एनटीपीसी NTPC
Transforming lives

एन टी पी सी लिमिटेड
(भारत सरकार का उद्यम)
NTPC Limited
(A Govt. of India Enterprise)

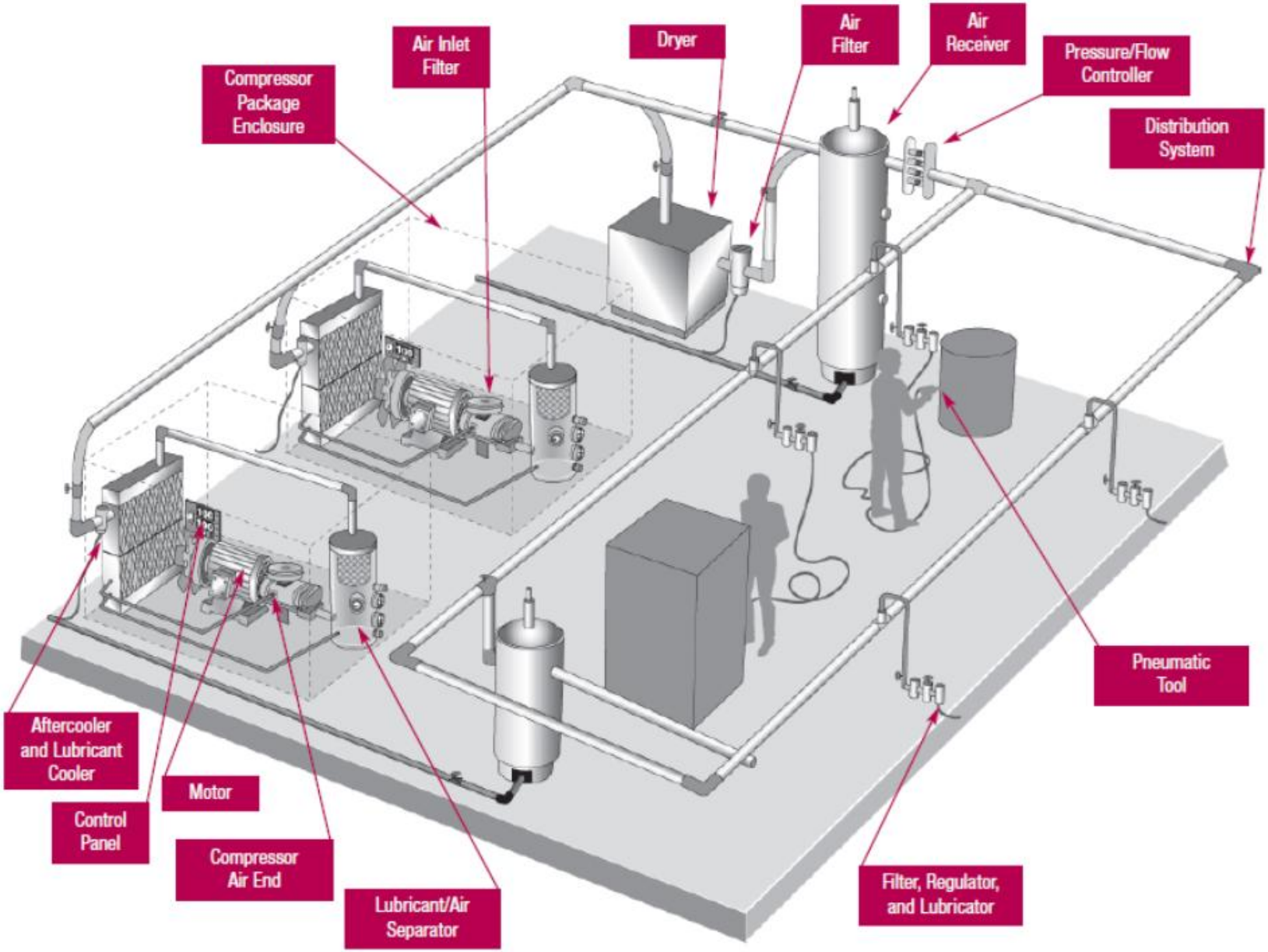
Compressors

For the Engineers of DEWA

18-20 April, 2011, Dubai

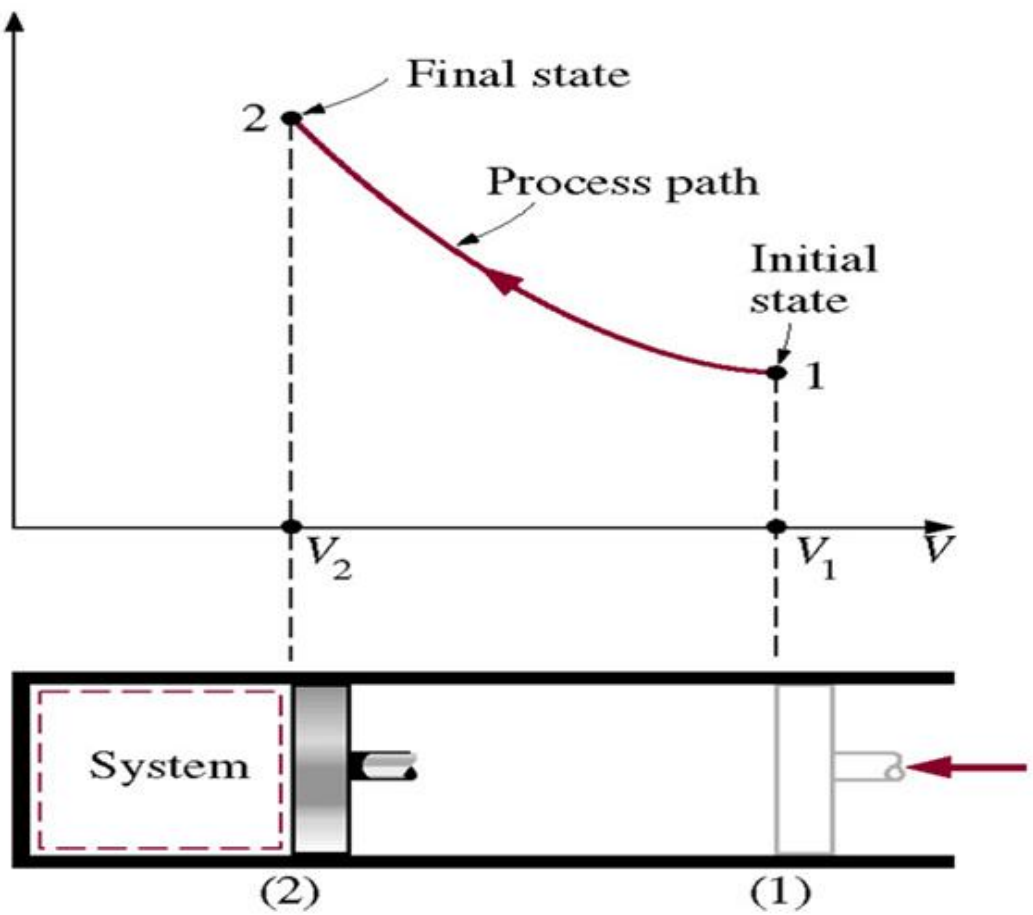
PMI NTPC Limited, India

Compressed air system



The compression process

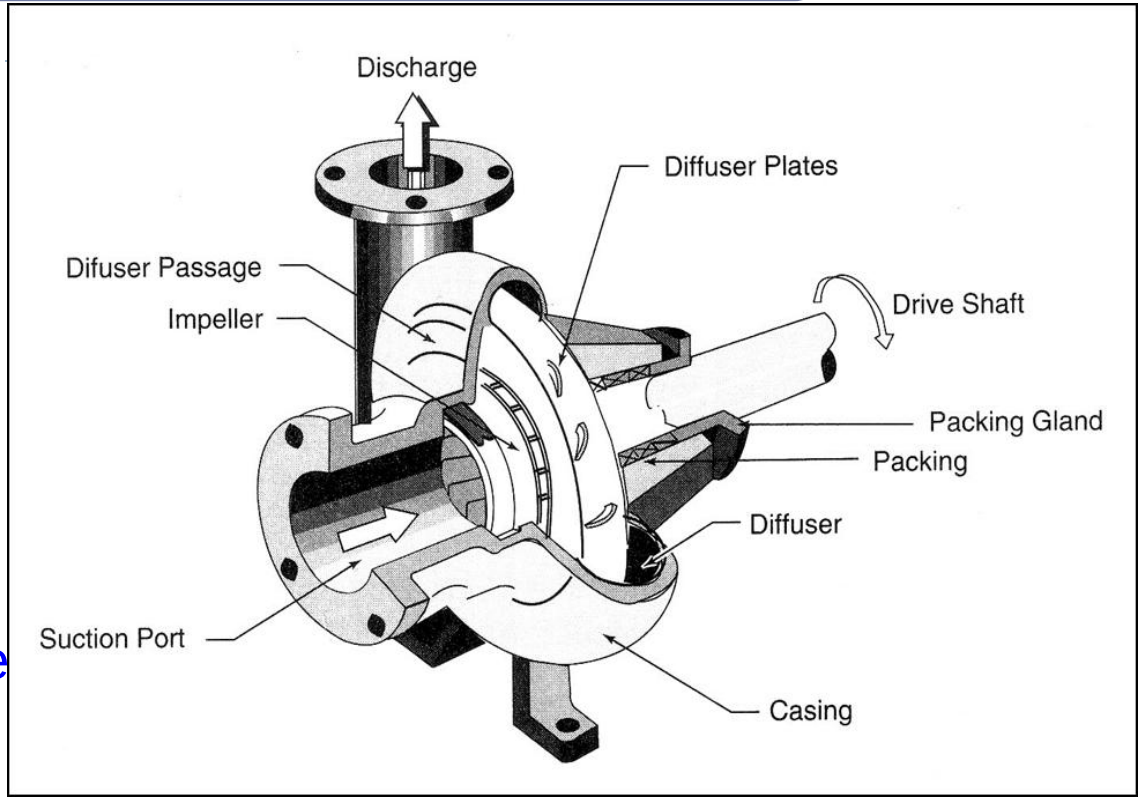
- Discontinuous flow
- Induce a fixed volume of gas into a chamber for compression
- The size of this pocket is then reduced mechanically, compressing the gas.
- At the end of the compression cycle pocket opens, discharging the high-pressure gas.
- There is never an open gas passage from delivery to suction



The P-V diagram of a PD compressor

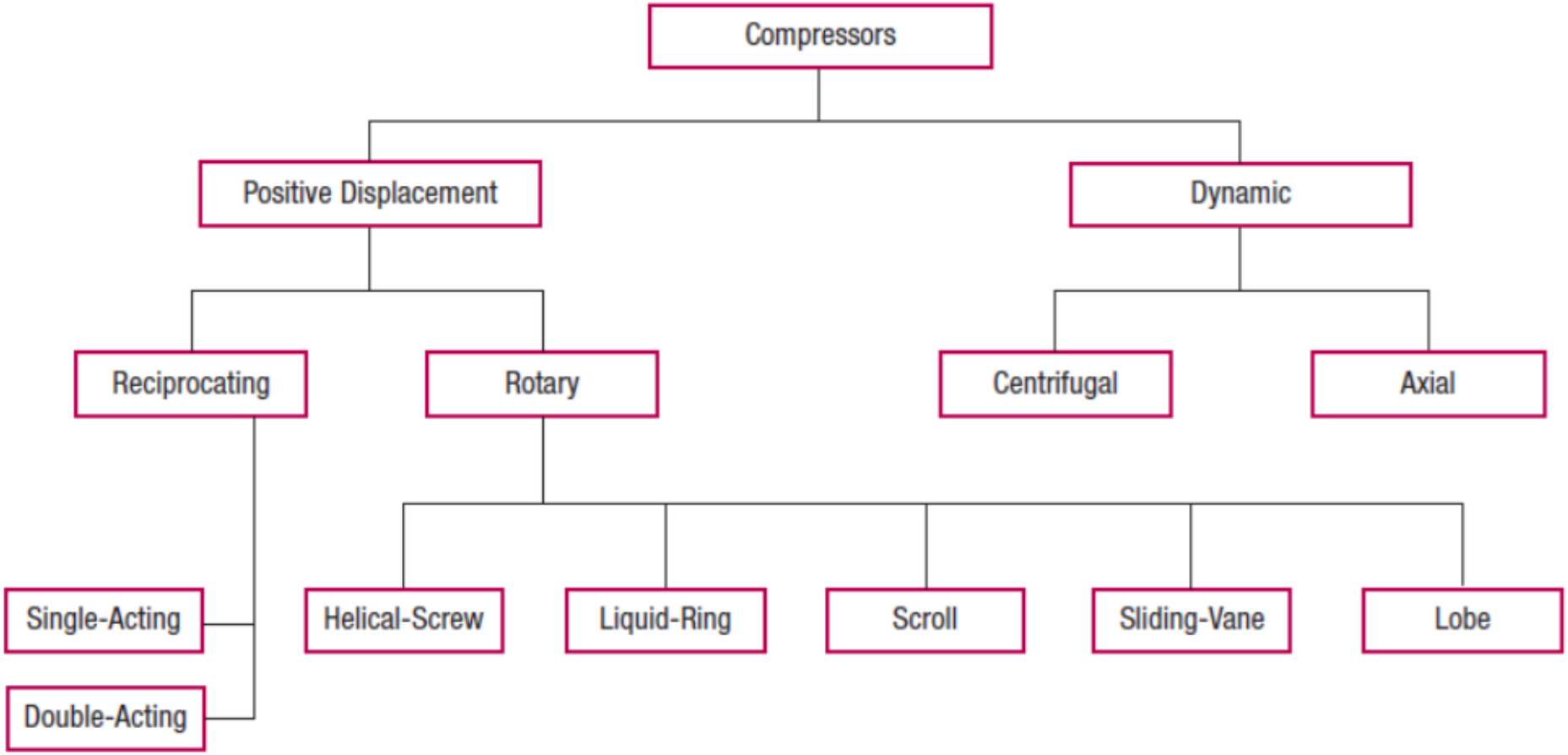
The compression process

- Air is drawn into the center of a rotating impeller with radial blades
- Thrown out towards the periphery of the impeller by centrifugal forces
- Before the air is led to the center of the next impeller it passes a diffuser and a volute
- The kinetic energy is converted to pressure.



