Factors affecting the performance of Vapour Compression Refrigeration System-A Review

Ashish Nathalal Khudaiwala

Lecturer,
Mechanical Engineering Department,
Government Polytechnic,Porbandar(Gujarat), India

Abstract: ***Vapour Compression Refrigeration System is an important engineering process in today's demanding scenario of the world engineering. It is widely used refrigeration method in industries as well as domestic applications from a long times. To improve the coefficient of performance of the VCRS system, it is required that compressor work should decrease and refrigerating effect should increase. The objective of this paper is to review some factors like sub-cooling, superheating, suction and discharge pressures, evaporating and condensing temperatures etc which affects the COP of VCRS systems.***

IndexTerms – VCRS-Vapour Compression Refrigeration System, COP-Coefficient Of Performance, sub-cooling, superheating.

I. INTRODUCTION

Vapour compression cycle is an improved type of air refrigeration cycle in which a suitable working substance, termed as refrigerant, is used. The refrigerants generally used for this purpose are ammonia (NH3), carbon dioxide (CO2), R-22, R134a etc. The refrigerant used, does not leave the system, but is circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the solution which is used for circulating it around the cold chamber and in condensing; it gives out its latent heat to the circulating water of the cooler. The vapour compression cycle which is used in vapour compression refrigeration system is now-a-days used for all purpose refrigeration. It is used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

I.I THEORITICAL ANALYSIS

The working principle of simple vapour compression refrigeration system is shown in Fig.1.1. It mainly consists compressor, condenser, expansion device, evaporator and essential piping and valves accessories. As power is to be given to the system from outside, it is run by electric supply.

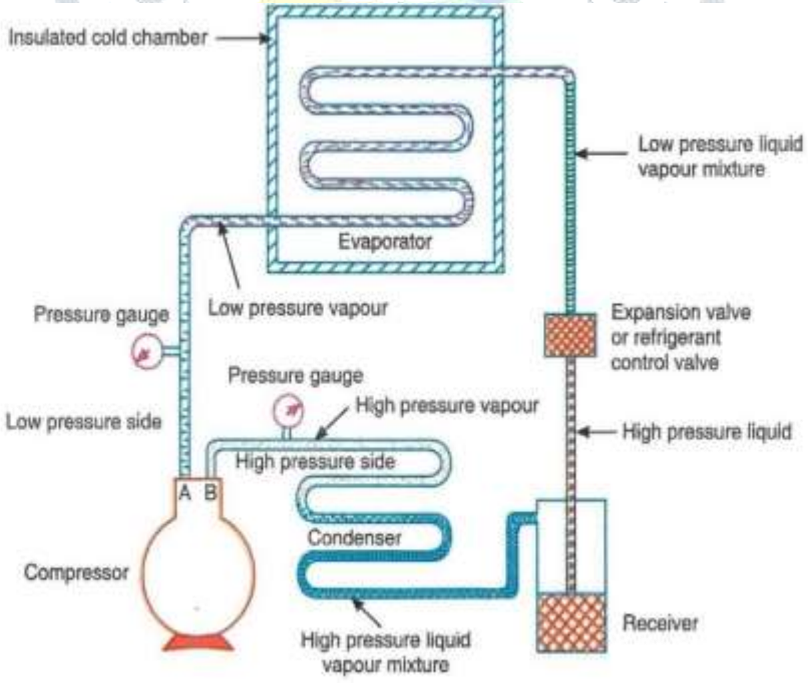

Figure 1.1 Simple Vapour Compression system

I.I I THEORETICAL VAPOUR COMPRESSION CYCLE WITH DRY SATURATED VAPOUR AFTER COMPRESSION

A vapour compression cycle with dry saturated vapour after compression is shown on T-s diagrams in Figures 1.2 and 1.3 respectively. At point 1, let T_1, p_1 and s_1 be the temperature, pressure and entropy of the vapour refrigerant respectively. The four processes of the cycle are as follows:

COMPRESSION PROCESS

The vapour refrigerant at low pressure p1 and temperatureT1 is compressed isentropic ally to dry saturated vapour as shown by the vertical line 1-2 on the T-s diagram and by the curve 1-2 on p-h diagram. The pressure and temperature rise from p_1 to p_2 and T_1 to T_2 respectively.

