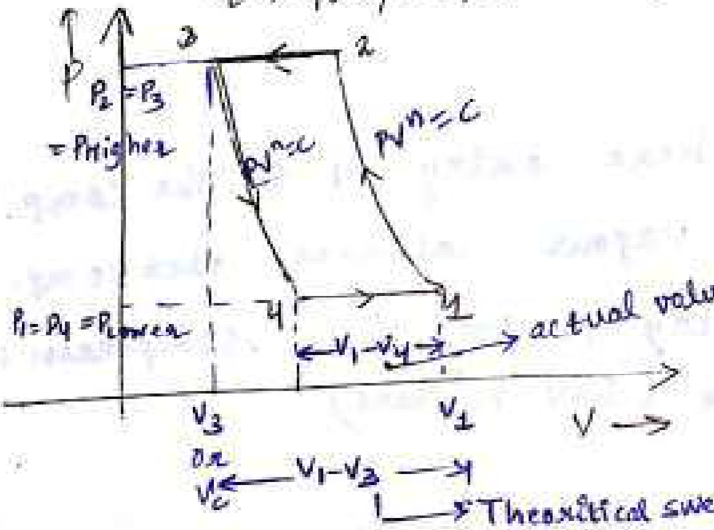
$$\eta_v = 1 + C - C\left(\frac{P_H}{P_L}\right)^{1/n}$$

$$\boxed{C \rightarrow \text{Clearence Ratio } \left(\frac{V_c}{V_s}\right)}$$

(It is defined as the Ratio of clearence volume to theoritical swept vol)

$n \rightarrow$ polytropic Index



$$\eta_v = \frac{A.V}{T.S.V}$$

$$\eta_v = \frac{V_1 - V_4}{V_1 - V_3} = \frac{V_1 - V_4 + V_3 - V_3}{V_1 - V_3}$$

$$\eta_v = \frac{(V_1 - V_3) + (V_3 - V_4)}{(V_1 - V_3)}$$

$$\Rightarrow \eta_v = \frac{V_1 - V_3}{V_1 - V_3} + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3}$$

$$\eta_v = 1 + \frac{V_c}{V_s} - \frac{V_4}{V_s} \cdot \frac{V_c}{V_c}$$

$$\left(\frac{V_4}{V_3}\right)^n = \left(\frac{P_3}{P_4}\right)$$

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

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

$$\Rightarrow \boxed{\eta_v = 1 + \underbrace{c}_{\text{Clearence Ratio}} - c\left(\frac{P_H}{P_L}\right)^{1/n}}$$

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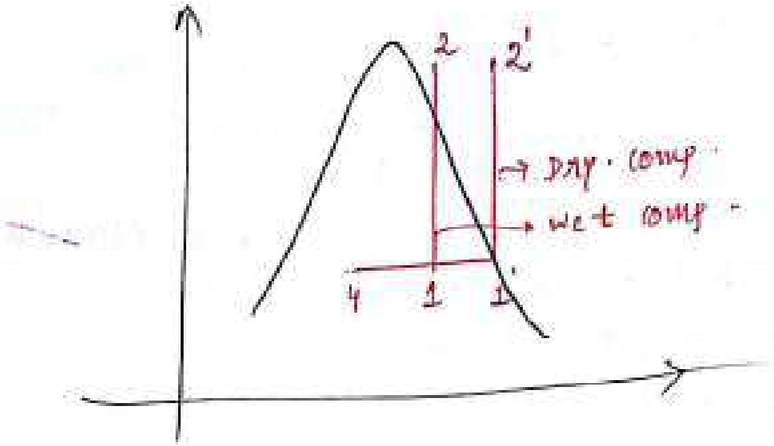
Dry compression Vs. Wet compression



Dry compression :- here entry pt to the comp. from saturated vapour whereas wet comp. means the entry pt to the compressor is from wet region (L+V mixture)

Disadvantage of wet compression over dry compres

1) R·E decreases

$(RE)_{DC} = h_1' - h_4$

$\downarrow (RE)_{WC} = h_1 - h_4$

2) wet compression represents the incomplete evaporation of the mixture.

3) At the entry of compressor, There is a mixture of liq. & Vapour & the liq. refrigerant which is present in the mixture may wash away the lubricant & hence increases the chances of wear & tear

Effect of variation in parameter on the Performance of VCRS

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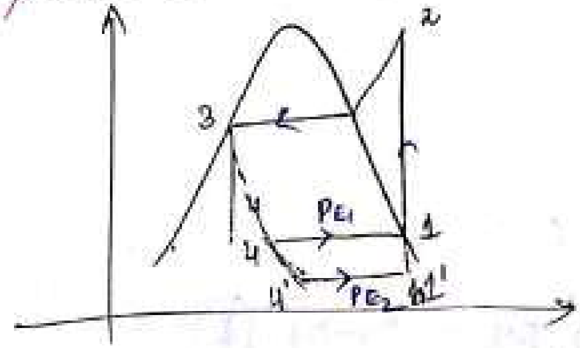
1) Decrease in Evaporator pressure



1 - 2 - 3 - 4 - 1

1) $R.E = h_1 - h_4$

2) $W_{I/P} = h_2 - h_1$

3) $COP = \frac{R.E}{W_{I/P}}$

4) $\frac{P_c}{P_{E_1}}$

1 - 2 - 3 - 4' - 1'

1) $R.E = h_1' - h_4'$ ⓓ$\downarrow$

2) $W_{I/P} = h_2 - h_1'$ $\uparrow$

3) $COP = \frac{R.E \downarrow}{W_{I/P} \uparrow} \Rightarrow \downarrow\downarrow$

4) $\frac{P_c}{P_{E_2}}$ $\uparrow$

$\eta_v = 1 + c - \left[c\left(\frac{P_H}{P_L}\right)^{1/n} \uparrow\right] \Rightarrow$ $\eta_v \downarrow$

1) R.E effect decreases
2) $W_{I/P}$ increases
3) COP decreases.
4) η_v decreases.

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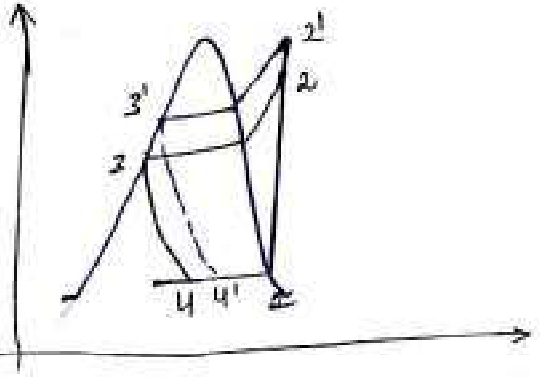
Notes by Vaibhav Sir

CASE-2

Inc. in cond. pressure



1 - 2 - 3 - 4 - 1	1 - 2' - 3' - 4' - 1
1) $R \cdot E = h_1 - h_4$	1) $R \cdot E = h_1 - h_4'$ (↓)
2) $W_{I/P} = h_2 - h_1$	2) $W_{I/P} = h_2' - h_1$ (↑)
3) COP ⟶	3) $COP = \dfrac{R \cdot E \downarrow}{W_{I/P} \uparrow}$ (↓↓)
4) $\dfrac{P_{C_1}}{P_E}$	4) $\dfrac{P_{C_2}}{P_E} \uparrow$, η_v (↓)

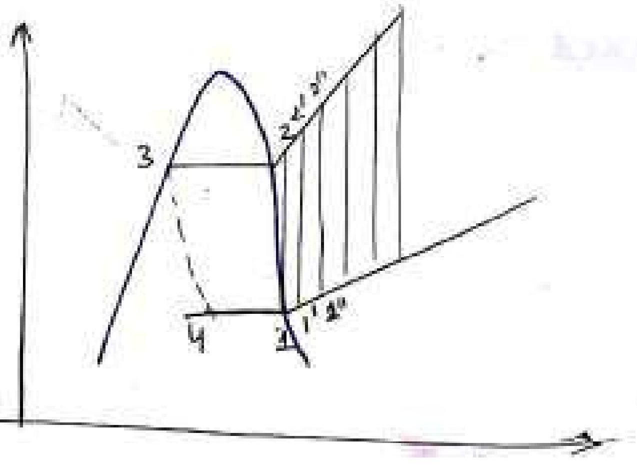
NOTE

Effect of Inc. in condenser pressure & dec in Evaporator pressure are exactly same

CASE-3

Superheating (within the evaporator):

It is the process of inc the Temperature at constt pressure above saturated vapour.



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Notes by Vaibhav Sir

$\boxed{1-2-3-4-1}$

1) $RE = h_1 - h_4$

2) $W_{I/P} = h_2 - h_1$

3) COP ⟶

(S4) $\boxed{1'-2'-3-4'-1'}$

2) $RE = h_1' - h_4 \uparrow$

2) $W_{I/P} = h_2' - h_1' \uparrow$

3) $COP = \dfrac{RE \uparrow}{W_{I/P} \uparrow} \Rightarrow$ can't say. ↑ or ↓

$W_{1-2} = n\left[W_{closed}\right]$

$$= n\left[\frac{P_I V_I - P_F V_F}{n-1}\right] = \frac{n}{n-1}\left[P_1 V_1 - P_2 V_2\right]$$

$PV = mRT$

$$\Rightarrow W_{1-2} = \frac{n}{n-1} \cdot mR\left[T_1 - T_2\right]$$

$$= \frac{n}{n-1} \times mR \cdot T_1\left(1 - \frac{T_2}{T_1}\right) \quad \text{—①}$$

$PV^n = C$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \Rightarrow \frac{T_2}{T_1} = \left(\frac{P_c}{P_E}\right)^{(n-1)/n} \quad \text{—②}$$

as $P_1 = P_1' = P_1''' = P_E$ & $P_2 = P_2' = P_2'' = P_2''' = P_c$.

