Mechanical Engineering

Refrigeration & Air-Conditioning

Comprehensive Theory

with Solved Examples and Practice Questions

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Refrigeration & Air-Conditioning

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CHAPTER 07

Refrigeration Equipment, Duct Design and Methods of Refrigeration

7.1 Compressors

The compressors used in vapour compression system are either reciprocating compressors (for small systems, or refrigerants whose boiling point at atmospheric pressure is less than evaporator temperature) or centrifugal compressors (for large systems, or refrigerants whose boiling point at atmospheric pressure is more than evaporator temperature).

Compressors for refrigeration systems are classified as

(a) **Hermetically sealed compressors :** Both compressor and motor are located inside a sealed casing which is initially subjected to high vacuum condition. This confines any leakage across the piston to casing only, which is sucked in by compressor. Suction vapours cool the electrical motor windings.

(b) **Semi hermetically sealed compressor :** The only difference between this and hermetically sealed compressor is that in this compressor the head of the compressor is located in such a way that it is accessible to repair in case of necessity. But, 100% leak proof can't be guaranteed.

(c) **Open type compressor :** The compressor and motor are connected by means of coupling/chain drive/belt drive. Both are kept separately exposed to the surroundings. Here frequent leakage of refrigerant occurs, hence the system has to be maintained at regular interval to make up the loss. It is used in very big systems which have capacity greater than 3.5 TR.

7.1.1 Positive Displacement Compressor

In these compressor the pressure of gas is increased by decreasing its volume in a confined cylinder i.e., rise in pressure is obtained by positively displacing fluid to a lower volume. The fluid is subjected to non-flow processes. Work is transferred through a hydrostatic force on the moving boundary.

Eg.: Reciprocating compressor, Rotary compressor, Scroll compressor, Screw compressor

7.1.1(a) Reciprocating compressor:

L = Length of stroke

D = Bore

V_c = Clearance volume = V_3

$$V_s = \text{Piston displacement or swept volume} = V_1 - V_3 = \frac{\pi}{4}D^2L$$

$$V_a = \text{Suction volume of vapour} = V_1 - V_4$$

$$\text{Clearance ratio} : C = \frac{\text{Clearance volume}}{\text{Stroke volume}} = \frac{V_c}{V_s}$$

Net external work required by the compressor is shown by the shaded area, i.e., Area 1-2-3-4-1.

$$\text{Area 1-2-3-4-1} = \int_1^2 Vdp + \int_3^4 Vdp$$

Let expansion and compression both follow the equation pV^n = constant. Then, putting the values and solving, we get:

Work required:

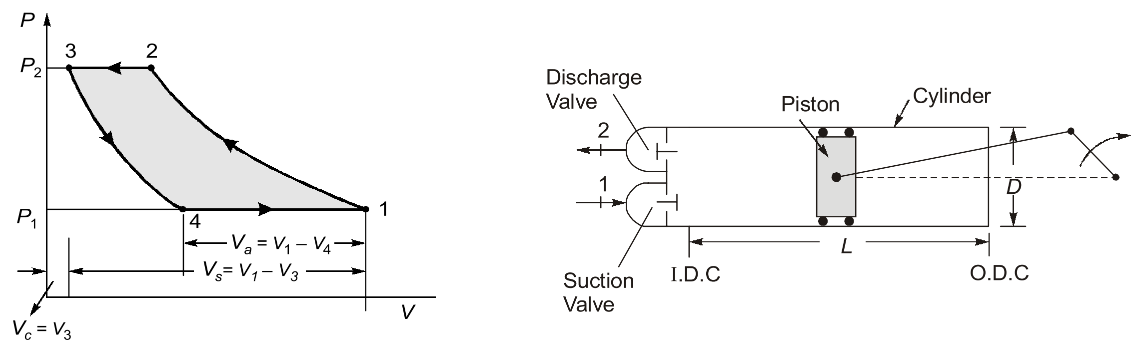


Figure: Schematic diagram and P-v diagram of a reciprocating compressor

$$W = \frac{n}{n-1}p_1(V_1 - V_4)\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

or
$$W = \frac{n}{n-1}p_1V_s\left[\left(\frac{p_2}{p_1}\right)^{\left(\frac{n-1}{n}\right)} - 1\right]$$