The work done during isentropic compression per kg of refrigerant is given by

$$w = h_2 - h_1$$

Where, h_1 = Enthalpy of vapour refrigerant at temperature T_1, i.e. at suction of the compressor, and

h_2 = Enthalpy of the vapour refrigerant at temperature T_2. i.e. at discharge of the compressor.

CONDENSING PROCESS

The high pressure and temperature vapour refrigerant from the compressor is passed through the condenser where it is completely condensed at constant pressure p_2 and temperature T_2 as shown by the horizontal line 2-3 on T-s and p-h diagrams. The vapour refrigerant is changed into liquid refrigerant. The refrigerant, while passing through the condenser, gives its latent heat to the surrounding condensing medium.

EXPANSION PROCESS

The liquid refrigerant at pressure $p_3 = p_2$ and temperature $T_3 = T_2$, is expanded by throttling process through the expansion valve to a low pressure $p_4 = p_1$ and Temperature $T_4 = T_1$ as shown by the curve 3-4 on T-s diagram and by the vertical line 3-4 on p-h diagram. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator. We know that during the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

VAPORIZING PROCESS

The liquid-vapour mixture of the refrigerant at pressure $p_4 = p_1$ and temperature $T_4 = T_1$ is evaporated and changed into vapour refrigerant at constant pressure and temperature, as shown by the horizontal line 4-1 on T-s and p-h diagrams. During evaporation, the liquid-vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which, is to be cooled, This heat which is absorbed by the refrigerant is called refrigerating effect and it is briefly written as RE. The process of vaporization continues up to point 1 which is the starting point and thus the cycle is completed.

We know that the refrigerating effect or the heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by

$$RE = h_1 - h_4 = h_1 - hf_3$$

Where, hf_3 = Sensible heat at temperature T_3, i.e. enthalpy of liquid refrigerant leaving the condenser.

It may be noticed from the cycle that the liquid-vapour refrigerant has extracted heat during evaporation and the work will be done by the compressor for isentropic compression of the high pressure and temperature vapour refrigerant.

