MODULE -5 REFRIGERATION

- Air refrigeration system

- Vapour compression refrigeration system - Components - Working - P-H and T-S diagrams - Calculation of COP - Effect of sub-cooling and super-heating

- Selection and properties of refrigerant - Vapour absorption system - NH_3 – water system,

- Vapour adsorption system.

- Cryogenic engineering - Introduction, Application, Cryo-coolers.

Numerical on VCR System

1. A refrigerator works between -7°C and 27°C. The vapour is dry at the end of adiabatic compression. There is no under cooling. Determine the following,

(i) C.O.P (ii) Power of compressor to remove 12140 kJ/h of heat. (iii) capacity of the system

Temp (°C)	Sensible heat h_f (kJ/kg)	Latent heat h_{fg} (kJ/kg)	Entropy of liquid (s_f) (kJ/kg-K)	Entropy of vapour (s_g) (kJ/kg-K)
-7	-29.3	1297.9	-0.109	4.748
27	117.23	1172.3	0.427	4.333

$$Given\,data:$$

$$R.E. = 12140\,kJ/hr = \frac{12140}{3600}\,kJ/s = 3.37\,kW$$

Numerical on VCR System

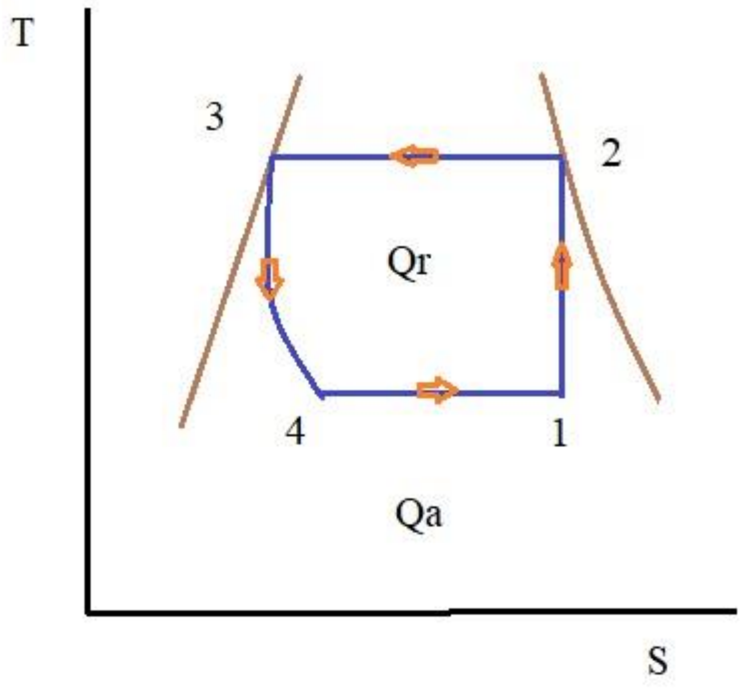
Temp (°C)	Sensible heat h_f (kJ/kg)	Latent heat h_{fg} (kJ/kg)	Entropy of liquid (s_f) (kJ/kg-K)	Entropy of vapour (s_g) (kJ/kg-K)
-7	-29.3	1297.9	-0.109	4.748
27	117.23	1172.3	0.427	4.333

To Find :