⇒ use —② in —①

$$\Rightarrow W_{1-2} = \frac{n}{n-1}\, mR \cdot \boxed{T_1}\left(1 - \left(\frac{P_c}{P_E}\right)^{(n-1)/n}\right)$$

$W_{1-2} = \text{const} \times T_1$

$$\Rightarrow W_{1-2} = f(T_1) \Rightarrow \boxed{W_{1-2} = f\left(T_{Inlet}\right)}$$

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1) Ref. effect increases if superheating occurs in evaporator.

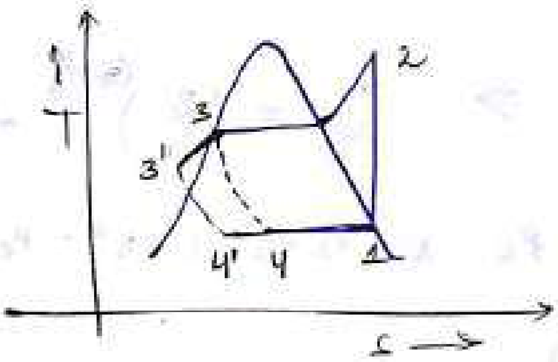
2) $W_{I/P}$ to the compressor increase because it is a f^n of inlet temp to the compressor

3) COP may increase or decrease depending on the refrigerant. eg R_{12}

In case of R_{12} ref. superheating will result an inc. in cop. whereas in case of ammonia superheating would result a decrease in COP.

CASE IV → Subcooling

It is a process of dec the temp at const. Pressure below saturated liquid.



1 - 2 - 3 - 4 - 1	1 - 2 - 3' - 4' - 1
1) $RE = h_1 - h_4$	1) $RE = h_1 - h_{4'}$ $\uparrow$
2) $W_{I/p} = h_2 - h_1$	2) $W_{I/p} = h_2 - h_1$ same
3) $COP = \frac{RE}{W_{I/p}}$ →	3) $COP = \frac{RE \uparrow}{W_{I/p}\ \text{const}} \Rightarrow COP \uparrow$

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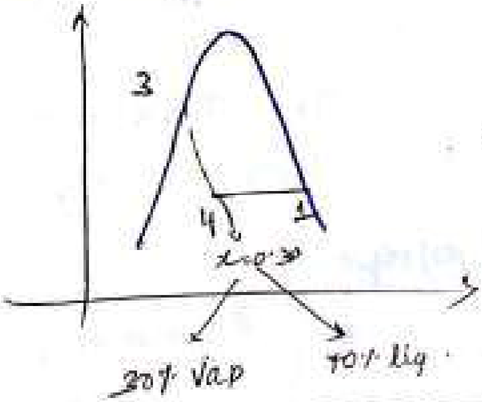
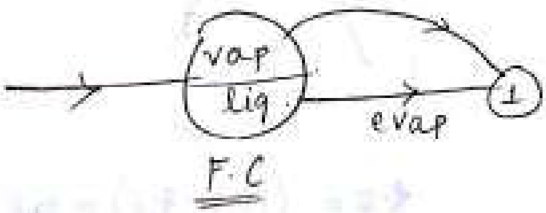
Use of Flash Chamber in VCRS

Notes by Vaibhav Sir

Flash chamber → It is a device which is used to separate liq. ref. From the vapour at the entry of evaporator and it is the only liq. refrigerant allowed to enter into the evaporator results in absorbtion of heat From the storage space.

NOTE Thermodynamically there is no change in COP with the use of Flash Chamber.





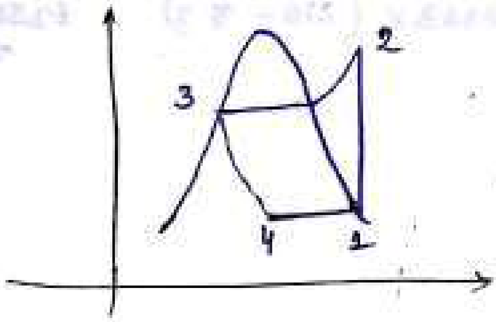
Q) In a VCRS the Following data are Obtained

i) Enthalpy at the inlet of comp is 180 KJ/kg

ii) " " " outlet of " " 210 KJ/kg

" " " exit of expander is 80 KJ/kg

Find the COP.



$h_1 = 180\ KJ/kg$

$h_2 = 210\ KJ/kg$

$h_4 = 80\ KJ/kg$.

$$COP = \frac{RE}{WI/p} = \frac{180-80}{210-180}$$

$$= \frac{100}{30} = \underline{\underline{3.33}}$$

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Q) In a 5 kW cooling capacity ref. s/m o/p on a Simple VCRS; the ref. enters the evaporator with the enthalpy of 75 KJ/kg, & leaves the at the enthalpy of 183 KJ/kg; the enthalpy of ref. after compression is 210 KJ/kg, then calculate

1) COP
2) Power
3) Rate of H.T across condenser in kW.

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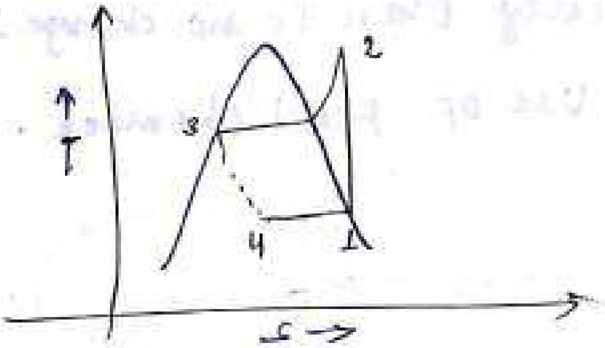

R.C = 5 KW.

$h_1 = 183$ KJ/kg
$h_4 = 75$ KJ/kg

$R.E = (183 - 75) = 108$ KJ/kg

1) $COP = \frac{R.E}{W_{I/p}} = \frac{183-75}{h_2-h_1} = 4$

$R.C = \dot{m} \times R.E$
$\dot{m} = \frac{5}{108}$
$\boxed{\dot{m} = 0.0463 \text{ kg/s}}$

2) $Power = \dot{m} \times W_{I/p}$

$= 0.0463 \times (h_2 - h_1) = 0.0463 (210 - 183)$
$= 1.2501$ kW.

3) Rate of H.T $= \dot{m}(h_2 - h_3)$

$= 0.0463 \times (210 - 75) = 6.2505$ kW

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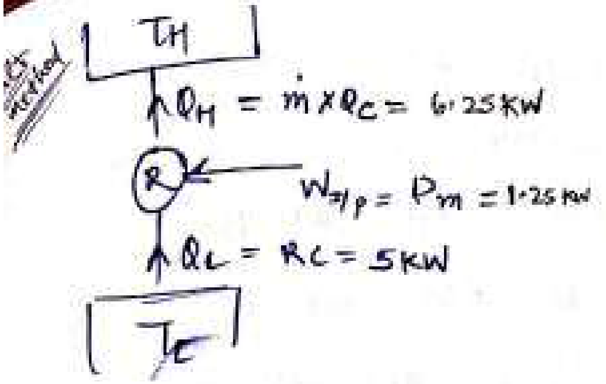

$$COP = \frac{RE}{W_{I/P}}$$

$$4 = \frac{\dot{m} \times R.E}{\dot{m} \times W_{I/P}} = \frac{R.C}{P}.$$

$$4 = \frac{5}{P} \Rightarrow \boxed{P = 1.25\,KW}$$

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2) In a simple VCRS following prop. of refrigerant at various points are given below.

	h (KJ/kg)	v (m3/kg)
comp. inlet	183.2	0.0767
comp. outlet	222.6	0.0614
cond. exit	84.9	0.00083

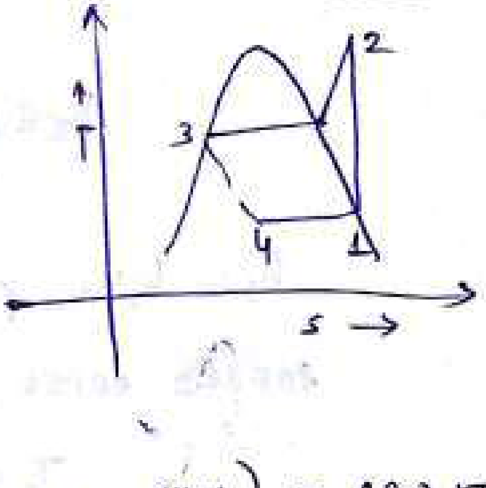
The piston displacement volume is 1.5 litres i.e swept volume having 80% volumetric eff. & speed is 1600 rpm. Find i) R.E (in KW).

ii) $P_{I/P}$ to comp (in KW)

$$\eta_v = \frac{m \times V_{entry}}{\left(\frac{\pi}{4} \times D^2 \times L\right) \times \frac{N}{60} \times K}$$

$$0.8 = \frac{\dot{m} \times 0.0767}{(1.5 \times 10^{-3}) \times \frac{1600}{60}}$$

$$\boxed{\dot{m} = 0.4172\ kg/s}$$



i) $R.E = (h_1 - h_4) = (183.2 - 84.9) = 98.3\ KJ/kg$

$RC = \dot{m}(h_1 - h_4) = \boxed{R.C = 41.4\ KW}$

ii) $P_{I/P} = \dot{m}(h_2 - h_1) = 0.4172(222.6 - 183.2)$

$= 16.437\ KW$

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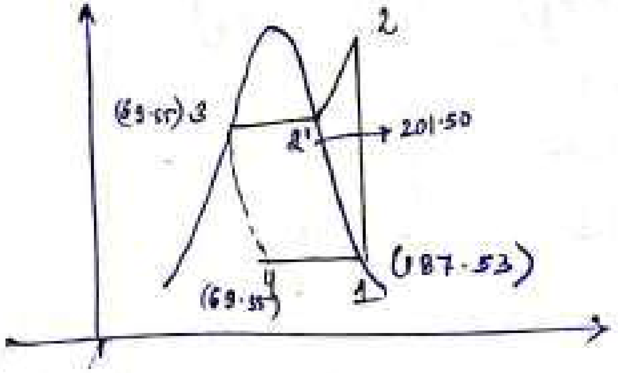
Q) A ref. operating on simple V-C-R-S having a COP of 6.5. The enthalpy of saturated liq. and saturated vapour ref. at the operating cond. temp of 35°C are 69.55 KJ/kg and ~~240~~ 201.50 KJ/kg. The saturated ref vapour leaving the evap. having a enthalpy of 187.53 KJ/kg, The sp. heat of vap. ref are 0.6155K

