10

Chapter

AIR COMPRESSORS

10.1 INTRODUCTION

Compressors are the mechanical devices used for increasing the pressure of a gas. Compressors used for producing high pressure air are called air compressors. Air is drawn from the atmosphere during suction, compressed to the required pressure and then delivered to the receiver. If the compression is done in a conventional cylinder with a closely fitted piston making reciprocating motion, the compressor then is called a reciprocating compressor. External work must be supplied from a prime mover to the compressor to achieve the required compression. The general arrangement of the compressor and prime-mover used to run the compressor is shown in Fig. 10.l. Part of the energy supplied to the prime mover is converted into work to run the compressor and the remaining part is lost in friction, heat radiation and to the coolant used to cool the compressor.

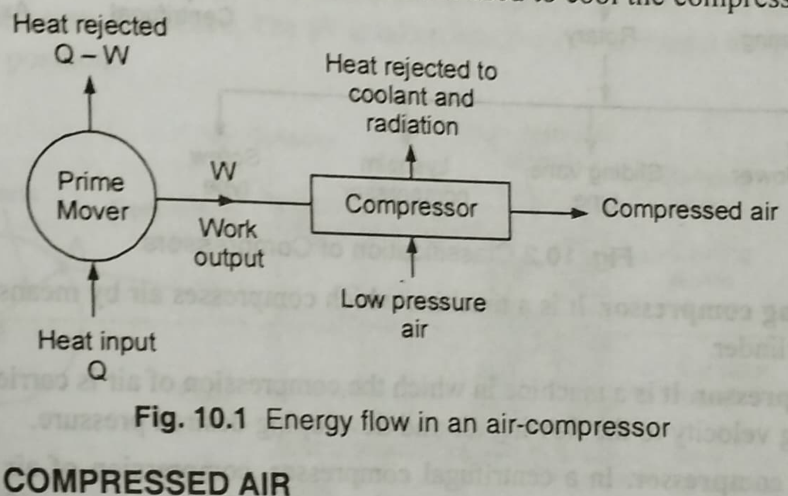

Fig. 10.1 Energy flow in an air-compressor

10.2 USES OF COMPRESSED AIR

The various uses of compressed air are given below :

(a) Industrial Uses

1. Food processing.
2. Spraying of insecticides.
3. Construction of roads, dams, etc.
4. Operating pneumatic tools like drills and hammers in mines and rock drilling.
5. For operating blast furnaces.
6. For sand blasting of castings in foundry.
7. Manufacture of acids and other chemical products.

(b) Commercial Uses

1. Cleaning of inaccessible parts of machinery.
2. Spray painting.
3. Driving compressed air motors.
4. Operating air brakes in automobiles and trains.
5. For filling air in automobile tyres.
6. For operating water pumps, lifts and elevators.
7. For glass blowing.

10.3 CLASSIFICATION OF COMPRESSORS

Air compressors may be classified as shown in Fig. 10.2.