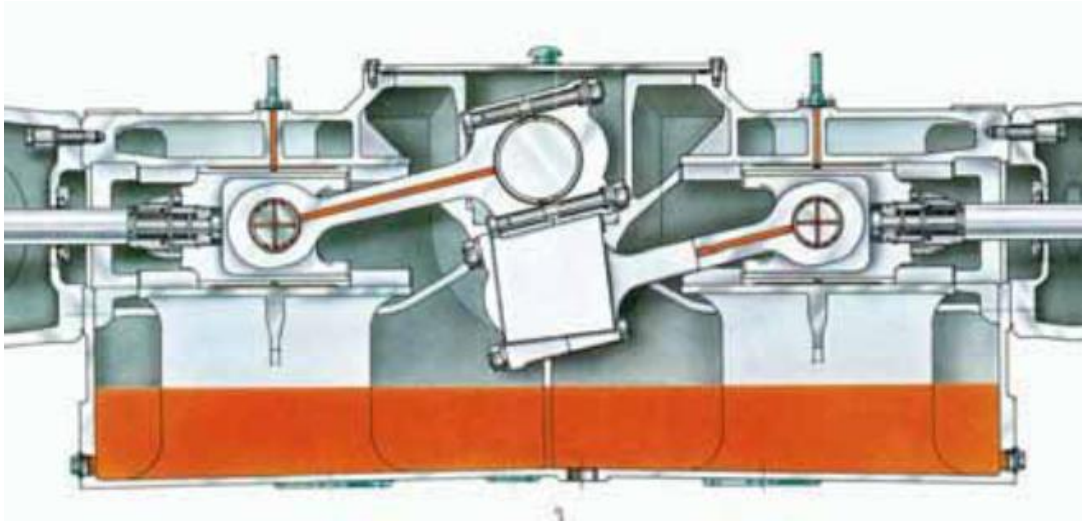
The working of a centrifugal compressor

The compressor classification



The reciprocating compressor

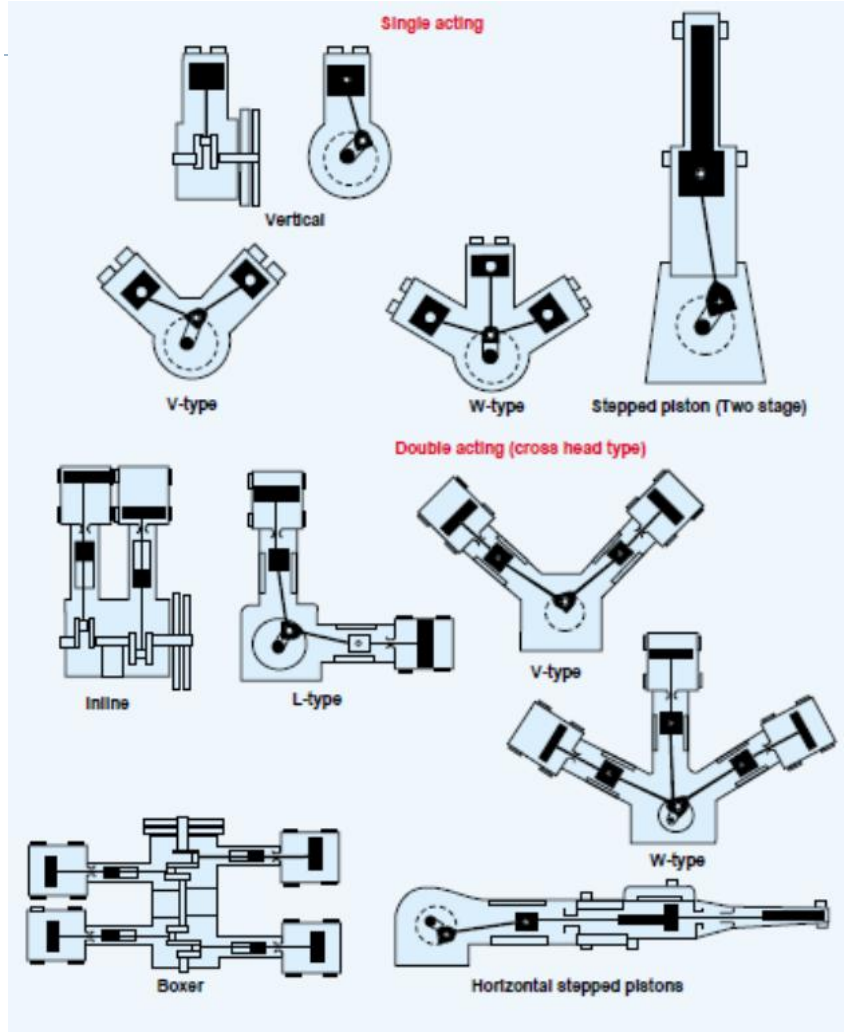
- Commonly used for small moderate air flow rates
- Can achieve high pressure ratios per stage at low volume flows
- Used for smaller flows than screw and centrifugal compressors
- Comprise sets of one or more cylinders, each with a matching piston
- Mechanically significantly more complicated than centrifugal compressors



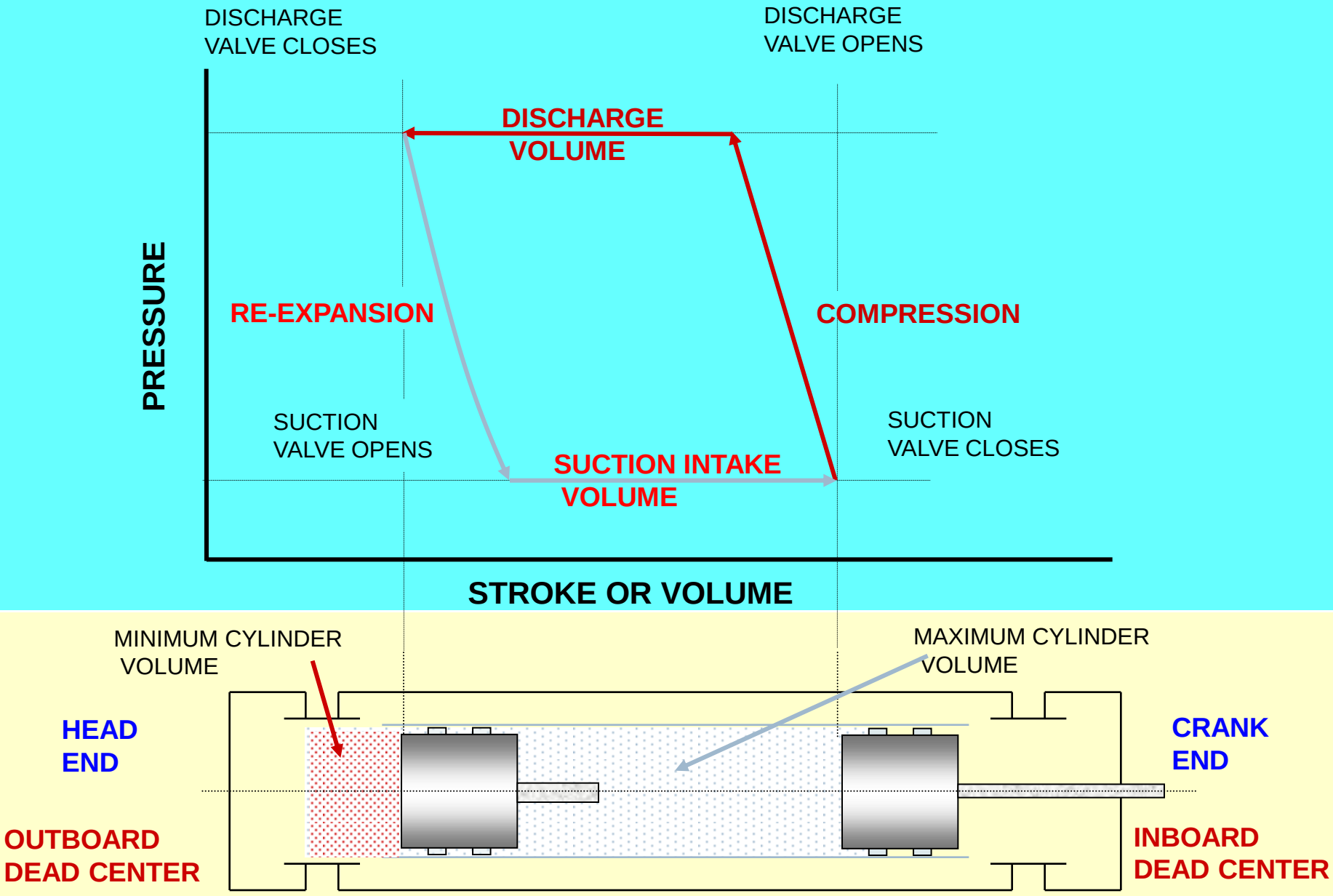
Crankshaft, Connecting Rods, Crossheads on an opposed Cylinder Machine

The reciprocating compressor

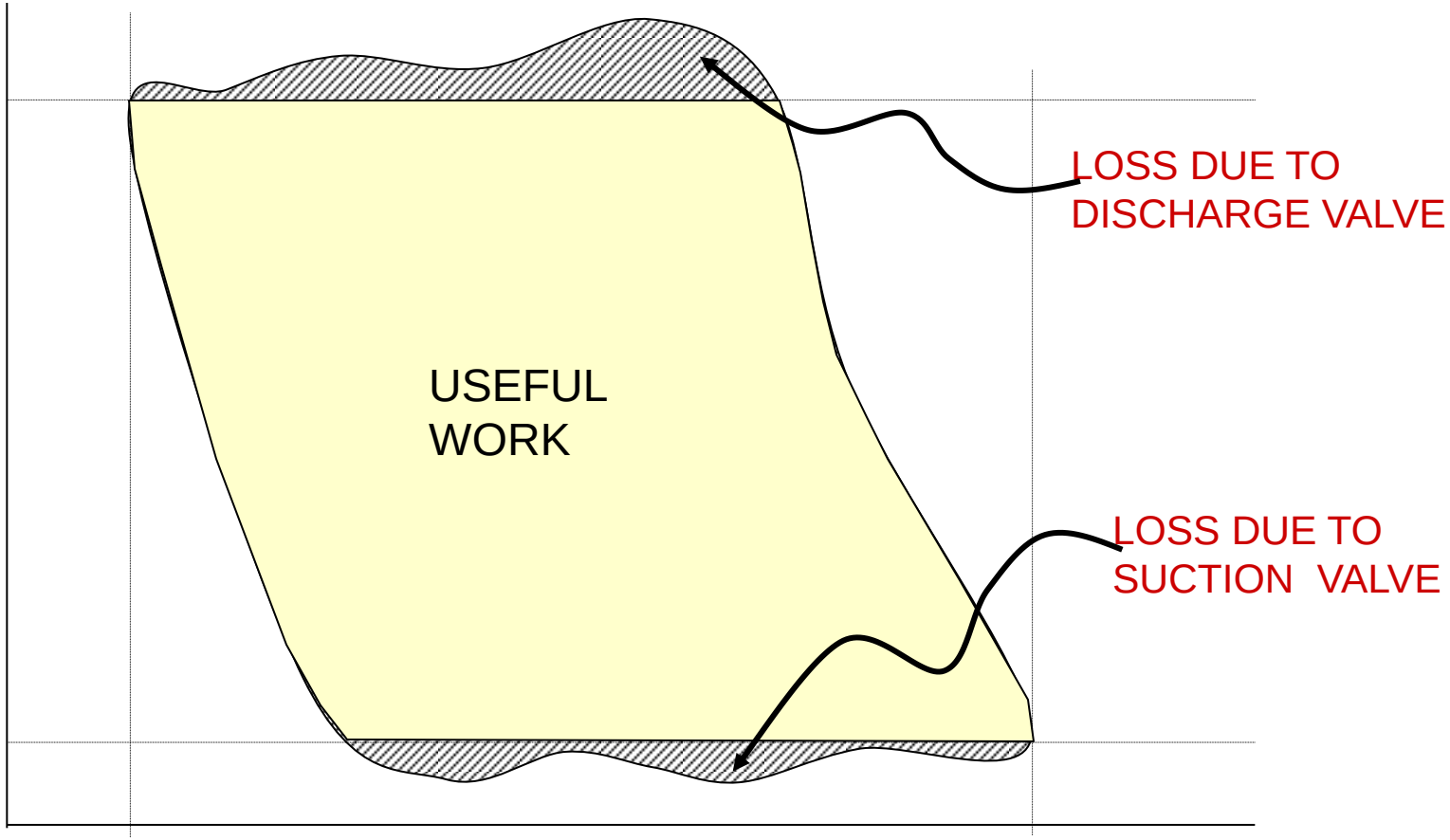
- The vast majority of compressors are shaft driven by a separate electric motor, gas turbine or diesel engine
- A drive GB may be required to match the compressor and driver speeds
- Reciprocating compressors are not normally variable speed as there are a number of ways to modify the output from such machines
  - control on suction valve opening
  - offloading cylinders.

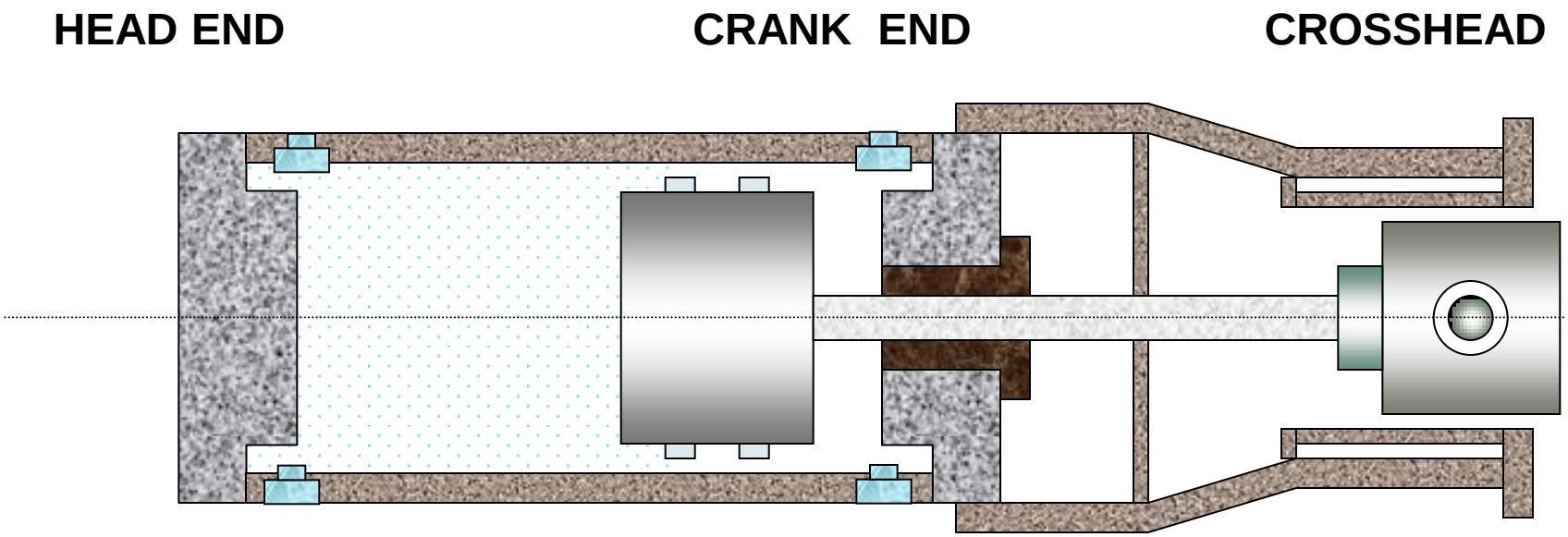


Examples of cylinder placement on piston compressors


DISCHARGE
VALVE CLOSES
DISCHARGE
VALVE OPENS
DISCHARGE
VOLUME
PRESSURE
RE-EXPANSION
COMPRESSION
SUCTION
VALVE OPENS
SUCTION
VALVE CLOSES
SUCTION INTAKE
VOLUME
STROKE OR VOLUME
MINIMUM CYLINDER
VOLUME
MAXIMUM CYLINDER
VOLUME
HEAD
END
CRANK
END
OUTBOARD
DEAD CENTER
INBOARD
DEAD CENTER

