UNIT 2 REFRIGERATION CYCLE

Structure

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2.1 INTRODUCTION

The term '*refrigeration'* may be defined as the process of removing heat from a substance under controlled conditions. It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings. In other words, the refrigeration means a continued extraction of heat from a body whose temperature is already below temperature of its surroundings. In a refrigerator, heat is virtually pumped from a lower temperature to a higher temperature. According to Second Law of Thermodynamics, this process can only be performed with the aid of some external work. It is thus obvious that supply of power is regularly required to drive a refrigerator. Theoretically, a refrigerator is a reversed heat engine or a heat pump which pumps heat from a cold body and delivers it to a hot body. The substance which works in a pump to extract heat from a cold body and to deliver it to a hot body is known as refrigerant.

Objectives

After studying this unit, you should be able to

- know what is refrigeration cycle,
- understand about the vapour compression cycle,
- describe the vapour compression refrigeration cycle, and
- solve the problem on refrigeration system.

Refrigeration cycle is the basis of all refrigeration systems. So refrigeration cycle should be known to understand the refrigeration system. Some basic refrigeration cycles are discussed here through different diagrams.

2.2 VAPOUR COMPRESSION CYCLE

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 (NH_3), carbon dioxide (CO_2) and sulphur-dioxide (SO_2). 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.

2.2.1 Simple Vapour Compression Refrigeration System

It consists of the following essential parts:

Compressor

The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery or discharge valve B.

Condenser

The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed.

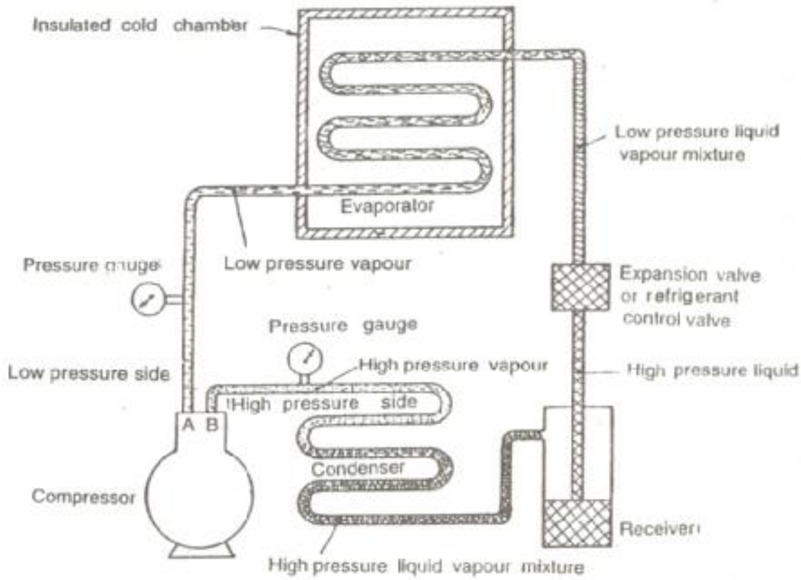


Figure 2.1 : Simple Vapour Compression Refrigeration System

The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

Receiver

The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

Expansion Valve

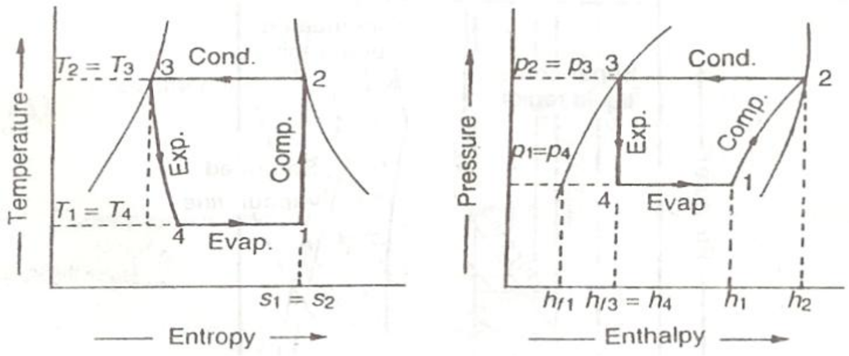
It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature

Evaporator

An evaporator consists of coils of pipe in which the liquid-vapour. refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

2.2.2 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 2.2(a) and (b) 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 :



(a) T-s Diagram **(b) p-h Diagram**

Figure 2.2 : Theoretical vapour Compression Cycle with Dry Saturated Vapour after Compression

Compression Process

The vapour refrigerant at low pressure p_1 and temperatureT_1 is compressed isentropically 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 R_E. 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

$$R_E = h_1 - h_4 = h_1 - hf_3$$

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.