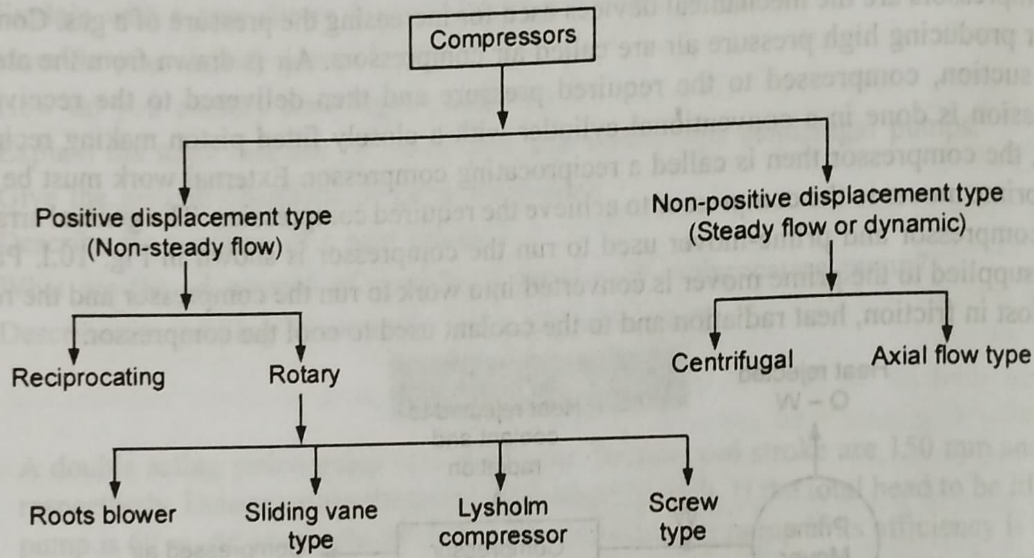

Fig. 10.2 Classification of Compressors

Reciprocating compressor. It is a machine which compresses air by means of a reciprocating piston inside a cylinder.

Rotary compressor. It is a machine in which the compression of air is carried out by a rotating element imparting velocity to the flowing air and developing desired pressure.

Centrifugal compressor. In a centrifugal compressor, compression of air from atmospheric pressure to any desired pressure is obtained by a rotating impeller due to centrifugal action.

Axial flow compressor. In an axial flow compressor, the air flows throughout the compressor, parallel to the compressor axis.

10.4 TERMINOLOGY

Single acting compressor. If the air admission from the atmosphere is on one side of the cylinder only.

Double acting compressor. When the air from the atmosphere is drawn on both sides of the cylinder.

Single-stage compressor. When the total compression of air is done fully in one cylinder.

Multi-stage compressor. When the compression is carried out in more than one cylinder, every cylinder carrying out a part of the compression.

Free Air Delivered, FAD. It is the actual volume delivered at the stated pressure, reduced to intake pressure and temperature and expressed in cubic metre per minute.

Swept volume. It is the product of area of piston and length of stroke.

$$\text{Swept volume, } V_s = \frac{\pi}{4} D^2 L$$

where

D = piston diameter, m
L = length of stroke, m

$$\text{Volumetric efficiency, } \eta_v = \frac{\text{Actual free air delivered per stroke}}{\text{Swept volume}}$$

Compression ratio. It is the ratio of discharge pressure to suction pressure of an air compressor.

Capacity. It is the volume of compressed air delivered by the compressor expressed in m^3/min.

Positive displacement compressor. When the pressure of air is increased by decreasing its volume, it is called a positive displacement compressor. Reciprocating and rotary compressors are positive displacement compressors.

Dynamic compressor. In these compressors, the kinetic energy imparted to air by the rotation of rotor is changed into pressure energy partly in rotor and partly in diffuser. Centrifugal and axial flow compressors are of this type.

10.5 OPERATION OF SINGLE-STAGE RECIPROCATING COMPRESSOR

The schematic arrangement of a single-stage reciprocating compressor is shown in Fig. 10.3. It consists of a cylinder with cooling jacket, piston, connecting rod, crank, suction and delivery values. The piston will be making to-and-fro motions through the crankshaft arrangement and generally run by an electric motor, diesel engine, petrol engine or steam engine. During the outward motion of the piston, the pressure inside the cylinder falls below the atmospheric pressure and the suction value is opened due to the pressure difference. The air is taken into the cylinder until the piston reaches the bottom dead centre position.