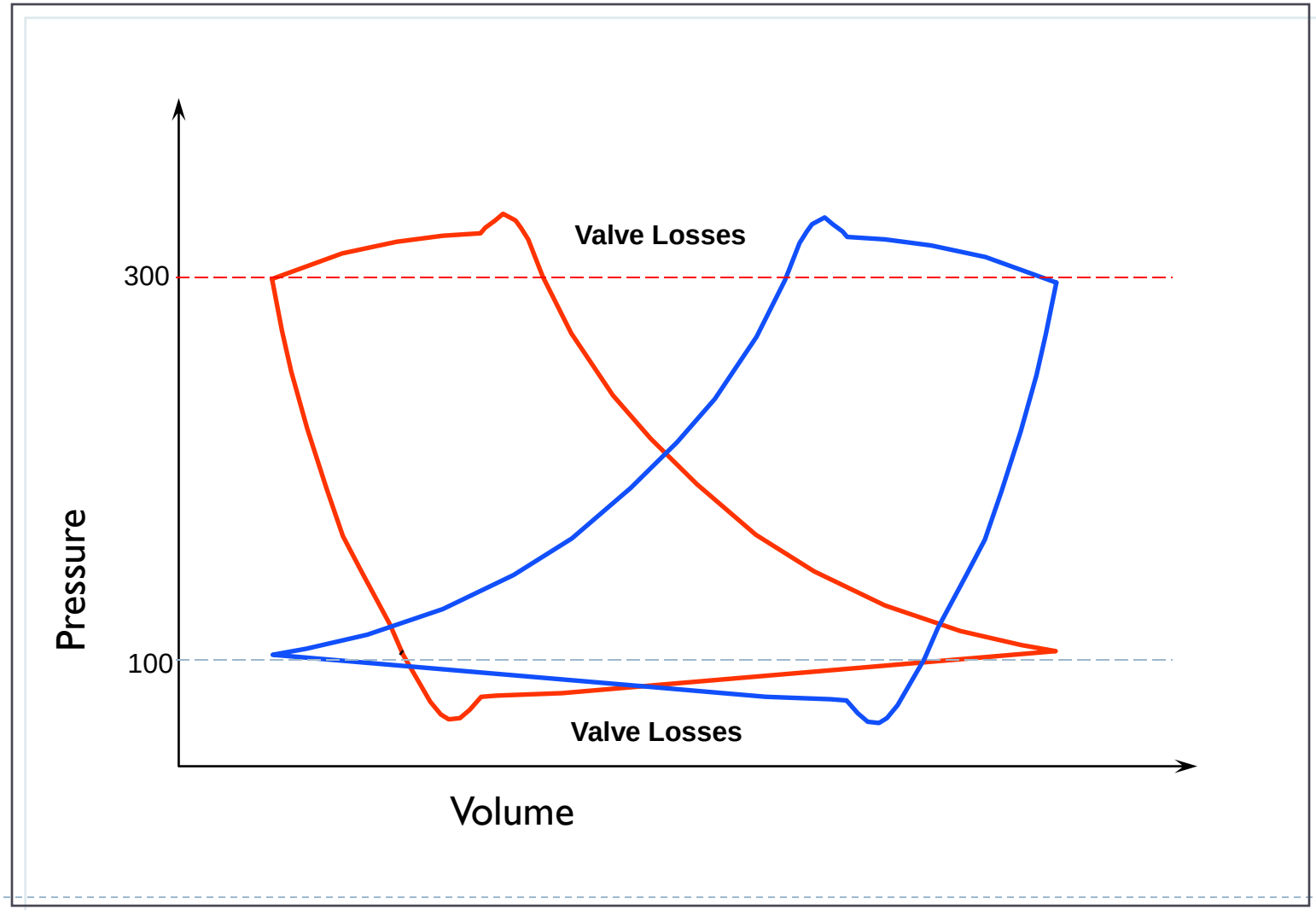
Typical Single Acting P-V Diagram

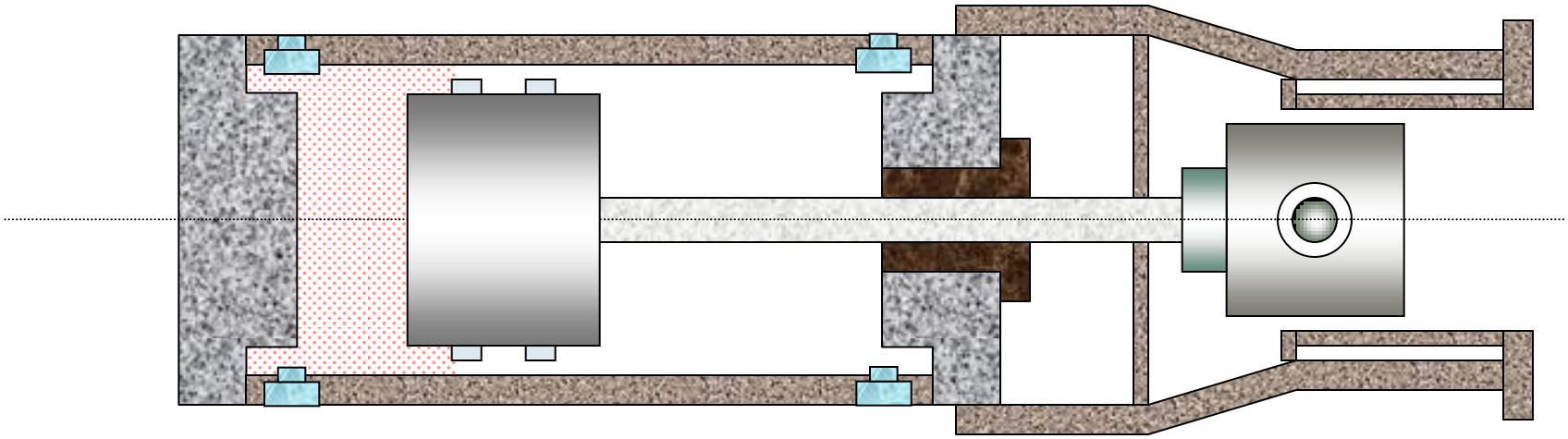




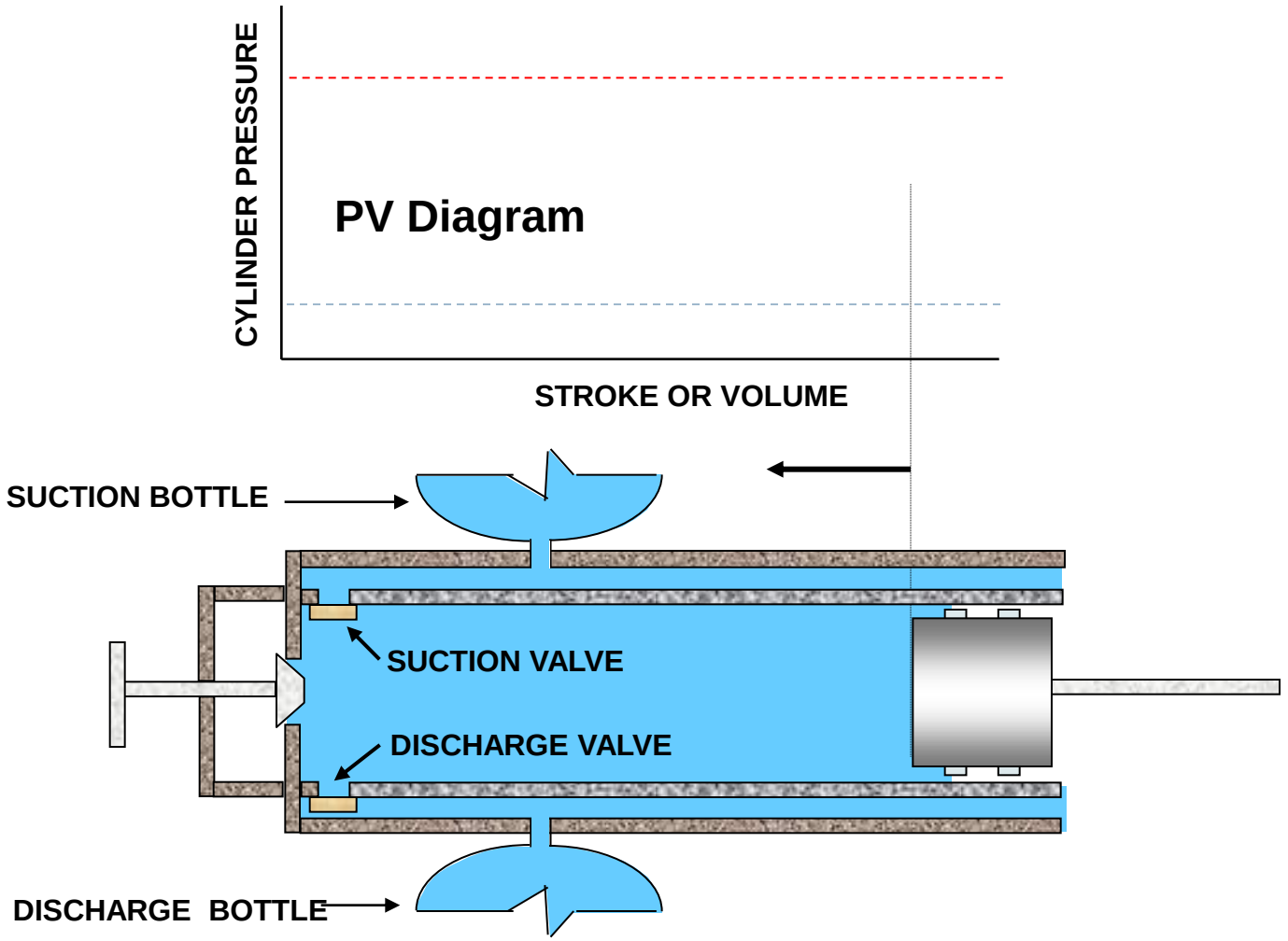
Typical double acting reciprocating compressor cylinder schematic

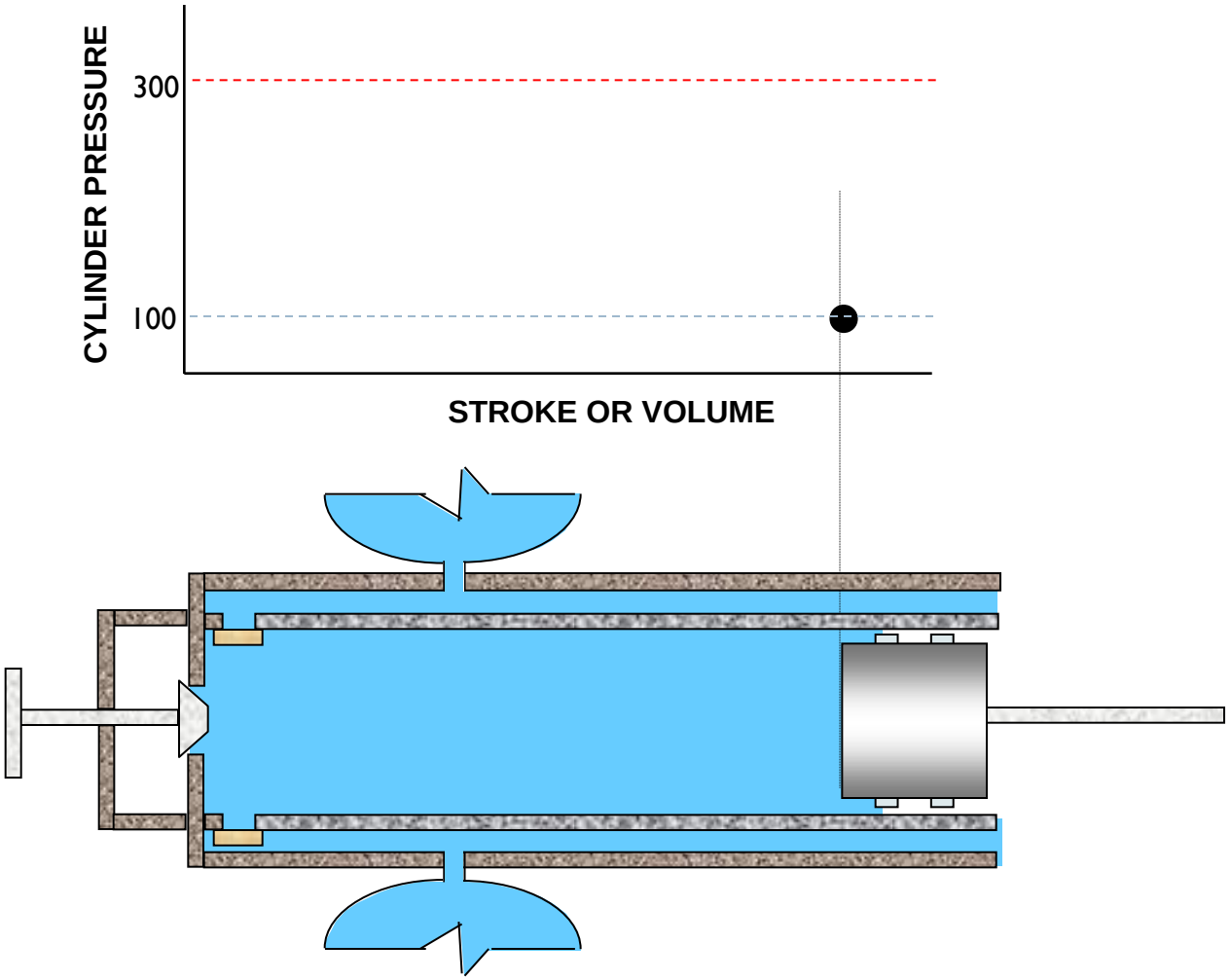
Typical Double Acting PV Diagram

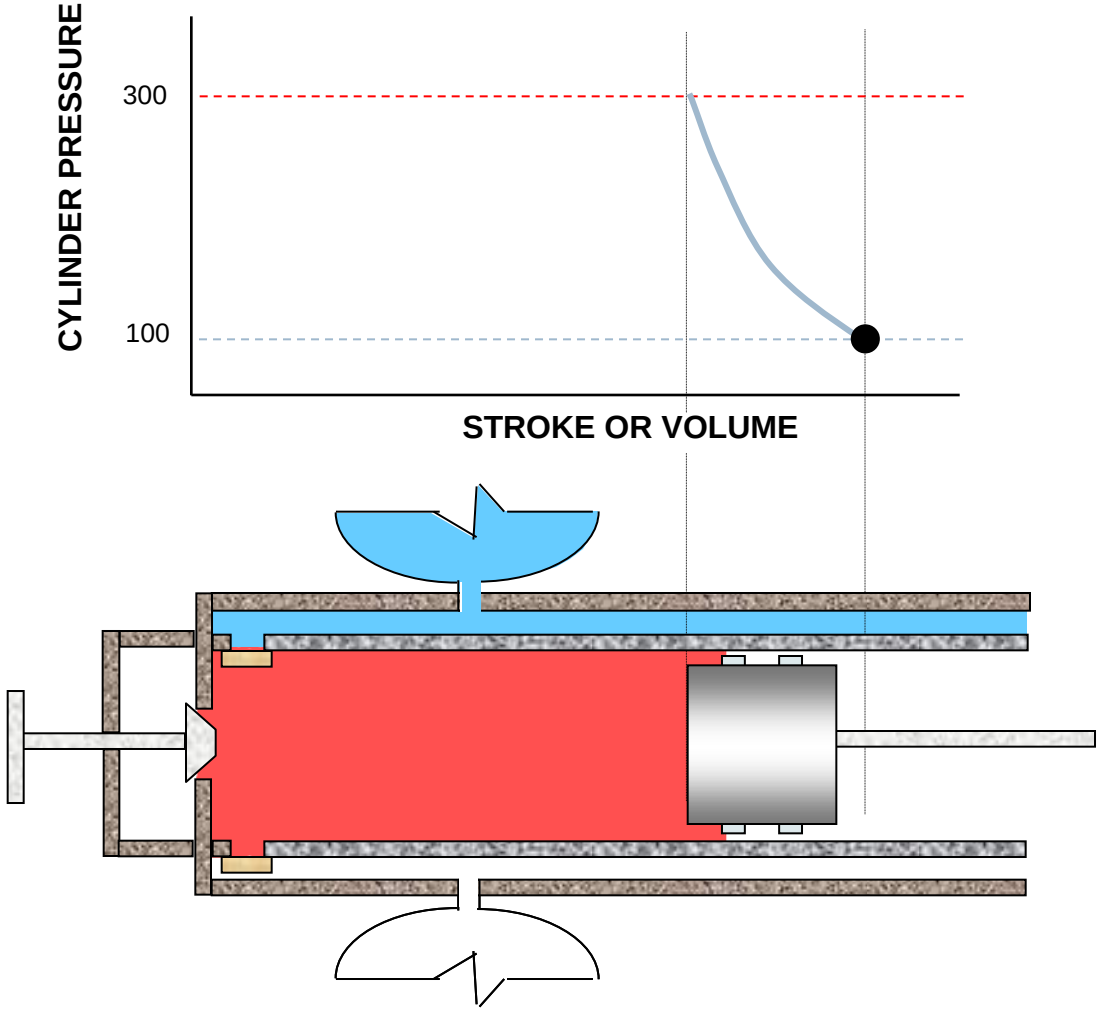




When compressing a gas its volume is reduced, along with an increase in pressure and temperature.