$$(i)\ C.O.P = \frac{h_1 - h_4}{h_2 - h_1}$$

$$(ii)\ Power\ of\ compressor = \dot{m}_r \times (h_2 - h_1)$$

$$(iii)\ capacity\ of\ the\ system = \frac{R.E\ in\ kW}{3.5\ kW}(TR)$$



Numerical on VCR System

$$Solution:$$

$$h_1 ...?$$

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

$$s_1 = s_{f1} + x_1\, s_{fg1} = s_{f1} + x_1 \left(s_{g1} - s_{f1} \right)$$

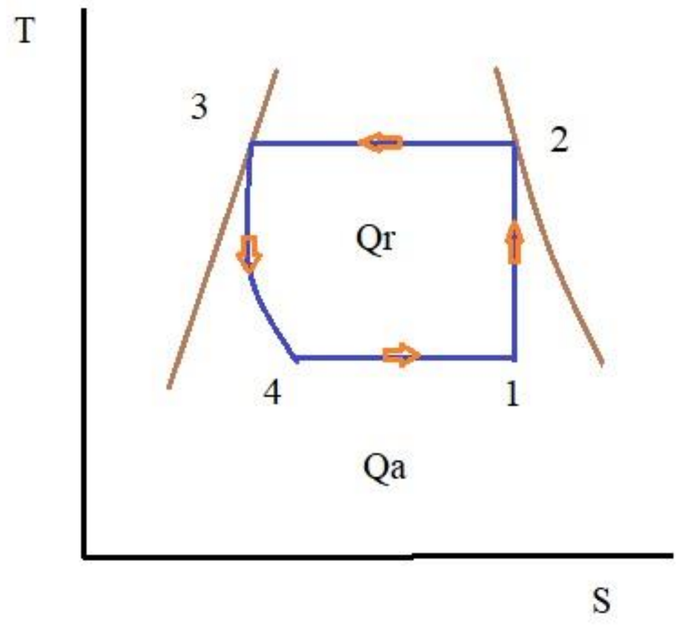
$$\because s_2 = s_{g2} = 4.333 (kJ / kg.K) = s_1$$

$$4.333 = -0.109 + x_1 \left(4.748 + 0.109 \right)$$

$$x_1 = 0.914$$

$$h_1 = h_{f1} + x_1\, h_{fg1} = -29.3 + 0.914(1297.9)$$

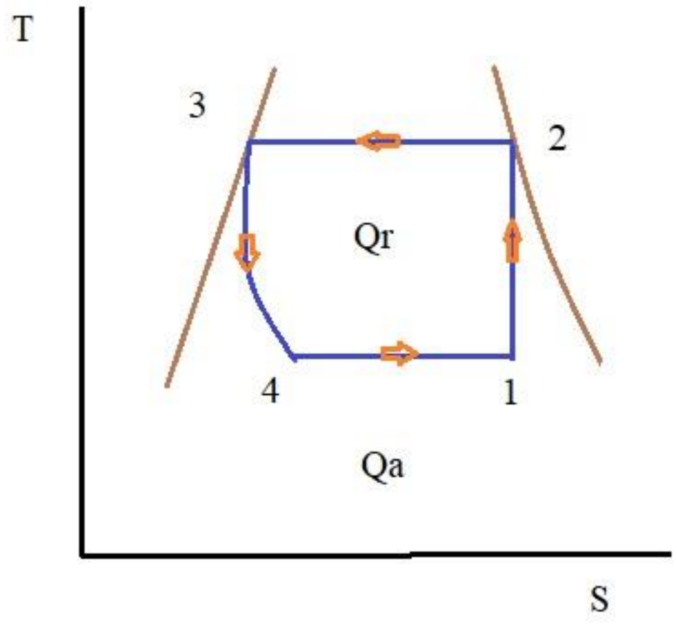
$$h_1 = 1157.7\, kJ / kg$$



Numerical on VCR System

$$Find : h_2 \ldots ?$$

$$h_2 = h_{f2} + x_2 h_{fg2} = 117.23 + 1172.3 = 1289.63 (kJ/kg)$$



$$Find : h_3 = h_{f3} = 117.23 (kJ/kg)$$

$$Answers :$$

$$(i) COP = \frac{h_1 - h_3}{h_2 - h_1} = 8$$

$$(ii) Power\ of\ compressor = \dot{m}_r \times (h_2 - h_1) = 0.0032 \times (1289.6 - 1157.7) = 0.424\, kW$$

$$Where,\ \dot{m}_r = \frac{12140/3600}{(h_1 - h_4)} = 0.0032\, kg/s$$

$$(iii) Capacity\ of\ the\ system = \frac{R.E. in\, kW}{3.5\, kW} = \frac{12140/3600}{3.5} = 0.96\ T.R.$$

Numerical on VCR System

2. A VCR system uses R-12 as a refrigerant. The liquid refrigerant evaporates in the evaporator at -15°C and the vapour is condensed in condenser at 10°C. The temperature of the refrigerant at the delivery of the compressor is 15°C. Determine the COP (i) if there is no under cooling, (ii) if the refrigerant is under cooled 5°C before throttling.

Take $C_{pv} = 0.658$ *kJ/kg-K* and $C_{pL} = 0.948$ *kJ/kg-K*.