Coefficient of performance, C.O.P. = (Refrigerating effect)/(Work done)

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

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

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 $p_{s'}$ as shown on p-h diagram in Figure 2.3.

It may be noted that the decrease in suction pressure :

(a) decreases the refrigerating effect from $(h_1 - h_4)$ to $(h_1^1 - h_4^1)$, and

(b) Increases the work required for compression from $(h_2 - h_1)$ to $(h_2^1 - h_1^1)$.

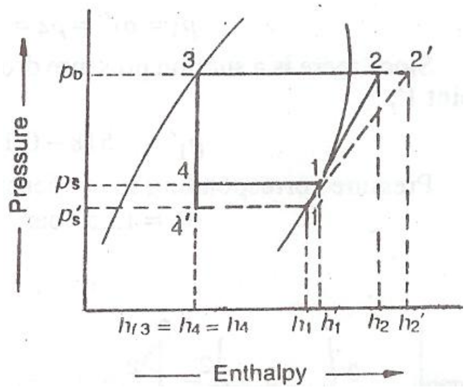


Figure 2.3 : Effect of Suction Pressure

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.

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 $p_{D'}$ as shown on p-h diagram in Figure 2.4 resulting in increased compressor work and reduced refrigeration effect.

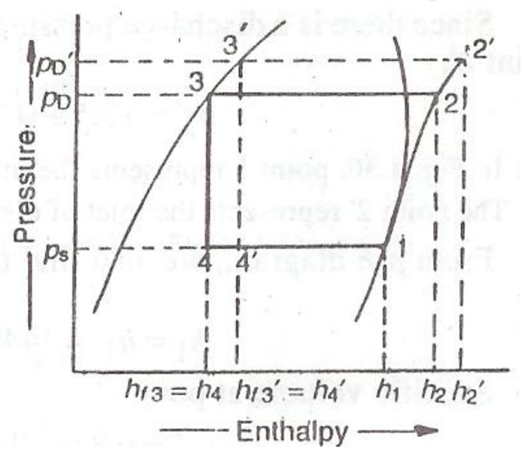


Figure 2.4 : Effect of Discharge Pressure

2.2.3 Conditions for Highest COP

Effect of Evaporator Pressure

Consider a simple saturation cycle 1-2-3-4 with Freon 12 as the refrigerant as shown in Figure 2.5 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 1′-2′-3-4′ in Figure 2.5.

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.

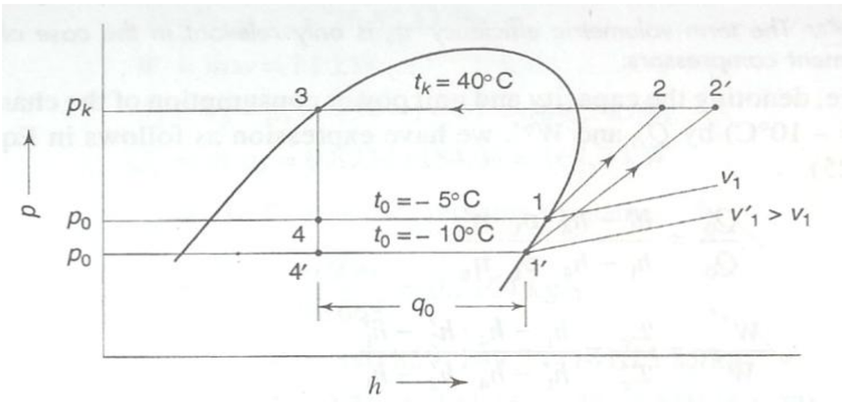


Figure 2.5 : Effect of Evaporator Pressure

It is observed that a decrease in evaporator temperature results in :

(a) Decrease in refrigerating effect from ($h_1 - h_4$) to ($h_1' - h_4'$)

(b) Increase in the specific volume of suction vapour from v_1 to v_1'

(c) Decrease in volumetric efficiency, due to increase in the pressure ratio, from η_v to $\eta_{v'}$

(d) Increase in compressor work from ($h_2 - h_1$) to ($h_2' - h_1'$) due to increase in the pressure ratio as well as change from steeper isentropic 1-2 to flatter isentropic 1′-2.

