

6.5 Simple Vapor Compression Refrigeration System:

A simple vapor compression refrigeration system consists of the following equipments:

- i) Compressor ii) Condenser iii) Expansion valve iv) Evaporator.

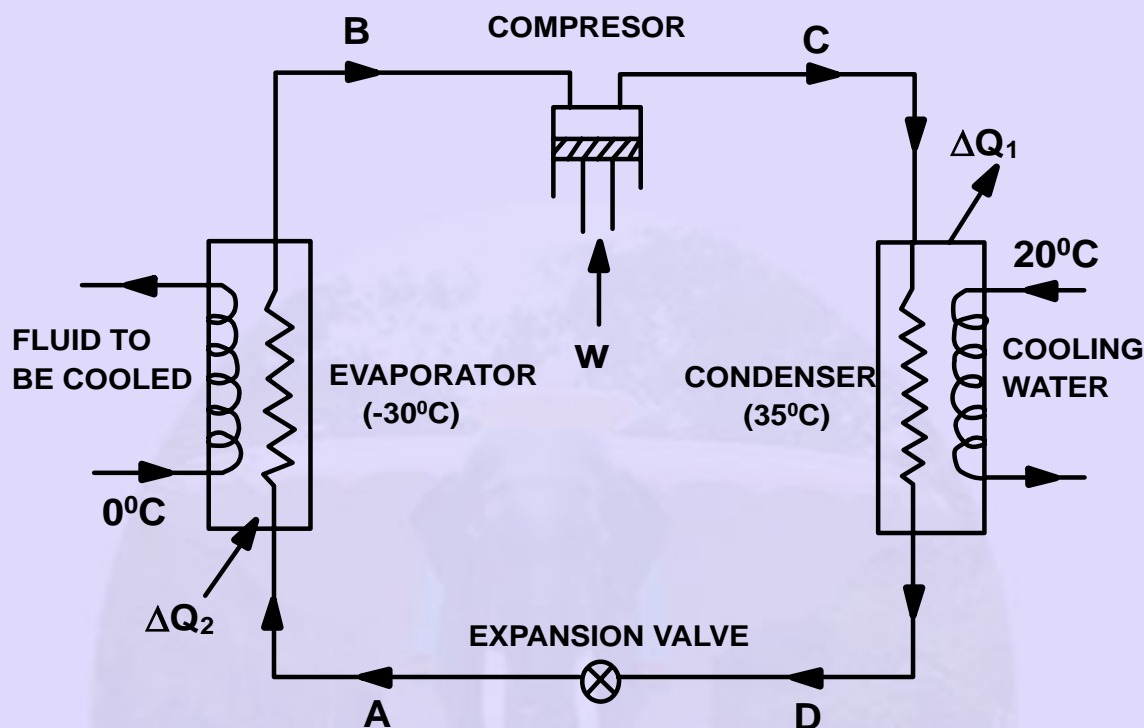


Fig.6.5. Simple vapour compression system

The schematic diagram of the arrangement is as shown in Fig.6.5. The low temperature, low pressure vapor at state B is compressed by a compressor to high temperature and pressure vapor at state C. This vapor is condensed into high pressure vapor at state D in the condenser and then passes through the expansion valve. Here, the vapor is throttled down to a low pressure liquid and passed on to an evaporator, where it absorbs heat from the surroundings from the circulating fluid (being refrigerated) and vaporizes into low pressure vapor at state B. The cycle then repeats. The exchange of energy is as follows:

- a) Compressor requires work, δw . The work is supplied to the system from the surroundings.
- b) During condensation, heat δQ_1 the equivalent of latent heat of condensation etc, is lost from the refrigerator.
- c) During evaporation, heat δQ_2 equivalent to latent heat of vaporization is absorbed by the refrigerant.
- d) There is no exchange of heat during throttling process through the expansion valve as this process occurs at constant enthalpy.