Properties of R-12:

Temp (°C)	Sensible heat h_f (kJ/kg)	Enthalpy of Vapour h_g (kJ/kg)	Entropy of liquid (s_f) (kJ/kg-K)	Entropy of vapour (s_g) (kJ/kg-K)
-15	185.32	345.39	0.9450	1.5675
10	209.41	357.05	1.0335	1.555

Numerical on VCR System

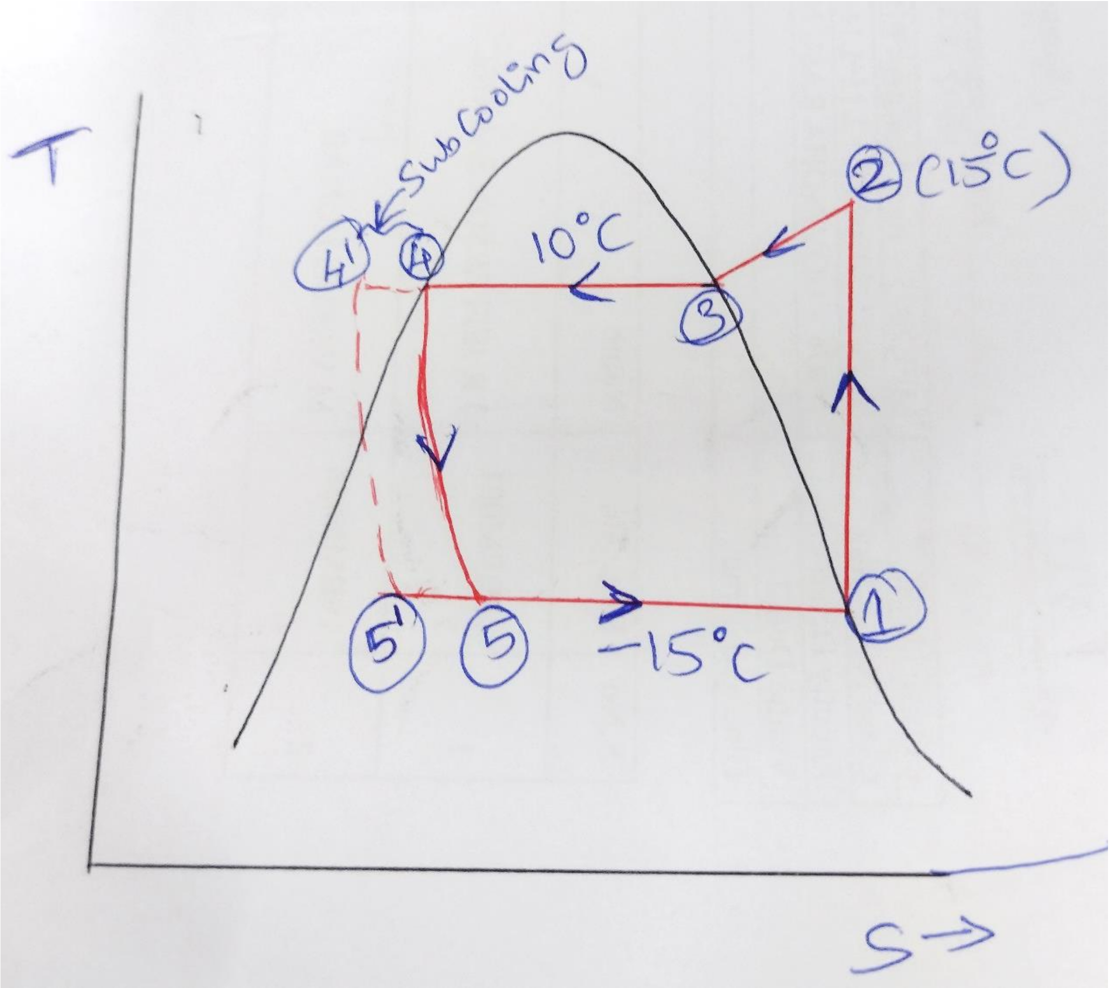
To Find :

