UNIT – IV
AIR COMPRESSORS

Industrial uses of compressed air. Classification of air compressors. Description of single reciprocating compressors. Effect of clearance, work done and volumetric efficiency. Description of multi-stage compressors. Advantages of multistage compression. Condition for maximum efficiency. Problems. Introduction to rotary compressors. Description of axial flow and centrifugal compressor.

1 INTRODUCTION

- *The process of increasing the pressure of a gas (usually air), by reducing its volume is called compression.*
- *A compressor is a mechanical device that is used to compress gases.*
- *A compressor compresses the low pressure gas and delivers it at a higher pressure in the right quality.*

1.1 Working Principle

- *Compressor is a work absorbing device.*
- *It increases the pressure of a gas by doing work on it.*
- *This means it requires work input and a prime mover is required for its working.*
- *The most common choice for a prime mover is the electric motor, but IC engine or a turbine can also be used.*

1.2 Air compressors

- *A compressor used for compressing air is called an air compressor.*
- *Air from atmosphere is sucked into the compressor.*
- *The compressor then compresses air to a high pressure and delivers it to a storage tank (reservoir).*
- *From the reservoir compressed air can be supplied to desired locations through pipe lines.*

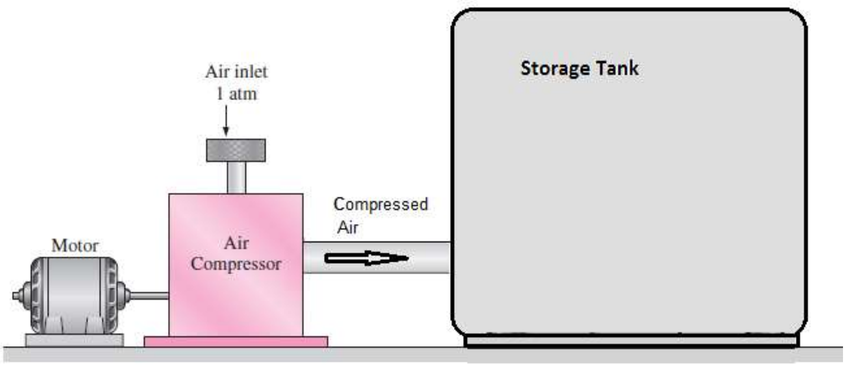


Figure 1: Schematic diagram of an Air Compressor unit.

2 INDUSTRIAL USES OF COMPRESSED AIR

Air compressors are used for supplying high-pressure air. Compressed air accounts for about 10% of the global energy used in industry today. There are many uses of high-pressure air in the industry.

The main uses of compressed air are :

- In compressed air engines (air motors) used in coal mines,
- Fuel injectors; to inject or spray fuel into the cylinder of a Diesel engine.
- Operating pneumatic machines and equipments such as drills, hammers etc.
- Air brakes for locomotives and railway carnages, buses and trucks.
- Water pumps and sprays paint machines,
- For starting of aircraft engines and large (heavy) Diesel engines,
- For industrial cleaning; such as to clean workshop machines, generators, automobiles etc.,
- To operate blast furnaces and gas turbine plants.
- Supercharging in I.C. engines.

2.1 Applications of Compressors:

- We may not realize the importance of compressors in our daily life.
- But the range of application of compressors is very wide.
- From small units such as refrigerator compressors to the huge industrial units.
- Reciprocating compressors are most commonly used, ranging in sizes from 0.1 hp to 25 hp.
- Rotary compressors are available from small size (in cars) to 500 hp.
- Centrifugal compressors are often used in sizes ranging up to 10,000 hp.
- The type and size of the compressor depends upon its application and cost.