Find the comp. discharge Temp in °C.



$$COP = \frac{R.E}{W_{I/p}}$$

$$6.5 = \frac{187.53-6}{W_{I/p}}$$

$$\boxed{W_{I/p} = 18.153K}$$

$$W_{I/p} = h_2 - h_1$$

$$\Rightarrow h_2 = 18.15 + 187.53$$

$$\boxed{h_2 = 205.68 \text{ KJ/kg}}$$

~~$h_2 = C_p T_2$~~

~~$T_2 = 334.168 K$~~

$$h_2 = h_2' + c_p (T_2 - T_2')$$

$$205.68 = 201.50 + 0.6155(T_2 - 35)$$

$$T_2 = 35 + 6.791$$

$$\boxed{T_2 = 41.79°C}$$

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Q) A ref based on simple VCRS operates b/w the temp limits of −20°C & +40°C. The ref enters the condenser as saturated vapour & leaves as saturated liquid. The enthalpy & entropy values for saturated liq. & sat vapour are given below in the form of table. Find i) COP

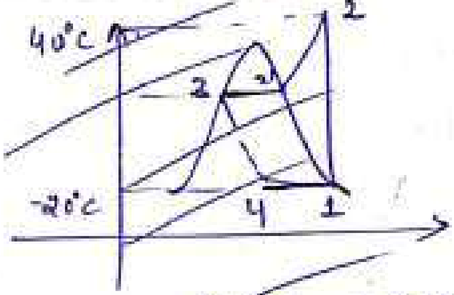
ii) If the ref. circulation rate is 0.025 kg/s then find R.E in KW.

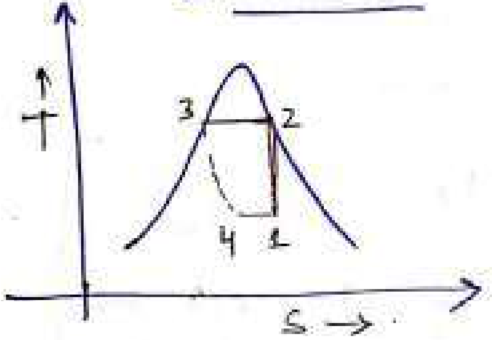
S/N

t°C	h_f	h_g	s_f	s_g
−20°C	20	180	0.07	0.7366
+ 40°C	80	200	0.3	0.67

~~i) $COP = \frac{R.E}{W_{I/P}} = \frac{h_1-h_4}{h_2-h_1}$~~

~~$= 180 - 20$~~





~~$S_1 = S_2 = 0.7366$~~

~~$S_2 = S_{g}' + c_p \ln\left(\frac{T_2}{T_3}\right)$~~

~~$0.7366 = 0.6 + c_p \ln\left(\frac{313}{T_1}\right)$~~

$S_1 = S_2 = 0.67$

~~$0.67 = 0.3 + x(0.67 - 0.3)$~~

$0.67 = 0.07 + x(0.7366 - 0.07)$

$\boxed{x = 0.9}$

$h_1 = h_f + x \times h_{fg}$

$= 20 + 0.9 \times (180 - 20)$

$\boxed{h_1 = 164 \text{ KJ/kg}}$

i) $COP = \frac{R.E}{W_{I/P}} = \frac{h_1 - h_4}{h_2 - h_1}$

$= \frac{164 - 80}{200 - 164}$

$\boxed{COP = 2.333}$

ii) $R.C = \dot{m} \times R.E$

$= 0.025 \times (164 - 80)$

$= \underline{2.1 \text{ KW}}.$

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Q) A VCRS s/m using R12 is employed to Produce 8640 kg of ice/day. The cond & evaporator of refrigerant are 48°C & -20°C respectively. Saturated liquid leaves the condenser and saturated vapour leaves the evaporator. The compression is isentropic & water at 35°C is used to form the ice and the temp. of ice should be -8°C. Heat flows into the brine tank from the surr. which is 10% of total heat removed from water to form ice. Determine the power req. to drive the compressor in kW.

Take C_p (ice) = 2.26 KJ/kg-K ;

L.H (ice) = 334 KJ/kg

C_p (water) = 4.187 KJ/kg K.

Assume C_p(vap ref) = 0.82 KJ/kg-K.

t°C	P(bar)	h_f	h_g	S_f	S_g
48	11.64	82.83	205.83	0.2973	0.6802
-20	1.51	17.82	178.74	0.0731	0.7087

$$\dot{m} = 8640 \text{ kg/day}$$

$$= \frac{8640}{24 \times 3600} = \underline{0.1 \text{ kg/s}}$$

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amt of heat removed/kg of ice

Notes by Vaibhav Sir

$= C_{pw}(35-0) + 334.72 + C_{pice}(0-(-8))$

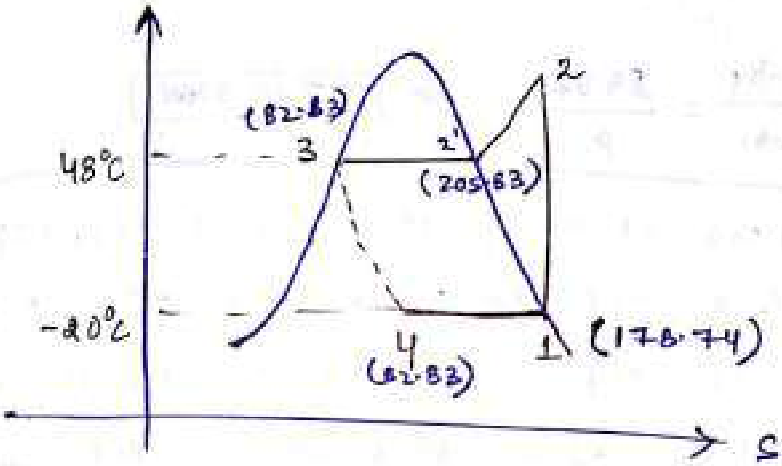
$= 4.187 \times 35 + 334.72 + 2.26 \times 8$

$= 499.345$ KJ/kg

Heat Flow to brine tank = 10% of 499.345

= 49.9345 KJ/kg

Net Heat to be Removed = R.E = 5492795 KJ/kg



$S_1 = S_2 = 0.7087$

~~$0.7087 = S_{2'} + C_p(T_2 - T_2')$~~

~~$0.7087 = 0.6802 + 0.82(T_2 - 48$~~

~~$\boxed{T_2 = 48.0347°C}$~~

$S_2 = S_2' + C_p \ln\left(\frac{T_2}{T_2'}\right)$

$0.7087 = 0.6802 + 0.82 \ln\left(\frac{T_2}{321}\right)$

$\boxed{T_2 = 332.352\,K}$

$h_2 = h_2' + C_p(T_2 - T_2')$

$= 205.83 + 0.82(332.352 - (273+48))$

$\boxed{h_2 = 215.139\ KJ/kg}$

$P_{I/P} = \dot{m}_R(h_2 - h_1) = 215.139 - 178.74$

$= \dot{m}_R(36.4)$ KJ/kg $= \dot{m}_R \times 36.4$ KW

$\downarrow$

?

$= 20.85$ KW ✓

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$h_3 = h_{f_3} = 82.83$ kJ/kg

$h_3 = h_4$

Heat absorbed by ice = R.C

$549.2785 \times 0.1 = \dot{m}_R \times (h_1 - h_4)$

$$\dot{m}_R = \frac{54.9275}{178.74 - 82.83}$$

$$= 0.5726 \text{ kg/s}$$

Alt Method

$$COP = \frac{R.E}{W_{I/P}} = \frac{RC}{P}$$

$$\frac{h_1 - h_4}{h_2 - h_1} = \frac{54.92}{P} \Rightarrow \boxed{P = 20.85 \text{kW}}$$

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Notes by Vaibhav Sir

⑧ In a 15 TR ammonia Refrigeration plant the condensing temperature is 25°C & evaporating temp −10°C. The refrigerant ammonia is sub-cooled by 5°C before passing through the throttle valve. The vapour leaving the evaporator is 0.97 dry. Find:-

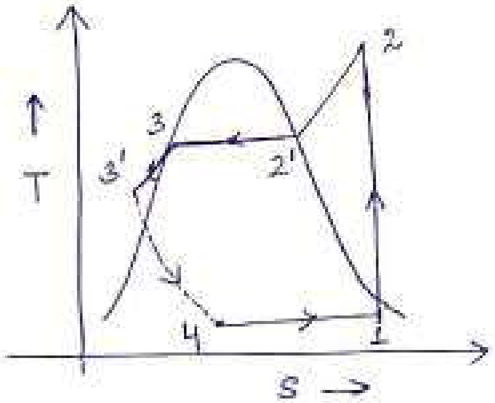
a) COP

b) power required.

