

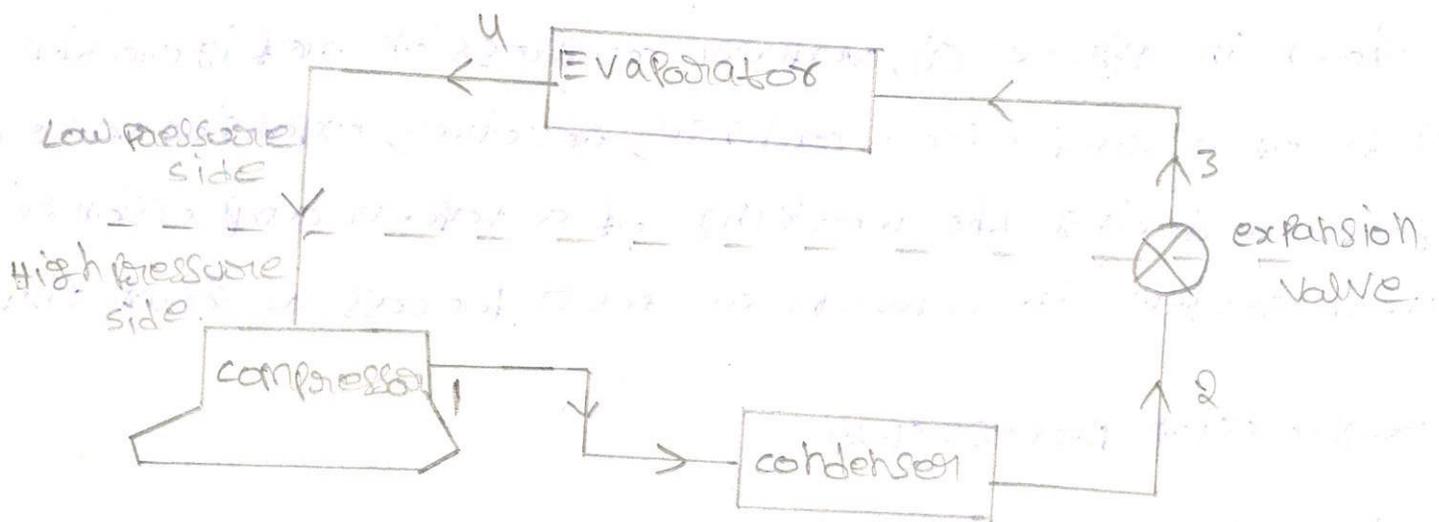
Unit - 2

①

Vapour compression Refrigeration systems

Working principle of vapour compression refrigeration system.

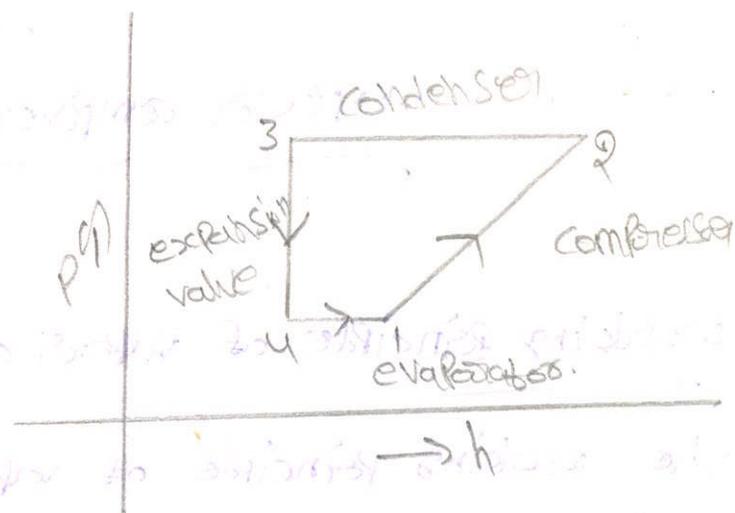
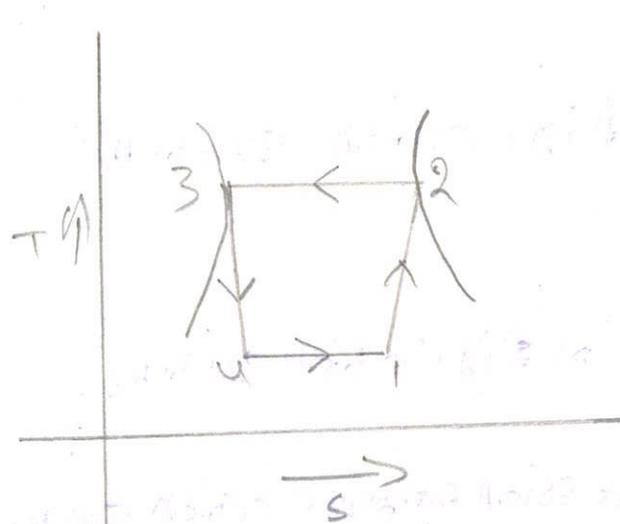
The working principle of vapour compression refrigeration system is shown in the below figure.



The main components of a vapour compression refrigeration system are

- 1) compressor
- 2) condenser
- 3) expansion valve, and
- 4) evaporator.

In its working the low temperature and pressure vapour is drawn from the evaporator and pressure is raised in to the compressor, where it gets compressed to high temperature and pressure. This high temperature and pressure refrigerant vapour again enters into the condenser where it is condensed to liquid. This liquid refrigerant passes through the expansion valve and enters into the evaporator. In this, the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant enters into the compressor completing the cycle.



As shown in figure (i), vapour compression refrigeration system consists of a compressor, condenser, receiver, expansion valve and evaporator. During the working of a vapour compression refrigeration system, it consists of four processes as shown figure.