3 CLASSIFICATION OF COMPRESSORS

Depending upon on the principle of compression employed, compressors are classified into two major categories:

1. *Positive displacement compressors*
2. *Dynamic displacement compressors*

3.1 Positive Displacement Compressors

- *In these types of air compressors, compression is achieved by positive displacement of a solid boundary, which compress the gas in a closed compression chamber.*
- *The compressor may have single or multiple intakes and compression chambers.*
- *These compressors are capable of producing very large pressure ratios.*

3.11 Working

- *Atmospheric air is drawn into the compression chamber(s) through intake valves,*
- *The valves are then closed and the volume of each chamber is gradually decreased mechanically.*
- *As a result air gets compressed in the chambers.*
- *When the designed pressure is reached, the delivery valve(s) are opened and the compressed air is discharged into the reservoirs.*

3.12 Types

Based on the compression mechanism used, Positive displacement compressors are divided into two main groups:

- *Reciprocating compressors*
- *Rotary compressors*

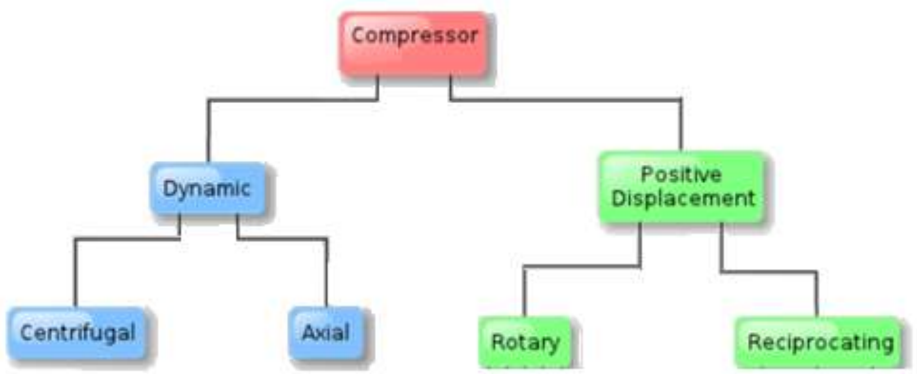


Figure 2: Types of Compressors.

3.2 Dynamic Displacement Compressors

- Also called **steady flow** or **turbo-compressors**.
- The dynamic compressors have a rotating impeller.
- Here compression of gas does not occur in a closed volume.
- The flow of gas is continuous in these compressors.
- The dynamic action of impeller on the gas increases its pressure.
- They are widely used in chemical and petroleum refineries.

Types:

Steady flow compressors are of two types:

- Centrifugal Compressor
- Axial Compressor

Advantages :

- Can handle large quantities of air or gas at lower pressures.
- Being high speed machines, they are smaller in size,
- Provide uniform delivery of gas without requiring a large receiver,
- Deliver more clean air, as there are fewer sliding parts requiring lubrication,
- Present no balancing problems,
- Lower maintenance expenses,
- Require less operating attention.