6.5.1 Simple Vapor Compression Cycle:

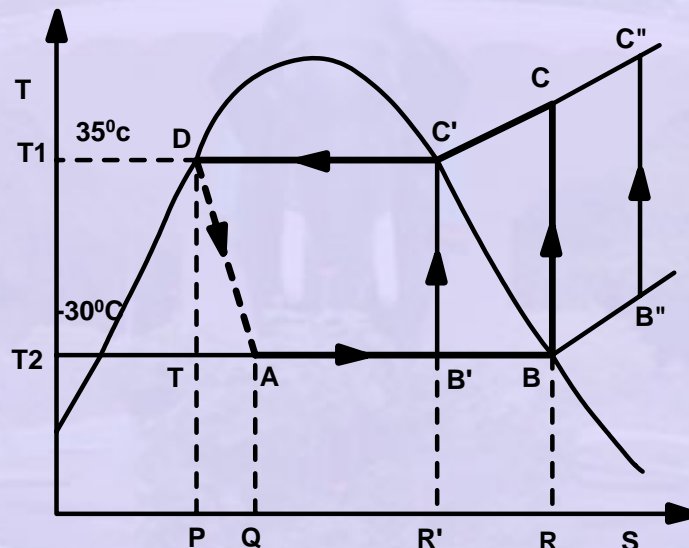


Fig.6.5.1. T-s diagram of refrigeration cycle

Figure 6.5.1 shows a simple vapor compression refrigeration cycle on T-s diagram for different compression processes. The cycle works between temperatures T_1 and T_2 representing the condenser and evaporator temperatures respectively. The various process of the cycle A-B-C-D (A-B'-C'-D and A-B''-C''-D) are as given below:

- i) *Process B-C (B'-C' or B''-C''):* Isentropic compression of the vapor from state B to C. If vapor state is saturated (B), or superheated (B''), the compression is called dry compression. If initial state is wet (B'), the compression is called wet compression as represented by B'-C'.
- ii) *Process C-D (C'-D or C''-D):* Heat rejection in condenser at constant pressure.
- iii) *Process D-A:* An irreversible adiabatic expansion of vapor through the expansion valve. The pressure and temperature of the liquid are reduced. The process is accompanied by partial evaporation of some liquid. The process is shown by dotted line.
- iv) *Process A-B (A-B' or A-B'') :* Heat absorption in evaporator at constant pressure. The final state depends on the quantity of heat absorbed and same may be wet (B') dry (B) or superheated (B'').

6.5.2 COP of Vapor Compression Cycle:

$$\text{COP} = \frac{\text{Heat extracted at low temperature}}{\text{Work supplied}}$$

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, $= q_1 = w + q_2$

$$= (h_C - h_B) + (h_B - h_A)$$

$$= (h_C - h_A) = (h_C - h_D)$$

6.5.3 Comparison of Simple Vapor Compression Cycle with Carnot Cycle:

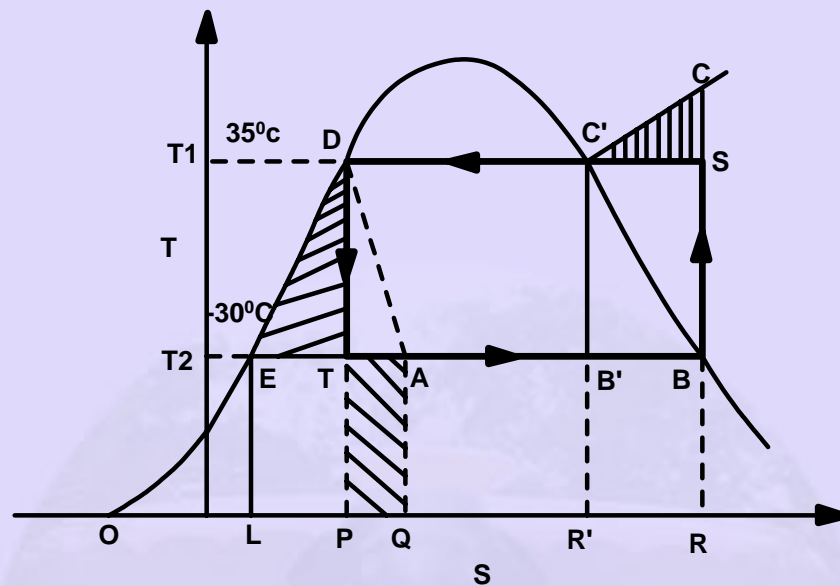


Fig.6.5.3. Comparison of simple vapor compression cycle with Carnot cycle

- In vapor compression cycle, de-superheating between C and C' is at constant pressure rather than constant temperature. Therefore, more work has to be supplied to the compressor. There is an equivalent amount of increase in the magnitude of heat rejected.*
- In vapor compression cycle, no work is done by the system during the throttling process. Hence, the network supplied to the cycle increases further by area EDT as compared to the reversed Carnot cycle. Because,*

$$\{(Area\ RSDO - Area\ RBEO) - Area\ EDT\} = Area\ BSCT$$
- In vapor compression cycle, there is a loss of refrigeration effect equivalent to area PQAT due to increase in entropy during the irreversible throttling expansion.*
- The effect of all these deviations is to increase the compression work required or to decrease the refrigeration effect and therefore the COP of the vapor compression cycle will be less than that of reversed Carnot cycle.*