1) compression process (1-2)

2) condensation process (2-3)

3) expansion process (3-4)

4) evaporation process (4-1)

1) compression process (1-2) :- In this process, low temperature and low pressure vapour refrigerant from the evaporator is drawn into the compressor, where it gets compressed to high temperature and high pressure. The compression process takes place adiabatically in which pressure, temperature, and enthalpy of the refrigerant increases from P_1, T_1 and P_2, T_2 and h_2 respectively.

2) condensation process :- The vapour at high temperature and high pressure from the compressor is then enters into the condenser where it is condensed to liquid. In this process, reversible rejection of heat takes place with the help of cooling medium circulated in the condenser at constant pressure. The enthalpy of the refrigerant decreases from $h_2 - h_3$ whereas pressure and temperature remains constant.

②
3) expansion process (3-4) : The condensate leaving the condenser enters into the receiver from where required amount of refrigerant is supplied to the expansion valve. In expansion valve the irreversible expansion of liquid takes place at constant enthalpy. During this process the temperature and pressure of the refrigerant falls from T_3 and P_3 to T_4 and P_4 respectively.

4) evaporation process (4-1) : In this process, reversible addition of heat takes place at constant pressure. Heat is absorbed by the liquid refrigerant present in the evaporator and vapourise to vapour state. During this process, enthalpy of the refrigerant increases from $h_4 = h_1$ and the temperature and pressure remains constant. The low pressure and temperature vapour refrigerant from the evaporator is then enters into the compressor, thus completing the cycle.

Advantages : advantages of vapour compression refrigeration system over air refrigeration system are as follows.

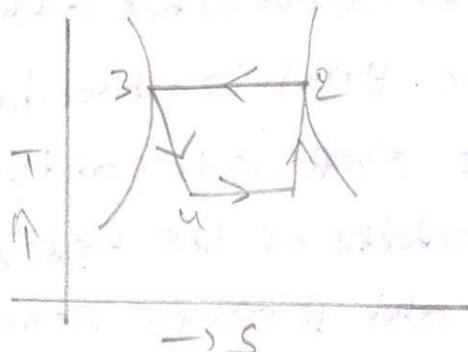
- 1) It has higher C.O.P than the air refrigeration system because the working of cycle is similar to that of reversed Carnot cycle.
- 2) Running cost is lower than the air refrigeration system.
- 3) For the same capacity it has smaller size when compared to the air refrigeration system.
- 4) It can function effectively for a larger range of temperature.
- 5) For the same refrigeration effect, the evaporator size is smaller in case of vapour compression system.

Types of vapour compression cycles.

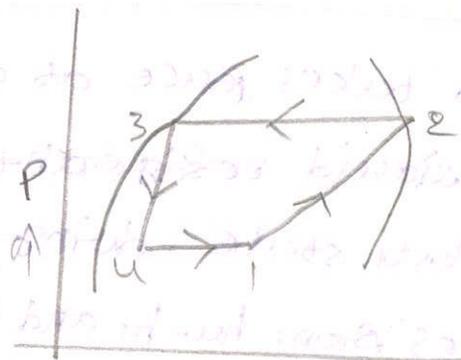
The important types of vapour compression cycles are.

1) cycle with dry saturated vapour after compression.

T-s and p-h diagrams for vapour compression cycle with dry saturated vapour after compression is shown in below fig.



T-s diagram



p-h diagram

In this, the liquid refrigerant after extracting heat enters into the compressor, where it gets compressed to dry saturated vapour state. all the process remains same as that of simple vapour compression cycle.

work done during isentropic compression for 1 kg of refrigerant.

$$w = h_2 - h_1$$

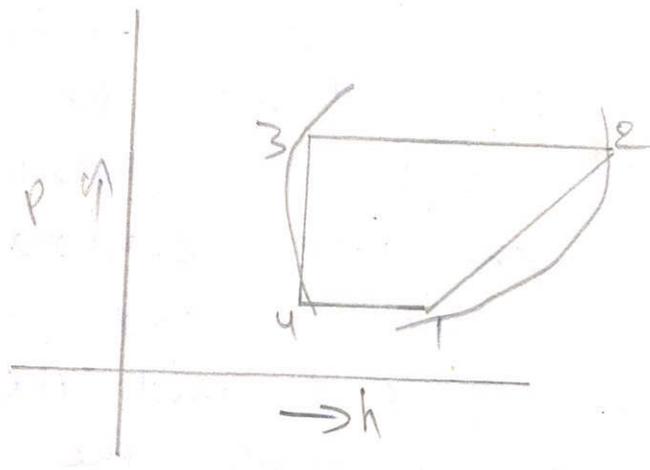
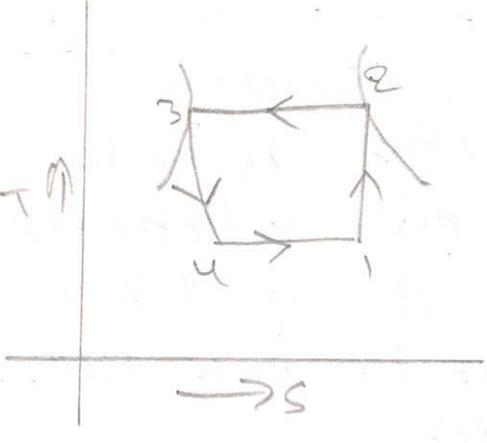
Net refrigerating effect.

$$N = h_1 - h_4 = h_1 - h_f3$$

$$\therefore \text{C.O.P} = \frac{N}{w} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_f3}{h_2 - h_1}$$

2) cycle with wet vapour after compression.

T-s and p-h diagram for vapour compression cycle with wet vapour after compression is shown in below fig. in this cycle, the refrigerant after compression is in wet state and the enthalpy at this point can be found out with the help of dryness fraction at this point.