Properties of ammonia :-

Saturation Temp (°C)	Enthalpy (KJ/Kg)		Entropy (KJ/kg-K)		Specific heat (KJ/kg-K)	
	Liquid	vapour	Liquid	vapour	Liq.	Vap
25°C	298.9	1465.84	1.1242	5.0391	4.6	2.8
−10°C	135.7	1433.05	0.5443	5.4770	—	—

Soln



given:-

R.C = 15 TR

$= 15 \times 3.5$ KJ/s

$\boxed{R.C = 52.5 \text{ KW}}$

$T_4 = T_1 = -10°C = 263K$

$T_3 = T_2' = 25°C = 298K$

$T_3 - T_3' = 5°C$

$x_1 = 0.97$

a) COP

$$COP = \frac{R.E}{W_{I/P}} = \frac{h_1 - h_4}{h_2 - h_1}$$

First calculate the values of enthalpies

$h_3' = h_4$

$h_3 = h_{f3} = 298.9$ K.

$h_3 = h_3' + c_{pl}(T_3 - T_3')$

$\Rightarrow h_3' = h_3 - c_{pl}(T_3 - T_3') \Rightarrow$

$h_3' = 298.9 - 4.6 \times 5$

$\boxed{h_3' = 275.9 \text{ KJ/kg}}$

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as $\underline{h_4 = h_3'}$

$\Rightarrow \boxed{h_4 = 275.9 \text{ KJ/Kg}}$

$\boxed{h_1}$

$h_1 = h_{f_1} + x_1 h_{fg}$

$= 135.7 + 0.97 \times (1433.05 - 135.7)$

$\Rightarrow \boxed{h_1 = 1394.13 \text{ KJ/Kg}}$

$\boxed{h_2}$

$\underline{s_1 = s_2}$

$s_1 = s_{f_1} + x_1 s_{fg}$

$= 0.5443 + 0.97 \times (5.4770 - 0.5443)$

$\Rightarrow \underline{s_1 = 5.329 \text{ KJ/kg K} = s_2}$

$s_2 = s_2' + c_{p_v} \ln\left(\frac{T_2}{T_2'}\right)$ $\qquad s_2' = s_g = 5.0391 \text{ KJ/kg K}$

$\Rightarrow s_2 = 5.0391 + 2.8 \ln\left(\frac{T_2}{298}\right)$

$\Rightarrow 5.329 = 5.0391 + 2.8 \ln\left(\frac{T_2}{298}\right)$

$\Rightarrow \boxed{T_2 = 330.51 \text{ K}}$

$h_2 = h_2' + C_{p_v}(T_2 - T_2')$ $\qquad h_2' = h_g =$ ~~5~~ 1465.84 KJ/kg K

$= 1465.84 + 2.8\,(330.51 - 298)$

$\Rightarrow \boxed{h_2 = 1556.867 \text{ KJ/Kg}}$

NOW

$COP = \frac{h_1 - h_4}{h_2 - h_1} = \frac{1394.13 - 275.9}{1556.867 - 1394.13}$

$\Rightarrow \boxed{COP = 6.87}$

b) Power $\qquad COP = \frac{R.C}{P} \Rightarrow P = \frac{52.5}{6.87} \Rightarrow \boxed{P = 7.64 \text{ KW}}$

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Notes by Vaibhav Sir

Q) A Freon-12 refrigerator producing a cooling effect of 20 KJ/s operates on a simple VCRS with pressure limits of 1.5 bar and 9.5 bar. The vapour leaves the evaporator dry saturated and there is no undercooling. Determine the power required by the machine, rating of evaporator & COP.

If the compressor operates at 300 RPM and has a clearence volume of 3% of the stroke volume. Determine the piston displacement of the compressor. For compressor assume that the expansion following the law $PV^{1.2} =$ constt.

assume $C_{Pv} = 1.0019$ KJ/kg-K.

Soln

given :-

R.C = 20 KJ/s.

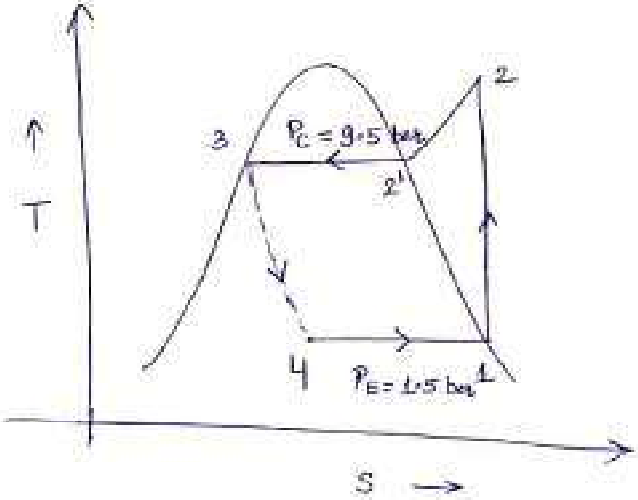
Evaporator pressure $(P_E) = 1.5$ bar

condensor Pressure $(P_c) = 9.5$ bar.

For compressor

N = 300 RPM

$\frac{V_c}{V_s} = 0.03$



From Refrigeration chart For R-12

corresponding to $P_E = 1.5$ bar

$v_g = 0.1090$ m³/kg

$h_f = 17.8$ KJ/kg

$\boxed{h_g = 178.7 \text{ KJ/Kg} = h_1}$

& $S_1 = S_g = 0.7088$ KJ/kg-K.

corresponding to $P_c = 9.5$ bar

$\boxed{h_g = 203 \text{ KJ/Kg} = h_{2'}}$

& $S_2' = 0.6812$ KJ/kg-K &

$\boxed{h_f = h_3 = 74.6 \text{ KJ/Kg}}$

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$R \cdot E = h_1 - h_4$

$= (178.7 - 74.6)\ KJ/Kg.$ $\quad [h_4 = h_3 = 74.6\ KJ/Kg]$

$R \cdot E = 104.1\ KJ/Kg.$

$R \cdot C = \dot{m}_R \times R \cdot E$

$20 = \dot{m}_R \times 104.1$

$\boxed{m_R = 0.192\ Kg/s}$

Power

$W_{I/P} = (\underset{?}{h_2} - \underset{\checkmark}{h_1})\ KJ/Kg$

calculating h_2

$S_1 = S_2 = 0.7088\ KJ/Kg\text{-}K$

& $S_2' = 0.6812\ KJ/Kg\text{-}K.$

& $S_2 = S_2' + C_p \ln\left(\frac{T_2}{T_2'}\right)$

$S_2 = 0.6812 + 1.0019 \ln\left(\frac{T_2}{313}\right)$

$\boxed{T_2 = 321.742\ K}$

$h_2 = h_2' + C_p(T_2 - T_2')$

$\Rightarrow h_2 = 203 + 1.0019 \times (321.742 - 313)$

$\boxed{h_2 = 211.75\ KJ/Kg}$

Power

$P = \dot{m}_R \times W_{I/P}$

$= 0.192(h_2 - h_1) = 0.192(211.75 - 178.7)$

$\Rightarrow \boxed{P = 6.347\ KW}$

$COP = \frac{RC}{P} = \frac{20}{6.347} \Rightarrow \boxed{COP = 3.151}$

Rating of Evaporator $= \frac{20}{3.5} = \underline{\underline{5.714\ TR}}$.

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Notes by Vaibhav Sir

Volumetric efficiency of compressor

$$\eta_v = 1 + C - C\left(\frac{P_H}{P_L}\right)^{1/n}.$$

$$= 1 + 0.03 - 0.03\left(\frac{9.5}{1.5}\right)^{1/1.3}$$

$$\boxed{\eta_v = 0.906}$$

given

$C = \frac{V_C}{V_G} = 0.03$

given

$PV^n = C$

$\boxed{n = 1.3}$

$$\eta_v = \frac{\text{Actual piston displacement}}{\text{Theoritical piston displacement}} = \frac{APD = \dot{m} v_1}{\frac{\pi}{4} \times D^2 \times L \times \frac{N}{60} \times K}$$

assume $K = 1$

⇒ ~~APD = 0.906 × π/4~~ ×

$$TPD = \frac{\dot{m} v_1}{\eta_v} = \frac{0.192 \times 0.1090}{0.906} \left(\frac{kg}{s} \times \frac{m^3}{kg}\right)$$

for P = 1.5 bar

$v_1 = v_g = 0.1090 \text{ m}^3/\text{kg}$

$$\boxed{TPD = 0.023099 \text{ m}^3/\text{s}} = 1.386 \text{ m}^3/\text{min}.$$

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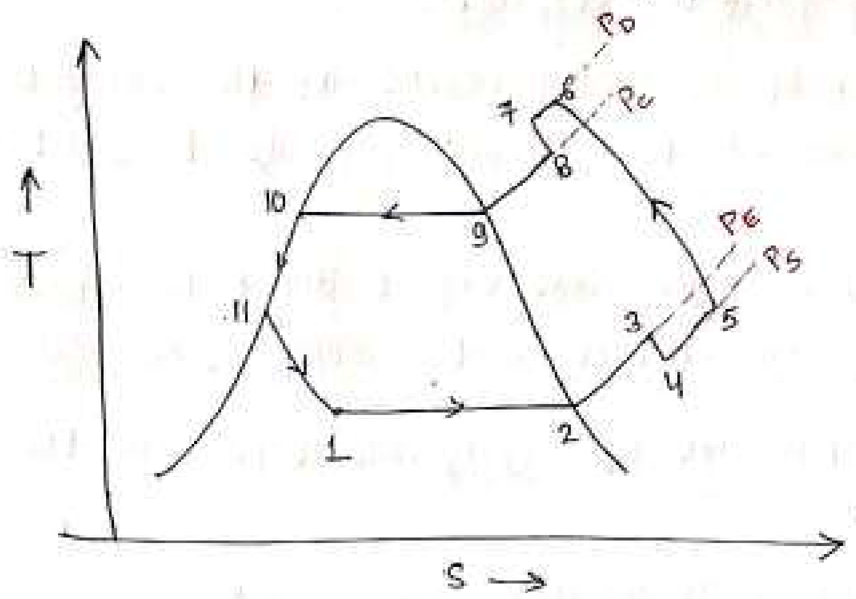
Actual vapour compression cycle.



main deviations between the Theoritical cycle and actual cycles

a) Vapour refrigerant leaving the evaporator is not dry saturated. It is in superheated state.

b) compression of refrigerant is neither isentropic nor polytropic.

c) Liquid refrigerant leaving the compressor is subcooled before entry to the expansion valve.

d) There occurs a pressure drop in the condensor & Evaporator.

