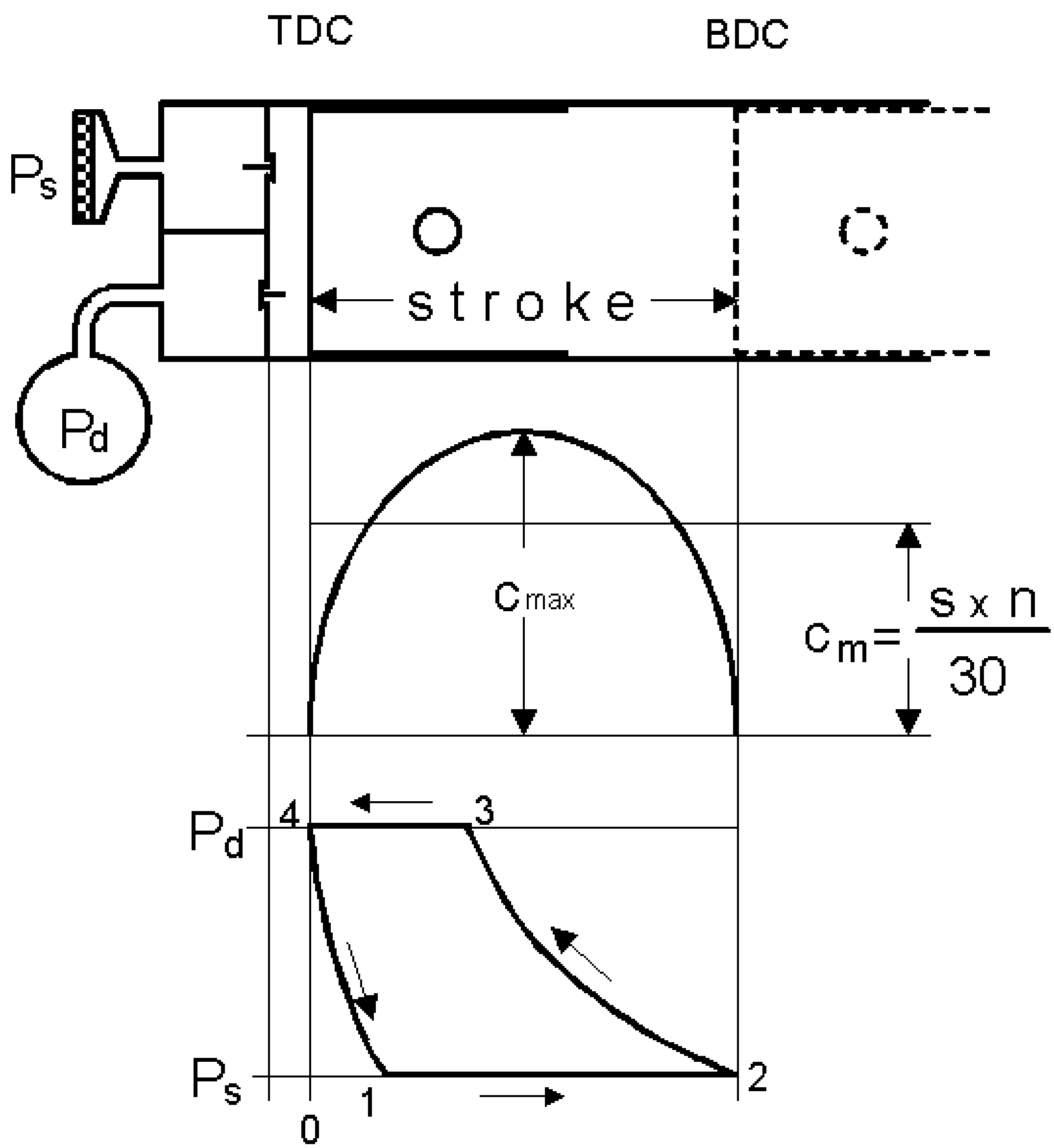
Compressor Theory

Ideal P-V Diagram

Given the laws governing and definitions describing gas behavior, let us look at how they are applied to a typical reciprocating compressor cycle. One of the preferred tools for analyzing compressor performance is the Pressure-Volume (P-V) diagram. The P-V diagram which is to be discussed here depicts the relationship of the pressure and volume of the gas within one end of a cylinder of a reciprocating compressor to the displacement of the piston. To start with we will look at an ideal P-V diagram in which there are no valve losses and the compression is adiabatic.

1. Suction valve opens and gas is drawn into the cylinder (1 - 2).
2. Suction valve closes and gas compression begins (2 - 3).
3. Discharge valve opens and the compressed gas is discharged from the cylinder (3 - 4).
4. Discharge valve closes. Note that a gap is shown in this diagram between zero volume and the volume at position 4. This represents the clearance volume in the cylinder. As the piston begins its return stroke, the gas which remains in this space re-expands (4 - 1).



Effect of Clearance Volume on Capacity

Gas is trapped in the clearance volume after each stroke. This volume of gas must be re-expanded before gas at suction conditions is admitted into the cylinder to be compressed.