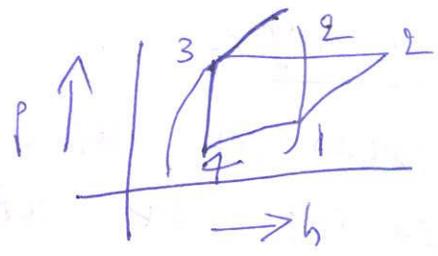
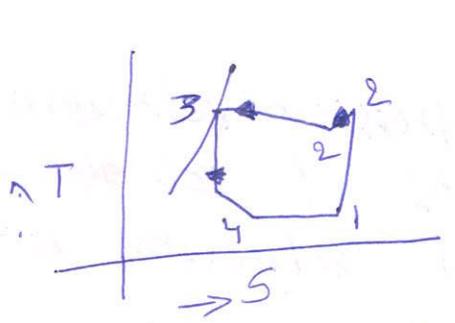


The dryness fraction can be found out by equating the entropies at point 1 and 2 as the compression process is isentropic

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

3) cycle with superheated vapour after compression

T-s and P-h diagram for vapour compression refrigeration cycle with superheated vapour after compression. here the vapour obtained after compression is in superheated state and enthalpy at that point can be found out by using degree of superheat. the degree of super heat can be found by equating the entropies at points 1 and 2.



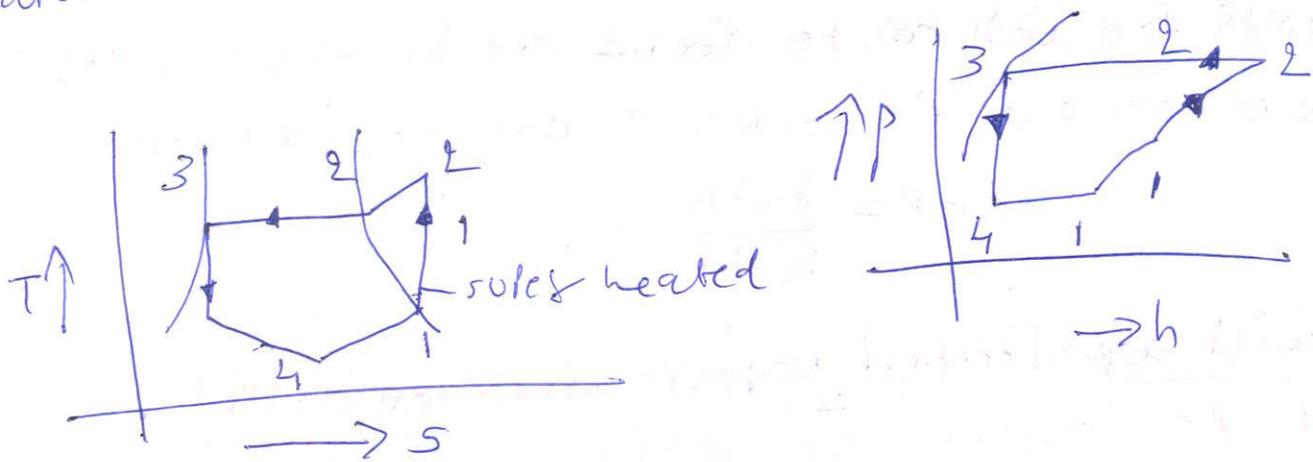
here the superheating of refrigerant increase the refrigerating effect as well as work done in compressor. The increase in work done is more as compared to increase in refrigerating effect. \therefore The superheating of refrigerant decrease the coefficient of performance.

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

in this cycle the cooling of refrigerant takes place in two stages. first is cooling of refrigerant from superheated state to dry saturated state at constant pressure and then dry saturated state to the point 3 at constant T_c .

4) cycle with superheated vapour before compression

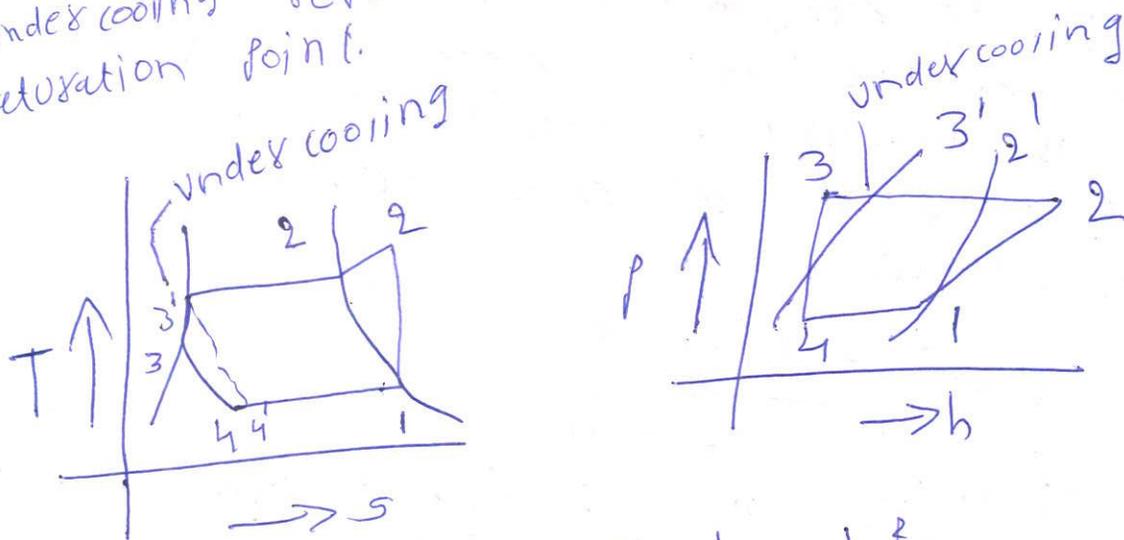
T-s and p-h diagram for a vapour compression refrigeration cycle with superheated vapour before compression. Here the evaporation of the refrigerant starts from point 4 and continues up to dry state i.e., up to point 1 and the vapour is now superheated before entering the compressor.