CYLINDER PRESSURE
PV Diagram
STROKE OR VOLUME
SUCTION BOTTLE
SUCTION VALVE
DISCHARGE VALVE
DISCHARGE BOTTLE

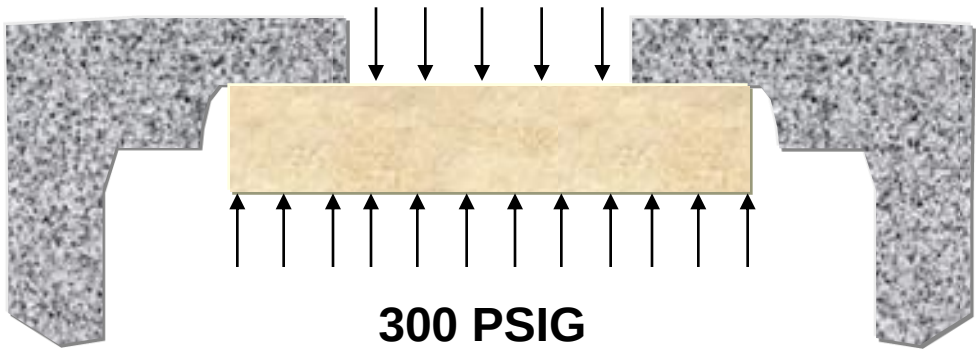

CYLINDER PRESSURE
300
100
STROKE OR VOLUME


CYLINDER PRESSURE
300
100
STROKE OR VOLUME

What's going on at the discharge valve?