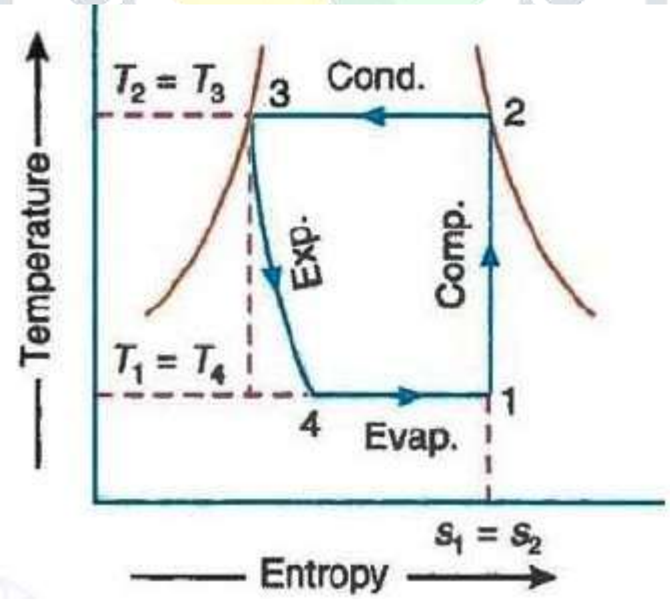

Figure 1.2 T-s diagram

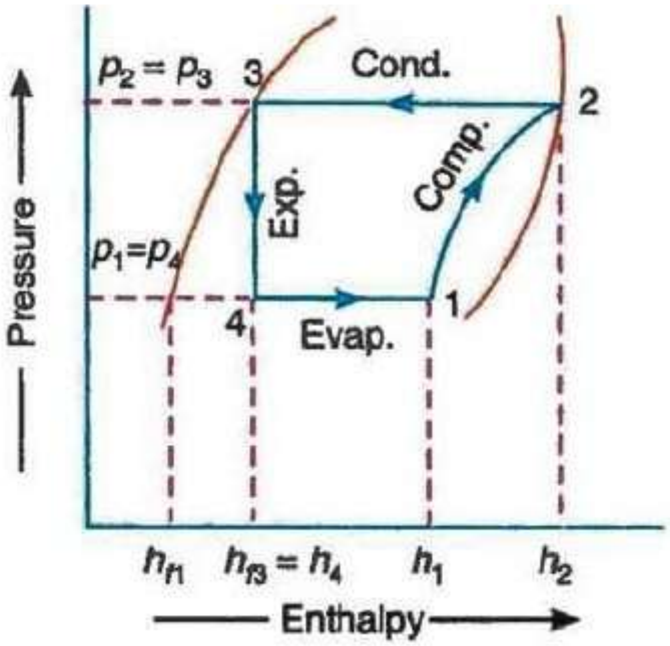

Figure 1.3 P-h diagram

As shown in Fig. 1.1 &1.3 the P-h diagram (Moeller diagram) for refrigeration cycle with four basic processes are frequently used in the analysis of vapour compression refrigeration cycle, process 1-2 is compression, process 2 -3 heat rejection in the condenser, process 3 - 4 expansion (Throttling) and process 4 -1 is Evaporation i.e. heat absorbed in the evaporator. [5-6] described the performance of air conditioner components. The performance characteristics are can be computed for compressor work (Wc), Refrigeration Effect (QE) and Coefficient of Performance (COP) is expressed by the ratio of amount of heat taken by the cold body to the amount of work supplied by the compressor; this ratio is called Coefficient of performance [2]. The system performance is calculated as follows:

The work done during the isentropic compression per kg of refrigerant is given by,

$$Wc = m_r \times (h_2 - h_1) \quad (1)$$

The refrigerant effect or heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by,

$$QE = m_r \times (h_1 - h_4) \quad (2)$$

The Coefficient of performance (C.O.P.) is the ratio of heat extracted in the refrigerator to work done on the refrigerator,

$$COP = \text{Refrigeration Effect/ Work Done} \quad (3)$$

$$COP = h_1 - h_4 / h_2 - h_1 \quad (4)$$

$$\text{Pressure ratio} = \frac{Pc}{Pe} \quad (5)$$

$$\text{Energy Efficiency Ratio (EER)} = 3.5 \times COP \quad (6)$$

$$\text{Capacity of the system} = 1\ TR = 3.5\ kW \quad (7)$$

$$\text{Heat rejected in the condenser} = mr \times (h2 - h3) \quad (8)$$

$$\text{Heat absorbed in the evaporator} = mr \times (h1 - h4) \quad (9)$$

Where,

h_1 and h_2= Enthalpies of refrigerant at the inlet and outlet of compressor respectively (kJ/kg).
h3 and h4= Enthalpies of refrigerant at the inlet and outlet of expansion valve respectively (kJ/kg).

II. FACTORS AFFECTING THE PERFORMANCE OF VCRS SYSTEM

II.I EFFECT OF SUCTION PRESSURE

The suction pressure (or evaporator pressure) decreases due to the frictional resistance of flow of the refrigerant. Let us consider a theoretical vapour compression cycle 1-2-3-4 when the suction pressure decreases from p_s to p_{s1} as shown on p-h diagram in Figure 2.1.

It may be noted that the decrease in suction pressure:

(a) decreases the refrigerating effect from $(h_1 - h_4)$ to $(h_1' - h_4')$

(b) Increases the work required for compression from $(h_2 - h_1)$ to $(h_2' - h_1')$.