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

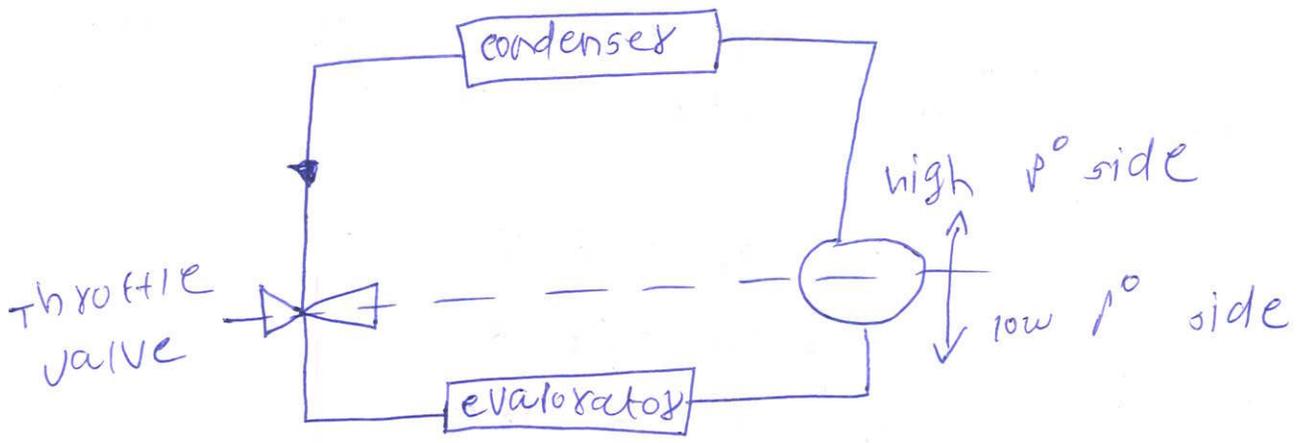
5) cycle with under cooling :-

T-s and p-h diagram for vapour compression refrigeration cycle with under cooling or sub cooling of refrigerant under cooling refers to the cooling of refrigerant below saturation point.



$$C.O.P = \frac{h_1 - h_f^3}{h_2 - h_1}$$

⊗ vapour compression system b/w condenser and evaporator. :-



vapour compression system

The main components of vapour compression system are compressor, condenser, evaporator and expansion device.

It is situated in between condenser and evaporator. The orifice of expansion valve or throttle valve is exact dividing point b/w high P° side and low P° side of system. It is used to control the flow of refrigerant under high P° & T° from condenser and at condensed state after reducing its P° & T° it is passed to evaporator.

Some of the liquid refrigerant evaporates as it passes through the valve but greater portion is vaporised in evaporator at low P° & T° .

In a vapour compression system just by adjusting the throttle valve of same unit the required T° of evaporator can be achieved.

Throttle valve is used in vapour compression systems instead of an expansion cylinder b/w condenser and evaporator.

Problems:

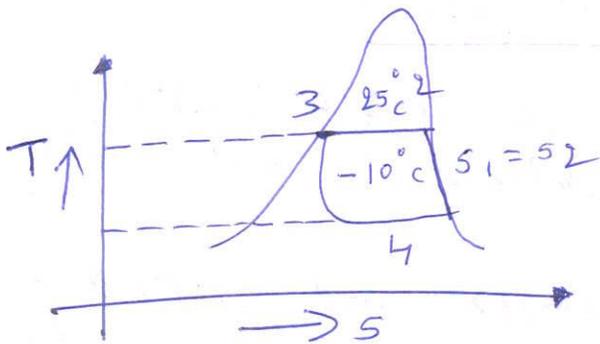
* A refrigerator using ammonia works between the T^0 -10 deg. C and 25 deg. C. The gas is dry at the end of compression and there is no under cooling of liquid. using the tables calculate the theoretical C.O.P of cycle.

Ans:-

given that

$$T_1 = T_4 = 263 \text{ K}$$

$$T_2 = T_3 = 298 \text{ K}$$



Process 1-2 it is isentropic ($s_1 = s_2$)