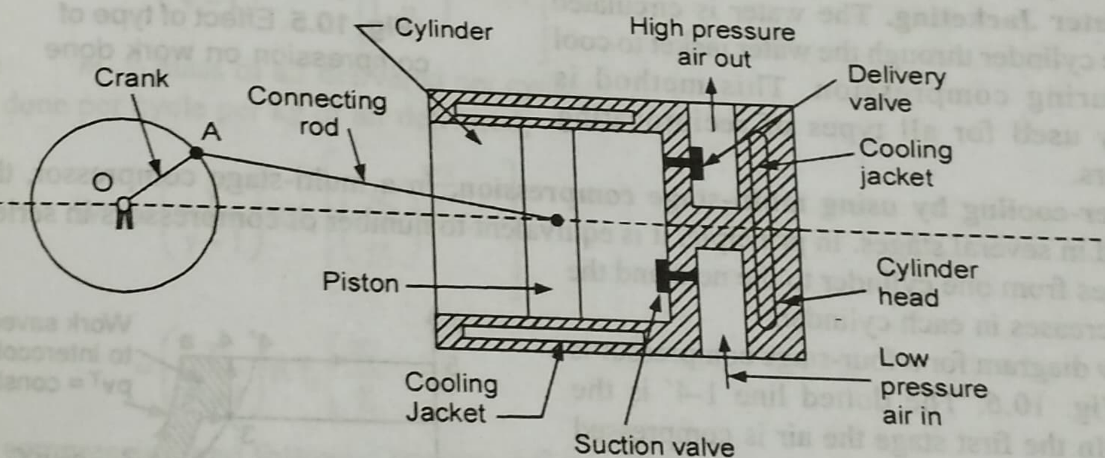

Fig. 10.3 Single-stage reciprocating air-compressor

As the piston stacks moving inwards, the suction value is closed and the pressure starts increasing until the pressure inside the cylinder is more than the pressure of the delivery side. Then the delivery valve opens and high pressure air is delivered to the receiver till the piston reaches the top dead centre. At the end of the delivery stroke the small volume of high pressure air left in the clearance volume expands as the piston starts moving outwards. Thus the cycle is repeated.

10.6 TYPES OF COMPRESSION

The p-υ diagram for an air compressor without clearance is shown in Fig. 10.4. The constant pressure p_1 line 4-1 represents the suction stroke, the air is then compressed adiabatically, as shown by the curve 1-2. It is then forced out of the cylinder at constant pressure p_2, as shown by the line 2-3. The work done is represented by the area '1-2-3-4-1'.

If the air had been compressed isothermally, as represented by the curve 1-2′, then the work done on the air would be the area '1-2′-3-4-1', which is considerably less than that due to adiabatic compression. However it is not possible in practice to compress the air isothermally because in that case the compressor would need to run extremely slow. In practice, the compressors are driven at fairly high speeds in order to compress as much air as possible in a given time. Hence the compression of air will approximate to an adiabatic. The work saved by compressing isothermally is shown by the shaded area '1-2-2′-1'.

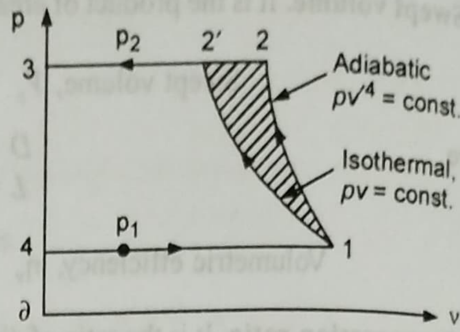

Fig. 10.4 Theoretical p-υ diagram for single acting compressor

10.6.1 Methods for Approximating to Isothermal Compression

The following practical methods are used to achieve nearly isothermal compression :

1. Cold Water Spray. In this method, cold water is sprayed onto the cylinder during compression, thus reducing the temperature of the air. Without the cold water spray, the compression would have been adiabatic, or $pv^{1.4}$ = constant. This effect is shown in Fig. 10.5, where now the compression would be between adiabatic and isothermal, or $pv^{1.2}$ = const. The work saved is represented by '1-2-2"-1'.