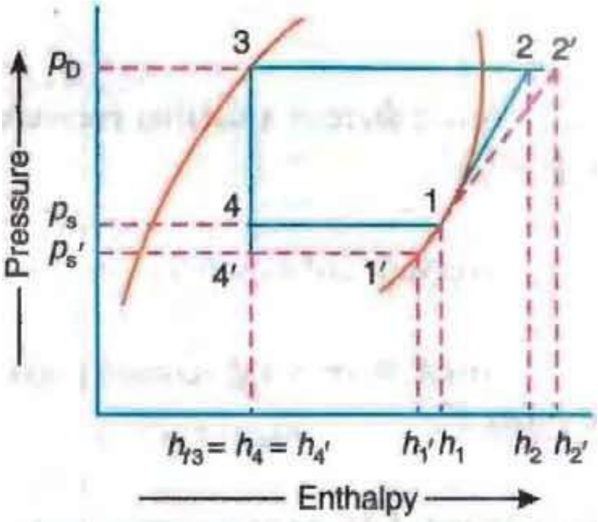

Figure 2.1Effect of Suction Pressure

Since the C.O.P, of the system is the ratio of refrigerating effect to the work done, therefore with the decrease in suction pressure, the net effect is to decrease the C.O.P. of the refrigerating system for the same refrigerant flow. Hence with the decrease in suction pressure the refrigerating capacity of the system decreases and the refrigeration cost increases.

II.II EFFECT OF DISCHARGE PRESSURE

In actual practice, the discharge pressure (or condenser pressure) increases due to frictional resistance of flow of the refrigerant. Let us consider a theoretical vapour compression cycle l-2-3-4 when the discharge pressure increases from P_D to P_{D1} as shown on p-h diagram in Figure 2.2 resulting in increased compressor work and reduced refrigeration effect.

The effect of increase in discharge pressure causes increase in the power consumption to run the compressor with reduction in refrigerating effect(similar to decrease in suction pressure).The only difference is that the effect of decrease in suction pressure is more predominant than the effect of increase in discharge pressure and hence COP decrease.

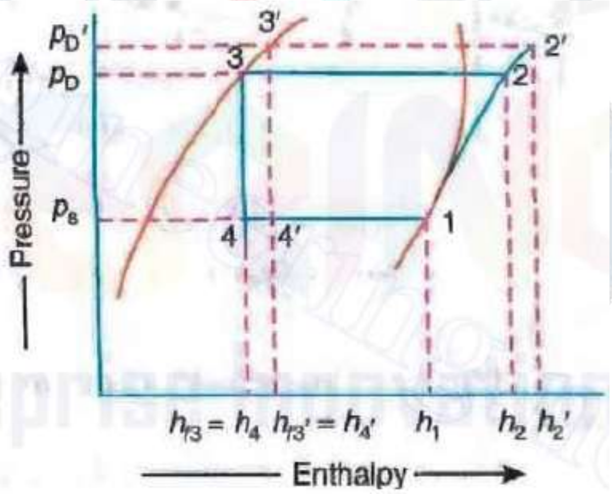

Figure 2.2 Effect of Discharge Pressure

II.III EFFECT OF EVAPORATOR PRESSURE

Consider a simple saturation cycle 1-2-3-4 with Freon 12 as the refrigerant as shown in Figure 2.3 for operating conditions of t_k = 40°C and t = – 5°C.

Now consider a change in the evaporator pressure corresponding to a decrease in the evaporator temperature to – 10°C. The changed cycle is shown as 11-21-31-41 in Figure 2.3.

It is therefore, seen that a drop in evaporator pressure corresponding to a drop of 5°C in saturated suction temperature increases the volume of suction vapour and hence decreases the capacity of a reciprocating compressor and increases the power consumption per unit refrigeration