Processes :-

1-2-3 ⇒ → 1 → entry to the Evaporator from exp^n valve.

→ 3 → exit of the evaporator (Refrigerant in Superheated state)

Superheating of Refrigerant (2-3) occurs due to .

i) automatically controlled expansion valve.

ii) Heat pickup from evaporator tubes located in cooled space.

iii) Heat pickup from suction pipe of compressor.

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b) 3-4-5-6-7-8

3 → Refrigerant exit from the evaporator

3-4 → Pressure drop of refrigerant vapour at the entry to the compressor in the suction pipe due to frictional resistance.

4-5 → Rise in temp of refrigerant vapour due to heat pickup after coming in contact with compressor walls.

5-6 → actual compression of refrigerant vapour in the compressor.

6-7 → slight cooling of refrigerant (reverse of 4-5)

7-8 → Pressure drop at the entry of discharge valve of the compressor.

c) 8-9-10-11

8-10 → constt pressure heat rejection from refrigerant to form saturated liquid.

10-11 → Subcooling of liquid refrigerant.

d) 11-1

→ constt ~~Pre~~ Enthalpy process in the expansion valve.

→ Expansion of subcooled liquid refrigerant by throttling from condensor pressure to Evaporator pressure.

Multistage compression & Multi-evaporator systems

Notes by Vaibhav Sir

Why Needed ?

→ Single stage systems are adequate as long as the temp. difference between evaporator & condenser is small.

→ There are many applications where the temperature lift can be quite high.

The temp. lift can become Large either due to requirem of very low evaporator temperatures or due to very high condensing Temperatures.

Eg on a low Temp. side

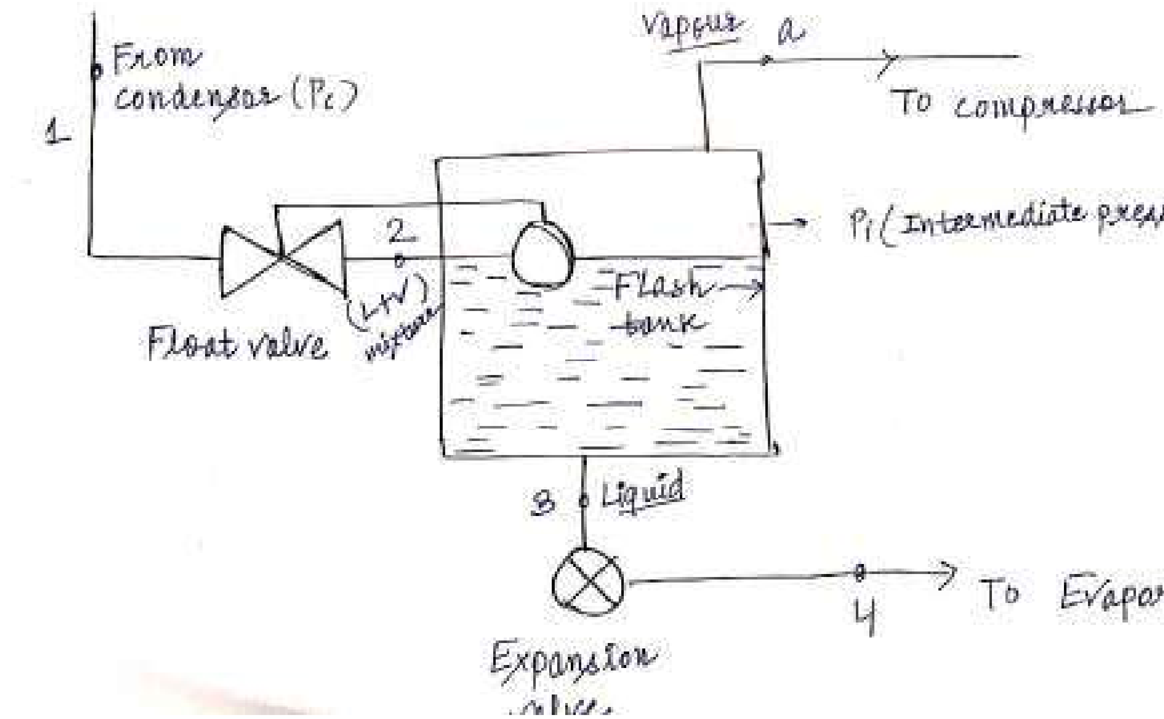
→ Frozen Food Industries −40°c or lower

→ Chemical Industries temps as low as −150°c for liquefaction of gases.

on a high temp. side

→ High condensing temps are required if the refrigeration system is used as a heat pump for heating applications such as process heating, drying.

Flash Tank



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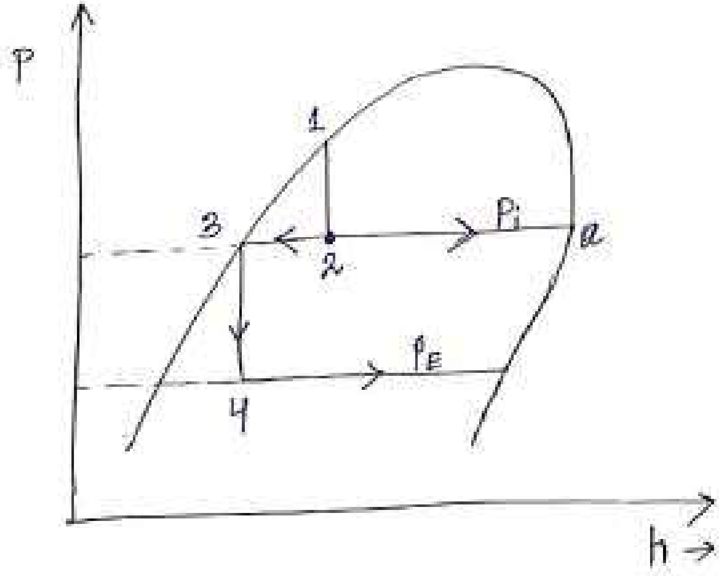
Simple VCRS with Flash chamber

- → A Flash tank is a pressure vessel in which the refrigerant liquid & vapour are separated by an Intermediate pressure.
- → Refrigerant from condensor is first expanded ~~in~~ to an intermediate flash tank pressure using a low side float valve.
- → The float valve maintains a constant liquid level in the flash tank.
- → Refrigerant liquid and vapour are separated in the flash tank.
- → Refrigerant liquid & vapour are separated in a flash tank.
- → saturated liquid from flash tank is fed into the evaporator after throttling it to the required evaporator pressure.



1 → Exit of condensor & Entry to Flash tank

2 → Pressure Reduction to an intermediate Pressure in Flash tank.

3-4 → throttling of liq. to evaporator Pressure.

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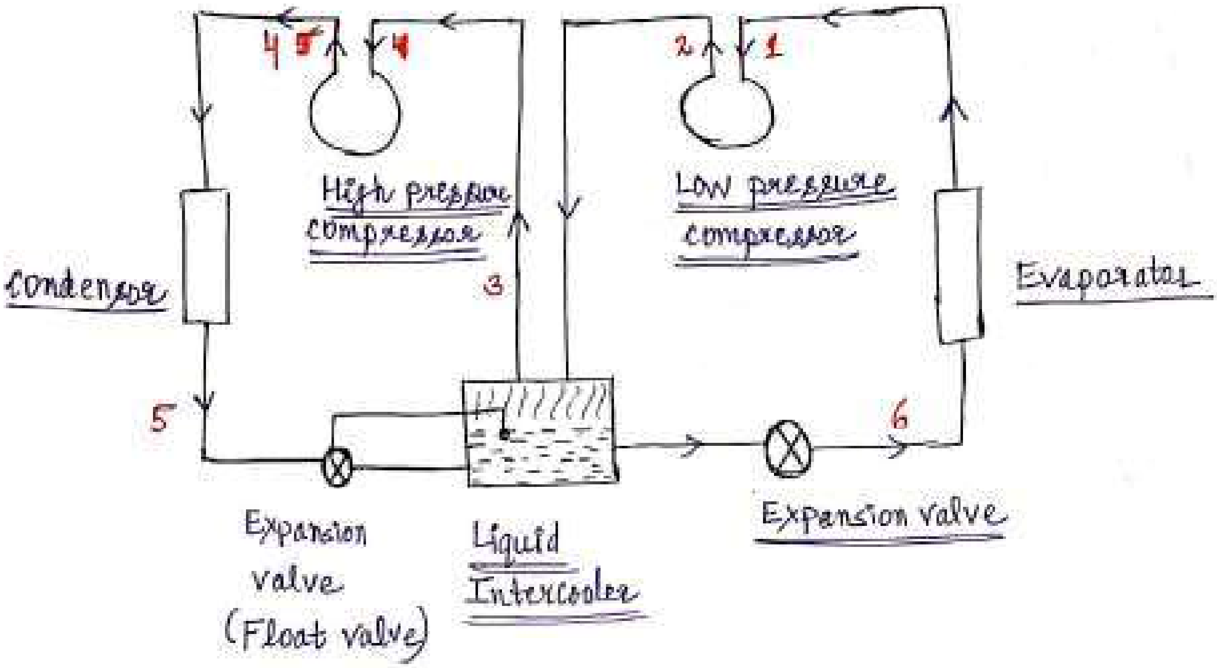
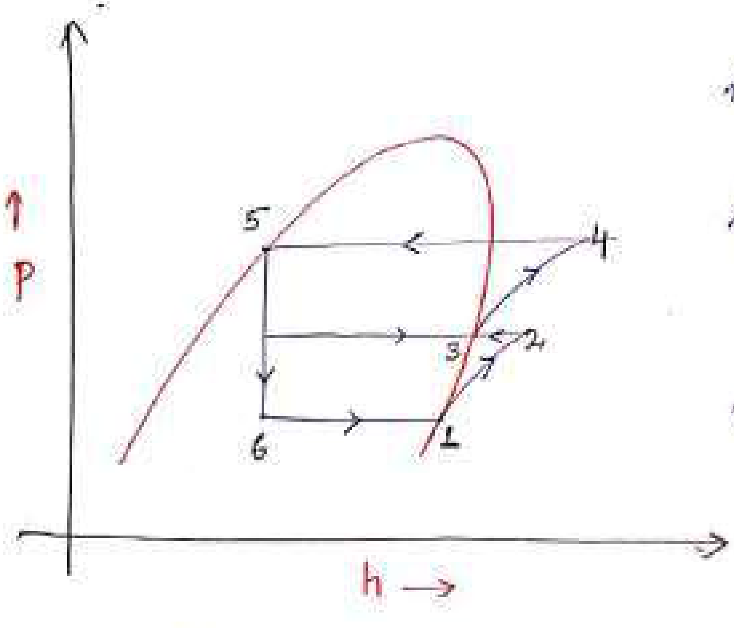
Two-stage compression with Liquid Intercooler