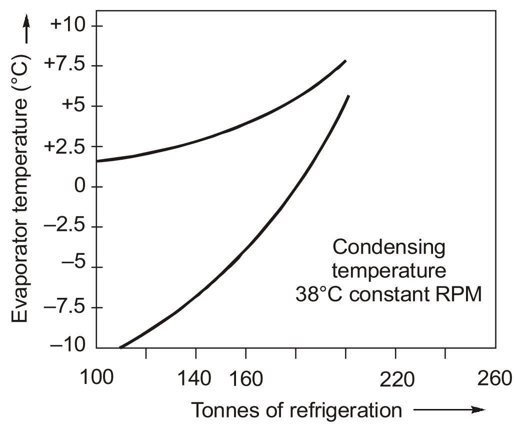
Volumetric efficiency:
$$\eta_V = \frac{\text{Volume sucked by compressor}}{\text{Piston displacement volume}} = \frac{V_a}{V_s} = 1 + C - C\left(\frac{p_2}{p_1}\right)^{1/n}$$

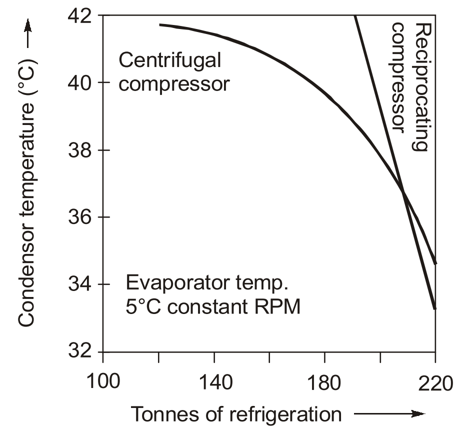
7.1.2 Dynamic Compressor

In these compressor high kinetic energy is given to fluid by a rotating element called rotor and then this high kinetic energy is transformed into pressure energy in the diffuser. i.e., pressure rise is obtained due to dynamic action of gas. Eg. Centrifugal compressor and Axial flow compressor.

7.1.3 Reciprocating compressor Vs Centrifugal compressor

- Reciprocating compressor are suitable for low discharge and high condensing pressure.
- Centrifugal compressor are suitable for high discharge and low condensing pressure.





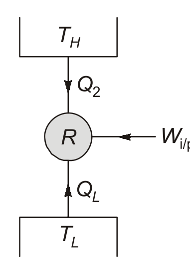
7.1.4 Compressors for Different Refrigerants

Refrigerant	Compressor
NH_3	Reciprocating & screw compressor
R-11	Centrifugal compressor
R-12	Reciprocating compressor
R-22	Reciprocating compressor
R-113	Centrifugal compressor
R-114	Rotary compressor

7.2 Condensors

In vapour compression cycle heat is rejected in condenser after compression. Sensible heat rejected during cooling (from superheated vapour to saturated vapour and from saturated liquid to subcooled liquid) is very less compared to latent heat during condensation.

7.2.1 Heat Rejection Ratio (H.R.R)



$$\text{HRR} = \frac{Q_2}{Q_1} = \frac{Q_1 + W_{i/p}}{Q_1} = 1 + \frac{W_{i/p}}{Q_1} = 1 + \frac{1}{\text{COP}}$$

$$\text{HRR} = 1 + \frac{1}{\text{COP}}$$

Heat rejection ratio helps in determining the size of condenser.

In hermetic compressor, since COP is less, HRR is high, therefore large size condenser are required.

7.2.2 Type of Condensers

(a) Air cooled condenser

Refrigerant flow inside the tube and air flows outside the tube. It is preferred when refrigeration capacity is less than 5 T.R. They are used in domestic refrigerators, window type air conditioner, water cooler (small capacity machines).

When refrigeration capacity increased above 5 T.R. the condenser size required with air cooling will become impractical. Therefore we need to switch towards water cooler condenser as specific heat of water is very high compared to air ($C_{p,\,w} \approx$ 4 times, $C_{p,\,\text{air}}$).

(b) Water cooled condenser

(i) Shell and tube condenser: Water flows through tube and refrigerant is made to flow through shell. This is done to avoid pressure less in refrigerant which may occur during flow from tube. Refrigeration capacity reached upto 1000 T.R.

(ii) Shell and coil condenser: In this water flows through coil hence increased surface area for heat transfer is obtained but it can be used when water does not has sealing problem. Refrigeration capacity achieved upto 50 T.R.

(iii) Evaporative condenser: Here the refrigerants first rejects its heat to water and then water rejects its heat to air so an evaporative condenser is a combined from of condenser and cooling tower. They require a large amount of refrigeration due to longer piping. It is used in ammonia plants. These are often used where the availability of water is less.

7.3 Throttling devices

Throttling devices perform following two activities:

(a) Reduce the pressure of refrigerant from condenser pressure to evaporator pressure.