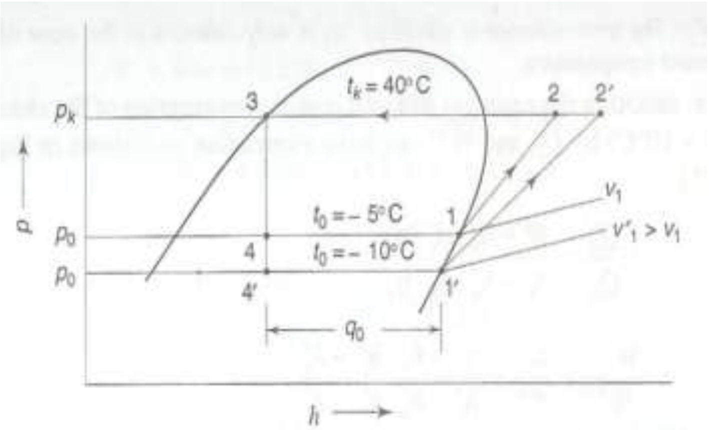

Figure 2.3 Effect of Evaporator Pressure

It is observed that a decrease in evaporator temperature results in:
(a) Decrease in refrigerating effect from (h1 – h4) to (h1' – h4').
(b) Increase in the specific volume of suction vapour from v1 to v11.
(c) Decrease in volumetric efficiency, due to increase in the pressure ratio.
(d) Increase in compressor work from (h2 – h1) to (h2' – h1') due to increase in the pressure ratio.

II.IV EFFECT OF LIQUID SUBCOOLING

Sub cooling is the condensation process carried out at the temperature lower than the saturation temperature at condenser pressure. It is possible to reduce the temperature of the liquid refrigerant to within a few degrees of the temperature of the water entering the condenser. In some condenser designs it is achieved by installing a sub-cooler between the condenser and the expansion valve.

The effect of sub-cooling of the liquid from $t_3 = t_k$ to t'_3 is shown in Figure 2.4. It will be seen that sub-cooling reduces flashing of the liquid during expansion and increases the refrigerating effect. Consequently, the piston displacement and horsepower per ton are reduced for all refrigerants. The percent gain is less pronounced in the case of ammonia because of its larger latent heat of vaporization as compared to liquid specific heat.

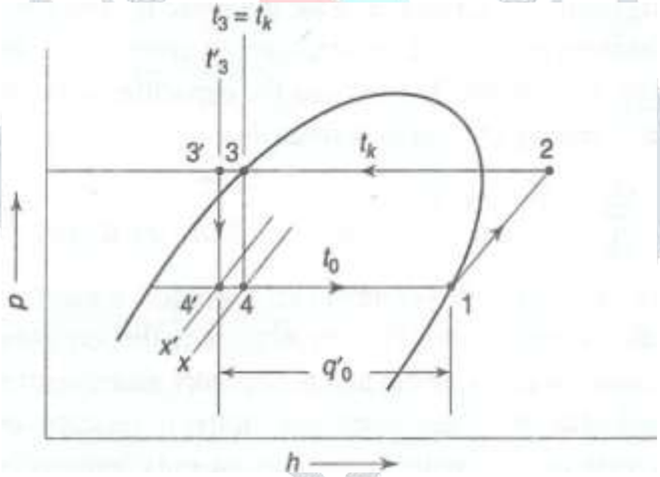

Figure 2.4 Effect of Liquid Subcooling

Normally, cooling water first passes through the sub cooler and then through the condenser. Thus, the coolest water comes in contact with the liquid being sub cooled. But this results in a warmer water entering the condenser and hence a higher condensing temperature and pressure. Thus, the advantage of sub cooling is offset by the increased work of compression.

This can be avoided by installing parallel cooling water inlets to the sub cooler and condenser. In that case, however, the degree of sub cooling will be small and the added cost of the sub cooler and pump work may not be worthwhile. It may be more desirable to use the cooling water effectively in the condenser itself to keep the condensing temperature as near to the temperature of the cooling water inlet as possible.

II.V EFFECT OF SUCTION VAPOUR SUPERHEAT

Superheating of the suction vapour is advisable in practice because it ensures complete vaporization of the liquid in the evaporator before it enters the compressor. Also, in most refrigeration and air-conditioning systems, the degree of superheat serves as a means of actuating and modulating the capacity of the expansion valve. It has also been seen that for some refrigerants such as Freon 12, maximum COP is obtained with superheating of the suction vapour.