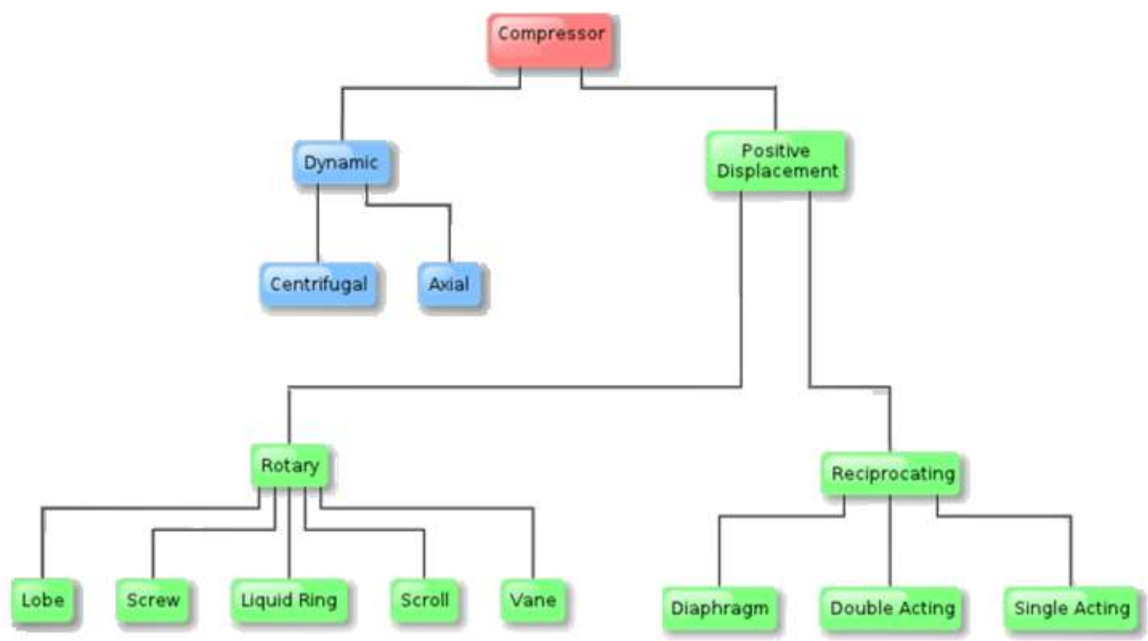


Figure 3: Classification of Compressor

4 RECIPROCATING COMPRESSORS

- *Reciprocating compressor is a positive displacement machine with constructional details similar to an IC engines.*
- *But, Unlike an IC engine there is no combustion of a gas to drive the piston, instead the piston is now used to compresses the gas in a closed volume.*

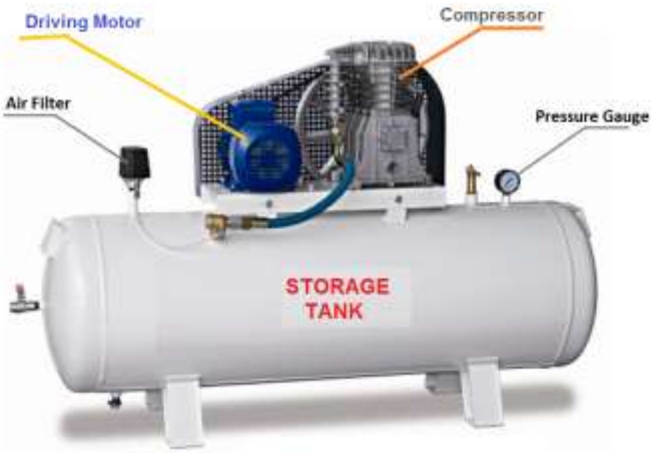


Figure 4 : A Reciprocating air compressor unit.

4.1 Constructional details:

- *A reciprocating Air Compressor consists of a piston which reciprocates inside a cylinder.*
- *The piston is connected to the crankshaft by means of a connecting rod and a crank.*
- *In this way the rotary movement of the crankshaft is converted into the reciprocating motion of the piston.*
- *Suction and delivery valves are provided at the top of the cylinder.*

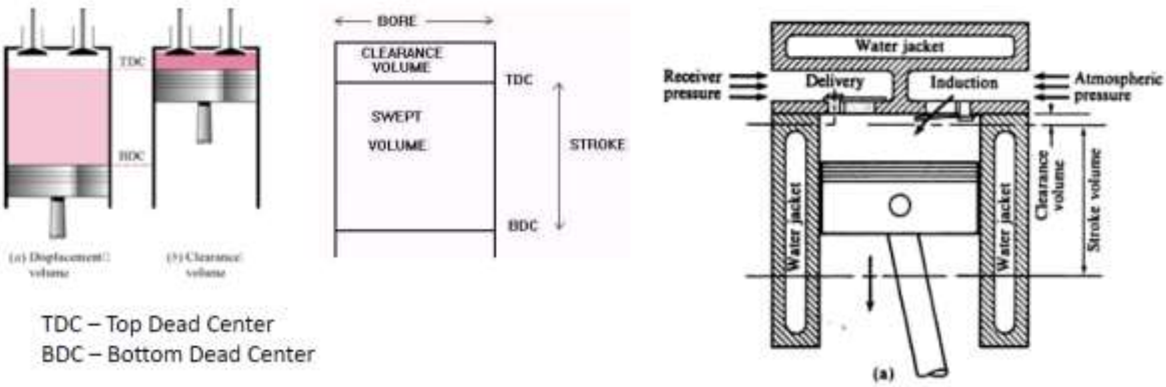


Figure 5: Constructional details of a single acting reciprocating air compressor.