Notes by Vaibhav Sir





$\dot{m}_1$ → mass flow rate of refrigerant entering the Evaporator (Kg/s) or L.P compressor.

$\dot{m}_2$ → mass flow rate of refrigerant passing through condenser or H.P compressor.

$\dot{m}_3$ → mass of liquid evaporated in Intercooler.

$$\Rightarrow \boxed{\dot{m}_3 = \dot{m}_2 - \dot{m}_1}$$

1-2 → Isentropic compression of vapour refrigerant in the LP compressor.

2-3 → Desuperheating of vapour refrigerant in Liquid Intercooler.

3-4 → Isentropic compression of vapour refrigerant in H.P compressor

4-5 → condensation of refrigerant to saturated liq. state.

5 → High pressure liquid ref. enters the liquid Intercooler where some of it is vapourised on the course of desuperheating ref from L.P compressor.

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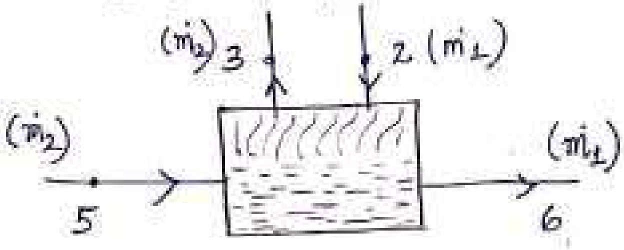
Notes by Vaibhav Sir

Energy balance of Liquid Intercooler:



$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}_2 h_5 + \dot{m}_1 h_2 = \dot{m}_1 h_6 + \dot{m}_2 h_3$$

$$\boxed{h_{f5} = h_6}$$

$$\dot{m}_2 h_{f5} + \dot{m}_1 h_2 = \dot{m}_1 h_{f5} + \dot{m}_2 h_3$$

$$\dot{m}_2 (h_3 - h_{f5}) = \dot{m}_1 (h_2 - h_{f5})$$

$$\Rightarrow \dot{m}_2 = \frac{\dot{m}_1 (h_2 - h_{f5})}{(h_3 - h_{f5})}$$

&

$$\dot{m}_3 = \dot{m}_2 - \dot{m}_1$$

$$= \dot{m}_1 \left(\frac{h_2 - h_{f5}}{h_3 - h_{f5}} \right) - \dot{m}_1 = \dot{m}_1 \left[\frac{h_2 - \cancel{h_{f5}} - h_3 + \cancel{h_{f5}}}{h_3 - h_{f5}} \right]$$

$$\Rightarrow \boxed{\dot{m}_3 = \frac{\dot{m}_1 (h_2 - h_3)}{(h_3 - h_{f5})}}$$

→ mass of liquid ref. evaporated in Liquid Intercooler.

Total work Input/s

$$P = \dot{W} = W_{C_1} + W_{C_2} \text{ or } W_{LP} + W_{HP}$$

$$= \dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_4 - h_3)$$

$$\boxed{P = \dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_4 - h_3)} \text{ kW}$$

Refrigeration capacity

$$\boxed{R{\cdot}C = \dot{m}_1 (h_1 - h_{f5}) \text{ kW}}$$

$$\Rightarrow COP = \frac{R{\cdot}C}{P} \Rightarrow \boxed{COP = \frac{\dot{m}_1 (h_1 - h_{f5})}{\dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_4 - h_3)}}$$

→ COP of System.

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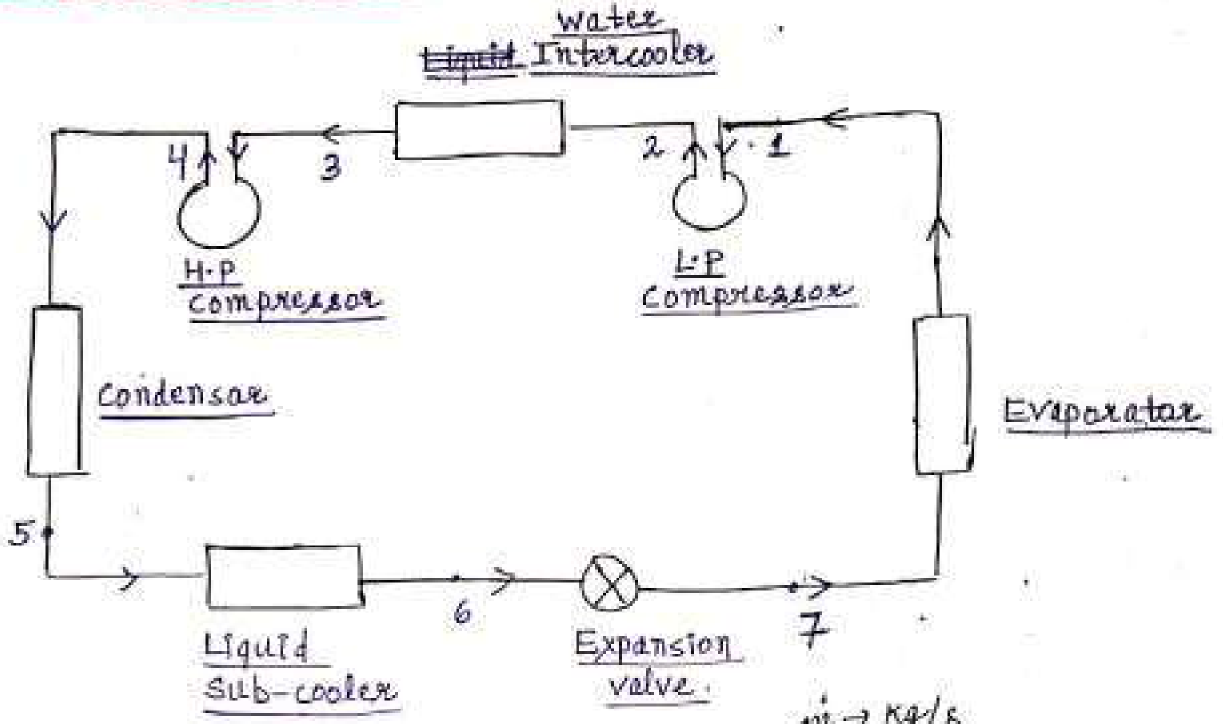
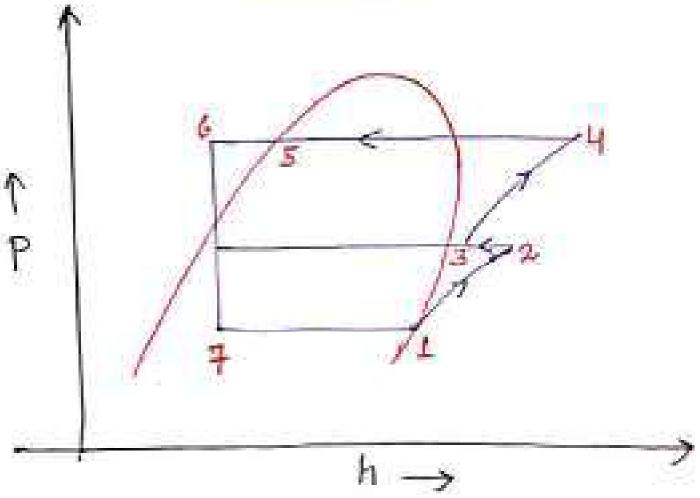
Two-stage compression with water Intercooler & Liquid-subcooler

Notes by Vaibhav Sir



$\dot{m} \rightarrow kg/s$



Here,

$R.C = \dot{m}(h_1 - h_7)$ KW.

* Power Input (P)

$P = \dot{m}(h_2 - h_1) + \dot{m}(h_4 - h_3)$ KW

$$\Rightarrow \boxed{COP = \frac{(h_1 - h_7)}{(h_2 - h_1) + (h_4 - h_3)}}$$

2-3 → desuperheating of vapour refrigerant at the exit of L.P compressor.