Since $$Q_0 = m q_0 = \frac{\eta_v V_p}{v_1} q_0 \qquad \ldots (2.1)$$

and $$W^* = m^* w \qquad \ldots (2.2)$$

Expressions for the dependence of capacity and unit power consumption may now be written as follows :

$$Q_0 \propto q_0 = (h_1 - h_2) \qquad \text{. . . (2.3)}$$

$$\propto \frac{1}{v_1}$$

$$\propto \eta_v$$

and

$$W^* \propto m^* \propto \frac{1}{q_0} = \frac{1}{h_1 - h_4} \qquad \text{. . . (2.4)}$$

$$\propto w = h_2 - h_1$$

Effect of Condenser Pressure

An increase in condenser pressure, similarly results in a decrease in the refrigerating capacity and an increase in power consumption, as seen from the changed cycle 1 -2′-3′-4′ for t_k' = 45°C in Figure 2.6. The decrease in refrigerating capacity is due to a decrease in the refrigerating effect and volumetric efficiency. The increase in power consumption is due to increased mass flow (due to decreased refrigerating effect) and an increase in specific work (due to increased pressure ratio), although the isentropic line remains unchanged. Accordingly, one can write for the ratios

$$\frac{Q_0'}{Q_0} = \frac{h_1 - h_4'}{h_1 - h_4} \times \frac{\eta_v'}{\eta_v} \qquad \text{. . . (2.5)}$$

$$\frac{W^{*'}}{W^*} = \frac{\varepsilon_c'}{\varepsilon_c} = \frac{h_1 - h_4}{h_1' - h_4} \times \frac{h_2' - h_1}{h_2 - h_1} \qquad \text{. . . (2.6)}$$

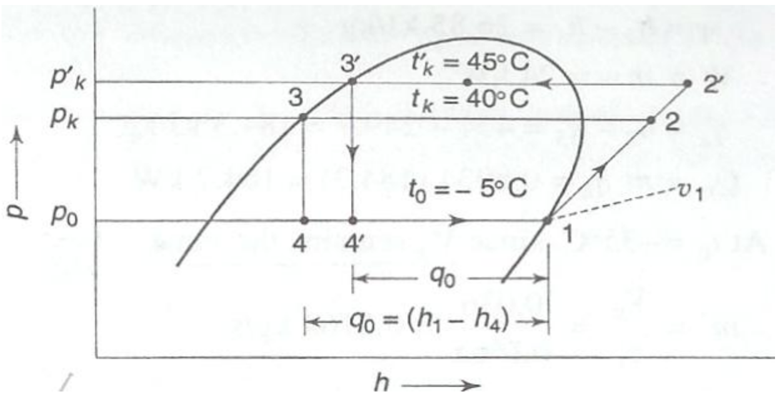


Figure 2.6 : Effect of Condenser Pressure

It is obvious that COP decreases both with decreasing evaporator and increasing condenser pressures.

It may, however, be noted that the effect of increase in condenser pressure is not as server, on the refrigerating capacity and power consumption per ton of refrigeration, as that of the decrease in evaporator pressure.

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.

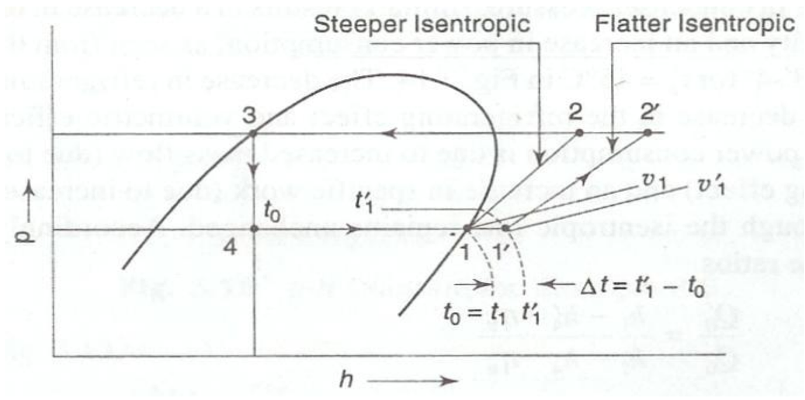


Figure 2.7: Effect of Suction Vapour Superheat

It can be seen from Figure 2.7, 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 and the work given by the expression

$$\frac{\gamma R T_1}{\gamma - 1}\left[\left(p_2 / p_1\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

Increases with the initial temperature. That is why isentropic lines on the p-h diagram become flatter in higher temperatures. An increase in specific volume decreases the capacity. On the contrary, an increase in refrigerating effect will increase the capacity effect of super- heating is to theoretically reduce the capacity in ammonia systems and to increase it in Freon 12 systems.

Effect of Liquid Subcooling

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 $t_3 = tk$ to $t_{3'}$ is shown in Figure 2.8. 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.

