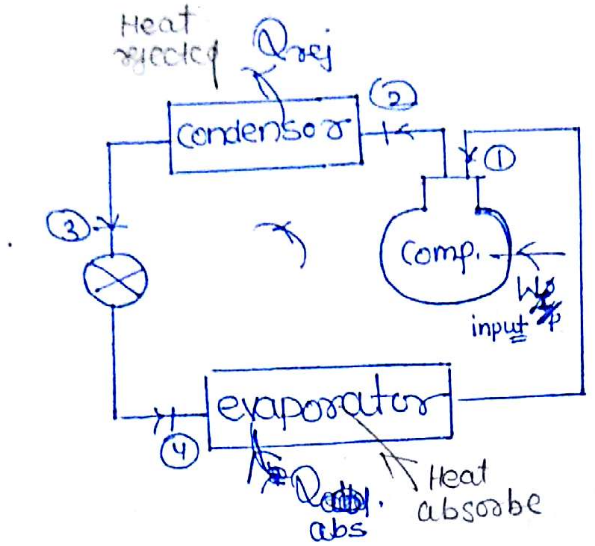
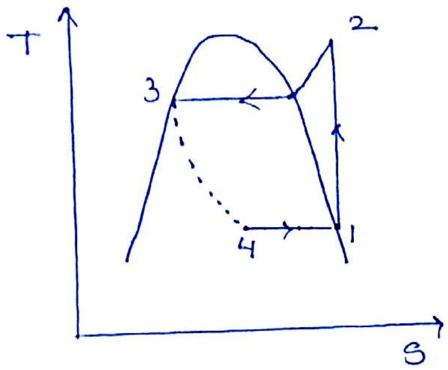
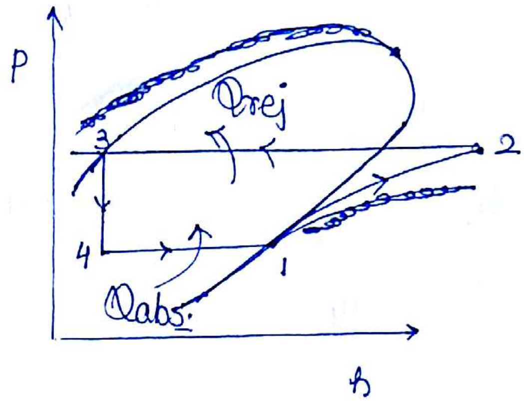
Vapour Compression Refrigeration System (VCRS)



- 1→2 isentropic Comp.
- 2→3 Isobaric heat rej.
- 3-4 throttling
- 4-1 Isobaric heat ab.

* In actual unit the ref. leaving the evaporator is superheated

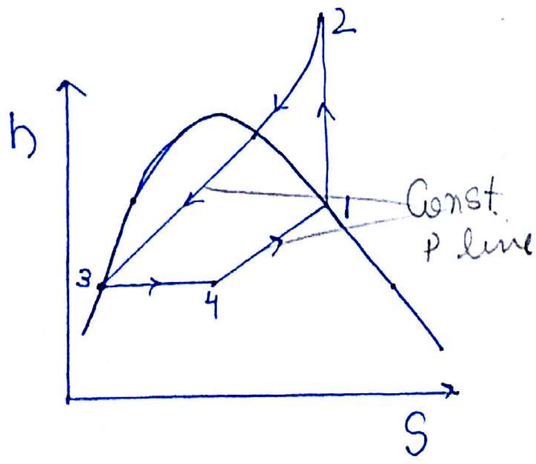




Simple V-C cycle or ideal V-C cycle

1. Sat. Vap.
3. Sat. liq.

Function is define so (3-4) throttling straigh line



$$Tds = dh - vdp$$ ($vdp \to 0$)

$$\left(\frac{dh}{ds}\right) = T$$

1. Sat. Vapour
3. Sat. liquid

⇒ Appling steady ~~state~~ flow energy eqⁿ in various stages
- steady state
- $\Delta KE = \Delta P.E. = 0$

$$h_i + q = h_e + w_{c.v.}$$

① **Compressor.**

isentropic $(Q=0)$

$\therefore w_{c.v.} = h_i - h_e$

$w_{i/p} = h_e - h_i = h_2 - h_1$

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

② **Condensor** $(w_{c.v.} = 0)$

$q = h_e - h_i$

$Q_{rej} = h_i - h_e = h_2 - h_3$

$Q_{rej} = h_2 - h_3$

③ **throttling**

$h_3 = h_4$

④ **Evaporator** $w_{c.v} = 0$

$h_i + q = h_e$

$Q_{ab} = h_1 - h_4$

* $$COP = \frac{R.E.}{w_{i/p}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_3}{h_2 - h_1}$$

Ref. Capacity, $(R.C) = \dot{m} \times (R.E.)$

$$\dot{W}_{i/p} = \dot{m} \times (w_{i/p})$$

Q.16
P.g 45
WB

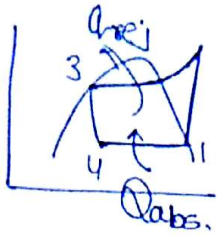
RC = 5 KW

$h_3 = 75$ kJ/kg $= h_4$

$h_1 = 183$ kJ/kg.