IN THE CYLINDER

300 PSIG



300 PSIG

DISCHARGE PRESSURE AT THE DRUM

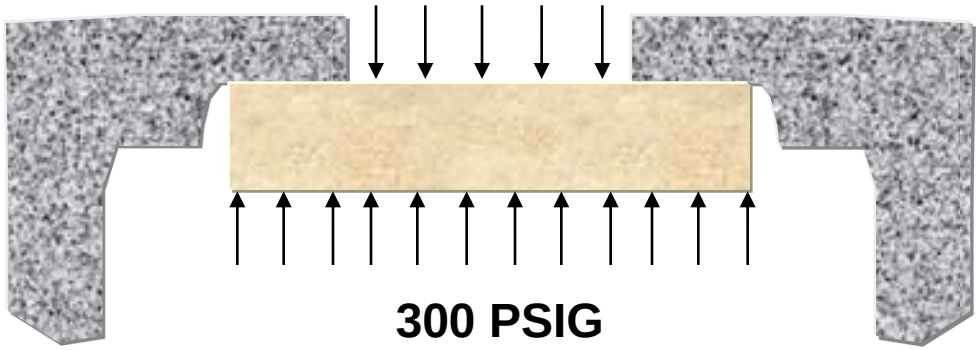
Area

Springs

TO OPEN THE VALVE

IN THE CYLINDER

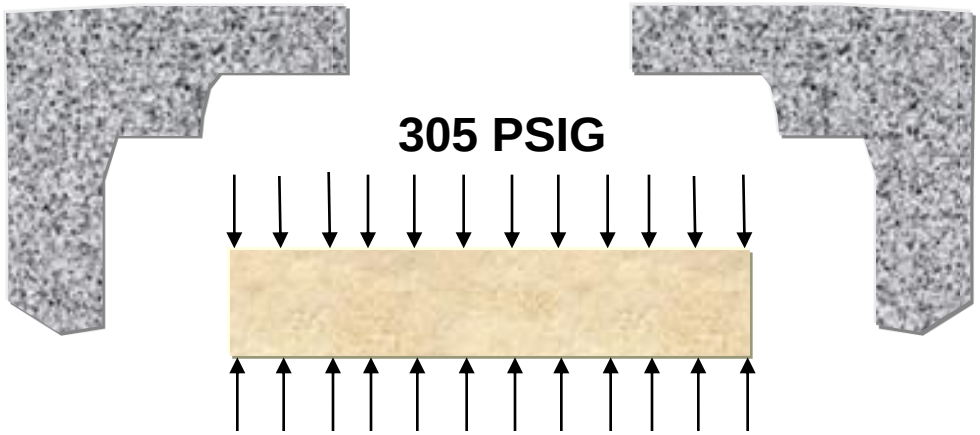
320 PSIG



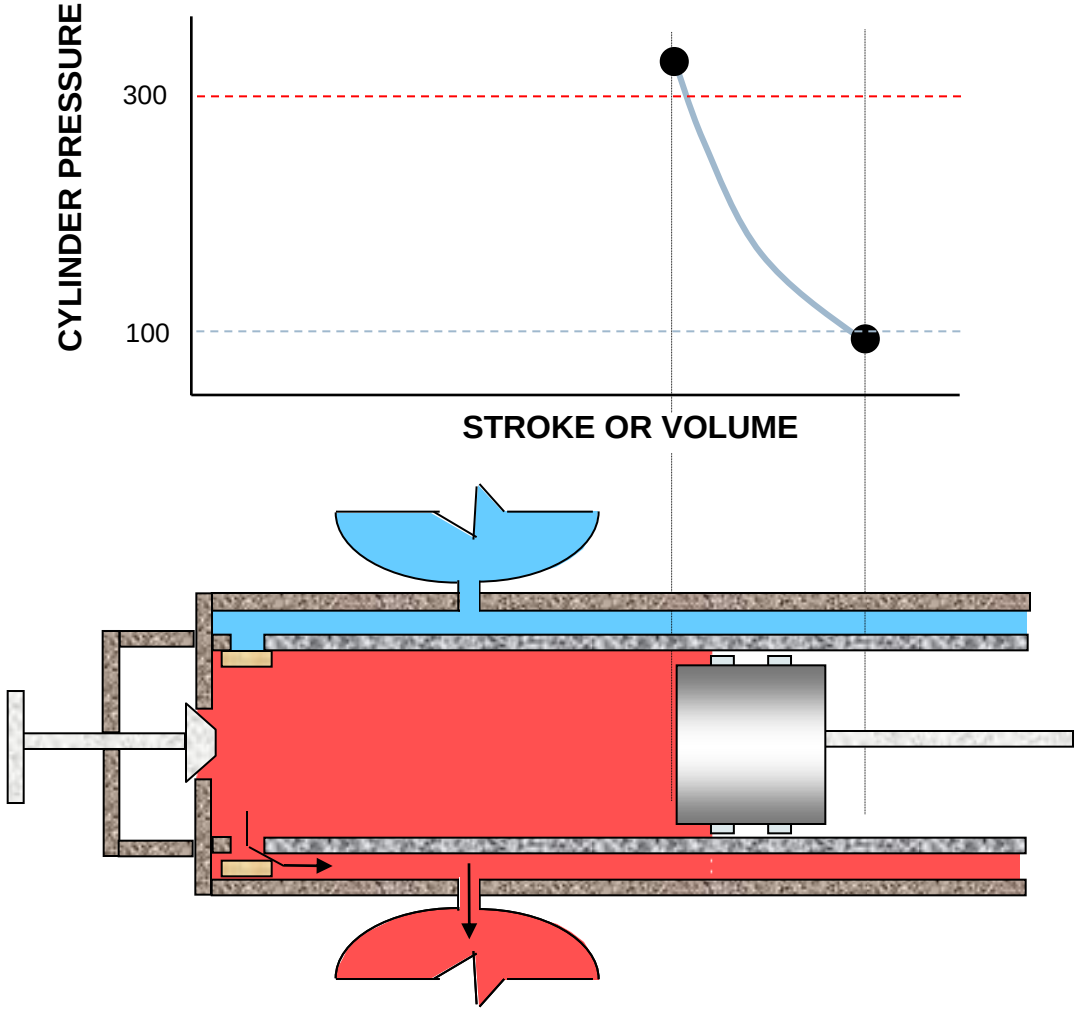
300 PSIG

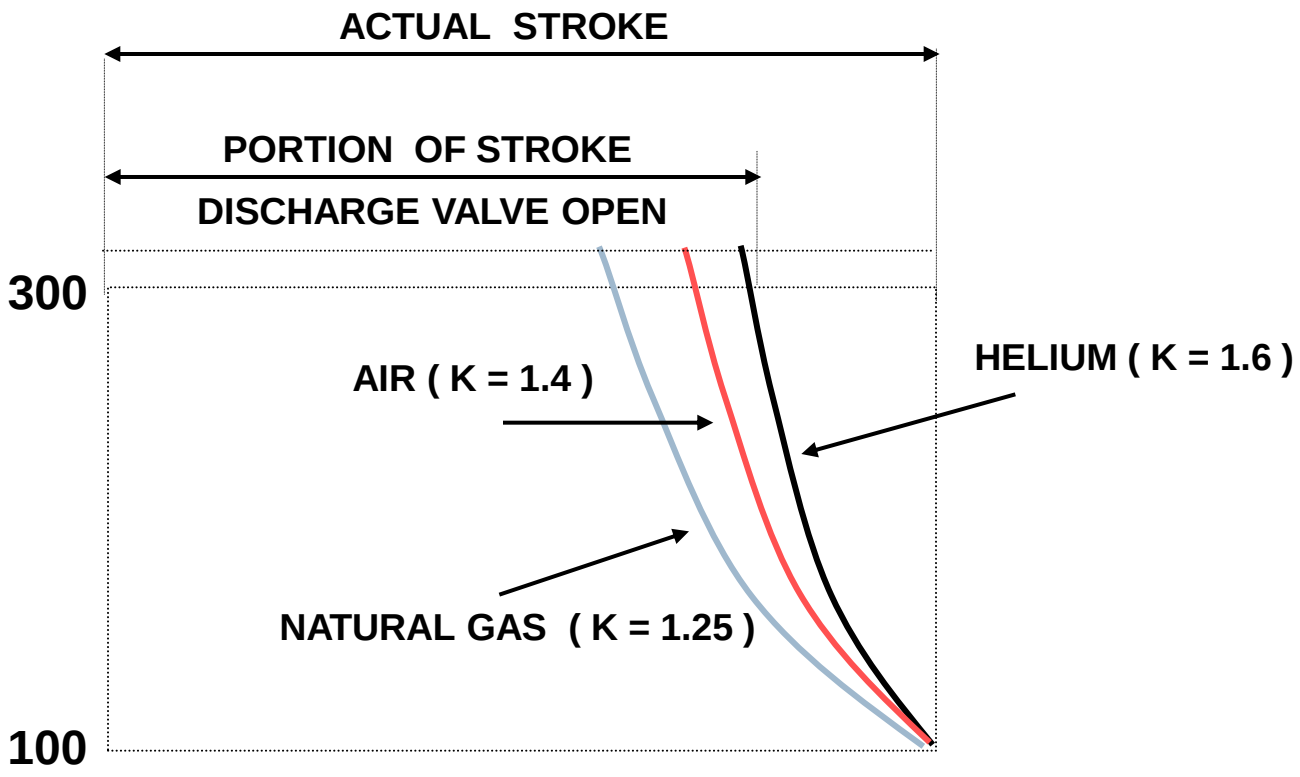
DISCHARGE PRESSURE AT THE DRUM

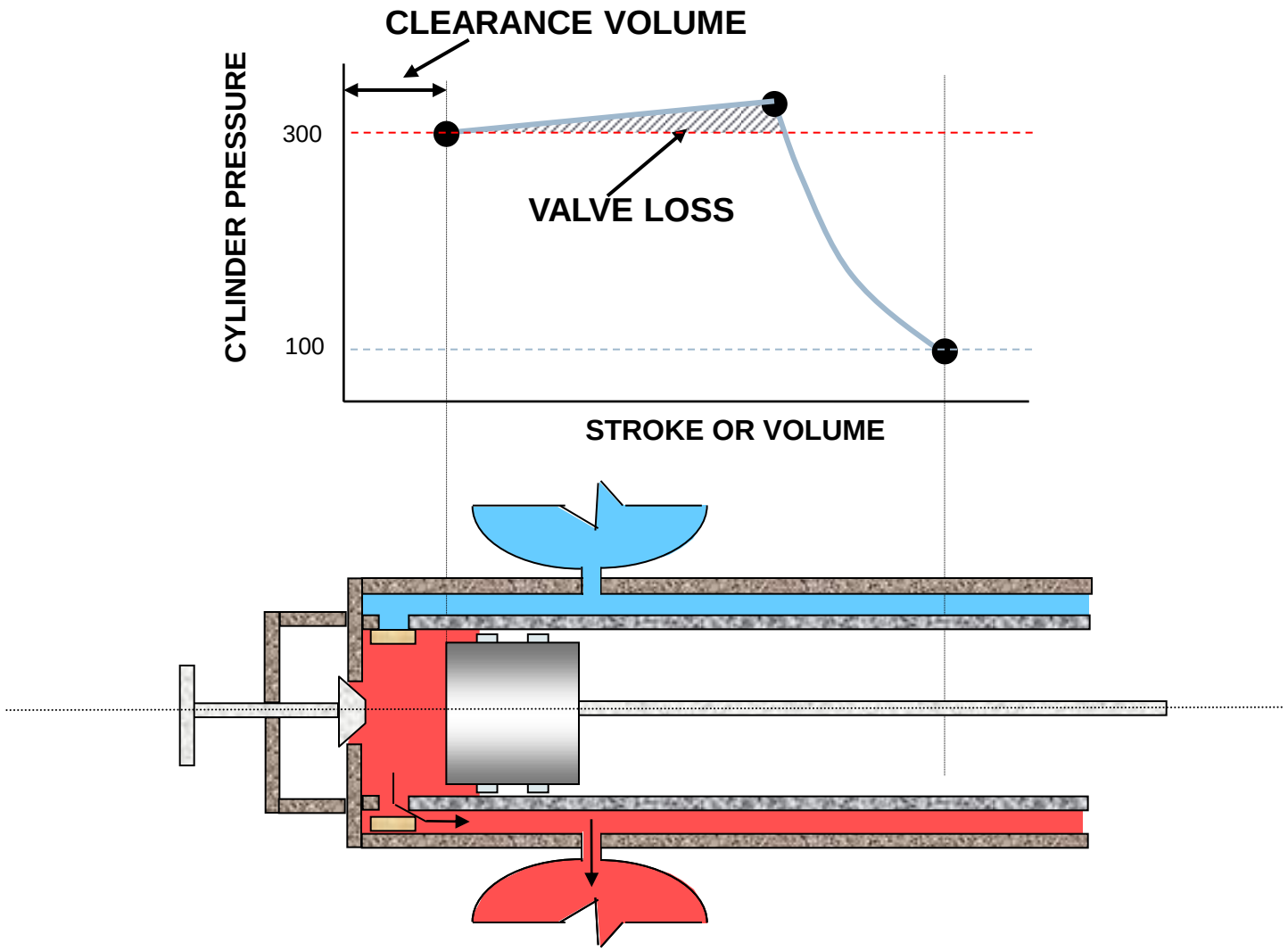
IN THE CYLINDER

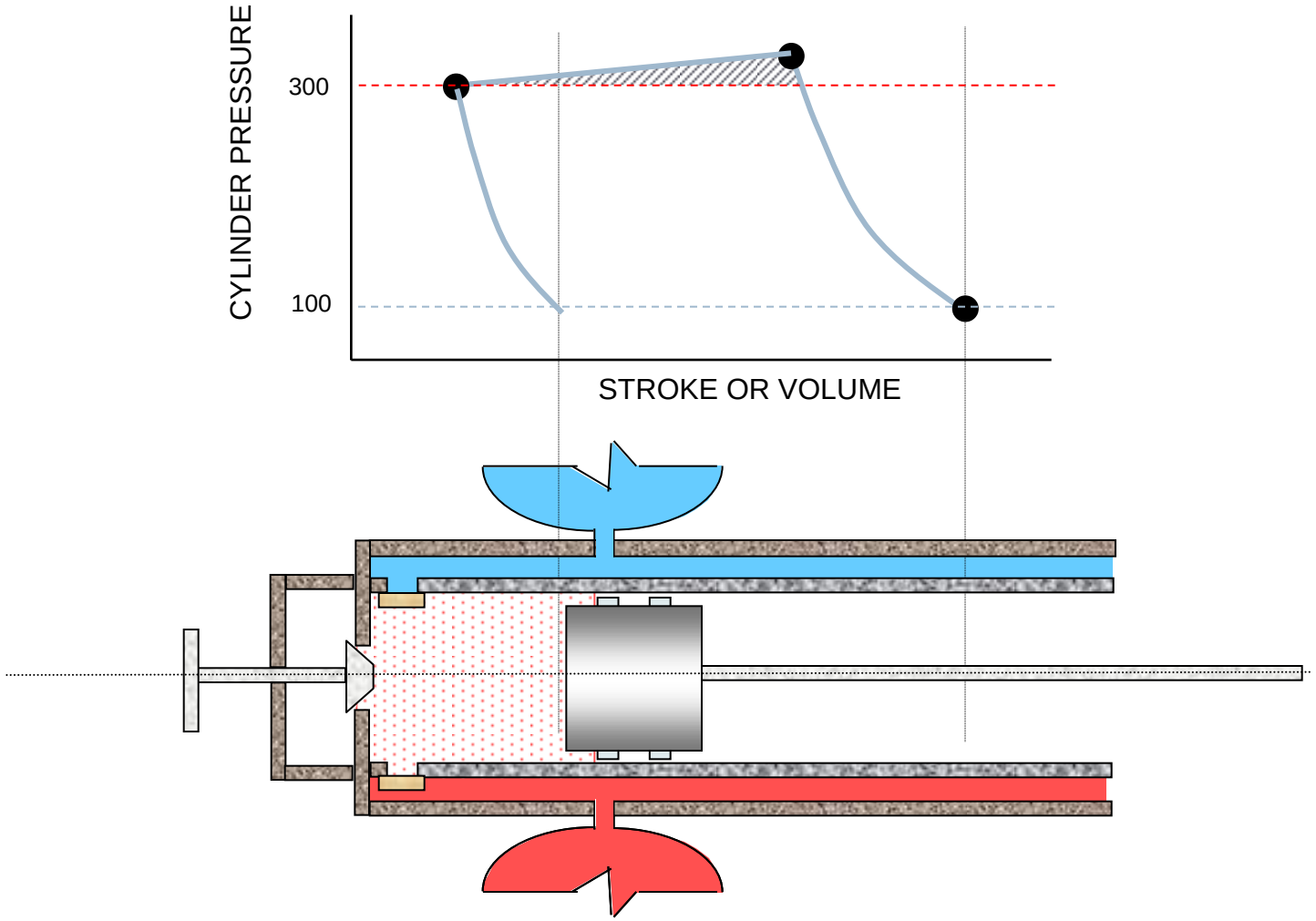


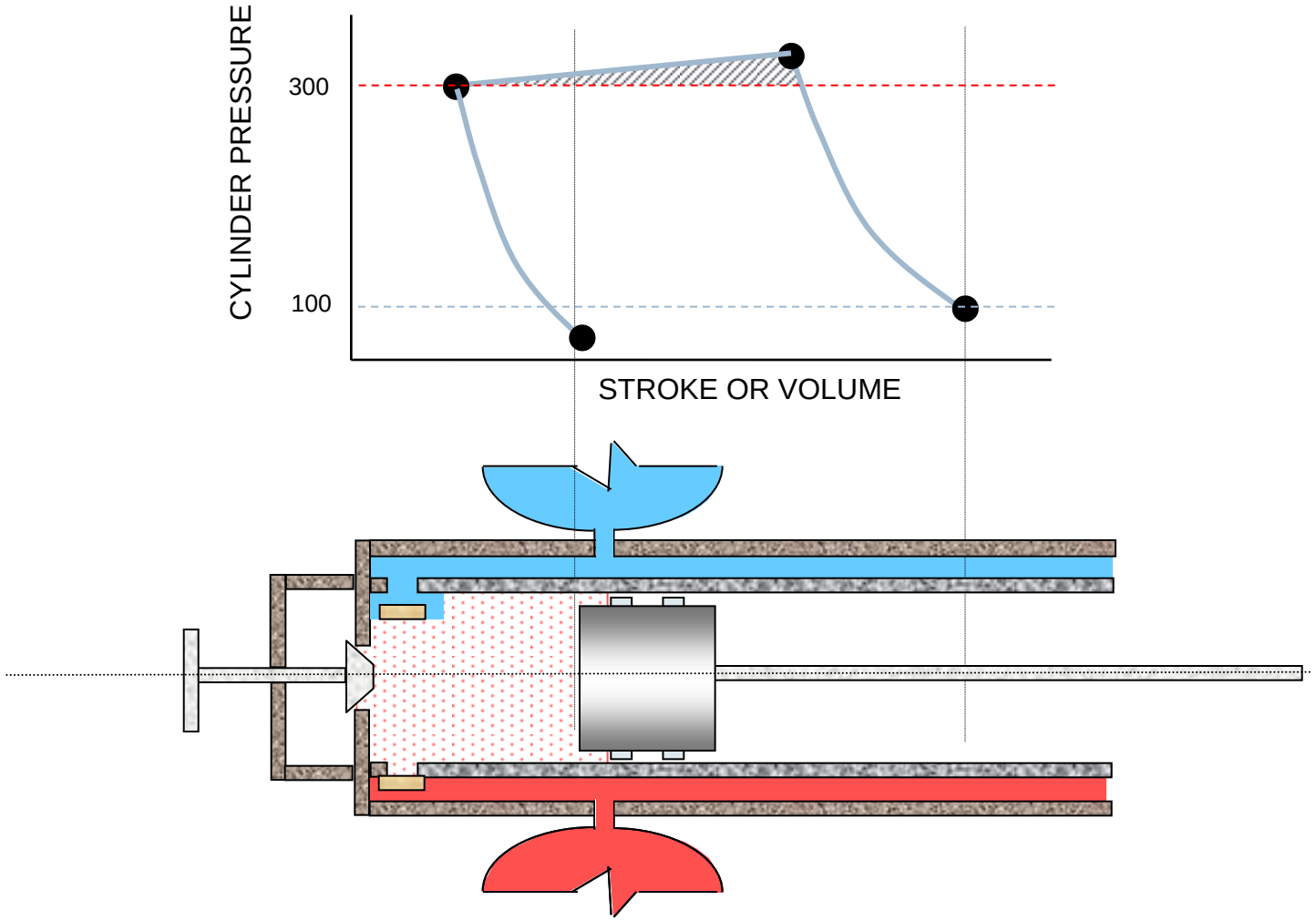
DISCHARGE PRESSURE AT THE DRUM

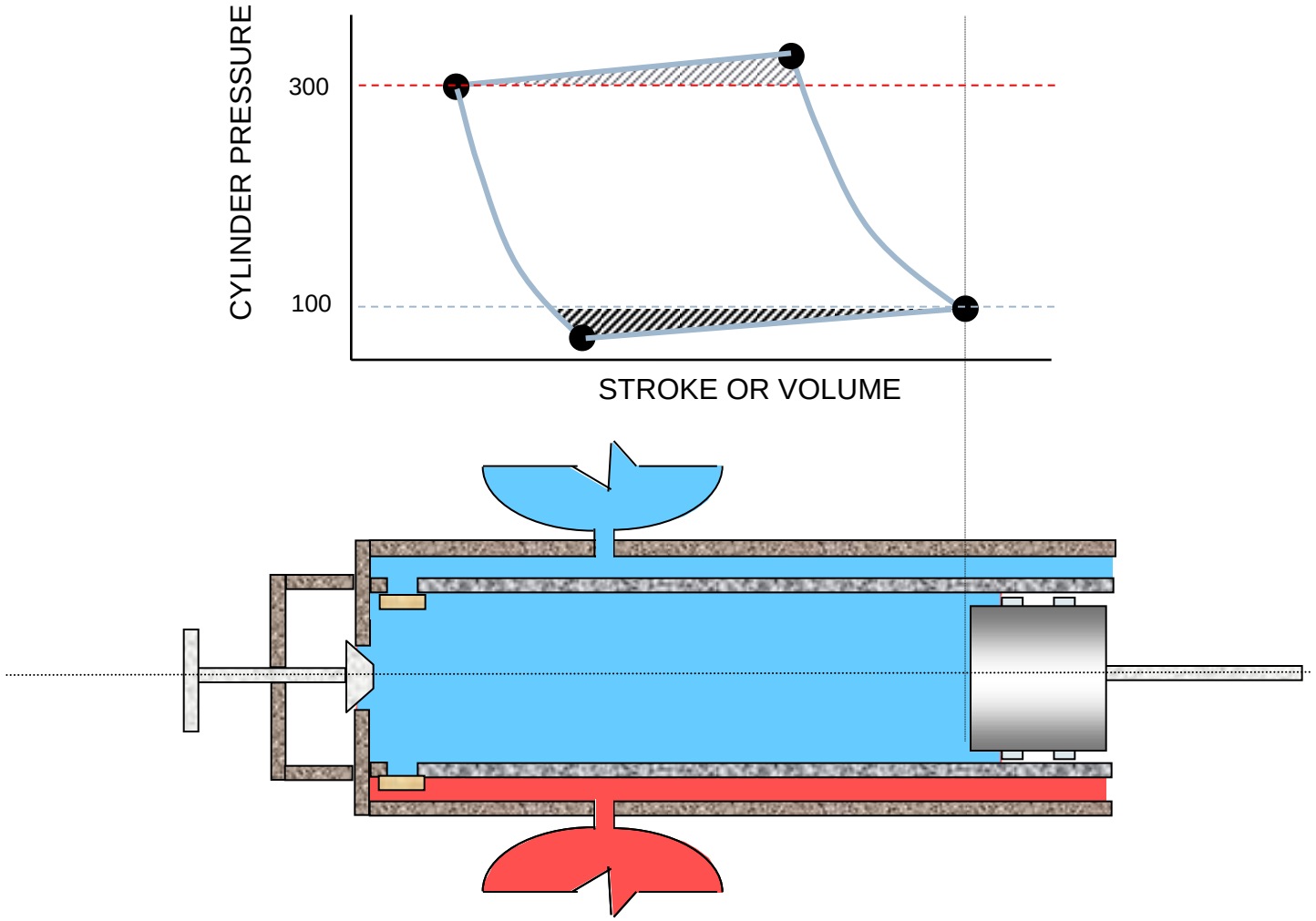

CYLINDER PRESSURE
300
100
STROKE OR VOLUME

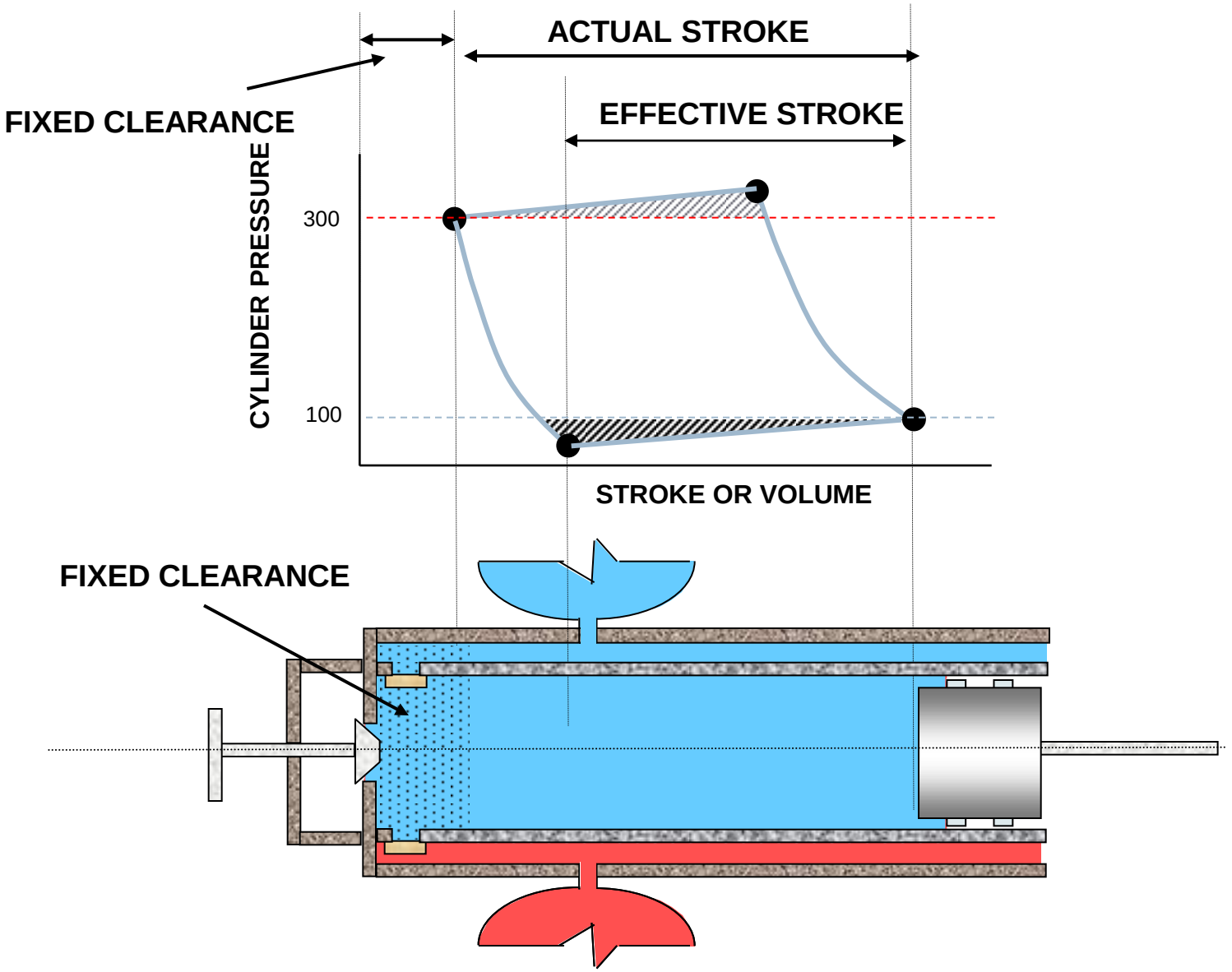

ACTUAL STROKE
PORTION OF STROKE
DISCHARGE VALVE OPEN
300
100
AIR (K = 1.4)
HELIUM (K = 1.6)
NATURAL GAS (K = 1.25)