4.2 Working of Reciprocating Compressor:

- *The whole compression cycle can be easily understood with the help of a series of processes on the pv-diagram as shown in figure-6.*

The cycle can be divided into four processes:

Process 3-4;	Expansion of clearance air
Process 4-1;	Suction of air
Process 1-2;	Compression of air
Process 2-3;	Delivery of compressed air

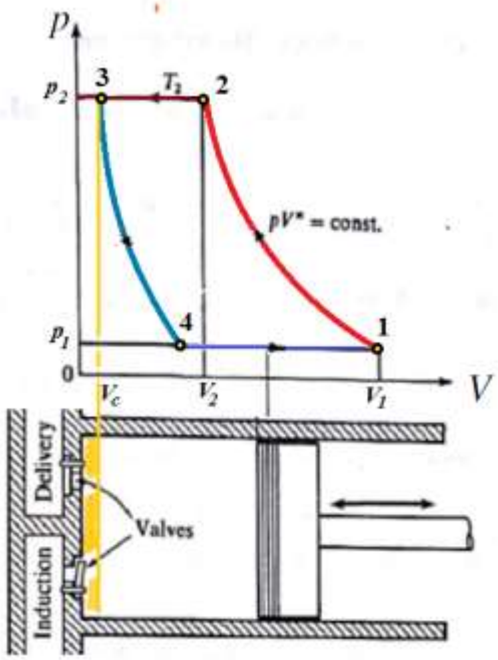


Figure 6: Single stage compression.

Process 3-4; Expansion

- *At the start of the cycle the piston is at its TDC or ODC position enclosing a small volume of air in the clearance space.*
- *This initial volume of air is called the clearance volume- V_c.*
- *The clearance volume is provided to prevent the piston from hitting the cylinder head and the valves.*
- *At the TDC/ODC position both the suction and the delivery valves are closed.*
- *The piston now begins its inward or the downward stroke.*
- *Due to the movement of the piston, air in the clearance volume expands and pressure inside the cylinder reduces.*
- *The expansion of clearance air continues till the cylinder pressure reaches the atmospheric value.*

Process 4-1; Suction

- *With further movement of the piston, cylinder pressure falls below atmospheric.*
- *As a result, the air outside forces the inlet valve to open and make its way into the cylinder; this process is called suction.*
- *As piston continues its stroke, more and more air gets sucked into the cylinder.*
- *The suction process continues till the end of the down-stroke.*

Process 1-2; Compression

- *At the end of suction stroke, when the piston reaches BDC or IDC position, its direction of motion is reversed because of the slider-crank mechanism.*
- *The piston now begins its upward stroke and the cylinder volume decreases causing an increase of air pressure.*
- *After a short while the pressure inside the cylinder exceeds the atmospheric pressure and as a result the inlet valve gets closed.*
- *The pressure of air inside the cylinder continues to increase steadily with the out-stroke of the piston.*

Process 2-3; Delivery

- *When the air pressure inside the cylinder reaches the desired value, the delivery valve gets opened.*
- *During the remainder of the out-stroke the delivery valve stays open and the high pressure air is delivered to the storage tank.*
- *As the piston reaches its top dead centre position the delivery valve is closed.*
- *At the end of stroke, a small volume of compressed air is left in clearance space.*
- *The final state is now same as the initial state and the cycle gets repeated.*