$h_2 = 210$ kJ/kg.

$$COP = \frac{R.E}{W_{inp}} = \frac{h_4 - h_1}{h_2 - h_1}$$



$$(COP) = \frac{183 - 75}{210 - 183} = 4$$

$W_{i/p}$ = Power $= \dot{m}\,(W_{inp})$

$= \dot{m}\,(h_2 - h_1)$

$(RE) \times \dot{m} = RC.$

$(h_1 - h_4)\,\dot{m} = 5$

$\dot{m} = \frac{5}{108}$ kg/s.

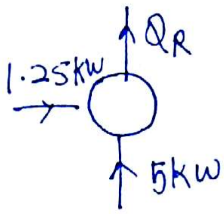
$$P_{i/p} = \frac{5}{108}(210 - 183)$$

$P_{i/p} = 1.25$ KW

Heat tran rate $= \frac{5}{108}(h_3 - h_2) = \frac{5}{108}(210 - 75)$

$= 6.25$ KW

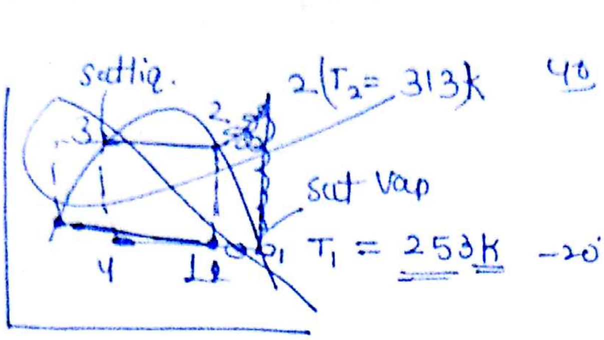
or $COP = \frac{R.C}{W_{inp}} \Rightarrow W_{inp} = \frac{5}{4} = 1.25$ KW.

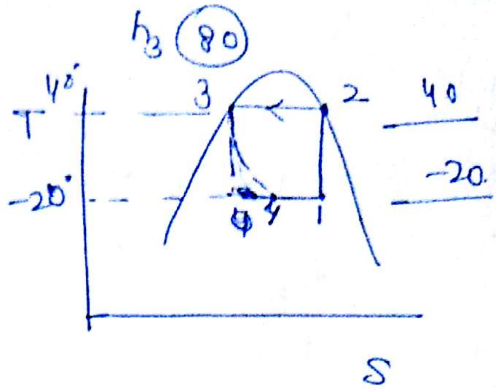


$Q_R = 1.25 + 5$

$= 6.25$ KW

Q. 19





$$COP = \frac{h_1 - h_3}{h_2 - h_1} = \frac{180 - 80}{200 - 180} = 5$$

COP =

$$S|_{40} = S_f + x(S_g - S_f)|_{-20°C}$$

$$0.67 = 0.07 + x(0.04)$$

$$x = 0.9$$

$$h_1|_{-20} = h_f + x\, h_{fg}|_{-20}$$

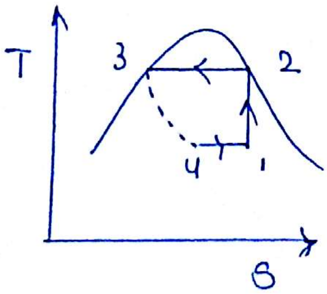
$$= 20 + 160 \times 0.9$$

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

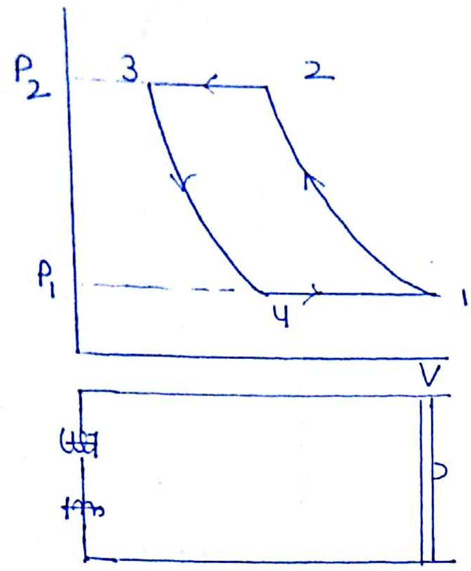
$$COP = \frac{164 - 80}{200 - 164} = 2.33$$

$$R.E. = \dot{m}(h_1 - h_4) = 0.025(164 - 80)$$

$$R.E. = 2.1 \text{ KW}$$



Volumetric efficiency in reciprocating Compression:-



$$\eta_v = \frac{\text{Vol. entering}}{\text{Vol. swept}}$$

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

Refer power plant notes for deriv.

$$\eta_v = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n}$$

$C = \frac{V_3}{V_1 - V_3}$ clearance ratio.

n - polytropic index.