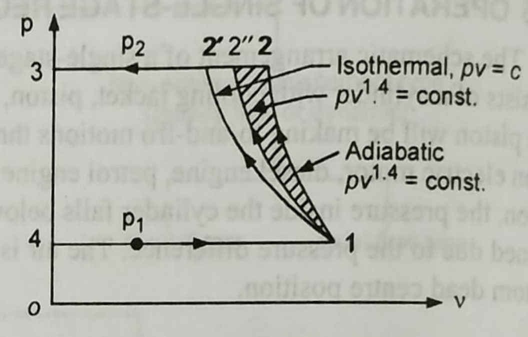

Fig. 10.5 Effect of type of compression on work done

2. Water Jacketing. The water is circulated around the cylinder through the water jacket to cool the air during compression. This method is commonly used for all types of reciprocating compressors.

3. Inter-cooling by using multi-stage compression. In a multi-stage compressor, the air is compressed in several stages. In principle, it is equivalent to number of compressors in series where the air passes from one cylinder to the next and the pressure increases in each cylinder.

The *p-v* diagram for a four-stage compressor is shown in Fig. 10.6. The dotted line 1-4′ is the isothermal. In the first stage the air is compressed adiabatically to '2', cooled at constant pressure to 2′ in the inter-cooler, possibly to the initial temperature. For complete inter cooling, the point 2′ is on the isothermal line 1-4′. The air is then drawn into the second cylinder for the second stage of its compression and the process is repeated for the subsequent cylinders. Line 1-*a* represents the adiabatic compression in a single cylinder. The compressor work saved by inter-cooling is represented by the area '2-*a*-4-3′-3-2′-2'.

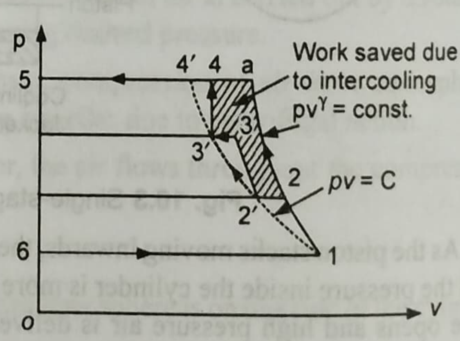

Fig. 10.6 Multi-stage compression

4. External Fins. Small capacity compressors are provided with fins to increase the heat transfer from the surface of the cylinder.