(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):

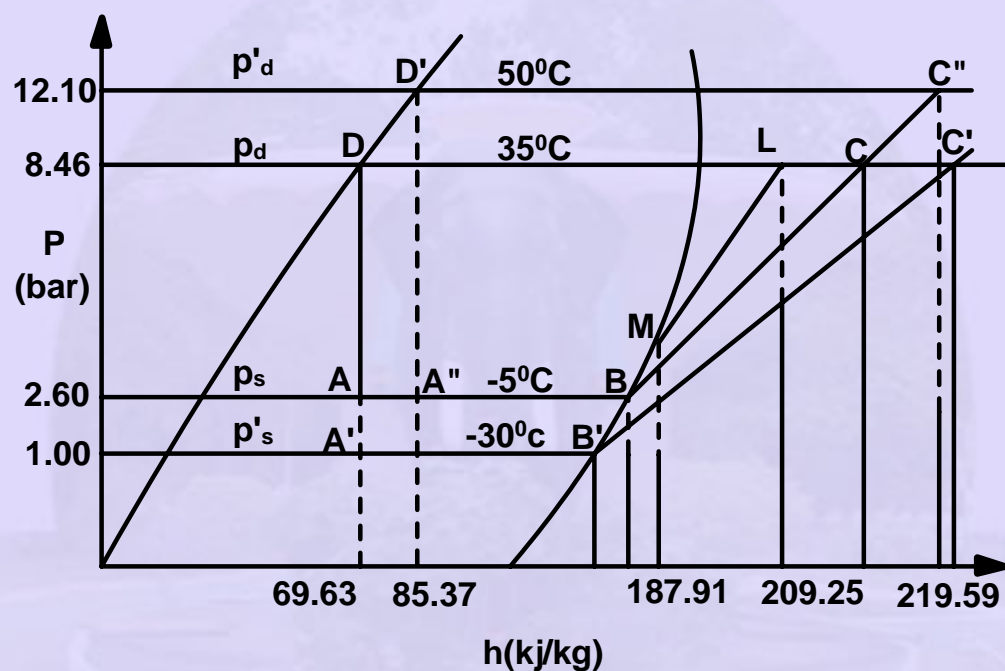


Fig.6.5.4(c). Effect of change in evaporator and condenser pressure

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: $(h'_C - h'_B) > (h_C - h_B)$

Hence, the decrease in suction pressure decreases the refrigeration effect and at the same time increases the work of compression. But, both the effects tend to decrease the COP.

(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:

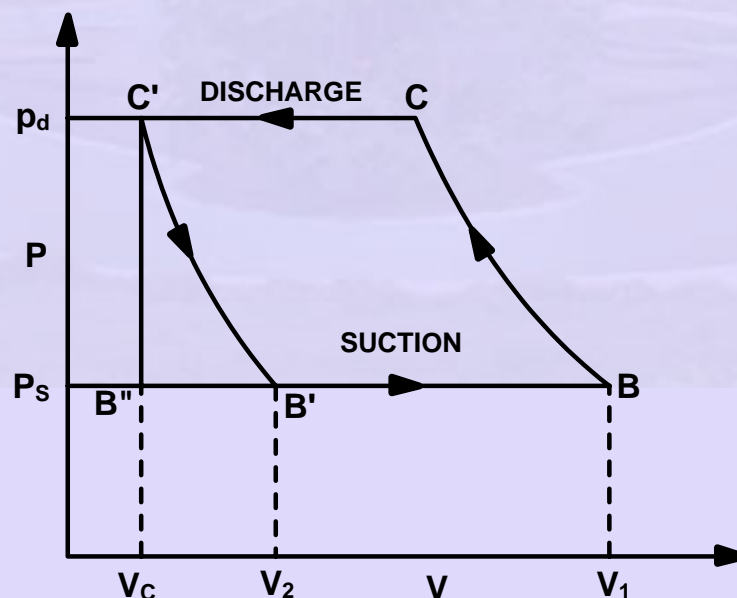


Fig.6.5.4(e). Effect of volumetric efficiency

The factors like clearance volume, pressure drop through discharge and suction valves, 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.