★ $$\eta_v = \frac{\dot{m} \times 60 \times v_1}{\frac{\pi}{4} D^2 L \times N \times K} = \frac{\dot{m} \times 60 \times v_1}{V_s \times N \times K}$$

($\dot{m} \times 60$ → kg/min; v_1 → m³/kg; $\frac{\pi}{4} D^2 L$ → m³/rev; N → rev/min; K → No. of Cylinder.)

Q.9 P.g 45 UB

$C = 0.03$

$$\eta_v = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n}$$

$$= 1 + 0.03 - 0.03\left(\frac{7.45}{1.5}\right)^{1/1.5}$$

$$\eta_v = 0.942$$

$$0.942 = \frac{\dot{m} \times 60 \times 0.1089}{}$$

1 TR = 3.561 kW

Ques

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

$$\eta_v = 1 + 0.03 - 0.030\left(\frac{7.45}{1.5}\right)^{1/1.15}$$

$$\eta_v = 0.9091$$

$$\eta_v = \frac{\text{Vol. entring}}{\text{Vol swept} \rightarrow ?} \quad \leftarrow \; \dot{m} \times v_1$$

$$R.C. = \dot{m} \cdot R.E.$$

$$2 \times 3.5167 = \dot{m}(h_1 - h_4) = \dot{m}(176 - 65)$$

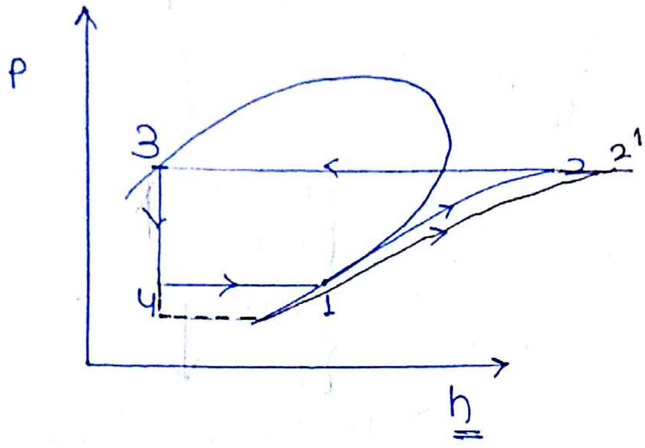
$$\dot{m} = 0.06336 \text{ kg/sec.}$$

$$(V)_{actue} = \frac{0.06336 \times 0.1089}{0.9091}$$

$$V_{act.} = 7.58 \times 10^{-3} \, m^3/s.$$

Effect of Variation of various properties on the performance of VC cycle.

1) Reduction in evaporator pressure:-



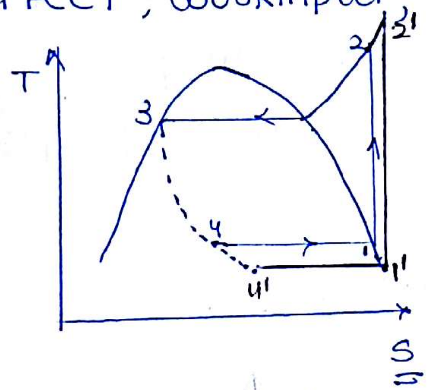
(i) R.E. ↓

(ii) $W_{I/P}$ ↑

(iii) ↓COP = $\frac{R.E.\downarrow}{W_{I/P}\uparrow}$

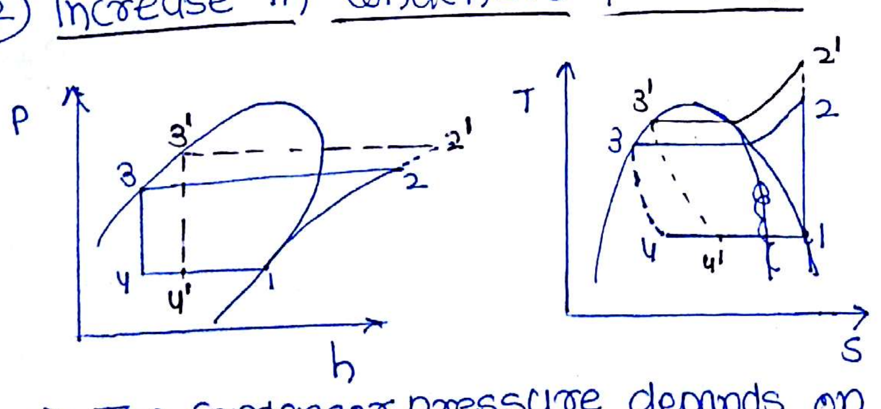
(iv) $\downarrow \eta_v = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n}$

→ Reduction in evaporator pressure decrease the Refrigeration effect, workinput, COP and Volumetric efficiency.