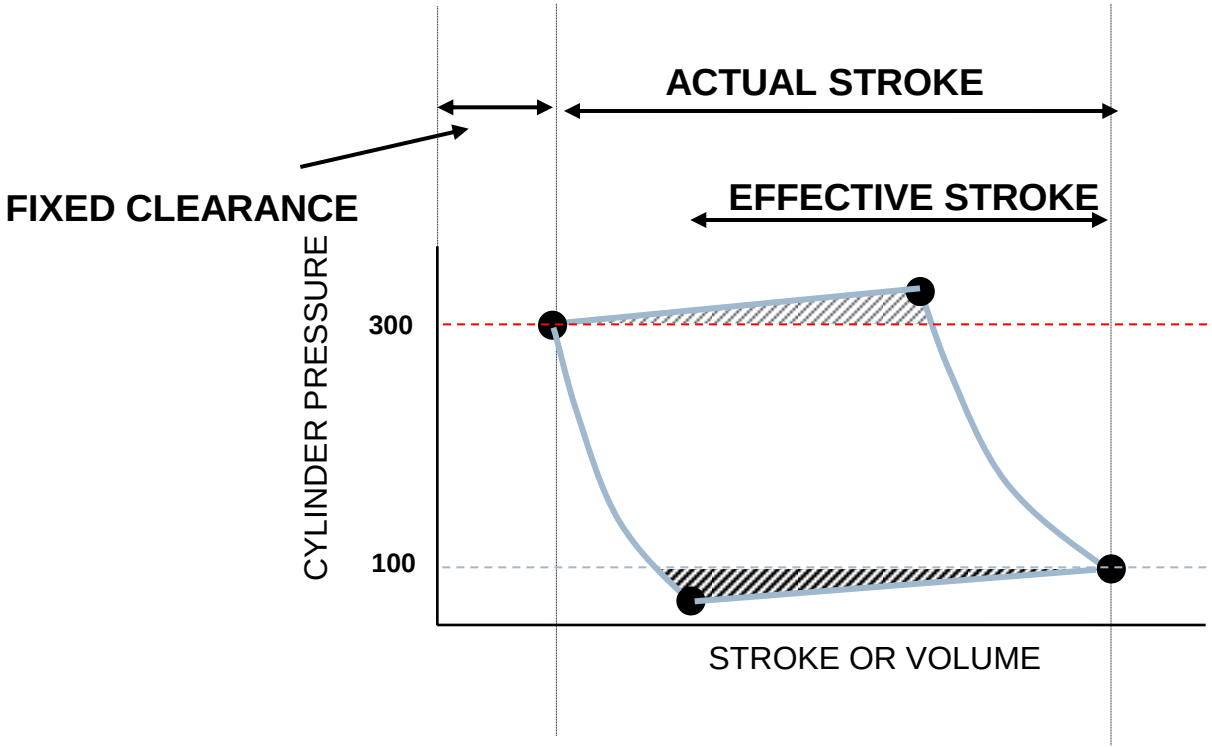

CLEARANCE VOLUME
CYLINDER PRESSURE
300
100
VALVE LOSS
STROKE OR VOLUME


CYLINDER PRESSURE
300
100
STROKE OR VOLUME

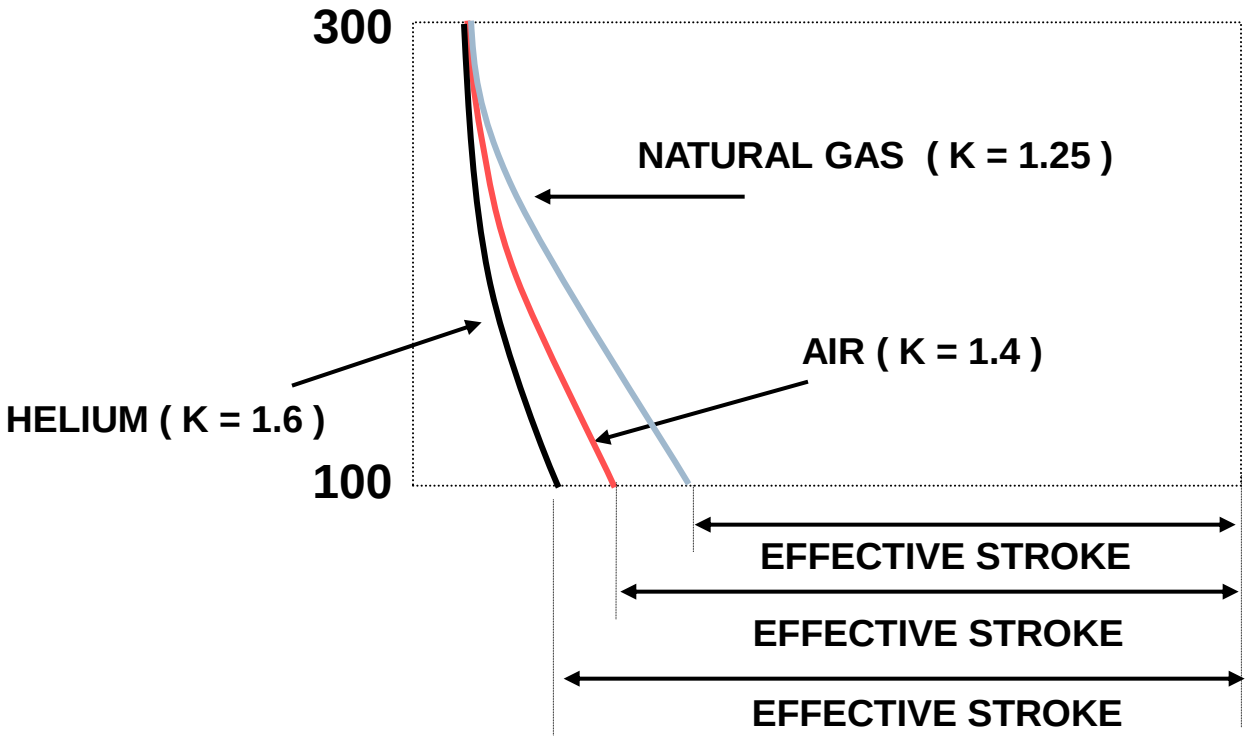

CYLINDER PRESSURE
300
100
STROKE OR VOLUME


CYLINDER PRESSURE
300
100
STROKE OR VOLUME

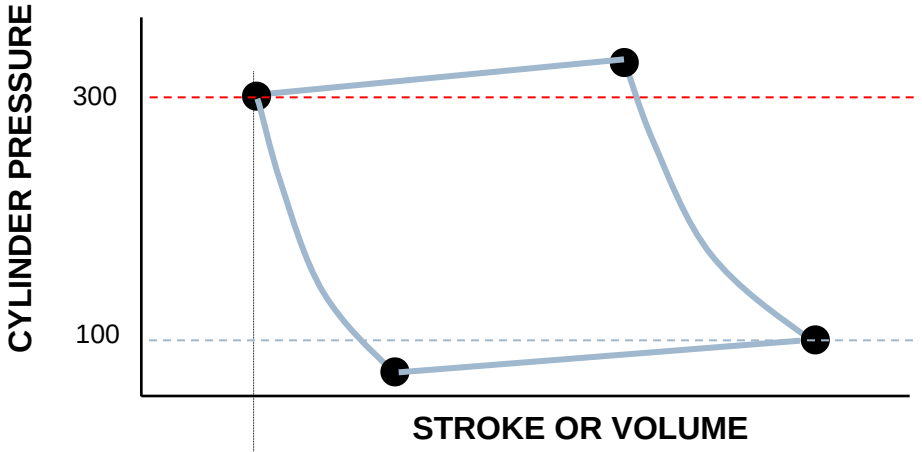

ACTUAL STROKE
EFFECTIVE STROKE
FIXED CLEARANCE
CYLINDER PRESSURE
300
100
STROKE OR VOLUME
FIXED CLEARANCE

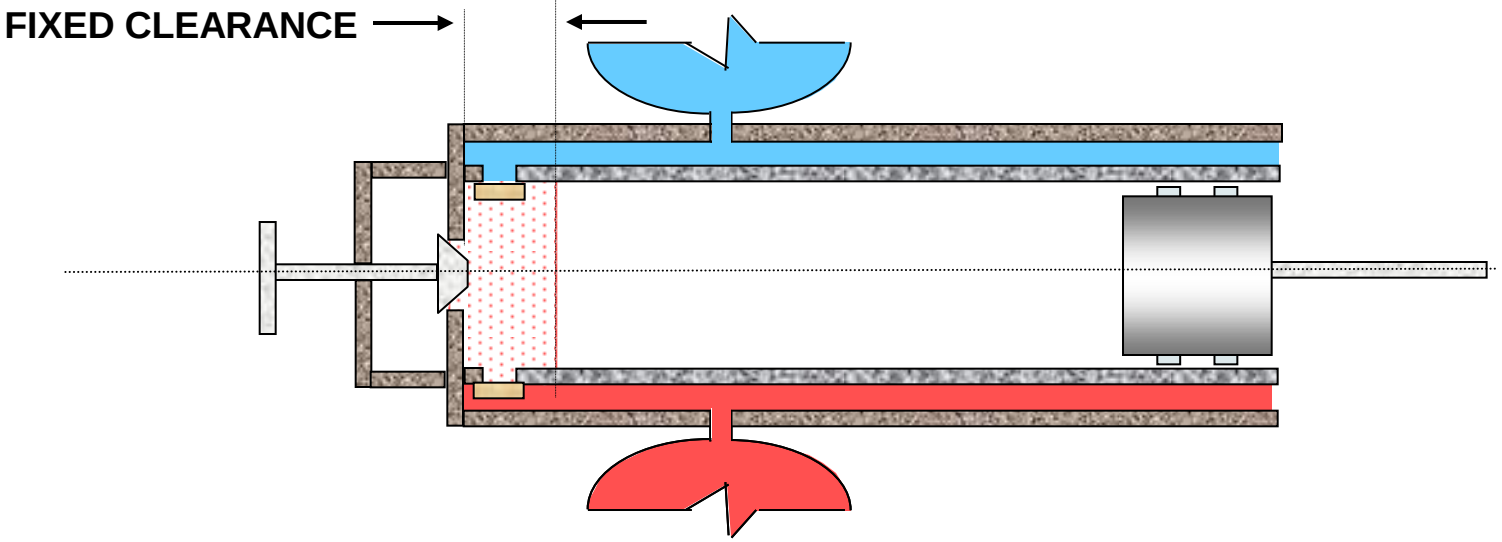


$$\text{VOLUMETRIC EFFICIENCY} = \frac{\text{EFFECTIVE STROKE}}{\text{ACTUAL STROKE}}$$