(b) Meet the refrigerant load, i.e., regulate the amount of refrigerant flowing in the evaporator as per load requirement.

Types of throttling devices

(i) Capillary tube:
- Simple, long tube having very less diameter.
- Pressure/head loss occurs due to friction
- Self controlling device, i.e. controls mass flow rate of refrigerant according to load requirement of the system.
- Used for system having capacity up to 2-3 TR like window AC, household refrigerator etc.

(ii) Constant pressure expansion valve/automatic expansion valve:

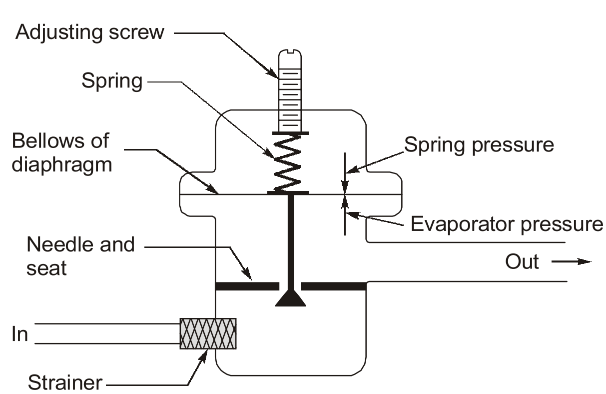


Figure: Constant pressure/Automatic Expansion valve

- The word "automatic" only means that this valve automatically maintains constant evaporator pressure.
- Equilibrium position of the valve is determined by downward forces, *i.e.*, spring pressure and atmospheric pressure, and upward force, *i.e.*, evaporator pressure.

- It is not a self controlling device, and hence can't meet the requirements of varying load and therefore it is rarely used.

(iii) Thermostatic expansion valve/T-X valve :

- T-X valve maintains a constant degree of superheat in the evaporator, and it maintains flow of refrigerant as per load requirement.
- The bulb and capillary tube are usually filled with the same refrigerant as in the refrigeration system, where it is at the same temperature t_0' which is the temperature of refrigerant at evaporator outlet and p_0', its corresponding saturation pressure.
- As load increases, heat taken by refrigerant in evaporator increases, hence t_0' increases, p_0'.
  Therefore opening at needle increases, which increases the mass flowing through evaporator and thereby bringing down evaporator outlet temperature back to t_0'.
- It has wide variety of uses which are beyond that of capillary tube as a throttling device. It is used in systems having capacity up to 4-5 TR, for example high capacity split ACs, central ACs *etc*.

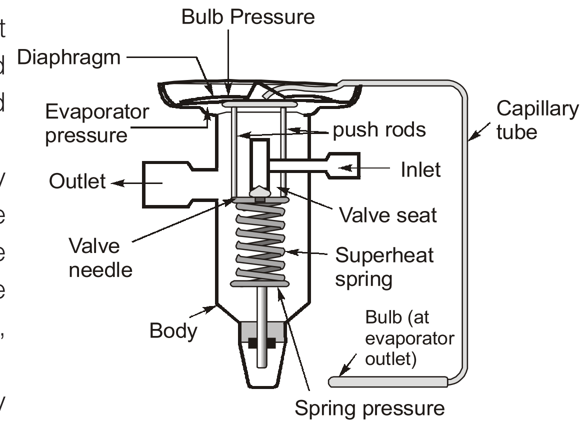


Figure: Thermostatic Expansion valve

(iv) Float valve:

- It is an ordinary valve located in liquid refrigerant chamber. It is used in high capacity systems like ice plants, chillers, milk plants *etc*.

7.4 Evaporators

It removes heat from air, water or whatever to be cooled in the refrigerating machine.

7.4.1 Flooded Evaporators

Refrigerants covers entire heat transfer surface. Here refrigerants flow outside the tube. Float valve expansion device is used with it. It is used in chillers and here pool boiling occurs.

7.4.2 Dry Evaporators

Here a part of heat transfer surface is used for superheating the vapour. Thermostatic expansion valve or capillary tube is used with this evaporator. Here refrigerant flow inside the tube. It is used in domestic refrigerator, ice plants. In the evaporator forced convection boiling occurs.

7.5 Introduction to duct design

The requirements of an air conditioning duct system are:

1. It should convey specified rates of air flow to prescribed locations.
2. It should be economical in combined initial cost, fan operating cost and cost of building space.
3. It should not transmit or generate objectionable noise.