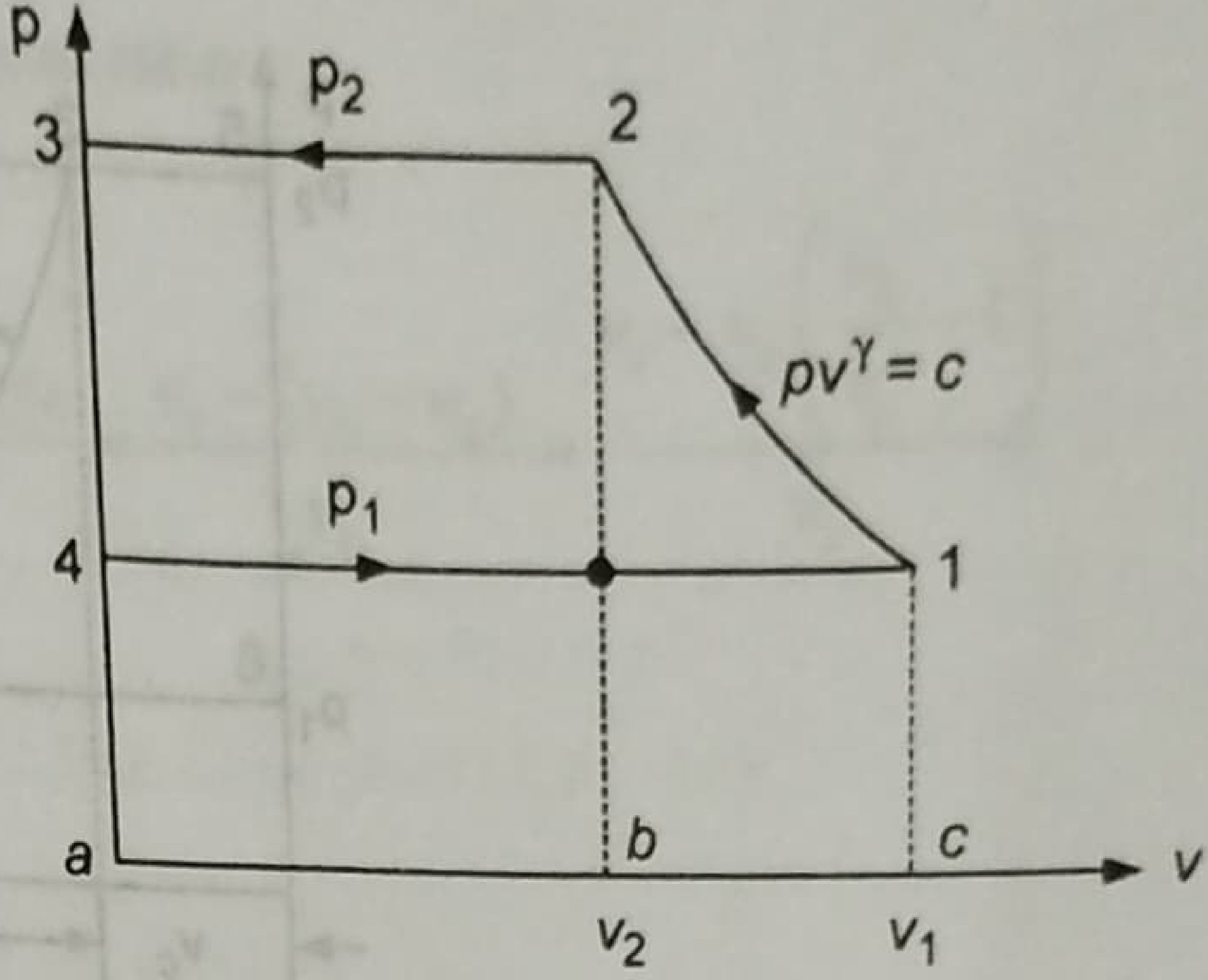

Fig. 10.7 p-υ diagram without clearance

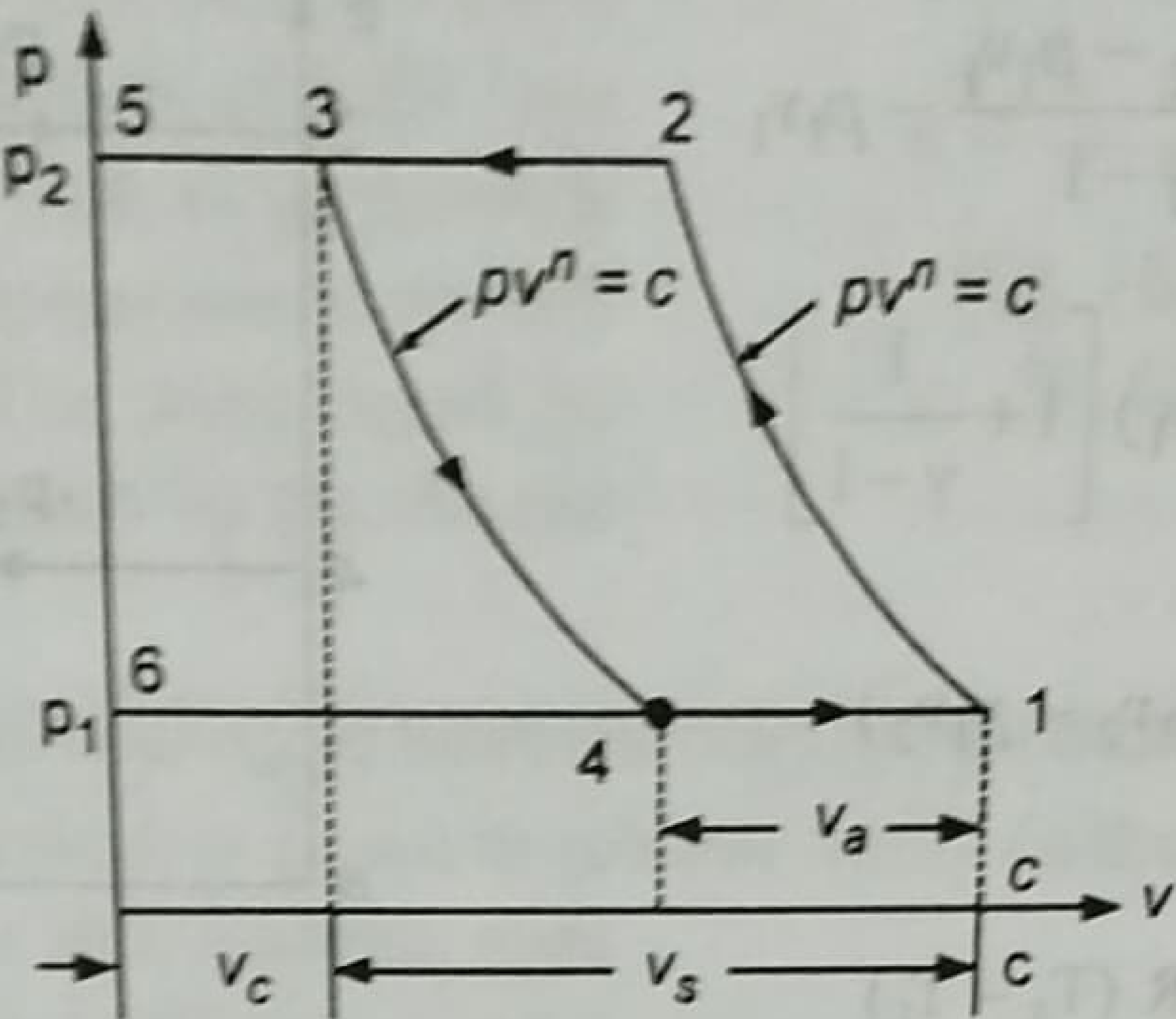

Fig. 10.8 p-υ diagram with clearance

10.7.2. Volumetric Efficiency

The ratio of the actual free air delivered to the swept volume of the compressor is called the volumetric efficiency.

$$\eta_v = \frac{v_a}{v_s} = \frac{v_1 - v_4}{v_1 - v_c}$$

Let

$$c = \frac{v_c}{v_s} = \text{clearance ratio}$$

Then

$$\eta_v = \frac{(v_c + v_s) - v_4}{v_s} = \frac{v_s - (v_4 - v_c)}{v_s} = \frac{v_s - v_c\left(\frac{v_4}{v_c} - 1\right)}{v_s}$$

Now

$$p_3 v_3^n = p_4 v_4^n$$

or

$$p_2 v_c^n = p_1 v_4^n$$

$$\frac{v_4}{v_c} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}}$$

$$n_v = 1 - c\left[\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} - 1\right] \quad \text{...(10.8a)}$$

$$= 1 + c - c\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} \quad \text{...(10.8b)}$$

$$= 1 + c - c\left(\frac{v_1}{v_2}\right) \quad \text{...(10.8c)}$$

When referred to ambient conditions,

$$n_v = \frac{\text{Volume of air sucked referred to ambient conditions}}{\text{Swept volume}}$$

$$= \frac{p_1 T_0}{p_0 T_1}\left(\frac{v_1 - v_4}{v_s}\right) = \frac{p_1 T_0}{p_0 T_1}\left[1 + c - c\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}}\right] \quad \text{...(10.9)}$$

Factors affecting volumetric efficiency

The volumetric efficiency of a compressor is lowered by any of the following conditions :

1. Very high speed.
2. Leakage through piston seals.
3. Too large a clearance volume.
4. Obstruction at inlet valves.
5. Overheating of air by contact with hot cylinder walls.
6. Inertia effect of air.

Volumetric efficiency decreases with increase in clearance ratio. Higher the delivery pressure, lower the volumetric efficiency. Further if $\frac{p_2}{p_1}$ increases, volumetric efficiency decreases.