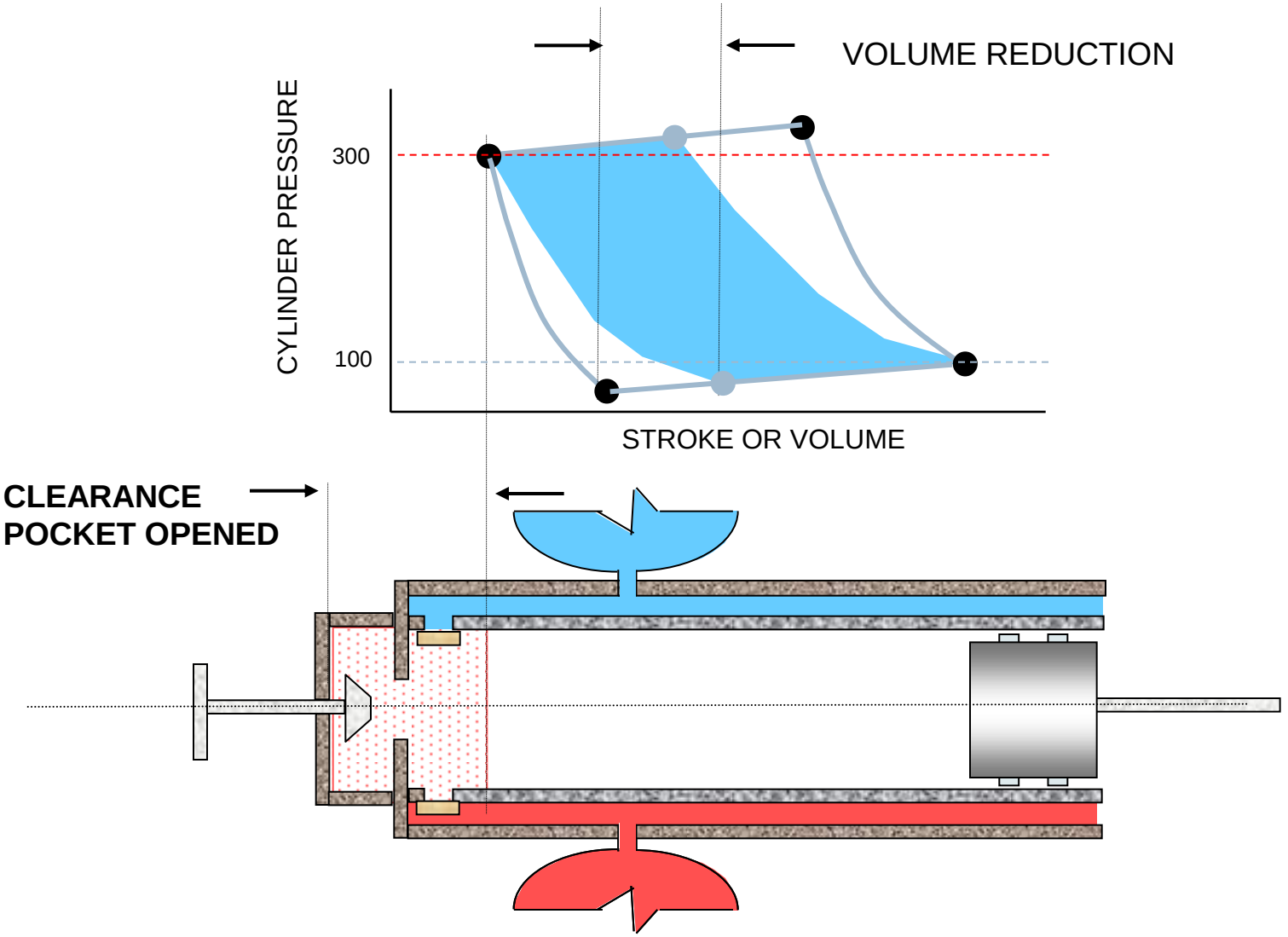

300
NATURAL GAS (K = 1.25)
AIR (K = 1.4)
HELIUM (K = 1.6)
100
EFFECTIVE STROKE
EFFECTIVE STROKE
EFFECTIVE STROKE

EFFECT OF CLEARANCE VARIATIONS

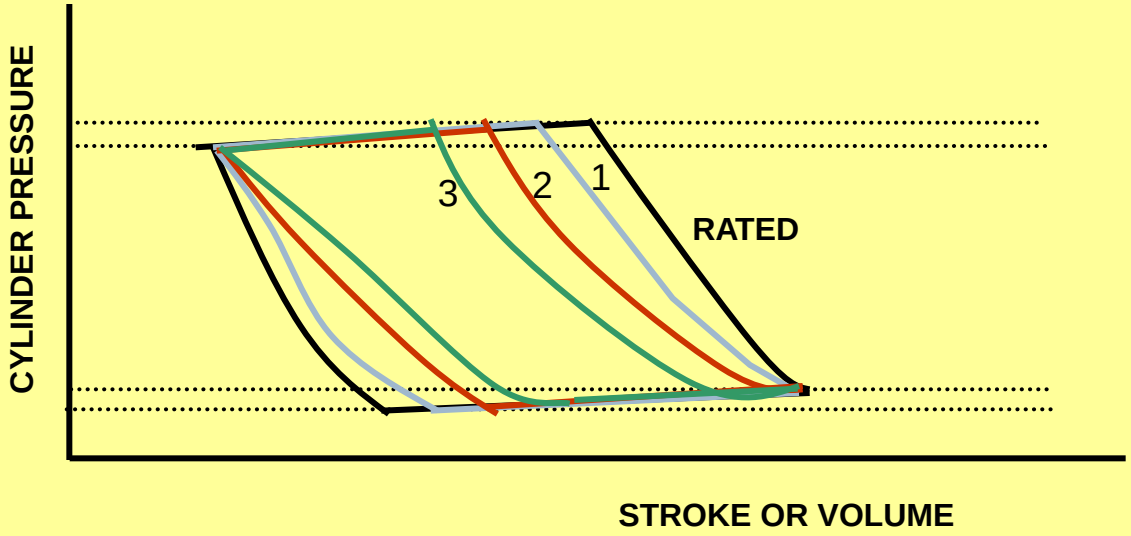


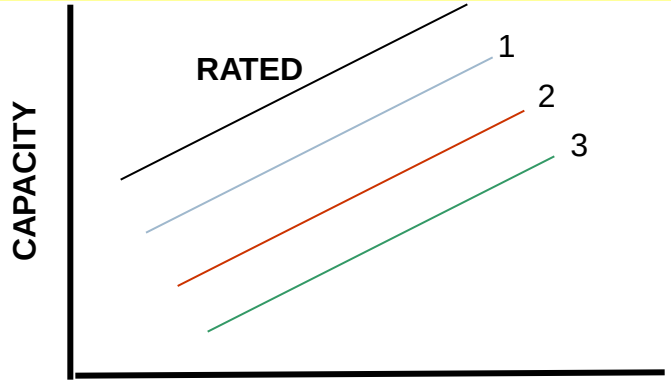


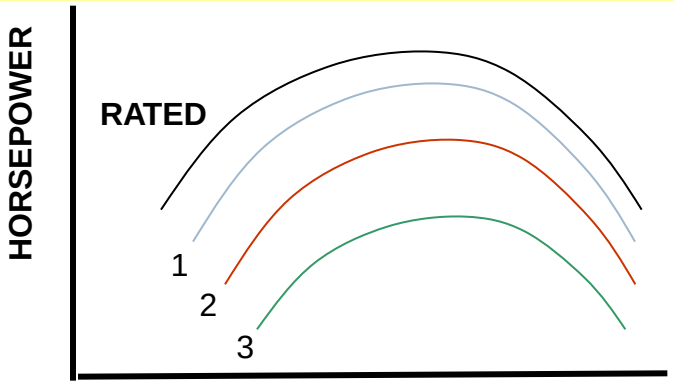
EFFECT OF CLEARANCE VARIATIONS



EFFECT OF CLEARANCE VARIATIONS

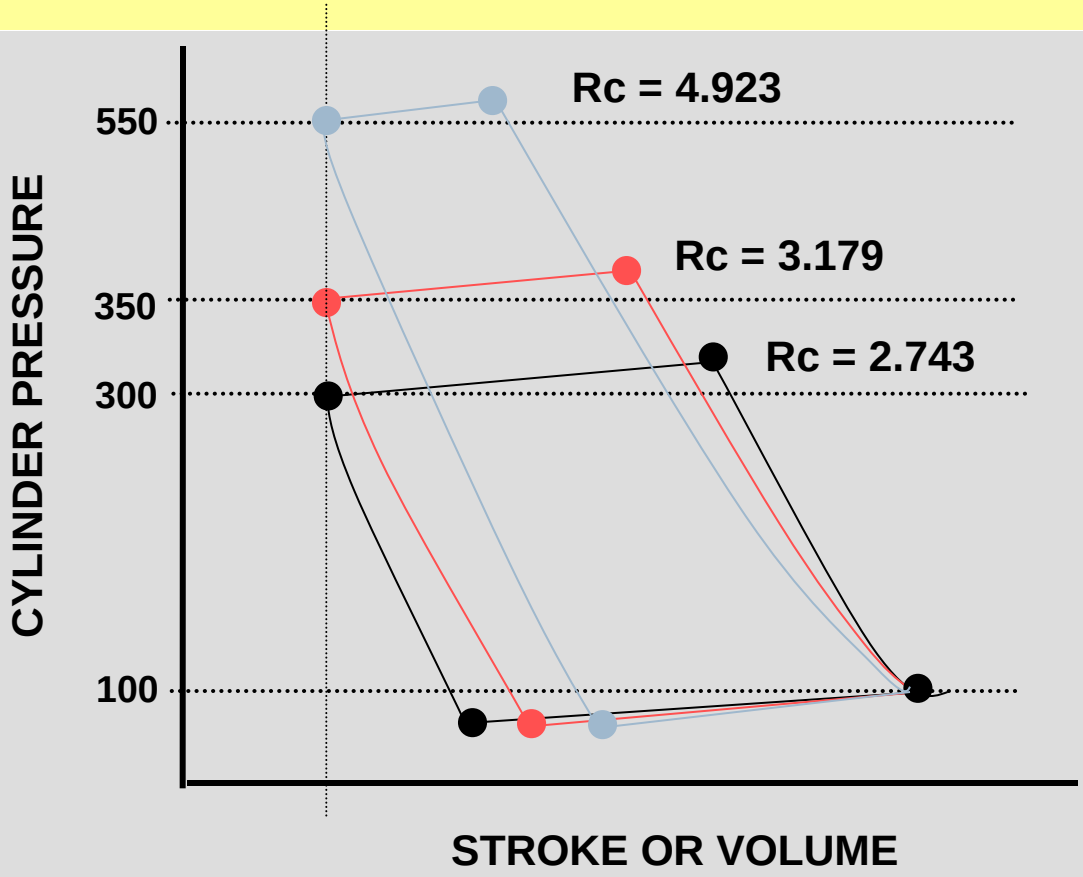






EFFECT OF COMPRESSION RATIO VARIATIONS

$$Rc = \frac{\text{Discharge Pressure (PSIA)}}{\text{Suction Pressure (PSIA)}}$$

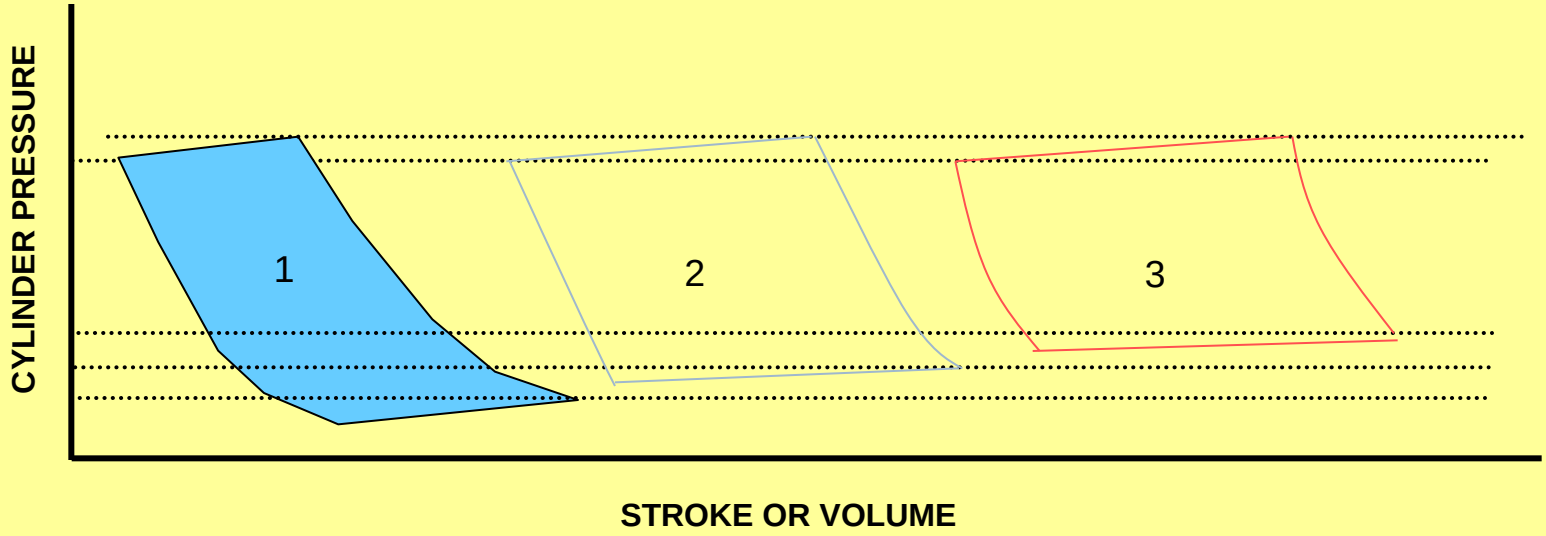


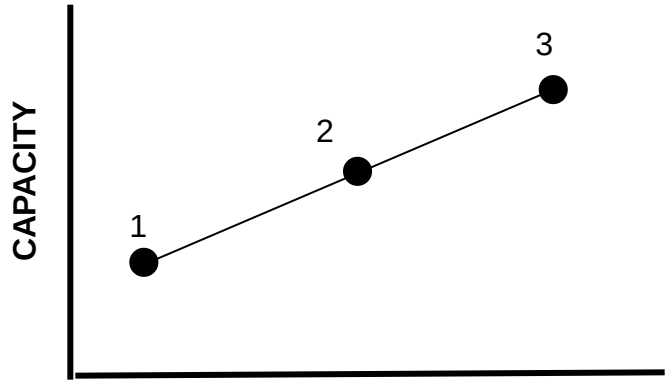
$$Rc = \frac{314.7}{114.7} = 2.743$$

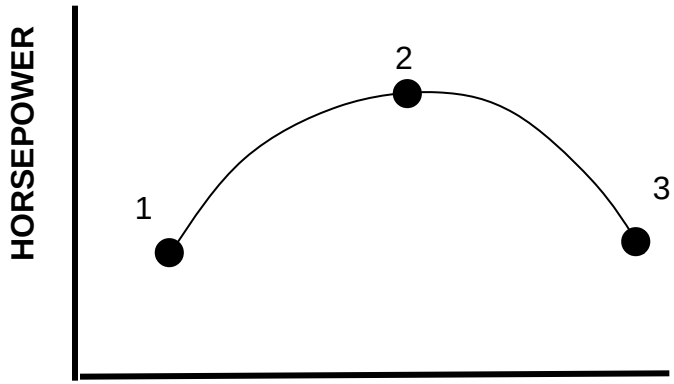
$$Rc = \frac{364.7}{114.7} = 3.179$$

$$Rc = \frac{564.7}{114.7} = 4.923$$

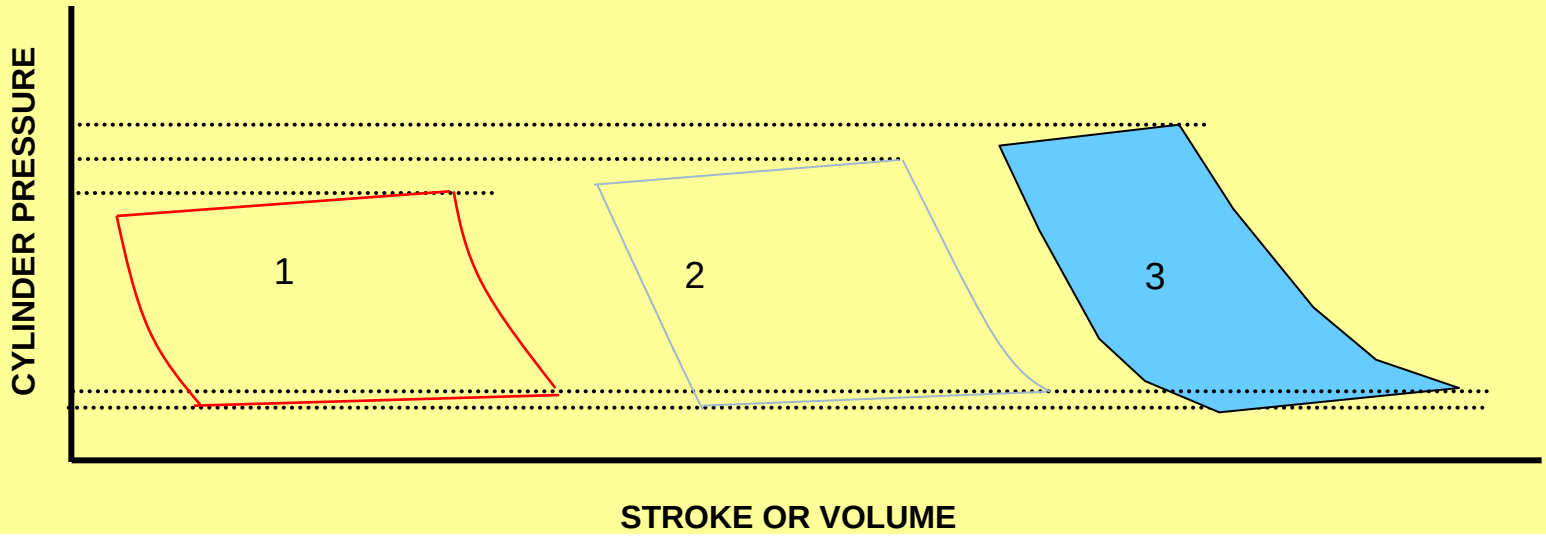
EFFECT OF SUCTION PRESSURE VARIATIONS

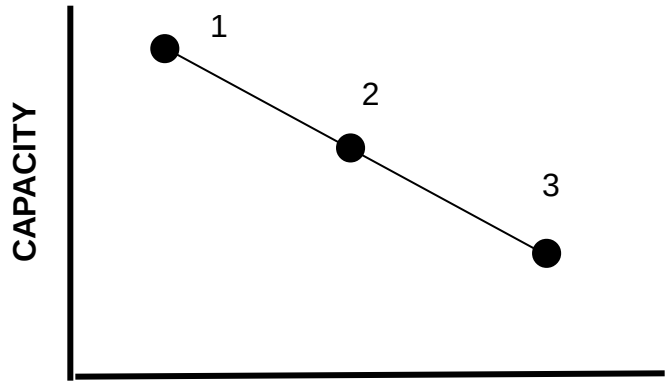


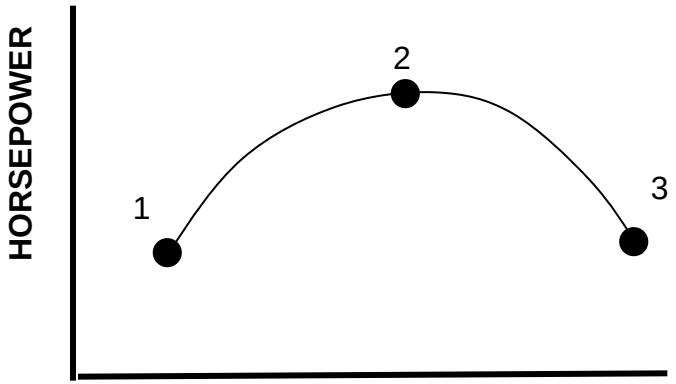




EFFECT OF DISCHARGE PRESSURE VARIATIONS

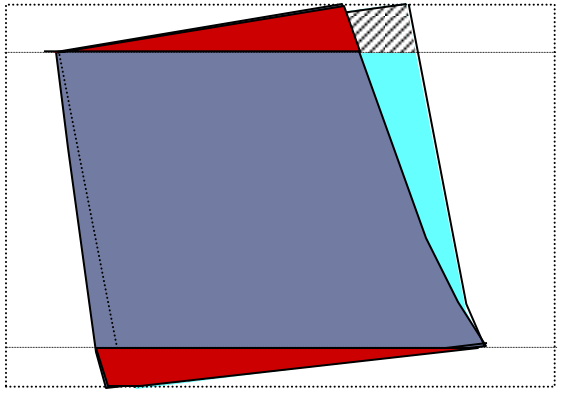


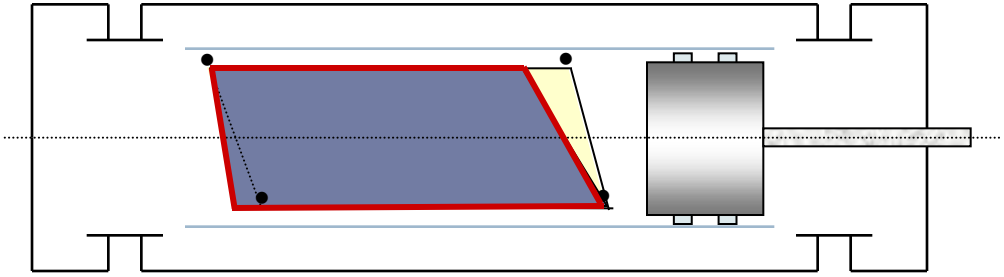




Some common Problems

Leaking Suction Valve





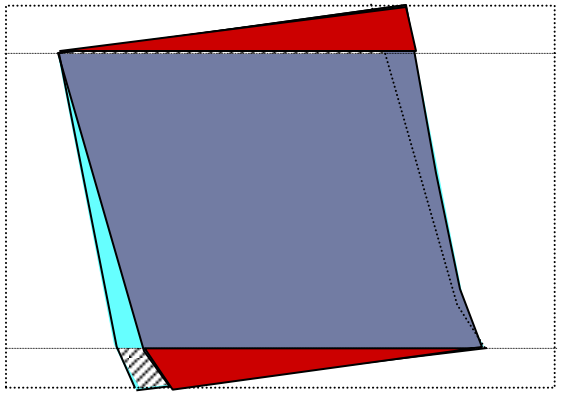
- When a leaking suction valve is present, it takes longer to reach the discharge pressure.
- The discharge line of the cycle is reduced.
- The expansion stroke reaches suction pressure sooner and the intake remains for a longer period.