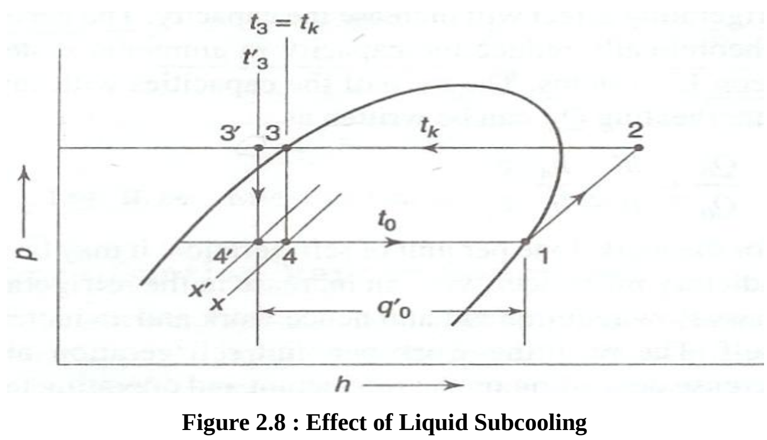


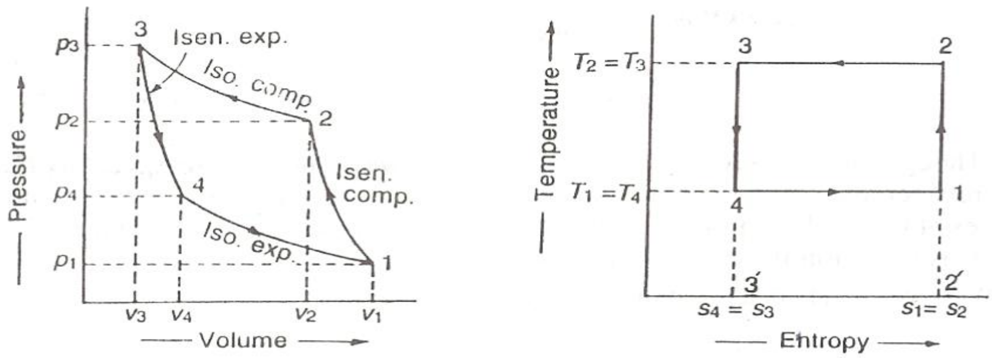
Figure 2.8 : Effect of Liquid Subcooling

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

This can be avoided by installing parallel cooling water inlets to the subcooler and condenser. In that case, however, the degree of subcooling will be small and the added cost of the subcooler 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.

2.2.4 Carnot Refrigeration Cycle

In refrigeration system, the Carnot cycle considered is reversed Carnot cycle. We know that a heat engine working on Carnot engine has the highest efficiency. Similarly, a refrigeration system working on the reversed cycle, has the maximum coefficient of performance.



(a) p-v Diagram **(b) T-s Diagram**

Figure 2.9 : Reversed Carnot Cycle

A reversed Carnot cycle, using air as the working medium is shown on *p-v* and *T-s* diagrams in Figures 2.9(a) and (b) respectively. At point 1, let p_1, v_1, T_1 be the pressure, specific volume and temperature of air respectively.

The four processes of the cycle are as follows:

Isentropic Compression Process

The air is compressed isentropically as shown by the curve 1-2 on p-v and T-s diagrams. During this process, the pressure of air increases from p_1 to p_2, specific volume decreases from v_1 to v_2 and temperature increases from T_1 to T_2. We know that during isentropic compression, no heat is absorbed or rejected by the air.

Isothermal Compression Process

The air is now compressed isothermally (i.e. at constant temperature, $T_2 = T_3$) as shown by the curve 2-3 on *p-v* and *T-s* diagrams. During this process, the pressure of air increases from p_2 to p_3 and specific volume decreases from v_2 to v_3. We know that the heat rejected by the air during isothermal compression per kg of air,

$$q_{2-3} = \text{area } 2\text{-}3\text{-}3'\text{-}2'$$

$$= T_3 (s_2 - s_3)$$

$$= T_2 (s_2 - s_3)$$

Isentropic Expansion Process

The air is now expanded isentropically as shown by the curve 3-4 on p-v and T-s diagrams. The pressure of air decreases from p_3 to p_4, specific volume increases from v_3 to v_4 and temperature decreases from T_3 to T_4. We know that during isentropic expansion, no heat is absorbed or rejected by the air.