Effect of Clearance Volume

The re-expansion of the gas trapped at the end of the discharge cycle does not influence the horsepower losses but has a direct effect on the volumetric efficiency of the cylinder. Figure: Effect of Clearance Volume shows two P-V curves with different clearance volumes superimposed. The opening positions of the valves change dramatically. With the higher clearance volume the volumetric efficiency is considerably lower but so is the horsepower consumption.

$$VE_s = 100\text{-}CL\% \left[\left(\frac{P_d}{P_s} \right)^{\frac{1}{k}} \text{-}1 \right]$$

$$VEd = \frac{VEs}{\left[\frac{Z_s}{Z_d}\left(\frac{P_d}{P_s}\right)^{\frac{1}{k}}\right]}$$

Pd = discharge pressure [psia]

Ps = suction pressure [psia]

CL% = clearance volume in %

k = effective cylinder isentropic exponent

Figure: PV vs Clearance

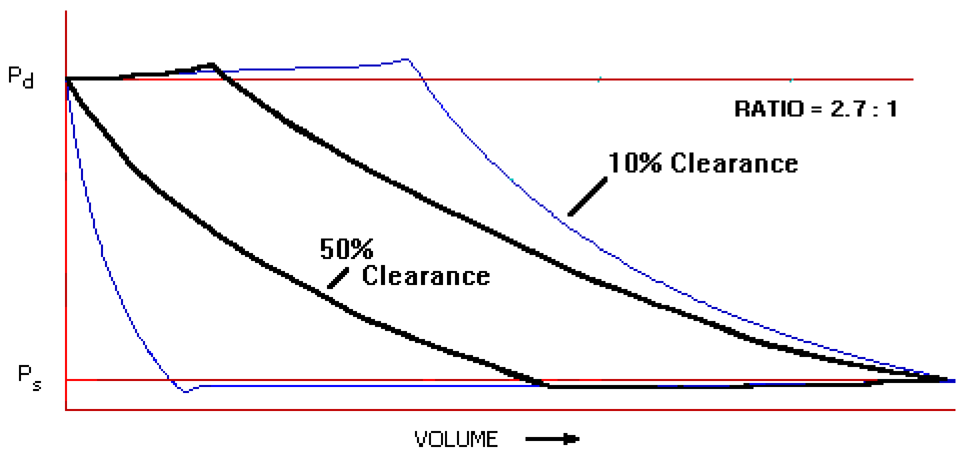
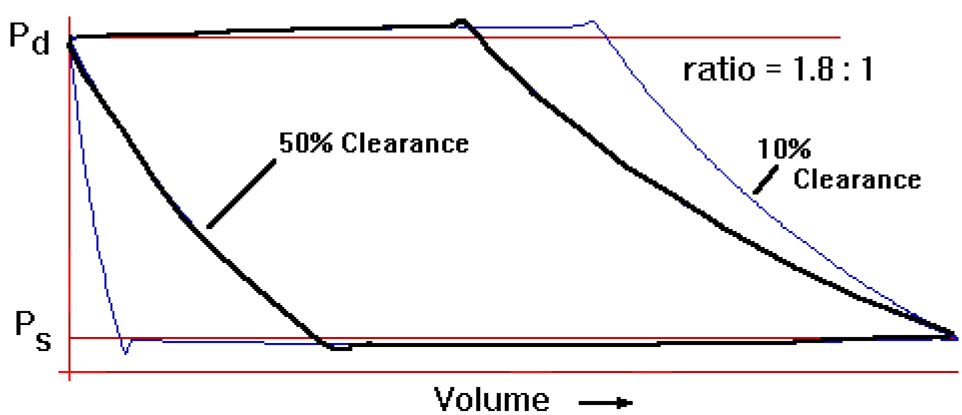


Figure: PV vs Clearance Low Ratio



Clearance Volume - Low Ratio

In applications where the compression ratio is relatively small, the extra clearance volume has a lesser effect on the volumetric efficiency. The reason for this is demonstrated in Figure: Effect of Clearance Volume and Figure PV vs Clearance Low Ratio. In Figure: PV vs Clearance Low Ratio an application with a 2.7:1 compression ratio is shown with clearance volumes of 10% and 50%. With more clearance volume, the piston must travel farther in its compression stroke before the cylinder pressure exceeds the discharge line pressure enough to open the discharge valve. The discharge volumetric efficiency (VEd) decreases and can be reduced to a point (especially in high-speed machines) where the compressed gas cannot be discharged quickly enough and the valve is forced to close late. A similar reduction in volumetric efficiency, and therefore incapacity, can be expected on the suction valve when the clearance volume is increased.

Adjusted Equivalent Valve Area

Adjusted equivalent valve area is a measure of the effective orifice area of the complete valve assembly. The equivalent area is a static measure and does not assure good dynamic behavior of the valve. This is a useful term to compare valve designs, as a valve with a higher adjusted equivalent area will generally have a lower pressure drop and better efficiency.

Equivalent area is a function of valve lift and port area. Increasing lift or port area increases equivalent area. However, higher lift valves generally have a shorter life than lower lift valves--thus the trade-off between efficiency and durability

Below is a comparison of lift vs. equivalent area for several valves.