$$s_2 = (s_f)_2 + (s_{fg})_2 \text{ (at } 298 \text{ K)}$$

$$(s_f)_2 + \frac{(h_{fg})_2}{T_2}$$

$$= 0.349 + \frac{1237.8}{298}$$

$$= 4.4926 \text{ kJ/kgK}$$

$$\text{Enthalpy } h_2 = (h_f)_2 + (h_{fg})_2$$

$$= 100.8 + 1237.8$$

$$(s_g)_1 = (s_f)_1 + \frac{(h_{fg})_1}{T_1}$$

$$= -0.139 + \frac{1352.5}{263}$$

$$= 5 \text{ kJ/kgK}$$

$$(h_g)_1 = (h_f)_1 + (h_{fg})_1$$

$$= -33.7 + 1352.5$$

$$= 1318.8 \text{ kJ/kg}$$

Unit - 2, Pg - 8/17

$$h_3 = 100.8 \text{ kJ/kg}$$

$$h_3 = h_4$$

$$h_4 = 100.8 \text{ kJ/kg}$$

$$s_1 = s_2$$

$$\Rightarrow s_2 = (s_f)_1 + x(s_{fg})_1$$

$$= -0.139 + x(5)$$

$$4.6316 = 5x$$

$$x = 0.926$$

$$h_1 = (h_f)_1 + x(h_{fg})_1$$

$$= -33.7 + 0.926 [1352.5]$$

$$h_1 = 1219 \text{ kJ/kg}$$

$$C.O.P = \frac{h_1 - h_4}{h_2 - h_1} = \frac{1219 - 100.8}{1335.6 - 1219}$$

$$C.O.P = 9.59$$

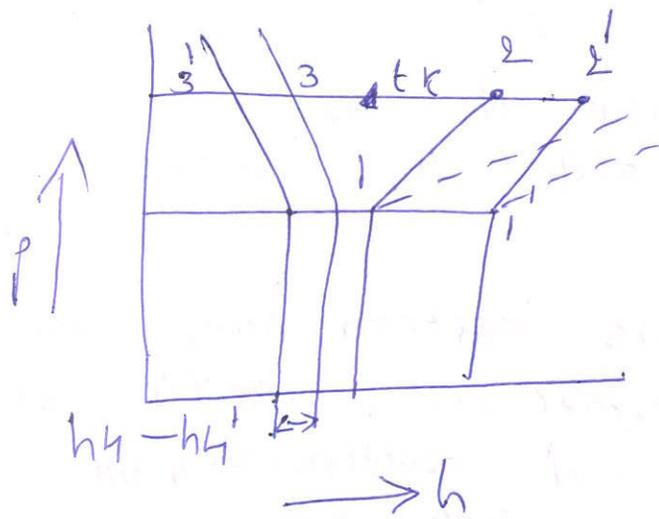
* A refrigeration system works on ammonia between P^o limits, 2.36 bar and 15.54 bar. If refrigerant is sub cooled by 10K before throttling determine the improvement in C.O.P over simple vapour compressor cycle.

given that

$$P_1 = 2.36 \text{ bar}$$

$$P_2 = 15.54 \text{ bar}$$

$$T = 10 \text{ K}$$



the effect on capacity is

$$\frac{Q_0}{Q_0} = \frac{h_1 - h_4}{h_1 - h_4'} \times \frac{V_1}{V_1'}$$

the effect on power requirement per unit refrigeration -

$$\frac{W^*}{W^*} = \frac{h_1 - h_4}{h_1 - h_4'} \times \frac{h_2 - h_1'}{h_2 - h_1}$$

the c.o.p of refrigeration is

$$\frac{(h_1 - h_4) + (h_1' - h_1)}{(h_2 - h_1) + (h_2' - h_1) - (h_2 - h_1)}$$



$$h_3 = 100.8 \text{ kJ/kg}$$

$$h_3 = h_4$$

$$h_4 = 100.8 \text{ kJ/kg}$$

$$s_1 = s_2$$

$$\Rightarrow s_2 = (s_f)_1 + x(s_g)_1$$
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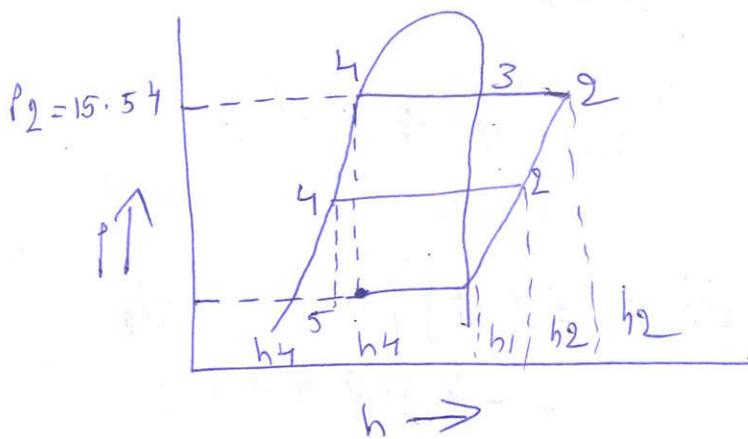
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given that

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$$T = 10 \text{ K}$$



enthalpy values corresponding to values

$$h_1 = 1426.5 \text{ kJ/kg}$$

$$h_2 = 1709.17 \text{ kJ/kg}$$

$$h_4 = 348.53 \text{ kJ/kg}$$

$$h_4 = 323.24 \text{ kJ/kg}$$

W.K.T

C.O.P of

simple cycle = $\frac{h_1 - h_4}{h_2 - h_1}$

$$= \frac{1426.51 - 348.53}{1709.17 - 1426.51}$$

$$= 3.8137$$

C.O.P of sub cooling cycle = $\frac{h_1 - h_4}{h_2 - h_1}$

$$= \frac{1426.51 - 323.54}{1709.17 - 1426.51}$$

$$= 3.9032$$

∴ improvement in C.O.P over simple vapour compression

$$= \frac{(\text{COP})_{\text{subcooling}} - (\text{COP})_{\text{simple cycle}}}{(\text{COP})_{\text{simple cycle}}}$$

$$= \frac{3.9032 - 3.8137}{3.8137}$$

$$= 2.34\%$$

⊗ a simple saturation cycle using F-12 is designed for taking a load of 10 tons. The refrigerant and ambient T^0 are $+0^\circ\text{C}$ and 30°C . a minimum T^0 difference of -5°C is required in evaporator and condenser for heat transfer find

i) mass flow rate through system

ii) power required in kW

iii) cylinder dimensions assuming $L/D = 1.2$ for single cylinder, single acting compressor. if it runs at 300 r.p.m with volumetric efficiency $\eta_v = 0.9$.

given data

$$\text{Load} = 10 \text{ tons}$$

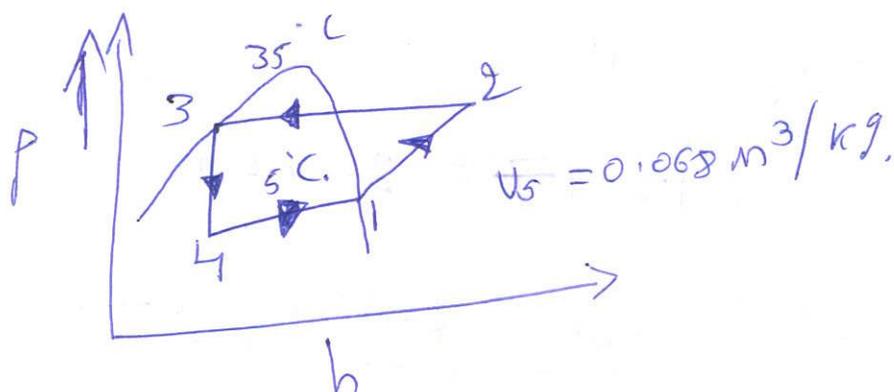
$$\text{refrigerator } T^0 T_r = 0^\circ\text{C}$$