→ The evaporator pressure depends on the temp. of the evaporator, which depends on the desired effect of the machine. (i.e. Air conditioning or ice making)

2) Increase in Condenser pressure:



(i) R.E. ↓

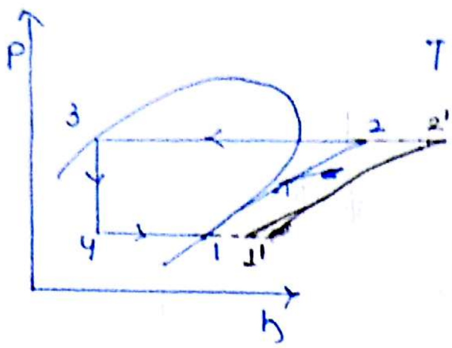
(ii) $W_{I/P}$ ↑

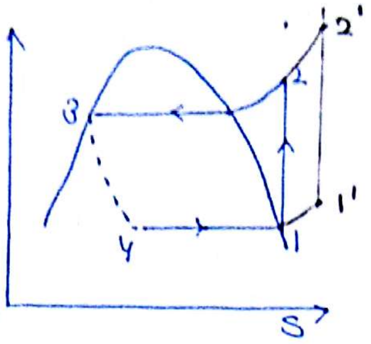
(iii) ↓COP = $\frac{R.E.\downarrow}{W_{I/P}\uparrow}$

(iv) $\downarrow \eta_v = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n}$

→ The condensor pressure depends on the condensor temp. Which further depends on the ambient temperature

3) Superheating of the suction vapour to the Compressor:-





→ (i) R.E. ↑

→ (ii) $W_{I/P}$ ↑

→ (iii) $COP = \frac{R.E.}{W_{I/P}}$

for $\left\{ \begin{array}{l} R\text{-}134a \\ R\text{-}12 \end{array} \right.$ ↑

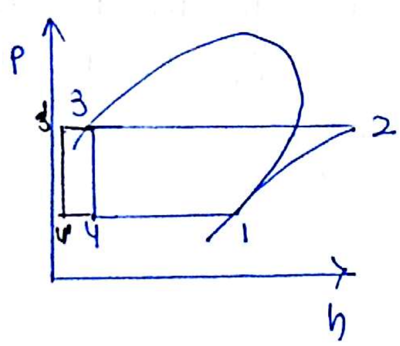
$\left\{ \begin{array}{l} NH_3 \\ R\text{-}22 \end{array} \right.$ ↓

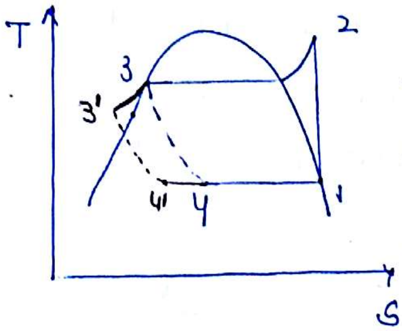
→ (iv) η_v = remain same

→ Work input increases due to superheating because superheating increase the Volume of the fluid.

Since both R.E and $W_{I/P}$ increases hence COP May increase, decrease or remain Constant. In case of R-134a and R-12 COP increases with superheating whereas in case of R-22 & NH_3 COP decrease with superheating.

4) Subcooling of liquid In the condensor:





→ (i) R.E. ↑

→ (ii) $W_{I/P}$ → Same

→ (iii) ↑ $COP = \frac{R.E\uparrow}{W_{I/P}}$

→ (iv) $\eta_v = 1 + c - c\left(\frac{P_2}{P_1}\right)^{1/n}$ → Same

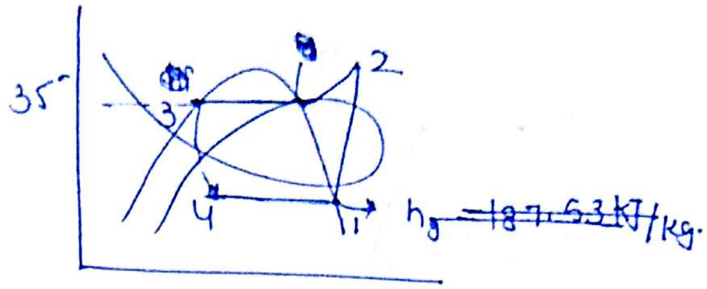
Q.18

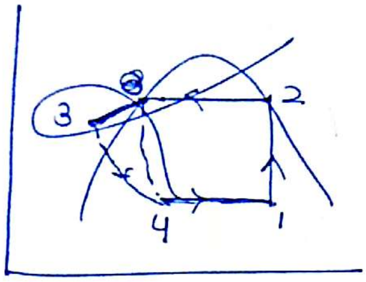
COP = 6.5

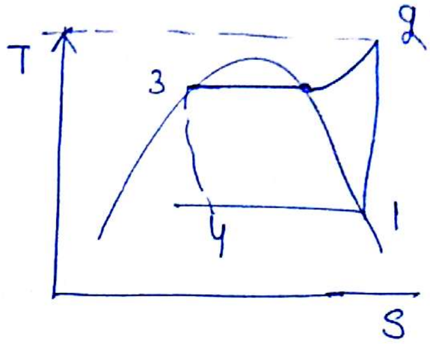
35°C: $h_f = 69.55\ kJ/kg$

$h_g = 201.50\ kJ/kg$

$C_p = 0.6155\ kJ/kg$.







$h_2 = h_g + C_p (T_2 - T_3)$

$h_2 = 201.5 + 0.6155 (T_2 - 308)$

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

$6.5 = \frac{h_1 - h_4}{h_2 - h_1}$

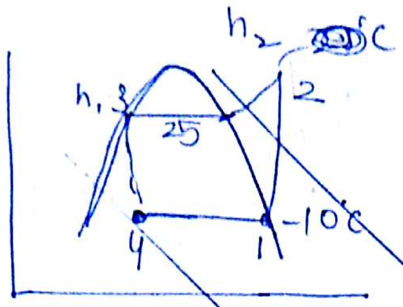
$6.5 = \frac{201.5 - 69.55}{h_2 - 201.5}$

$h_2 = 205.68\ kJ/kg$.

$205.68 = 201.5 + 0.6155 (T_2 - 35)$

$T_2 = 41.79\ °C$

Q.17



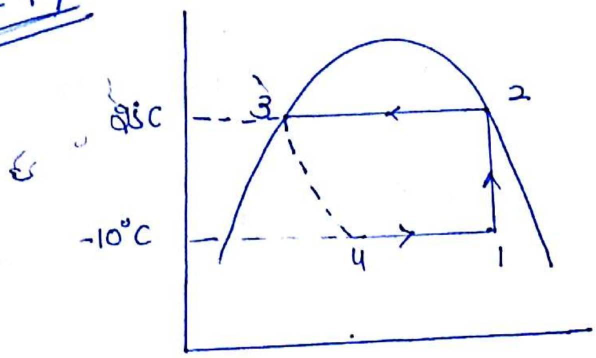
$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP = \frac{1465.84 - 298.9}{-1465.84} \qquad COP = \frac{1433.05 - 298.9}{-1433.05}$$

$h_3 = h_4 = h_f + x h_{fg}$ $\quad h_2 = h_g$

$$S_2 = S_g\big|_{-10°C} = S_g + C_v \ln\left(\frac{T_2}{T_3}\right)$$

Q 17



$h_2 = 1465.84$

$h_3 = h_4 = 298.9$

$S_1 = S_2$

$$S_f + x(S_g - S_f)\big|_{-10°C} = S_g\big|_{25°C}$$

@ 25°C

$$S_{fg} = \frac{h_g - h_f}{T_{sat}}$$

$$S_g - S_f = S_g - 1.125 = \frac{1465.84 - 298.9}{298}$$

$S_g = 5.046$ at 25°C

@ -10°C

$$S_g - S_f = \frac{h_g - h_f}{T_{sat}} \Rightarrow S_g - S_f = \frac{1433.05 - 135.37}{263}$$

$S_{fg} = 4.934$

Now

$$0.5443 + x(4.934) = 1.1242$$

$$x = 0.91$$

So $h_1 = h_f + x_1 h_{fg}$ at $-10°C$

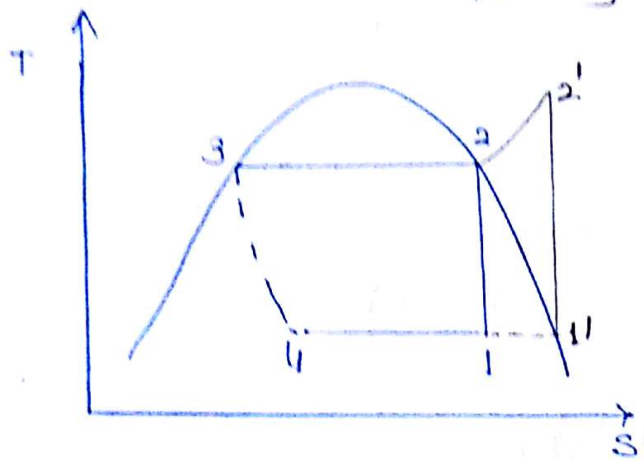
$$= 135.37 + 0.91(1433.5)$$

$$h_1 = 1317.57 \text{ KJ/kg}$$

$$COP = \frac{h_1 - h_4}{h_2 - h_1} = \frac{1317.54 - 298.9}{1465.84 - 1317.54}$$

$$COP = 6.8$$ Ans

Wet Compression V/s Dry Compression:-



1-2. wet Comp.

