VAPOR COMPRESSION REFRIGERATION SYSTEM (VCRS)

UNIT II (Refrigeration & Air Conditioning)

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TOPICS:

- Introduction Simple Vapor Compression Refrigeration system,
- Analysis of vapor compression cycle, Use of T-s and P-h charts,
- Effect of change in suction and discharge pressures on C.O.P
- Effect of sub cooling of condensate & superheating of refrigerant vapor on C.O.P of the cycle,
- Actual vapor compression refrigeration cycle

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INTRODUCTION OF VAPOR COMPRESSION REFRIGERATION SYSTEM (VCRS)

- As mentioned, vapor compression refrigeration systems are the most commonly used among all refrigeration systems.

- As the name implies, these systems belong to the general class of vapor cycles, wherein the working fluid (refrigerant) undergoes phase change at least during one process.
INTRODUCTION OF VAPOR COMPRESSION REFRIGERATION SYSTEM (VCRS)

- In a vapor compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. The input to the system is in the form of mechanical energy required to run the compressor. Hence these systems are also called as mechanical refrigeration systems. Vapor compression refrigeration systems are available to suit almost all applications with the refrigeration capacities ranging from few Watts to few megawatts. A wide variety of refrigerants can be used in these systems to suit different applications, capacities etc.
A simple vapor compression refrigeration system consists of the following equipments:

i) Compressor

ii) Condenser

iii) Expansion valve

iv) Evaporator.
Functions Of Compressor In VCRS

- A gas compressor is a mechanical device that increases the pressure of a gas refrigerant by reducing its volume. Compression of a gas naturally increases its temperature.

- Compressors are similar to pumps both increase the pressure on a fluid and both can transport the fluid through a pipe. Thus compressor are necessary to move refrigerant through the VCRS.

- As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible, so the main action of a pump is to move the liquid elsewhere.
Functions Of Condenser In VCRS

- A device used to condense vapors into liquid is called a **condenser**
- Condenser is used to change the phase of refrigerant from vapour to liquid i.e. from light to denser phase.
- Condensation of vapor into liquid is the **opposite of evaporation or boiling** and is an exothermic process, meaning it releases heat.
- Refrigerant while passing through the **condenser pipes or tubes**, gives up its **latent heat** to the surrounding cooling medium.
- Cooling medium is usually air or water.
- Condensers are typically coolers or **heat exchangers**
Functions Of Expansion Valve In VCRS

• Expansion valve *controls the rate of flow of* refrigerant.

• The high pressure and high temperature liquid refrigerant from condenser enters the narrow opening of expansion valve, where due to expansion at constant enthalpy, *pressure of refrigerant reduces.*

• It is necessary to maintain the required *low pressure* in evaporator so that vaporization of refrigerant at *desired low temperature,* absorbing sufficient amount of *latent heat* can occur in evaporator.
Functions Of Evaporator In VCRS

• An evaporator consists pipes or tubes through which cold mixture is then routed.

• A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture.

• That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled by giving latent heat to refrigerant and thus lowers the temperature of the enclosed space to the desired temperature.

• The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser.
Thermodynamic Analysis Of VCRS

The **thermodynamics** of the vapor compression cycle can be analyzed on a **temperature** versus **entropy** diagram as depicted in Figure.

1 to 2 = Compression of vapor
2 to 3 = Vapor superheat removed in condenser
3 to 4 = Vapor converted to liquid in condenser
4 to 5 = Liquid flashes into liquid + vapor across expansion valve
5 to 1 = Liquid + vapor converted to all vapor in evaporator
Simple VCRS SCHEMATIC DIAGRAM WITH P-h & T-s DAIGRAM

Figure 3.28 (a) A basic vapor-compression refrigeration system, (b) its T-s diagram and (c) its log P-h diagram.
Process of vapor compression cycle

- **Process 1-2:**
  Isentropic compression of saturated vapor in compressor (P increases, T increases @ constant s(entropy), v (specific volume) decreases

- **Process 2-3:**
  Constant (P) heat rejection in condenser

- **Process 3-4:**
  Isenthalpic expansion of saturated liquid in expansion device, (P decreases, T decreases @ constant h(enthalpy), v (specific volume) increases

- **Process 4-1:**
  Constant (P) heat extraction in the evaporator
Evaporator: Heat transfer rate at evaporator or refrigeration capacity, $Q_e$:

$$Q_e = m_r (h_1 - h_4)$$

Compressor: Power input to the compressor, $W_c$ is given by:

$$W_c = m_r (h_2 - h_1)$$

Condenser: Heat transfer rate at condenser, $Q_c$ is given by:

$$Q_c = m_r (h_2 - h_3)$$

Expansion device: For the isenthalpic expansion process, the kinetic energy change across the expansion device could be considerable, however, if we take the control volume, well downstream of the expansion device, then the kinetic energy gets dissipated due to viscous effects, and

$$h_4 = (1 - x_4) h_{f,e} + x_4 h_{g,e} = h_f + x_4 h_{fg}$$
COP of the Simple VCRS

- The COP of the system is given by:

\[
COP = \left( \frac{\dot{Q}_e}{\dot{W}_c} \right) = \frac{\dot{m}_r \left( h_1 - h_4 \right)}{\dot{m}_r \left( h_2 - h_1 \right)} = \frac{h_1 - h_4}{h_2 - h_1}
\]
TYPES OF VAPOR COMPRESSION CYCLE