$(i)\, COP\,(without\ under-cooling\ or\ sub-cooling)$

$$= \frac{h_1 - h_5}{h_2 - h_1} = \frac{h_1 - h_4}{h_2 - h_1}$$

$(ii)\, COP\,(with\ undercooling\ or\ sub-cooling)$

$$= \frac{h_1 - h_5^1}{h_2 - h_1} = \frac{h_1 - h_4^1}{h_2 - h_1}$$



Numerical on VCR System

$$(i)\,COP\,(without\,undercooling) = \frac{h_1 - h_4}{h_2 - h_1}$$

$$State - 1 @ -15^\circ C$$

$$h_1 = h_f + x_1 h_{fg_1}$$

$$s_1 = s_f + x_1 s_{fg_1} \Rightarrow x_1\,?$$

$$here,$$

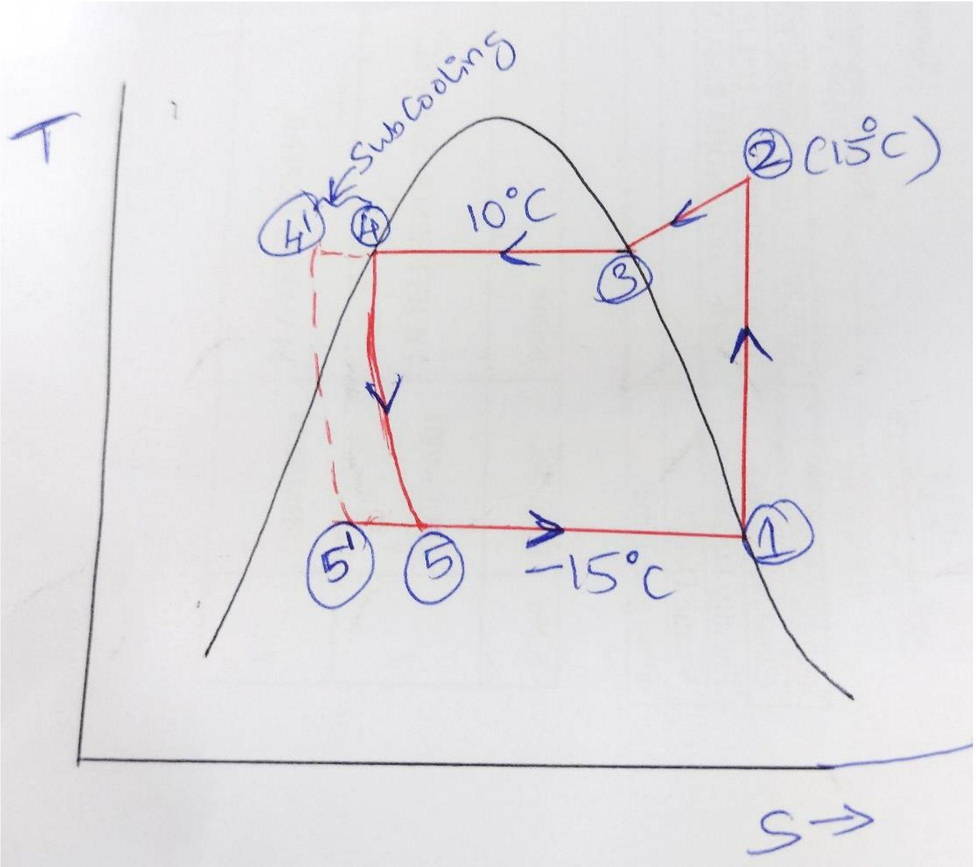
$$h_{fg} = h_g - h_f$$

$$s_{fg} = s_g - s_f$$

$$State - 2 @ 10^\circ C$$

$$h_2 = h_{g_2} + c_{pv}(T_{sup} - T_{sat})$$

$$s_2 = s_{g_2} + c_{pv} \ln\left(\frac{T_{sup}}{T_{sat}}\right) = s_1$$



Numerical on VCR System

$$State-2@10^\circ C$$

$$h_2 = h_{g_2} + c_{pv}(T_{\sup} - T_{sat}) = 357.05 + 0.658(288-283) = 360.29\, kJ/kg$$

$$s_2 = s_{g_2} + c_{pv}\ln\left(\frac{T_{\sup}}{T_{sat}}\right) = 1.555 + 0.658\ln\left(\frac{288}{283}\right) = 1.56\,(kJ/kg.K)$$

$$State-1@-15^\circ C\,(\because s_1 = s_2)$$

$$s_1 = s_{f1} + x_1 s_{fg_1} \Rightarrow 1.566 = 0.945 + x_1(1.5675 - 0.945) \Rightarrow x_1 = 0.997$$

$$h_1 = h_{f1} + x_1 h_{fg_1} = 185.32 + 0.997(345.39 - 185.32) = 344.9\ kJ/kg$$

$$h_4 = h_{f@10^\circ C} = 209.41\ kJ/kg = h_5$$

$$(i)\,COP\,(without\,undercooling) = \frac{h_1 - h_5}{h_2 - h_1} = \frac{h_1 - h_4}{h_2 - h_1} = 8.41$$