But here after desuperheating the vapour refrigerant stays in superheated state unlike in case of liquid (refrigerant) Intercooler.

⇒ mass flow rate $(\dot{m})$ of refrigerant remains constt.

5-6 → sub-cooling of high pressure liquid refrigerant from the condensor in Liquid sub-cooler.

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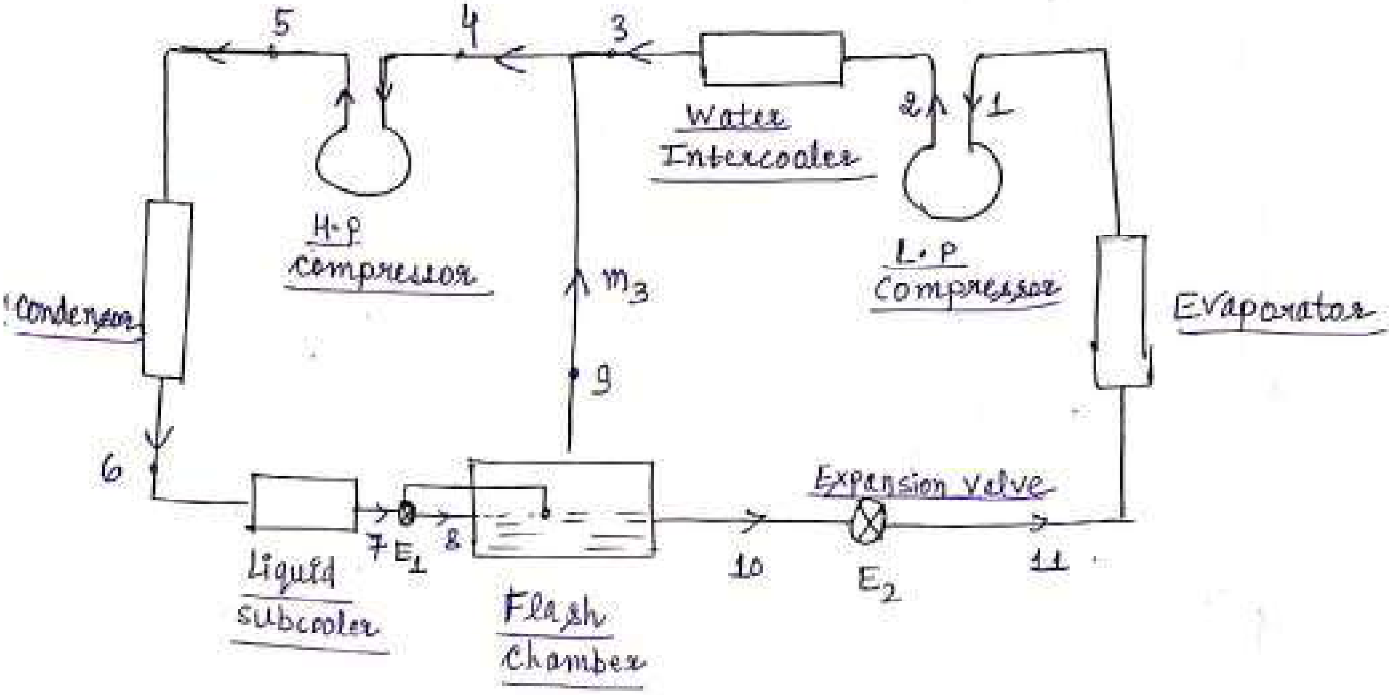
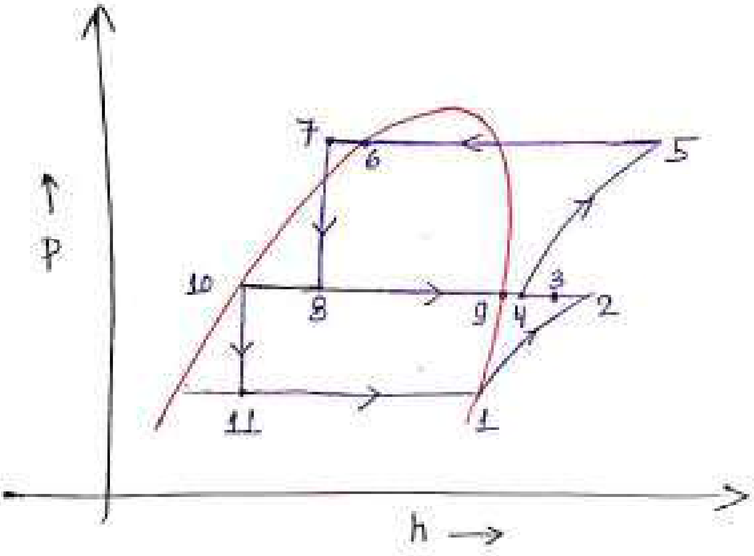
Two-stage compression with Water intercooler, Liquid subcooler & liquid Flash chamber

Notes by Vaibhav Sir



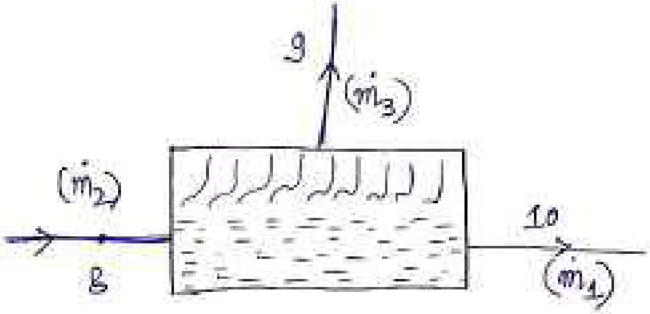


$\dot{m}_1$ → mass of refrigerant/s Passing through the Evaporator or L.P compressor

$\dot{m}_2$ → mass of refrigerant/s Passing through the condensor or H.P compressor

$\dot{m}_3$ → mass of vapour refrigerant formed in flash chamber

Energy balance for Flash chamber.



Flash Chamber

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Notes by Vaibhav Sir

$$\boxed{E_{in} = E_{out}}$$

$\dot{m}_3 = \dot{m}_2 - \dot{m}_1$

$\Rightarrow \boxed{\dot{m}_1 = \dot{m}_1 - \dot{m}_3}$

$\dot{m}_2 h_8 = \dot{m}_3 h_9 + \dot{m}_1 h_{10}$

$\dot{m}_2 h_8 = \dot{m}_3 h_9 + (\dot{m}_2 - \dot{m}_3) h_{f10}$

$\Rightarrow \dot{m}_3 (h_9 - h_{f10}) = \dot{m}_2 (h_8 - h_{f10})$

$\boxed{h_8 = h_{f7}}$

$$\Rightarrow \boxed{\dot{m}_3 = \dot{m}_2 \left(\frac{h_{f7} - h_{f10}}{h_9 - h_{f10}} \right)}$$

Mixing of vapour refrigerant from Intercooler & vapour refrigerant from Flash chamber at an Intermediate pressure.

$\Rightarrow \dot{m}_2 h_4 = \dot{m}_3 h_9 + \dot{m}_1 h_3$

$$\boxed{\dot{m}_2 h_4 = \dot{m}_3 h_9 + (\dot{m}_2 - \dot{m}_3) h_3}$$

Refrigeration capacity $(R \cdot C) = \dot{m}_1 (h_1 - h_{11})$ kW

Power $= \dot{W}_{LP} + \dot{W}_{HP}$

$= \dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_5 - h_4)$ kW

$$\boxed{COP = \frac{\dot{m}_1 (h_1 - h_{11})}{\dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_5 - h_4)}}$$

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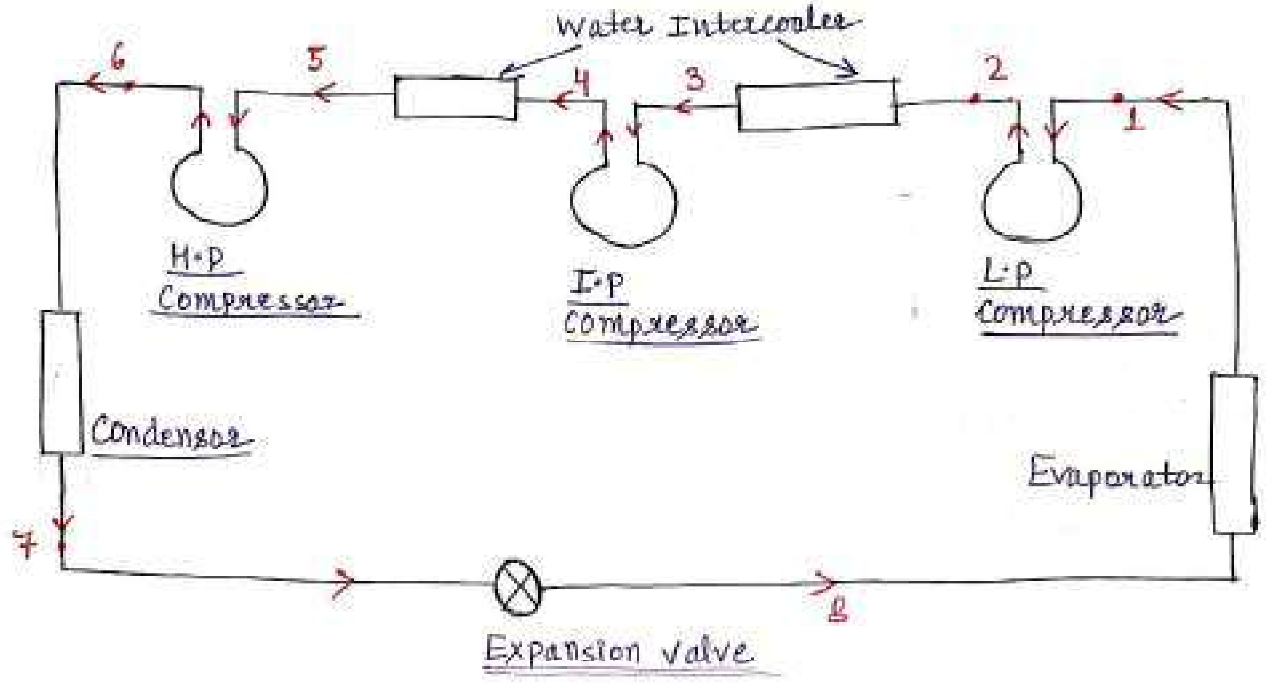
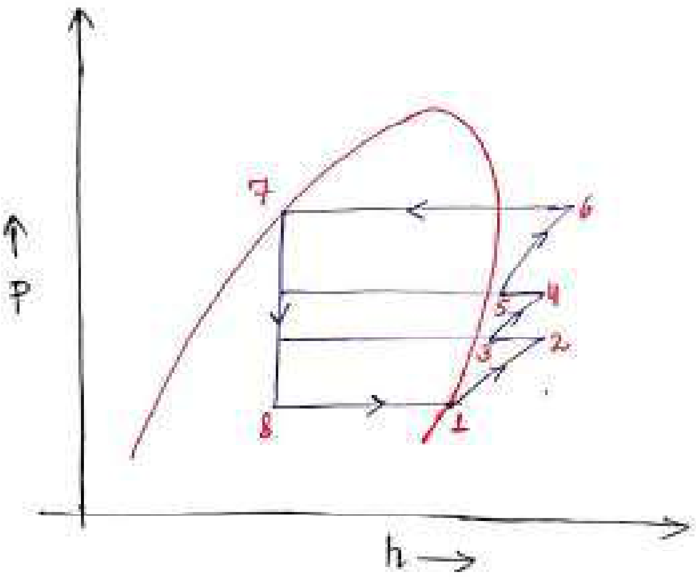
Three stage compression with Water Intercooler