Isothermal Expansion Process

The air is now expanded isothermally (i.e. at constant temperature, $T_4 = T_1$) as shown by the curve 4-1 on *p-v* and *T-s* diagrams. During this process, the pressure of air decreases from p_4 to p_1 and specific volume increases from v_4 to v_1. We know that the heat absorbed by the air during isothermal compression per kg of air,

$$q_{4\text{-}1} = \text{area } 4\text{-}1\text{-}2'\text{-}3'$$

$$= T_4 (s_1 - s_4)$$

$$= T_4 (s_2 - s_3)$$

$$= T_1 (s_2 - s_3)$$

We know that work done during the cycle per kg of air

$$= \text{Heat rejected} - \text{Heat absorbed}$$

$$= q_{2\text{-}3} - q_{4\text{-}1}$$

$$= T_2 (s_2 - s_3) - T_1 (s_2 - s_3)$$

Therefore, coefficient of performance of the refrigeration system working on reversed Carnot cycle,

$$\text{C.O.P.} = \frac{HeatAbsorbed}{WorkDone}$$

$$= \frac{T_1 (s_2 - s_3)}{(T_2 - T_1)(s_2 - s_3)}$$

$$= \frac{T_1}{T_2 - T_1}$$

2.2.5 Temperature Limitations for Reversed Carnot Cycle

We have seen that the C.O.P. of the reversed Carnot cycle is given by,

$$\text{C.O.P.} = \frac{T_1}{T_2 - T_1}$$

where T_1 = Lower temperature, and

T_2 = Higher temperature.

The C.O.P. of the reversed Carnot cycle can be improved by

(a) Decreasing the higher temperature (i.e. temperature of hot body, T_2) or

(b) Increasing the lower temperature (i.e. temperature of cold body, T_1).

It may be noted that temperature T_1 and T_2 cannot be varied at will, due to certain functional limitations. It should be kept in mind that the higher temperature (T_2) is the temperature of cooling water or air available for rejection of heat and the lower temperature (T_1) is the temperature to be maintained in the refrigerator. The heat transfer will take place in the right direction only when the higher temperature is more than the temperature of cooling water or air to which heat is to be rejected, while the lower temperature must be less than the temperature of substance to be cooled.

Thus if the temperature of cooling water or air (i.e. T_2) available for heat rejection is low, the C.O.P. will be high. Since T_2 in winter is less than T_2 in summer, therefore, C.O.P. in winter will be higher than C.O.P. in summer. In other words, the Carnot refrigerator works more efficiently in winter than in summer. Similarly, if the lower temperature (T_1) is high, the C.O.P. of the Carnot refrigerator will be high.

2.2.6 Difference between Refrigeration and Heat Pump System

The major difference between the refrigeration and heat pump system is that refrigerator delivers heat from lower temperature to a higher temperature, whereas heat pump delivers heat from higher temperature to lower temperature body. The difference between refrigerator and heat pump is shown in the Figure 2.10 schematically.