5 COMPRESSION NEGLECTING CLEARANCE VOLUME:

- *For the sake of simplicity the compression cycle is first studied neglecting the clearance volume, as represented by p-v diagram; figure-7.*
- *During the suction stroke the air is drawn into the cylinder along line 4-1.*
- *All valves being closed, air is compressed along the compression curve 1-2.*
- *At point 2, discharge valve opens and compressed air is delivered along line 2-3.*
- *The net work required per cycle, for compression and the delivery of compressed air, is given by the area enclosed by the pv-diagram.*

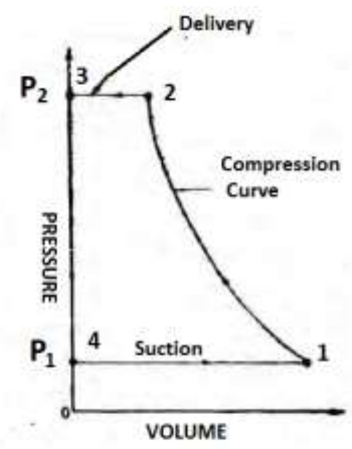


Figure 7: Compression neglecting clearance volume.

5.1 Types of Compression Curves

- PV diagram for compression process without clearance volume is shown in fig-8.
- Compression of air may be carried out along the following three types of curves:

1. Isentropic compression,
2. Isothermal compression
3. Polytropic compression

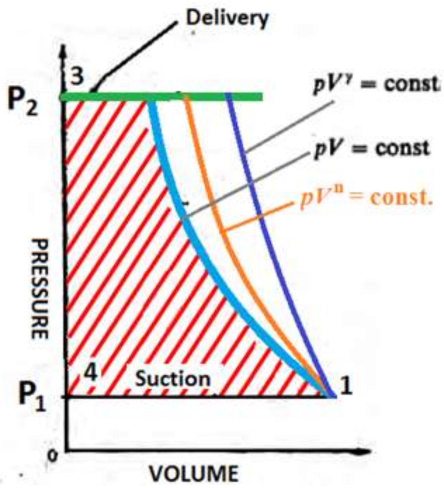


Figure 8; Types of Compression Curves.

Isentropic compression

- If the compression occurs very rapidly in a non-conducting cylinder.
- Then there is little time available for heat transfer and the process will be nearly isentropic.
- The law for isentropic compression is

$$PV^{\gamma} = const.$$

Isothermal compression

- The compression of air is now carried out slowly.
- In this case the heat of the compression gets extracted from the air by the cooling water circulating in the cylinder jackets.
- The compression will then approach isothermal conditions.
- The law for an isothermal or hyperbolic compression is

$$\text{PV} = \text{const.}$$

here the value of index n is 1.

Polytropic compression

- In actual practice neither isentropic nor the isothermal conditions exists.
- The actual compression process is between the two; called polytropic compression.
- The compression curve follows the law:

$$PV^{n} = const.$$

Where, n is the index of compression.

6 AIR COMPRESSOR TERMINOLOGY

The following terminology should be well understood analysing the performance of air compressors.

***Free air delivered** FAD*

It is the volume of air delivered under the conditions of temperature and pressure existing at the compressor intake, i.e., volume of air delivered at surrounding air temperature and pressure.

Capacity of a compressor

It is the quantity of the free air actually delivered by a compressor in cubic metres per minute.

Swept Volume

It is the volume in cubic metres obtained as the product of the piston area in m^2 and the piston stroke in metre.

Indicated power or air power

It is the power determined from the actual indicator diagram taken during a test on the compressor.

Shaft or brake power

It is the power delivered to the shaft of the compressor or the power required to drive the compressor. The compressor may be driven by an engine or an electric motor.