Numerical on VCR System

$$(ii)\, COP\,(with\, under\, cooling) = \frac{h_1 - h_5^1}{h_2 - h_1} = \frac{h_1 - h_4^1}{h_2 - h_1}$$

$$h_4^1 = h_{f\,4} - c_{p_L}\,(T_{sat} - T_{sub}) = 209.41 - 0.948\,(5) = 204.67\,(kJ\,/\,kg)$$

$$COP = \left(\frac{344 - 204.67}{360 - 344}\right) = 8.7$$

Numerical on VCR System

3. A vapour compression refrigeration system uses R22 refrigerant as refrigerant. It is working between the pressure limits of 3 bar and 20 bar. Refrigerant temperatures are at the outlet of the evaporator 8°C, at the exit of the compressor 83°C, at the exit of the condenser 40°C and at the exit of the expansion valve 3°C. The condenser water inlet temperature is 18.8°C, and the outlet temperature is 38°C. The water flow rate to the condenser is 100 cm^3/s. The power required to drive the compressor is 2.6 kW. Calculate the following: (using p-h chart)

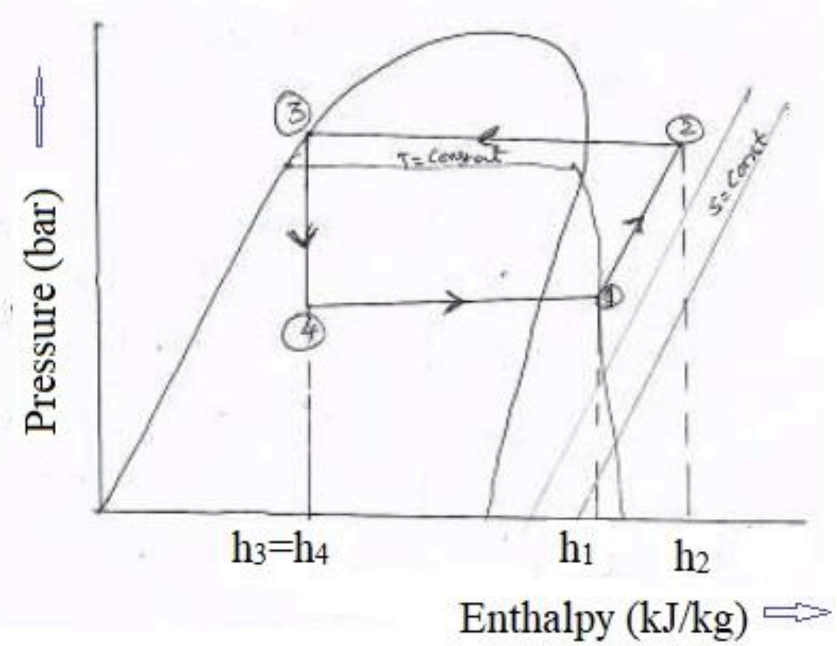
(i) Mass flow of refrigerant

(ii) Refrigerating capacity

(iii) Heat rejected by condenser

(iv) Actual COP of the system

(v) Carnot COP



Numerical on VCR System

$$Formula:$$

$$(i)\, m_r = \frac{W_{compressor}}{h_2 - h_1} (kg/s)$$

$$(ii)\, Cooling\ capacity = \frac{m_r (h_1 - h_4)}{3.5} (in\, TR)$$

$$(iii)\, Q_{condenser} = m_w c_{pw} (T_{out} - T_{in})$$

$$(iv)\, Actual\ COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$(v)\, Carnot\ COP = \frac{T_1}{T_2 - T_1}$$

Numerical on VCR System

Solution:

$h_1 = 410$ kJ/kg

$h_2 = 460$ kJ/kg

$h_3 = h_4 = 240$ kJ/kg

Mass flow rate of the refrigerant, $m_r = W/\ (h_2 - h_1) = 0.0523$kg/sec

Refrigerating capacity $= m_r.(h_1 - h_4)\ /\ 3.5167\ = 2.53$ TR

Heat rejected by the condenser, $Q_r = m_w C_{pw}(T_5\text{-}T_6) = 8.02$ kW

Actual COP = Refrigeration effect / Work done $= (h_1 - h_4)\ /\ (h_2 - h_1) = 3.4$

$$\text{Carnot COP} = \frac{T_1}{T_2 - T_1} = 3.71$$