1'-2' Dry Comp.

→ In wet compression the refrigeration effect is less than the dry compression due to incomplate vapourisation of refrigerant.

→ In wet compression the work input is also less as compared of dry comp. because of lower specific volume.

Generally the cop is more with wet comp.

→ but whenever reciprocating Compressor is used wet compressor is not preferred because

(i) liquid particles in the refrigarent wash away the lubricating oil hence increase wear and tear of the Compressor

(ii) liq. particles damage the valves in the reciprocating Compressor.

Secondary Refrigerent and Primary Refrigerent :-

→ The refrigerent which flows through the refrigeration equipment is called primary refrigerent.

→ Secondary refrigerent which absorbs heat from the refrigerated space and rejects to the primary refrigerent.

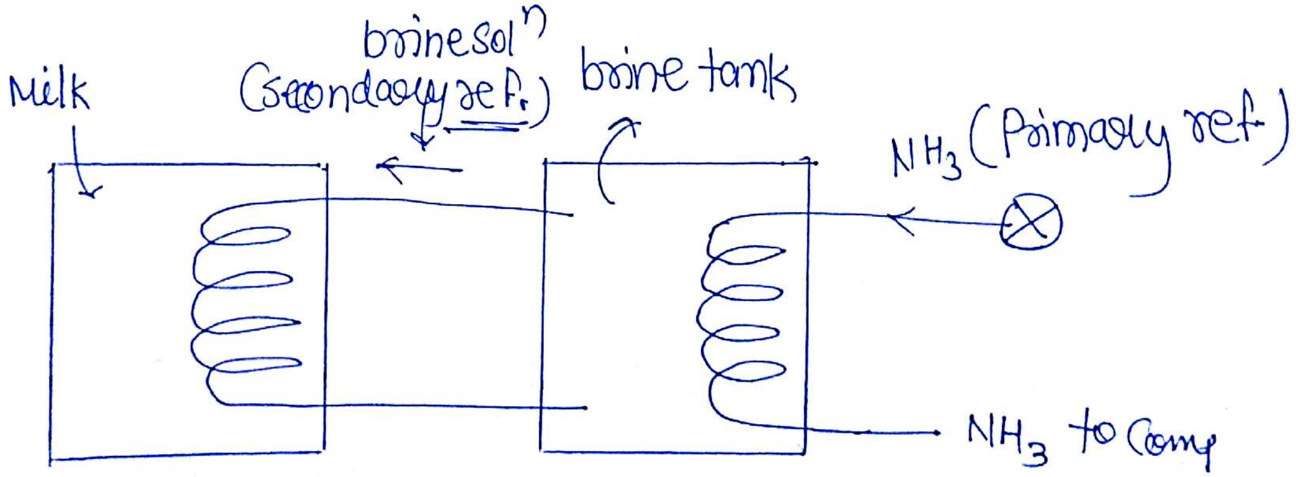
Secondary refrigerent used in milk chilling plants is brine solution. (water + salt)

In Air conditioning the secondary refrigerent is air.

Use of secondary refrigerent helps in

(i) Saving the cost associated with the amount of primary refrigerent.

(ii) It facilitates the use of A primary refrigerent having good thermodynamic properties irrespective of it toxic nature. (eliminate direct mixing)



water 35 °C $\xrightarrow{w}$ 0 w ⟶ 0 °C ice ⟶ −8 °C ice

Q.20

$Q = m\{C_w\,dT + L.H. + C_{ice}\,dT\}$

$= 8640(4.18 \times 35 + 334.72 + 2.26 \times 8)$

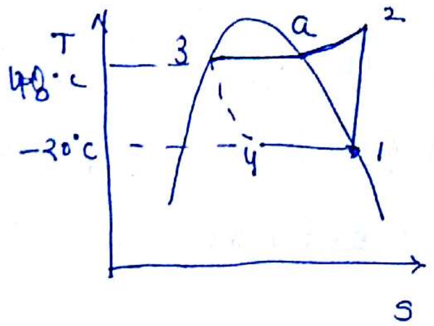
$Q =$ ~~4991 kW~~ 4312222.4 kW

$\dot{Q} = \dfrac{Q}{24 \times 3600} = 49.91\,kW$ P

$R.C. = \dot{Q} \times 1.1$

$= 49.91 \times 1.1$

$R.C = 54.901\,kW$ primary ref. remove this amount of heat.