$$\text{ambient } T^0 = 30^\circ\text{C}$$

$$L/D = 1.2$$

$$\text{speed } N = 300 \text{ r.p.m}$$

$$\text{volumetric } \eta_v = 0.9$$



since all the enthalpies are taken from P-h chart

$$\begin{aligned} \therefore T_r &= +0^\circ\text{C} \\ &= 0 - (-5) = 5^\circ\text{C} \end{aligned}$$

$$T_a = 30^\circ\text{C}$$

$$= 30 - (-5) = 35^\circ\text{C}$$

$$h_1 = 185 \text{ kJ/kg}$$

$$h_2 = 210 \text{ kJ/kg}$$

$$h_4 = 72 \text{ kJ/kg}$$

a) mass flow rate

$$M = \frac{10 \times 3.5}{h_1 - h_4} = \frac{35}{185 - 72}$$

$$= 0.31 \text{ kg/sec}$$

b) power required in kW = $m(h_2 - h_1)$
 $= 0.31(210 - 185) = 7.75 \text{ kW}$

c) cylinder dimensions

$$m v_s = \frac{\pi d^2}{4} L \times n v \times N/60$$

$$0.31 \times 0.068 = \frac{\pi}{4} \times 1.2 d^3 \times 0.9 \times \frac{300}{60}$$

$$\therefore d^3 = \frac{0.31 \times 0.068 \times 4}{\pi \times 1.2 \times 0.9 \times 5} = 0.000481$$

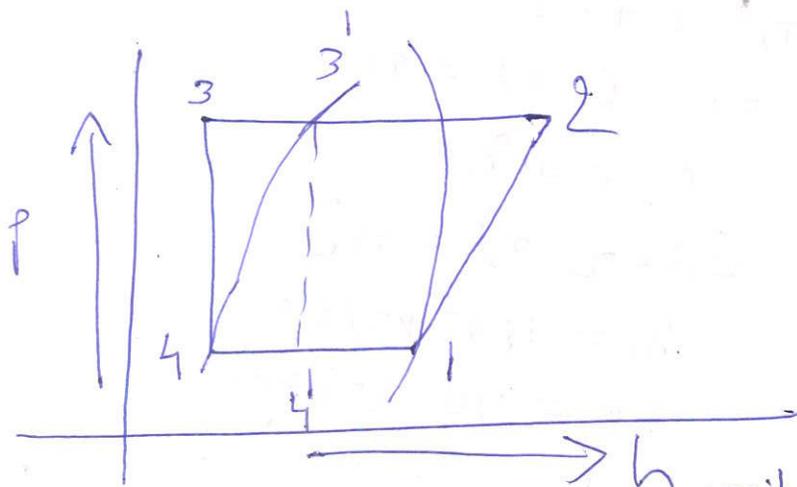
$$\therefore d = 0.17 \text{ m} = 17 \text{ cm}$$