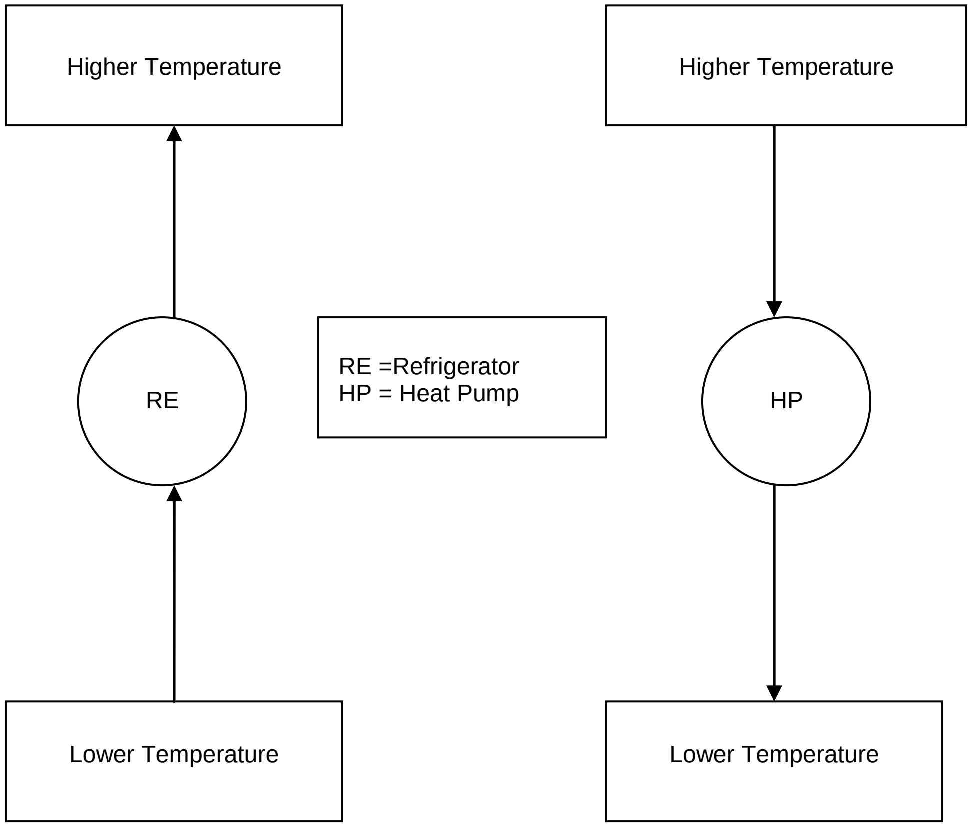


Figure 2.10 : Schematic Representation of Refrigerator and Heat Pump

2.3 VAPOUR ABSORPTION SYSTEM

The vapour absorption refrigeration is heat operated system. It is quite similar to the vapour compression system. In both the systems, there are evaporator and condenser. The process of evaporation and condensation of the refrigerant takes place at two different pressure levels to achieve refrigeration in both the cases. The method employed to create the two pressure levels in the system for evaporation and condensation of the refrigeration makes the two processes different. Circulation of refrigerant in both the cases is also different.

In the absorption system the compressor of the vapour compression system is replaced by the combination of 'absorber' and 'generator'. A solution known as the absorbent, which has an affinity for the refrigerant used, is circulated between the absorber and the generator by a pump (solution pump). The absorbent in the absorber draws (or sucks) the refrigerant vapour formed in the evaporator thus maintaining a low pressure in the evaporator to enable the refrigerant to evaporate at low temperature. In the generator the absorbent is heated. There by releasing the refrigerant vapour (absorbed in the absorber) as high pressure vapour, to be condensed in the condenser. Thus the suction function is performed by absorbent in the absorber and the generator performs the function of the compression and discharge. The absorbent solution carries the refrigerant vapour from the low side (evaporator–absorber) to the high side (generator-condenser). The liquefied refrigerant flows from the condenser to the evaporator due to the pressure difference between the two vessels; thus establishing circulation of the refrigerant through the system.

Figure 2.11 is a schematic diagram of the absorption cycle. As can be seen from the figure, the refrigerant and absorbent have separate flow paths. The refrigerant path is:

Evaporator → Absorber → Generator → Condenser → Evaporator and for the absorbent it is,

Absorber → Generator → Absorber

The absorbent solution passing from the generator to the absorber is hot and ha to be cooled. On the other hand the absorbent solution sent to the generator is cooled and has to be heated in the generator for the regeneration of the refrigerant. A shell and tube heat exchanger is introduced between the generator and the absorber.