$h_1 = 178.74\ KJ/kg$

$h_4 = h_3 = 82.83\ KJ/kg$

$S_1 = S_2$

$0.7087 = S_g + C_{p_v} \ln\left(\dfrac{T_2}{T_{sat}}\right)$

$0.7078 = 0.6802 + 0.82 \ln\left(\dfrac{T_2}{321}\right)$

$T_2 = 331.9\ K$

$h_2 - h_a = C_{pa}(T_2 - T_a)$

$h_2 = 205.83 + 0.82(331.9 - 321)$

$h_2 = 215.135\ KJ/kg.$

$$COP = \frac{h_1 - h_4}{h_2 - h_1} = 2.63$$

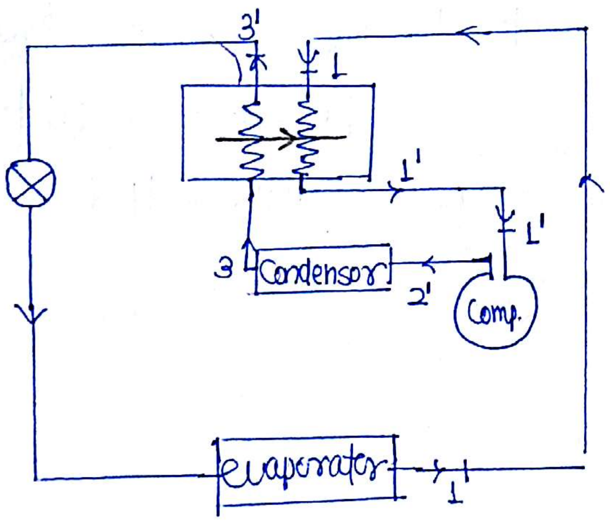
$$2.63 = \frac{R_c}{W_{I/P}}$$

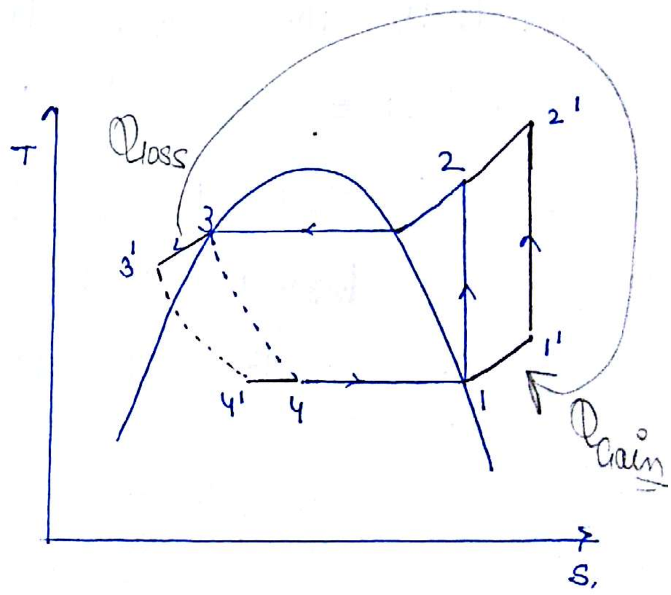
$$W_{I/P} = \frac{54,901}{2.63}$$

$$W_{I/P} = \text{~~2.63~~ } 20.84 \text{ kW}$$

Use of Regenerative heat exchanger

(liquid line heat exchanger or Sub Cooling H.E.)





$Q_{lost} = Q_{gain}$ R.E $= (h_1 - h_4) + (h_4 - h_{4'})$

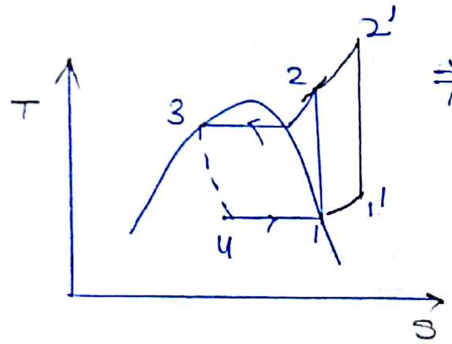
$$h_3 - h_{3'} = h_{1'} - h_1$$

$$C_{p_{liq.}} (T_3 - T_{3'}) = C_{p_v} (T_{1'} - T_1)$$

Degree of ~~Superheating~~ Subcooling $\neq$ Degree of Super heating

→ In regerative heat exchanger Heat loss is equal to heat gained by degree of Subcooling is not equal to Degree of superheating because specific heat of liquid & vapour is different.