- WET COMPRESSION
- DRY SATURATED COMPRESSION
- SUPERHEATED COMPRESSION
Fig. 6.5.1. T-s diagram of refrigeration cycle
TYPES OF VAPOR COMPRESSION CYCLE

- Wet Compression: Cycle: B’C’DA
- Dry Saturated Compression: Cycle: BCDA
- Superheated Compression: Cycle B”C”DA
\[
\text{COP} = \frac{\text{Heat extracted at low temperature}}{\text{Work supplied}}
\]

Heat extracted at low temperature = Heat transfer during the process A-B = refrigerating effect.

\[
q_2 = (h_B - h_A)
\]

Work of compression = \( w = (h_c - h_B) \) (adiabatic compression).

\[
\text{So, COP} = \left\{ \frac{h_B - h_A}{h_c - h_B} \right\}
\]

Now, heat rejected to the condenser, = \( q_1 = w + q_2 \)

\[
= (h_C - h_B) + (h_B - h_A)
\]

\[
= (h_C - h_A) = (h_c - h_D)
\]
Factors Affecting the Performance of Vapor Compression Refrigeration System:

(a) Sub-cooling of Liquids:
In the Fig. 6.5.4(a) of simple vapor compression cycle, condensation process CD resulted in the liquid at saturated state D. If it was possible to further cool down the liquid to some lower value say upto D’, then the net refrigeration effect will be increased as (h_b - h_A) > (h_b - h_A). Hence, the sub cooling of the liquid increases the refrigerating effect without increasing the work requirement. Thus COP is improved. The sub cooling may be achieved by any of the following methods:

(i) By passing the liquid refrigerant from condenser through a heat exchanger through which the cold vapor at suction from the evaporator is allowed to flow in the reversed direction. This process subcools the liquid but superheats the vapor. Thus, COP is not improved though refrigeration effect is increased.

(ii) By making use of enough quantity of cooling water so that the liquid refrigerant is further cooled below the temperature of saturation. In some cases, a separate subcooler is also provided for this purpose. In this case, COP is improved.
(b) Superheating of Vapor:

If the vapor at the compressor entry is in the superheated state B", which is produced due to higher heat absorption in the evaporator, then the refrigerating effect is increased as \((h"_B - h_A) > (h_B - h_A)\). However, COP may increase, decrease or remain unchanged depending upon the range of pressure of the cycle.

(c) Change in suction pressure \((P_s)\):

![Diagram showing change in suction pressure](image)

**Fig. 6.5.4(c). Effect of change in evaporator and condenser pressure**

Let the suction pressure or the evaporating pressure in a simple refrigeration cycle be reduced from \(P_s\) to \(P'_s\). It will be clear from the figure that:

- The refrigerating effect is reduced to: \((h'_B - h'_A) < (h_B - h_A)\)
- The work of compression is increased to: \((h'_C - h'_B) > (h_C - h_B)\)
Fig. 11.5: Effect of superheat on specific refrigeration effect and work of compression (a) on P-h diagram (b) on T-s diagram
(d) Change in discharge pressure \((P_d)\):

In Fig.6.5.4(c), let us assume that the pressure at the discharge or the condensing pressure is increased from \(P_d\) to \(P'_d\). It will have effects as follows:

The compressor work requirement is increased to: \((h'_C - h_B) > (h_C - h_B)\)

The refrigerating effect is reduced to: \((h_B - h'_A) < (h_B - h_A)\)

Therefore, the increase in discharge pressure results in lower COP. Hence, the discharge pressure should be kept as low as possible depending upon the temperature of the cooling medium available.
(e) Effect of Volumetric Efficiency of Compressor:
The factors like clearance volume, pressure drop through discharge and suction values, leakage of vapor along the piston and superheating of cold vapor due to contact with hot cylinder walls, affects the volume of the vapor actually pumped by the compressor. The volumetric efficiency of a compressor is defined as:

\[
\eta_{\text{vol}} = \frac{\text{Actual mass of vapor drawn at suction conditions}}{\text{Theoretical mass that can be filled in the displacement volume}}
\]

Figure 6.5.4(e) represents the p-v diagram of a compressor. Now, during suction stroke B”–B, the vapor filled in clearance space at pressure \(P_d\) expands along C’-B’ and the suction valve opens only when the pressure has dropped down to \(P_s\). Therefore, the actual amount of vapor sucked during the suction stroke is \((v_1 - v_2)\) while the stroke volume is \((v_1 - v_c)\). Volumetric efficiency decreases the refrigeration effect.
Actual VCRS systems

The cycles considered so far are internally reversible and no change of refrigerant state takes place in the connecting pipelines. However, in actual VCRS several irreversibilities exist. These are due to:

1. Pressure drops in evaporator, condenser and LSHX
2. Pressure drop across suction and discharge valves of the compressor
3. Heat transfer in compressor
4. Pressure drop and heat transfer in connecting pipe lines
Actual P-h Chart
Actual T-s Chart
Process & State

- Pressure drop in evaporator: 4-1d
- Superheat of vapour in evaporator: 1d-1c
- Useless superheat in suction line: 1c-1b
- Suction line pressure drop: 1b-1a
- Pressure drop across suction valve: 1a-1
- Non-isentropic compression: 1-2
- Pressure drop across discharge valve: 2-2a
- Pressure drop in the delivery line: 2a-2b
- Desuperheating of vapour in delivery pipe: 2b-2c
- Pressure drop in the condenser: 2c-3
- Subcooling of liquid refrigerant: 3-3a
- Heat gain in liquid line: 3a-3b