7.6 Commonly used duct design methods

The purpose of the duct design is to select suitable dimensions of duct for each run and then to select a fan, which can provide the required supply airflow rate to each conditioned zone.

However, the following methods are most commonly used for simpler layouts

1. Velocity reduction method
2. Equal Friction Method
3. Static Regain method

7.6.1 Velocity Reduction Method

The velocity method is one of the simplest ways of designing the duct system for both supply and return air. However, the application of this method requires selection of suitable velocities in different duct runs, which requires experience. Wrong selection of velocities can lead to very large ducts, which, occupy large building space and increases the cost, or very small ducts which lead to large pressure drop and hence necessitates the selection of a large fan leading to higher fan cost and running cost. In addition, the method is not very efficient as it requires partial closing of all the dampers except the one in the index run, so that the total pressure drop in each run will be same.

7.6.2 Equal friction method:

Equal friction method is simple and is most widely used conventional method. This method usually yields a better design than the velocity method as most of the available pressure drop is dissipated as friction in the duct runs, rather than in the balancing dampers. This method is generally suitable when the ducts are not too long, and it can be used for both supply and return ducts. However, similar to velocity method, the equal friction method also requires partial closure of dampers in all but the index run, which may generate noise. If the ducts are too long then the total pressure drop will be high and due to dampering, ducts near the fan get over-pressurized.

7.6.3 Static Regain Method:

Static Regain method yields a more balanced system and does not call for unnecessary dampering. However, as velocity reduces in the direction of airflow, the duct size may increase in the airflow direction. Also the velocity at the exit of the longer duct runs may become too small for proper air distribution in the conditioned space.

7.7 Refrigeration Systems

Refrigeration systems are grouped into the following three systems:

(i) **Non-cyclic refrigeration systems:** Such system include refrigeration using ice, refrigeration by evaporation, and refrigeration by dry ice. These systems were used before the invention of cyclic refrigeration systems. For example, natural ice was used to preserve flesh during its shipment from one country to another.

(ii) **Cyclic refrigeration systems:** These include the air refrigeration cycle, the vapour compression refrigeration cycle, and the vapour absorption cycle.

(iii) **Other refrigeration systems:** These are thermoelectric refrigeration cycle, steam-jet refrigeration cycle, vortex tube refrigeration system, magnetic refrigeration system, solar refrigeration systems, and so on.

A few of the above systems are discussed in the following sub-sections.

Objective Brain Teasers

Q.1 Thermoelectric refrigeration system is based on
(a) Peltier effect
(b) Joule effect
(c) Joule-Thomson throttling
(d) Adiabatic demagnetization

Q.2 The capacity of refrigerating machine is expressed as
(a) inside volume of cabinet
(b) lowest temperature attained
(c) gross weight of machine in tons
(d) rate of abstraction of heat from the space being cooled

Q.3 Match the **List-I** (Application) with **List-II** (Refrigeration temperature):

List-I	List-II
A. Air conditioning in summer	**1.** –10 to 2°C
B. Cold storages	**2.** –35 to –45°C
C. Domestic refrigerators	**3.** 0 to 10°C
D. Freeze drying and instant quick freezing	**4.** –25°C

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	1	4	2
(c)	1	3	2	4
(d)	2	1	4	3

Q.4 The air cooling system mostly used in transport type aircrafts is
(a) simple air cooling system
(b) simple evaporative air cooling system
(c) boot-strap air cooling system
(d) regenerative cooling

Q.5 In steam-injection system compression is achieved by
(a) Centrifugal compressor
(b) Reciprocating compressor
(c) Generator-absorber assembly
(d) None of the above

Q.6 In milk chilling plants, the usual secondary refrigerant is
(a) Ammonia solution
(b) Sodium silicate
(c) Glycol
(d) Brine

ANSWERS

1. (a) 2. (d) 3. (b) 4. (c) 5. (d)
6. (d)

Student's Assignments

Q.1 Define the terms refrigeration, refrigerant and refrigerating equipment.

Q.2 Write a short note on the systems of refrigeration.

Q.3 Briefly explain the applications of a refrigeration system.

Q.4 Explain the working of ice refrigeration with the help of a simple schematic diagram. What are its drawbacks?

Q.5 What do you understand by evaporative refrigeration? Explain with the help of examples.

Q.6 What is dry ice? How can it be used for the refrigeration purpose? List its drawbacks.

Q.7 Draw a neat diagram of a simple steam jet refrigeration system and explain its working.

Q.8 Explain the concept of vortex tube. What are its advantages and disadvantages?

Q.9 Explain the concept of thermoelectric refrigeration.

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