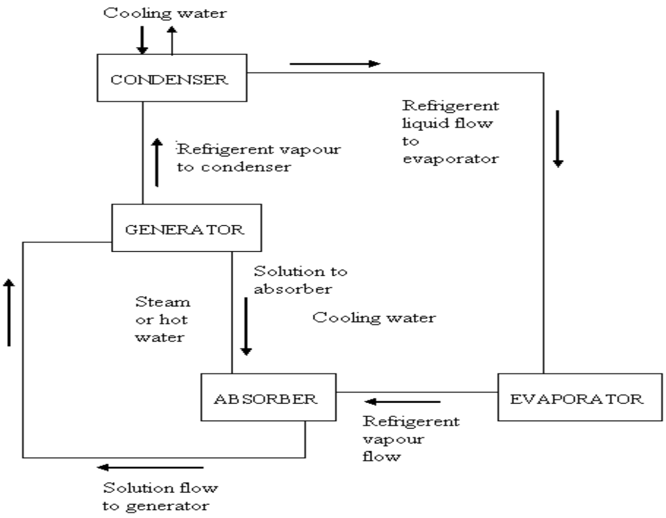


Figure 2.11 : Schematic Diagram of Absorption System of Refrigeration

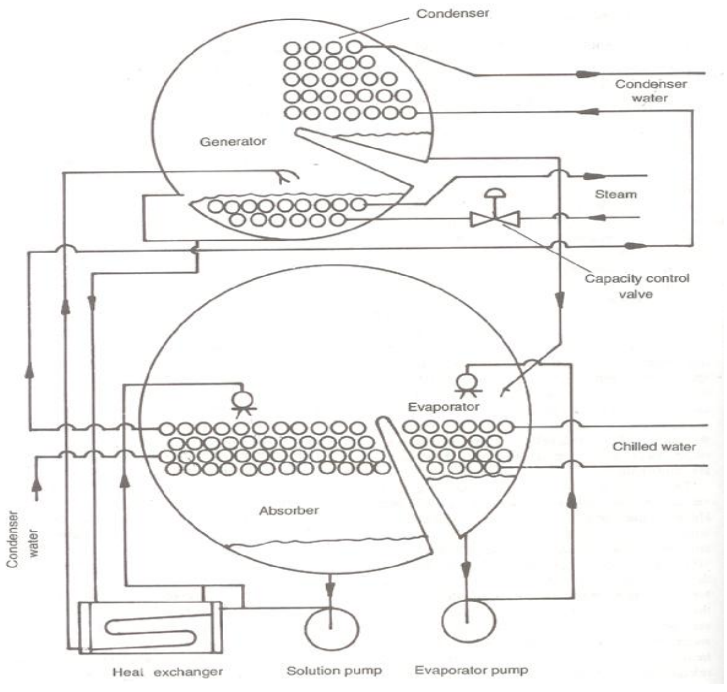


Figure 2.12 : Schematic Sketch of a Lithium-Bromide Absorption Machine – Single Stage

There is number of vapour absorption system depending on the absorbent e.g. ammonia absorbent system, lithium bromide absorption system etc. Ammonia absorbent systems were used in the early stages of refrigeration. This system uses ammonia as the refrigerant and water as absorbent. In lithium bromide absorption system lithium bromide salt solution is used as the absorbent and water as the refrigerant. A concentrated solution of lithium bromide has a great affinity for water. Since water is the refrigerant, the refrigerant operating temperature in the evaporator has to be above the freezing point of water (0^oC) of water.

2.4 ILLUSTRATIVE PROBLEMS

Example 2.1

Carnot refrigeration cycle absorbs heat at 270 K and rejects heat at 300 K.

(a) Calculate the coefficient of performance of this refrigeration cycle.

(b) If the cycle is absorbing 1130 kJ/min at 270 K, how many kJ of work is required per second.

(c) If the Carnot heat pump operates between the same temperatures as the above refrigeration cycle, what is the coefficient of performance.

(d) How many kJ/min will the heat pump deliver at 300 K if it absorbs 1130 kJ/min at 270 K.

Solution

Given : $T_1 = 270$ K; $T_2 = 300$ K

(a) Coeff*icient of performance of Carnot refrigeration cycle*

We know that coefficient of performance of Carnot refrigeration cycle,

$$(\text{C.O.P.})_R = \frac{T_1}{T_2 - T_1} = \frac{270}{300 - 270} = 9$$ **Ans.**

(b) Work *required per second*

Let WR = Work required per second

Heat absorbed at 270 K (i.e. T_1),

Q_1 = ll30 kJ/min= 18.83 kJ/s

We know that $(\text{C.O.P})_R = \frac{Q_1}{W_R}$

$$\because \qquad W_R = \frac{Q_1}{(C.O.P)_R} = \frac{18.83}{9}$$

W_R = 2.1 kJ/s **Ans.**

(c) *Coefficient of performance of Carnot heat pump*

We know that coefficient of performance of a Carnot heat pump,

$$(\text{C.O.P.})p = \frac{T_2}{T_2 - T_1} = \frac{300}{300 - 270} = 10$$ **Ans.**

(d) *Heat delivered by heat pump at 300 K*

Let Q_2 = Heat delivered by heat pump at 300 K.

Heat absorbed at 270 K (i.e. T1),

Q_1 = 1130 kJ/min (Given)

We know that $(\text{C.O.P.})p = \frac{Q_2}{Q_2 - Q_1}$

Q_2 = 1256 kJ/min **Ans.**

Example 2.2

The capacity of a refrigerator is 200 TR when working between – 6°C and 25°C. Determine the mass of ice produced per day from water at 25°C. Also find the power required to drive the unit. Assume that the cycle operates on reversed Carnot cycle and latent heat of ice is 335 kJ/kg.

Solution

Given : Q = 200TR; T_1 = – 6°C = – 6 + 273 = 267 K; T_2 = 25°C;

Tw = 250 C : hfg = 335 kJ/kg

Mass of ice produced per day

We know that heat extraction capacity of the refrigerator

= 200 × 210 = 42000 kJ/min

heat removed from 1 kg of water at 25°C to form ice at 0°C

(1 TR = 210 kJ/min)

= Mass × Sp. heat × Rise in temperature + hfg (ice)

= 1 × 4.187 (25 – 0) + 335 = 439.7 kJ/kg

Mass of ice produced per min

$$= \frac{42000}{439.7} = 95.52 \text{ kg/min}$$

and mass of ice produced per day = 95.52 × 60 × 24 = 137550 kg = 137.55 tonnes

Power required to drive the unit

We know that C.O.P. of the reversed Carnot cycle

$$= \frac{T_1}{T_2 - T_1} = \frac{267}{298 - 267} = 8.6$$

COP. = (Heat extraction capacity)/(Work done per mm)

Work done per min = 42 000/8.6 = 4884 kJ/min

Power required to drive the unit

$$= = \frac{4884}{60} = 81.4 \text{ kW}$$ **Ans.**

Example 2.3

Five hundred kgs of fruits are supplied to a cold storage at 20°C. The cold storage is maintained at 5°C and the fruits get cooled to the storage temperature in 10 hours. The latent heat of freezing is 105 kJ/kg and specific heat of fruit is 1.256 kJ/kg K. Find the refrigeration capacity of the plant.