Use of Regenrative heat exchanger V/s superheating in evaporator



⇒ R.E. = $(h_1 - h_4) + (h_{1'} - h_1)$ — x
↓
in evap. super heating

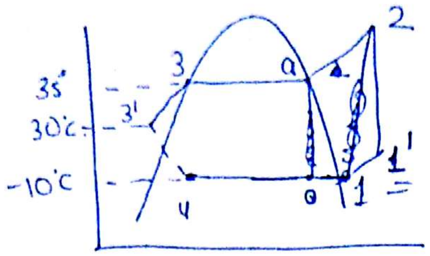
⇒ R.E. = $(h_1 - h_4) + (h_{4'} - h_4)$ — x
↓
in regenrative HE

(both equal)

* In both the cases the ~~refr~~ R.E., work input and hence COP comes out to be same but the increased refrigeration effect is obtain at a lower temp. in regenrative H.E. Compare to evaporator.

(22)

R.C. = 50 kW



$RC = \dot{m}(RE)$

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

$h_a = 1488.57$ kJ/kg.

$h_3 = 366.07$ kJ/kg

$h_3' = h_3 - C_p \ln\left(\frac{T_3}{T_3'}\right)(T_3 - T_{3'})$

273
35
·8

$h_3' = 366.07 - 4.556 \ln\left(\frac{308}{303}\right)(308 - 303)$

$h_4 = h_3' = 343.29$ kJ/kg

$s_2|_{35} = s_f + x\, s_{fg}|_{-10°}$

$5.2086 = 0.82965 + x(\quad)$

$x = 0.88$

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

$h_1 = 1294.68$

$50\ kJ/s = \dot{m}\,(1294.68 - 343.29)$

$\dot{m} = 9$

$W = 0.0525(1488.57 - 1294.68)$

$= 10.18$ kW

$L = 1.2D$

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

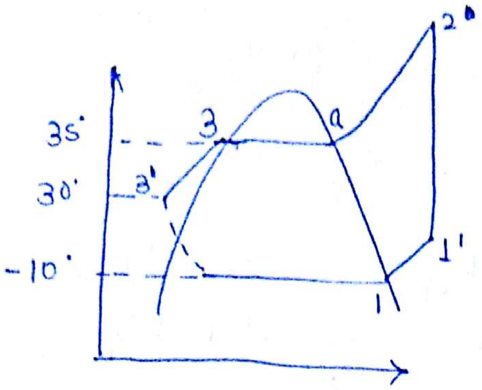
$= \frac{\pi}{4}(D^2)\,1.2D$

$D = 0.67$ m

$v_1 = v_f + x\, v_{fg}$

$=$

Q.22



$h_1 = 1450.22$

$h_3 = 366.07$

$h_a = 1488.07$

$h_3 - h_{3'} = C_{p_l}(T_3 - T_{3'})$

(C_{p_l} = 4.556, $T_3 - T_{3'}$ = 5)

$h_3' = 343.29$ kJ/kg.

$Q_{loss} = Q_{gain}$

$h_3 - h_{3'} = h_{1'} - h_1$

$366.07 - 343.29 = h_1' - 1450.22$

$h_1' = 1473.$

$h_{1'} - h_1 = C_{p_v}(T_{1'} - T_1)$

(C_{p_v} = 2.492, T_1 = 263)

$T_{1'} = 272.14\,K.$

$S_{1'} = S_1 + C_{p_v} \ln \frac{T_1'}{T_1} = 5.755 + 2.492 \ln \frac{272.14}{263}$

$S_{1'} = 5.840$ kJ/kgK

$S_1' = S_2' = S_a + C_{p_v} \ln \frac{T_2'}{T_a}$

$5.2086 = 5.2086 + 2.903 \ln \frac{T_2'}{308}$

$T_2' = 382.84\,K$

$$h_{2'} - h_a = C_{p_v}(T_{2'} - T_a)$$

$$h_{2'} = 1488.57 + 2.903(382.84 - 308)$$

$$h_2' = 1705.86$$

$$COP = \frac{R.E.}{W/p} = \frac{h_1 - h_{4'}}{h_2' - h_1'}$$

$$COP = 4.75$$

$$COP = \frac{R_C}{W_{i/p}} = 4.75 = \frac{50}{W_{i/p}}$$

$$W_{i/p} = 10.51 \text{ kW}$$

$$\eta_v = \frac{(\dot{m} \times 60)\, v_1'}{\frac{\pi}{4} D^2 L \times N \times K} \qquad \eta_v = 1 \text{ (let)}$$

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

$$\dot{m} = \frac{50}{(h_1 - h_{4'})}$$

$$\dot{m} = 0.045 \text{ kg/s.}$$

$$L = 1.2D, \quad K = 1$$

$1 \to 1'$

$$\frac{v_1}{T_1} = \frac{v_1'}{T_1'}$$

$$\frac{0.41749}{263} = \frac{v_1'}{272.14}$$

$$v_1' = 0.4319$$

$$\frac{(0.045 \times 60) \times 0.4319}{\frac{\pi}{4} D^2\, 1.2D \times 1000 \times 1} = 1$$

$$D = 107.49 \text{ mm}$$

$$L = 128.9 \text{ mm}$$