Shaft or brake power – Air/ indicated power = [Friction power]

$$\text{Mechanical efficiency, } \eta_m = \frac{\text{Air (indicated) power}}{\text{Shaft (brake) power}}$$

Isothermal power

It is the power of a compressor calculated from the theoretical indicator diagram drawn by assuming the isothermal compression.

$$\textit{Isothermal efficiency} = \frac{\text{Isothermal power in watts}}{\text{Indicated or actural power in watts}}$$

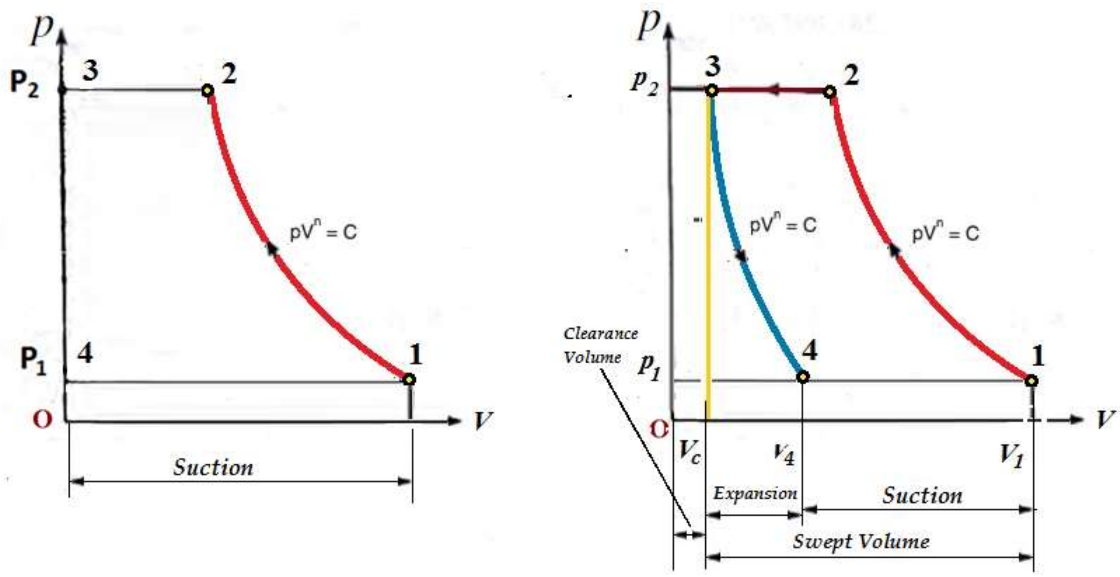
Volumetric efficiency

It is the ratio of the actual volume of the free air at standard atmospheric conditions discharged in one delivery stroke, to the volume swept by the piston during the stroke.

$$\text{Volumetric efficiency} = \frac{\text{Volume of free air delivered per stroke}}{\text{Volume swept by piston per stroke}}$$

7 EFFECT OF CLEARANCE VOLUME

- The clearance space is provided in an actual compressor to prevent the piston from striking the cylinder head.
- The suction process taking place in the compressor with clearance space is different from the suction without clearance as shown in figure-8.



(a) Without clearance volume (b) With clearance volume

Figure 8, Single stage polytropic compression cycle.

- With the presence of the clearance volume, all the compressed air in the cylinder is not delivered from it at the end of stroke.
- But, a small amount of compressed air is left in the clearance space.
- This high pressure air in clearance space will first re-expand polytropically along the curve 3-4.
- At state point-4, suction valves open and the suction of fresh charge begins.
- Thus, it can be clearly seen that the volume of air drawn into the cylinder with the presence of the clearance volume gets **considerably reduced.**

  Volume of suction air with clearance volume gets reduced from V_1 to $V_1 - V_r$.
- Therefore, there occurs a significant reduction in the volumetric efficiency of the compressor due to the presence of clearance volume.

- The volumetric efficiency of compressor with clearance volume can be written as

$$\mu_{vol} = \frac{V_1 - V_4}{V_1 - V_3} = \frac{V_1 - V_4}{V_{Sw}}$$

- In practice the clearance volume is limited to, two or three per cent of the displacement or swept volume.