Solution

Given : m = 500 kg; T_2 = 20°C = 20 + 273 = 293K;

T_1 = – 5C = – 5 + 273 = 268 K; hfg = 105 kJ/kg, cF = 1.256 kJ/kg K

We know that heat removed from the fruits in 10 hrs,

$Q_1 = m\, cF\, (T_2 - T_1)$

= 500 × 1.256(293 – 268) = 15700 kJ

and total latent heat of freezing,

$Q_2 = m\,.\,hfg$ = 500 × 105 = 52500 kJ

Total heat removed in 10 hrs,

$Q = Q_1 + Q_2$ = 15700 + 52500 = 68200 kJ

and total heat removed in one minute

= 68200/10 × 60 = 113.7 kJ/min

Refrigeration capacity of the plant

= 113.7/210 = 0.541 TR (1 TR = 210 kJ/min) **Ans.**

Example 2.4

A cold storage plant is required to store 20 tonnes of fish. The fish is supplied at a temperature of 30°C. The specific heat of fish above freezing point is 2.93 kJ/kg K. The specific heat offish below freezing point is 1.26 kJ/kg K. The fish is stored in cold storage which is maintained at – 8°C. The freezing point of fish is – 4°C. The latent heat of fish is 235 kJ/kg. If the plant requires 75 kW to drive it, find

(a) The capacity of the plant, and

(b) Time taken to achieve cooling.

Assume actual C.O.P. of the plant as 0.3 of the Carnot C.O.P.

Solution

Given : $m = 20\ t = 20000$ kg; $T_2 = 30°C = 30 + 273 = 303$ K;

$cAF = 2.93$ kJ/kg K; $cBF = 1.26$ kJ/kgK; $T_1 = -8°C = -8 + 273 = 265$ K;

$T_3 = -4°C = -4 + 273 = 269$ k; $hfg = 235$ kJ/kg; $P = 75$ kW = 75 kJ/s

(a) Capacity of the plant

We know that Carnot C.O.P.

$$= \frac{T_1}{T_2 - T_1} = \frac{265}{303 - 265} = 6.97$$

Actual COP. = 0.3 × 6.97 = 2.091

and heat removed by the plant

= Actual COP. × Work required

= 2.091 × 75 = 156.8 kJ/s = 156.8 × 60 = 9408 kJ/min

Capacity of the plant

= 9408 /210 = 44.8 TR **Ans.**

(b) *Time taken to achieve cooling*

We know that heat removed from the fish above freezing point,

$$Q_1 = m \times c_{AF} (T_2 - T_3)$$
$$= 20000 \times 2.93\ (303 - 269)$$
$$= 1.992 \times 10^6 \text{ kJ}$$

Similarly, heat removed from the fish below freezing point,

$$Q_2 = m \text{ x } c_{BF} (T_3 - T_1)$$
$$= 20000 \times 1.26\ (269 - 265)$$
$$= 0.101 \times 10^6 \text{ kJ}$$

and total latent heat of fish,

$$Q_3 = m \times h_{fg\ \text{(fish)}}$$
$$= 20000 \times 235$$
$$= 4.7 \times 10^6 \text{ kJ}$$

Total heat removed by the plant

$$= Q_1 + Q_2 + Q_3$$
$$= 1.992 \times 10^6 + 0.101 \times 10^6 + 4.7 \times 10^6$$
$$= 6.793 \times 10^6 \text{ kJ}$$

and time taken to achieve cooling

$$= \frac{6.793 \times 10^6}{9408} = 722 \text{ min} = 12.03 \text{ h}$$ **Ans.**

2.6 SUMMARY

A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant is used. It condenses and evaporates at temperatures and pressures close to atmospheric conditions. The refrigerant used, does not leave the system, but is circulated throughout the system alternately condensing and evaporating. The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. In vapour compression system compressor is used to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapour can reject heat in the condenser. But in the vapour absorption system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. These components in vapour absorption system, perform the same functions as that of a compressor in vapour compression system. In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

2.7 ANSWERS TO SAQs

Refer the relevant preceding texts in the unit or other useful books on the topic listed in the section “Further Readings” to get the answers of the SAQs.