$$\text{As } \frac{L}{D} = 1.2$$

$$\therefore L = 1.2 \times 17 = 20.4 \text{ cm}$$

* Effect of sub cooling :-

* What is effect of sub cooling :-

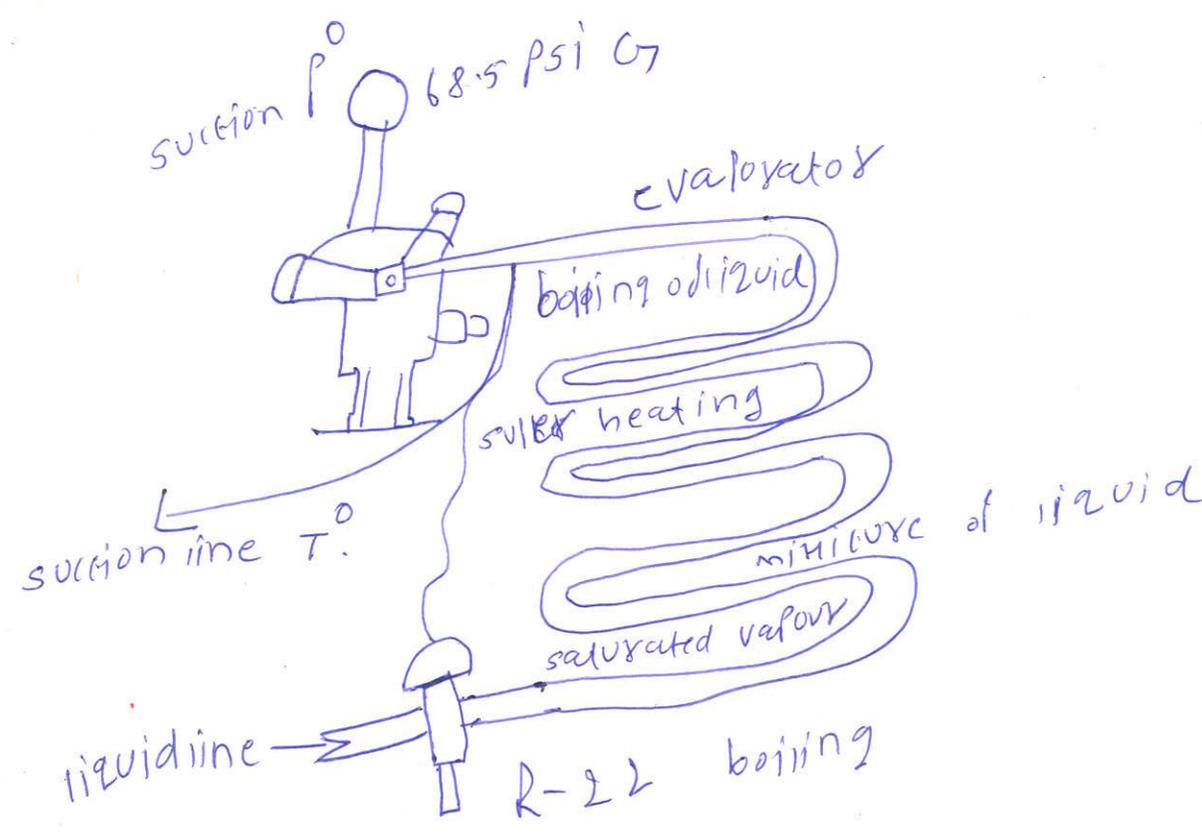


P-h diagram for a vapour compression refrigeration system with sub cooling of refrigerant is shown. Sub cooling refers to the process of cooling the refrigerant below the condensing T° for a given P° . This is done by installing a sub cooler b/w the condenser and expander. By this the refrigerant coming out of condenser is cooled to T° below its saturation T° .

Effect of sub cooling are to increase the refrigerating effect which increase the C.O.P of system.

* super heating of refrigerant: -

super heating: -
 it is defined as phenomenon is which the T° of refrigerant gas is increased above evaporating T° .



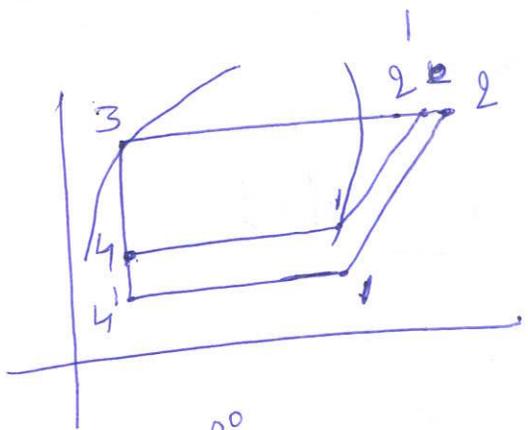
* cycle analysis actual cycle in fluence of various parameters on system performance:-

* What are the parameters that effect the vapour compression refrigeration?

the parameters which effect the vapour compression refrigeration.

- evaporator P^0
- condenser P^0
- suction vapour superheat
- liquid sub cooling

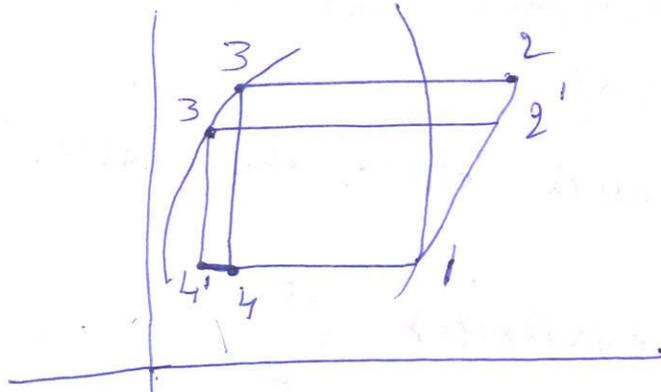
1. effect of evaporator P^0 :-



- Decrease in evaporator P^0
- i) decrease in refrigerating effect
 - ii) increase in specific volume thus reducing mass flow rate
 - iii) η volumetric decrease
 - iv) compressor work increase
 - v) C.O.P decrease

effect of condenser p^0

the effect of changing the condenser p^0 .

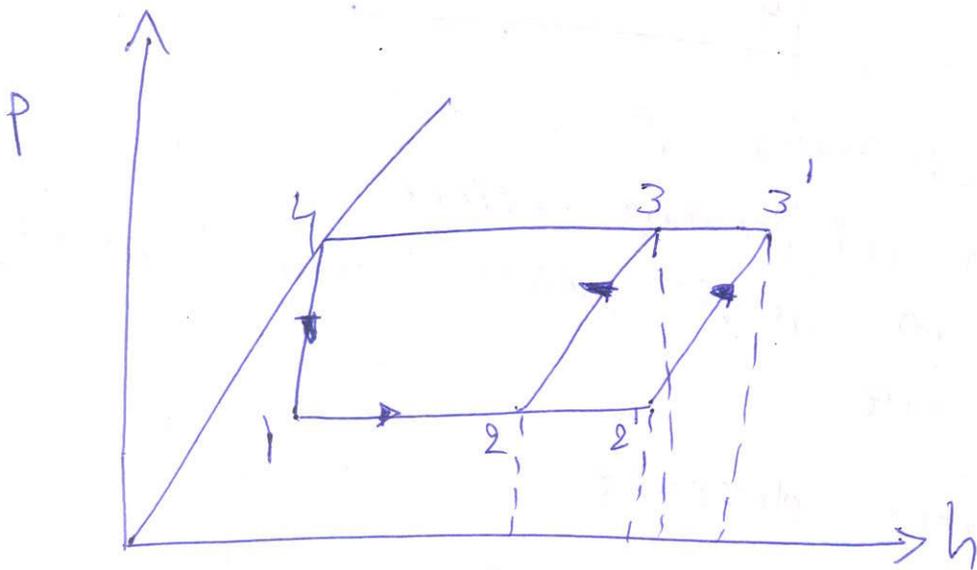


with an increase in condenser p^0

- i) Power consumption increases
- ii) Refrigerating effect decrease
- iii) C.O.P. decrease

3) sub cooling refer pg (7)

4) effect of liquid sub cooling

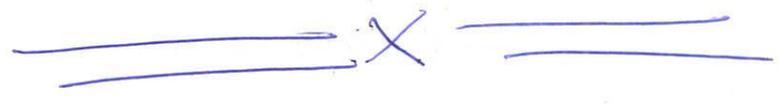


The flow of refrigerant is controlled with help of an automatic control expansion valve which makes the refrigerant superheated as it leaves the evaporator.