Notes by Vaibhav Sir





$\underline{R.C} = \dot{m}(h_1 - h_8)$ KW.

$\underline{\text{Power}}\,(P) = \dot{m}(h_2 - h_1) + \dot{m}(h_4 - h_3) + \dot{m}(h_6 - h_5)$. KW

$$\boxed{COP = \frac{(h_1 - h_8)}{(h_2 - h_1) + (h_4 - h_3) + (h_6 - h_5)}}$$

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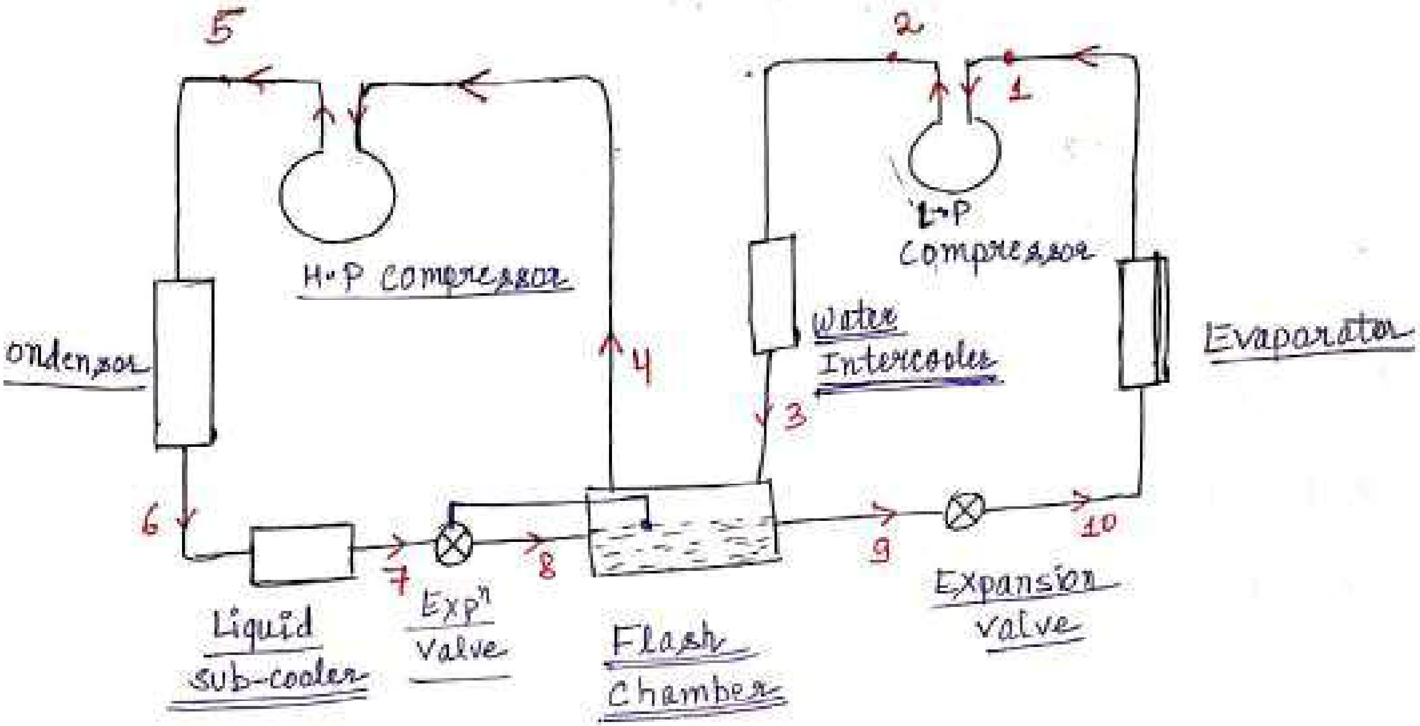
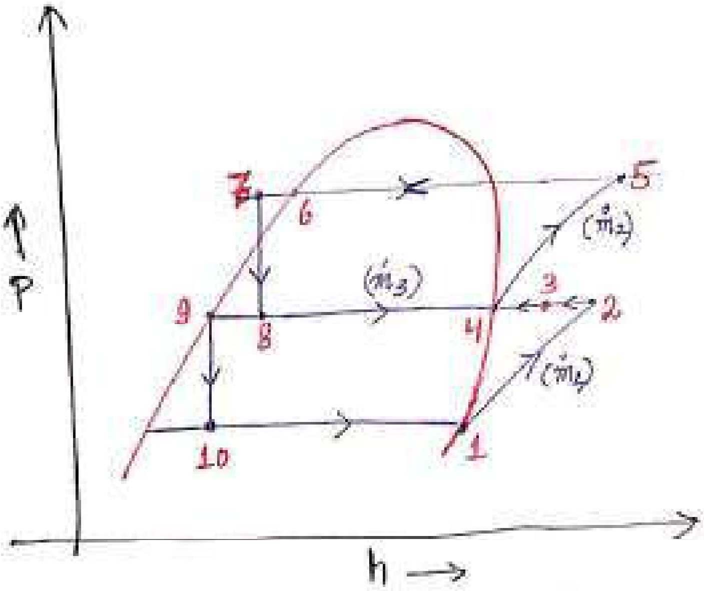
Two-stage compression with Water Intercooler, Liquid subcooler and Flash Intercooler.

Notes by Vaibhav Sir





$\dot{m}_1$ → mass of refrigerant passing through the Evaporator.

$\dot{m}_2$ → mass of refrigerant passing through the condensor.

$\dot{m}_3$ → mass of liq. refrig. evaporated in flash chamber.

2-3 → slight desuperheating of vapour refrigerant in water Intercooler.

3-4 → Flash chamber acts as an Intercooler where slightly superheated refrigerant at '3' is cooled by liq. ref in flash chamber.

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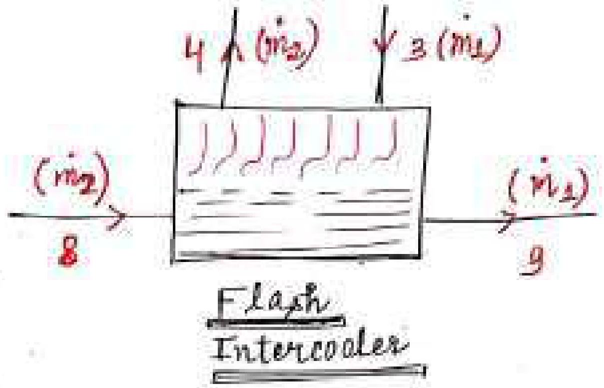
$$\boxed{R.E = \dot{m}_1 (h_1 - h_{10})} \quad \underline{kW}$$



Flash Intercooler

Ein = Eout

$$\dot{m}_2 h_8 + \dot{m}_1 h_3 = \dot{m}_1 h_9 + \dot{m}_2 h_4$$

$$\dot{m}_2 (h_4 - h_8) = \dot{m}_1 (h_3 - h_9)$$

$$\dot{m}_2 = \frac{\dot{m}_1 (h_3 - h_{f9})}{(h_4 - h_8)}$$

$$\& \quad \dot{m}_3 = \dot{m}_2 - \dot{m}_1 = \dot{m}_1 \left(\frac{h_3 - h_{f9}}{h_4 - h_8} \right) - \dot{m}_1 = \dot{m}_1 \left(\frac{h_3 - h_{f9} - h_4 + h_8}{h_4 - h_8} \right)$$

Power Input

$$P = P_{LPC} + P_{HPC}$$

$$\boxed{P = \dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_5 - h_4)} \quad \underline{kW}$$

$$\boxed{COP = \frac{R.C}{P} = \frac{\dot{m}_1 (h_1 - h_{10})}{\dot{m}_1 (h_2 - h_1) + \dot{m}_2 (h_5 - h_4)}}$$

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