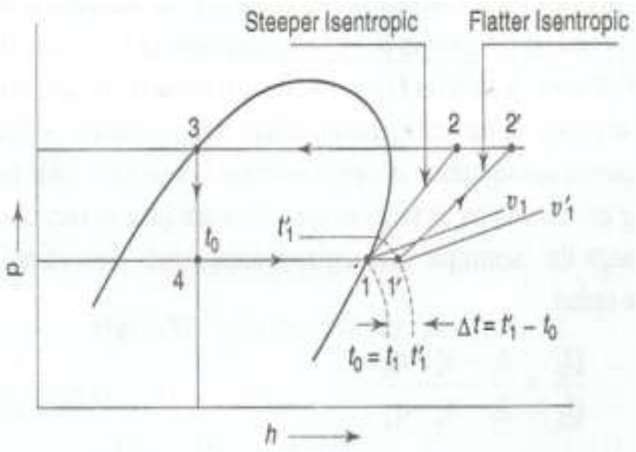

Figure 2.5 Effect of Suction Vapour Superheat

It can be seen from Figure 2.5, that the effect of superheating of the vapour from $t_1 = t_0$ to t_1' is as follows:
(a) Increase in specific volume of suction vapour from v_1 to v_1'
(b) Increase in refrigerating effect from ($h_1 - h_4$) to (h_1' – h_4')
(c) Increase in specific work from ($h_2 - h_1$) to (h_2' – h_1')

It is to be noted that (h_2' – h_1') is greater than ($h_2 - h_1$). This is because, although the pressure ratio is the same for both lines, the initial temperature t_1', is greater than t_1.

II.VI Effect of evaporating temperature

The evaporating temperature of the plant is maintained depending on the temperature requirement for the given application. Lower evaporating temperature reduces the refrigerating effect per kg of refrigerant circulated in the system and increases the work of compression leading to reduction in COP of the plant. Therefore, it is desirable to operate a refrigeration plant with highest possible evaporating temperature and undue lower evaporating temperature should be avoided.

II.VII Effect of condensing temperature

The condensing temperature is fixed by the temperature of cooling medium available as well as the efficiency of heat transfer at the condenser. The rate of heat rejected at the condenser is function of overall heat transfer co-efficient, heat transfer area and the temperature difference between the refrigerant and the cooling medium. Lower condensing temperature is desirable to get higher COP of the system. The efficiency of cooling tower is very important to get lower temperature of water for water-cooled condenser of the plant. In case of evaporative condenser, dry bulb temperature, wet bulb temperature and velocity of air play important role in heat transfer at the condenser. It is possible to save energy by operating the refrigeration plant during colder hours of the day.

III.CONCLUSION

In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. COP of Vapour Compression Cycle is increased by lowering the power consumption /work input or increasing the refrigerating effect. The COP will increase with decrease in condenser pressure and temperature and with increase in pressure and temperature of evaporator. Superheating ensures the entry of refrigerant to the compressor in pure gaseous state and thus enhances the COP. Also the increase of sub-cooling and superheating significantly reduces the compressor work input and increases the coefficient of performance.

REFERENCES

[1] B.O.Bolaji, M.A. Akintundeand T.O.Falade,2011, "Comparative Analysis of Performance of three Ozone- Friends HFC Refrigerants in a Vapour Compression Refrigerator", Journal of Sustainable Energy &Environment (2), pp: 61-64.
[2] Dr. Boda Hadya , "ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH SUB- COOLING AND SUPER HEATING WITH THREE DIFFERENT REFRIGERANTS FOR AIR-CONDITIONING APPLICATIONS ",IJESRT , ISSN: 2277-9655 , November, 2016 :70-72.
[3] R.S. Khurmi, J.K. Gupta; "Refrigeration and Air Conditioning". ISBN: 81-219-1687-9.:175-176
[4] C. P.Arora:" Refrigeration and Air Conditioning":Second Edition:ISBN:0-07-463010-5:109-115
[5] A. G. Bhadania & S. Ravikumar : "Refrigeration and Air Conditioning",:22-23