The vapour after leaving the evaporator also gets superheated through pipes located within the cooled space. The refrigeration effect again increases.

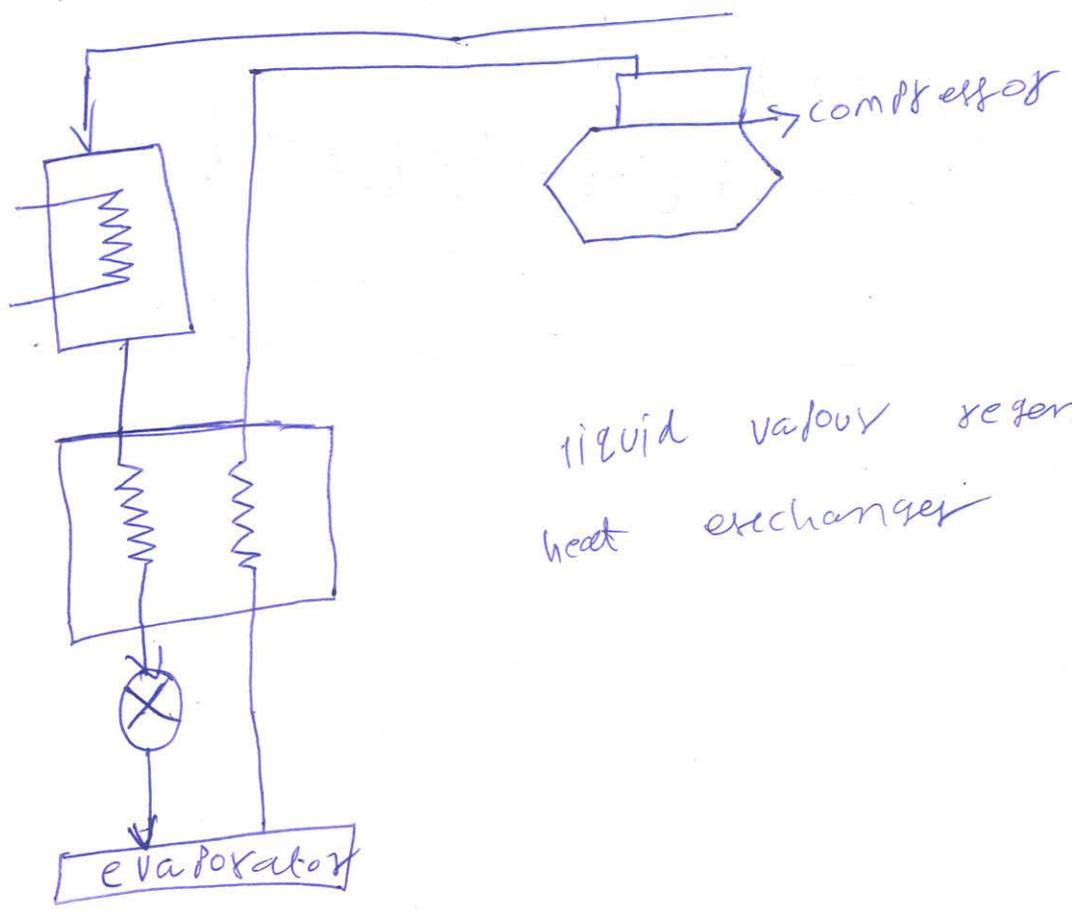
superheating is also possible in connecting piping outside the cooled space. in this case there is increase in work of compression decrease in refrigerating effect and also reduction of C.O.P.

heat again in this system may cause some trouble due to increase in specific volume of vapour at beginning of compression and pushes increase the required displacement.

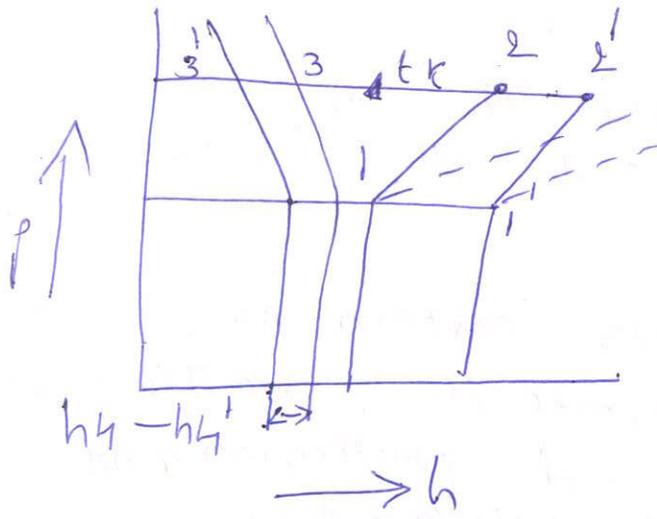


* Describe use of liquid vapour regenerative heat exchanger in vapour compression.

sol The combination of superheating of vapour with liquid sub cooling gives liquid vapour regenerative heat exchanger. The vapour coming out from evaporator is superheated in regenerative heat exchanger and consequently liquid from condenser is sub cooled.



liquid vapour regenerative heat exchanger



the effect on capacity is

$$\frac{Q_0}{Q_0} = \frac{h_1 - h_4}{h_1 - h_4'} \times \frac{V_1}{V_1'}$$

the effect on power requirement per unit refrigeration is

$$\frac{w^*}{w^*} = \frac{h_1 - h_4}{h_1 - h_4'} \times \frac{h_2 - h_1}{h_2 - h_1'}$$

the c.o.p of refrigeration is

$$\frac{(h_1 - h_4) + (h_1' - h_1)}{(h_2 - h_1) + (h_2' - h_1) - (h_2 - h_1)}$$