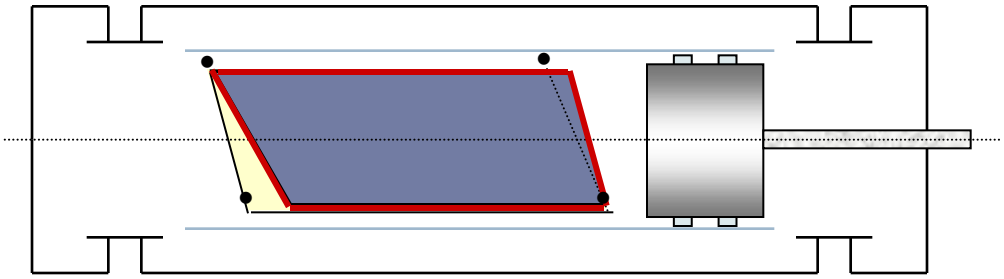
Leaking Suction Valve

Symptoms:

- **The Cylinder capacity is less than design.**
- **The inlet gas temperature will be greater than expected.**
- **The discharge gas temperature will be greater than design.**
- **The actual compression and re-expansion lines will not match the design lines.**

Leaking Discharge Valve





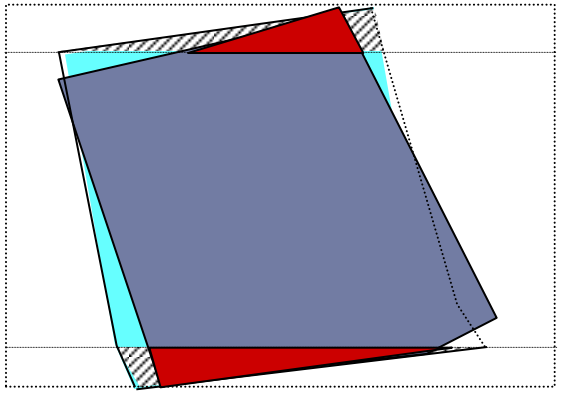
- When a leaking discharge valve is present, it takes less time to reach the discharge pressure.
- The discharge line of the cycle has been increased.
- The expansion stroke takes more time to reach suction pressure and the intake line remains for a shorter period.
- During the expansion portion of cycle, the trapped gas in the cylinder is expanding and leaking back to the cylinder through the discharge valve.

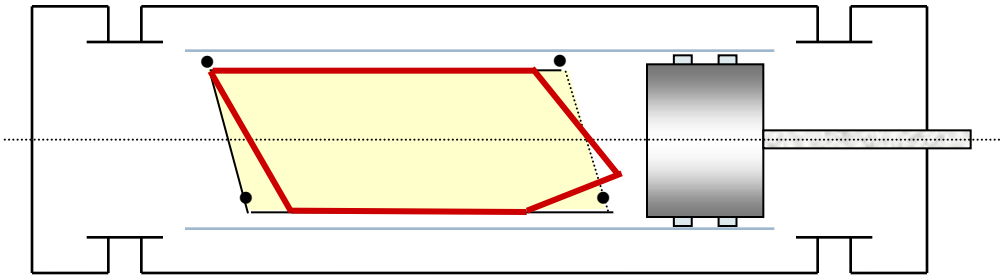
Leaking Discharge Valve

Symptoms:

- **The Cylinder capacity is less than design.**
- **The discharge gas temperature will be greater than design.**
- **The actual compression and re-expansion lines will not match the design lines.**

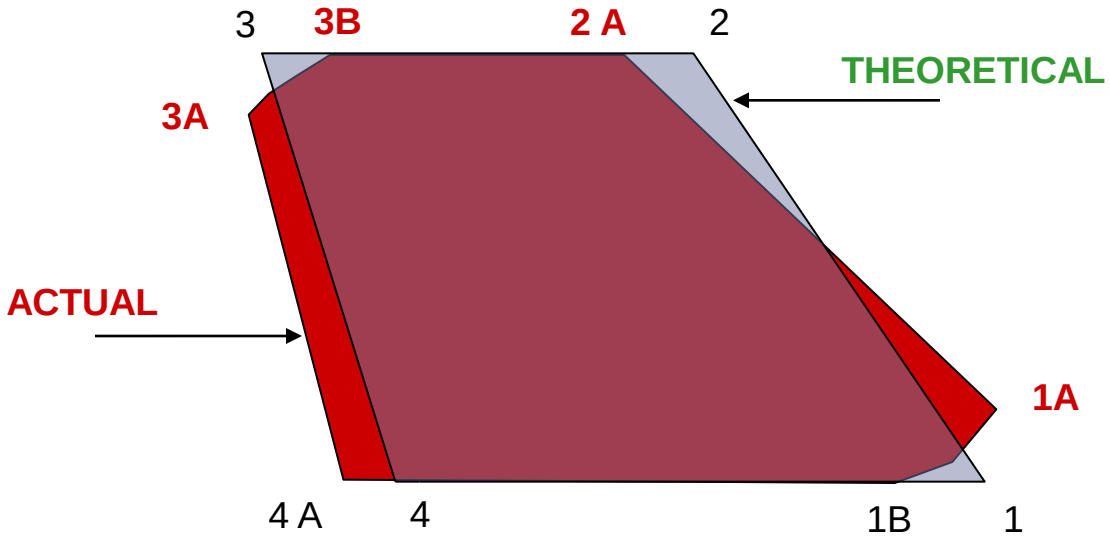
Piston Ring Leakage





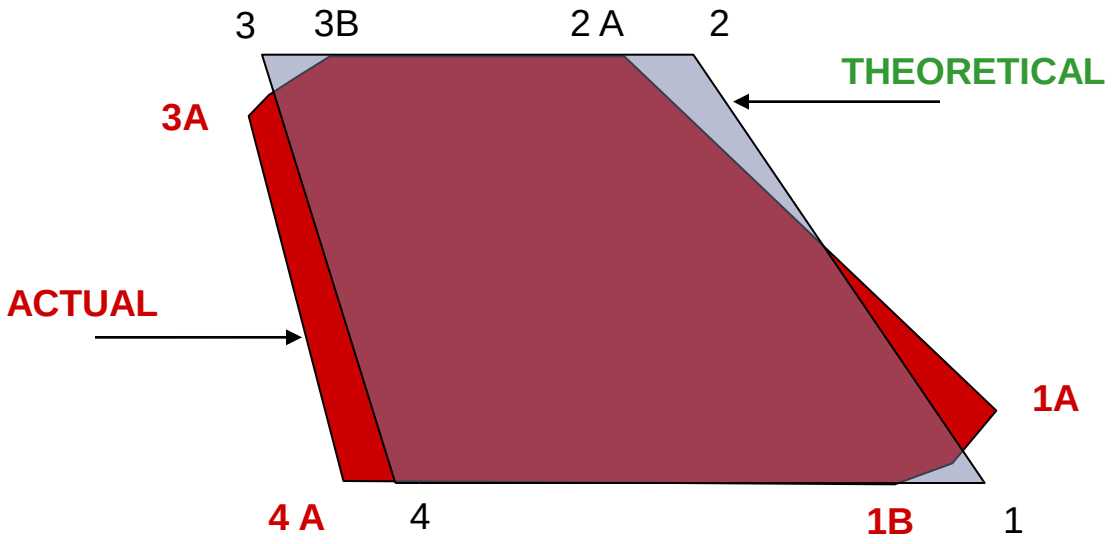
- **As the pressure in the cylinder increases, greater amount of gas escapes from the cylinder past the piston rings.**
- **Greater piston travel is required to bring the internal pressure of the cylinder to the discharge valve opening pressure than designed.**

Piston Ring Leakage



- **Line 1A-2A: The discharge valve opening is delayed, occurring at point 2A instead of point 2.**
- **Line 2A-3B: During the discharge portion of the cycle, gas is exiting the cylinder through the discharge valve and leaking out of the cylinder past the piston rings. When the leakage gets severe, premature closing of the discharge valve can occur at point 3B.**
- **Line 3B-3A: The discharge valves have closed, the cylinder volume continues to decrease, and gas continues to leak from the cylinder past the piston rings.**

Piston Ring Leakage



- **Line 3A-4A: Gas continues to leak out of the cylinder during the re-expansion line cycle. The additional gas leakage results in the premature opening of the suction valves.**
- **Line 4A-1B: Gas is entering the cylinder through the suction valves and is leaking into the cylinder past the piston rings. The leakage results in the premature closing of the suction valves at point 1B. (double-acting cylinder).**
- **Line 1B-1A: Suction valves have closed, the cylinder volume is increasing, and the pressure in the cylinder is increasing due to the continued piston rings leakage.**

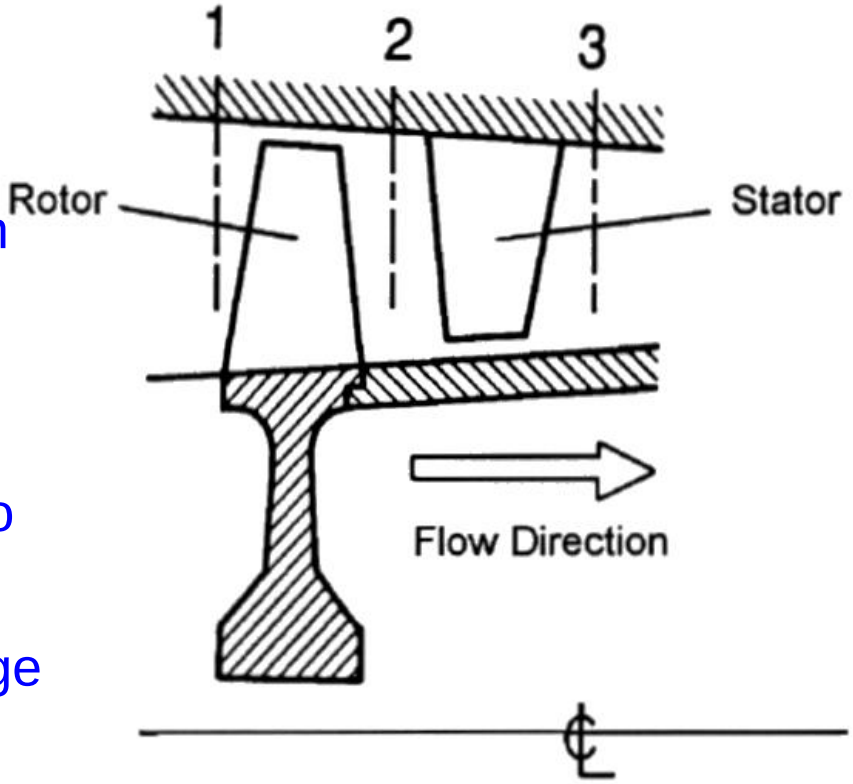
Barrel type multistage centrifugal compressor

- Dynamic compressors have relatively few moving parts
- Low vibration levels and thus high intrinsic reliability
- Preferred where they can be used effectively
- Multiple compression stages generally mounted on the same shaft within a common casing.

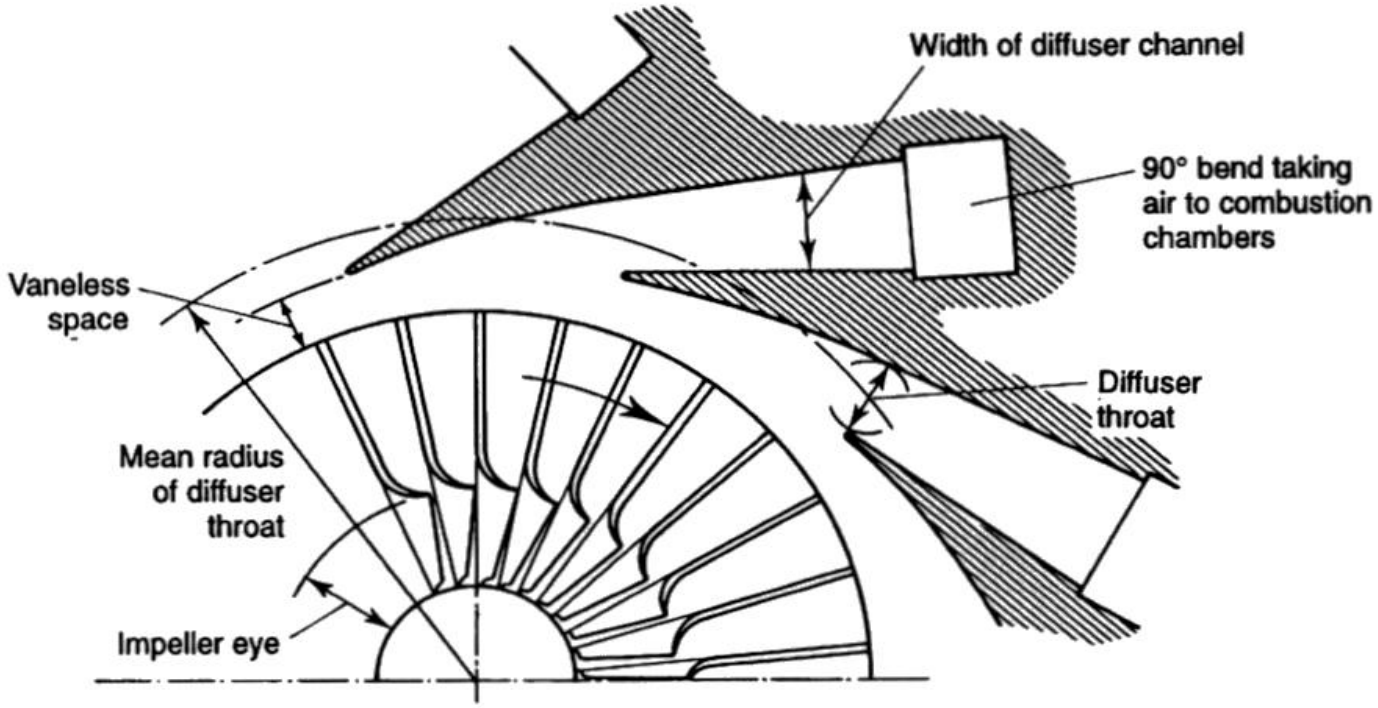
- For pres. ratios above 10 : 1, and for pres. above 20 bar g, this would be a reasonable selection
- Gearboxes to match the various shaft speeds
- To achieve reasonably practical shaft alignment and permit thermal expansion, flexible couplings are used between co-axial shafts.

Axial Compressor Stage

- Axial compressors use a rotating disc of blades to accelerate the gas in an axial direction
- The blades are shrouded at the tips to keep the gas with in the blade flow path
- Rotating blades accelerate the gas and increase its pres. as it flows to the stationary blades where the gas is decelerated and its KE is converted into pres. Energy
- Generally, the pres. rise across the stage is evenly distributed
- With improved aerodynamic pres. ratio exceeding 30:1 with 20 stages



Centrifugal compressor

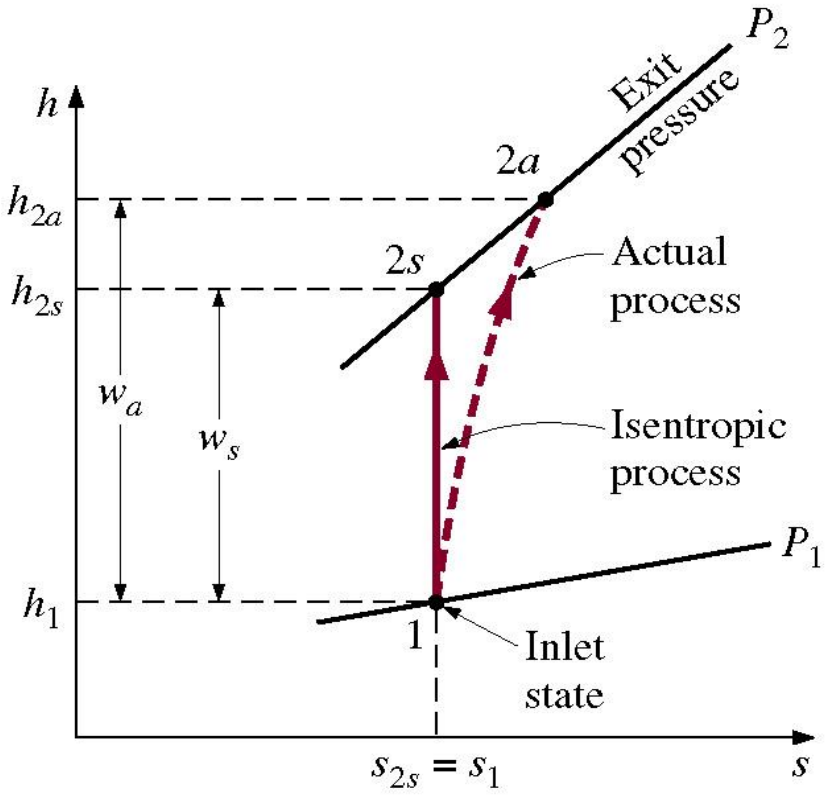


- Use one or more rotating impellers to accelerate the gas in radial direction
- Has an impeller with radial or backward leaning vanes usually shrouded to direct the gas to the diffuser
- The gas is forced through the rotating impeller by the mechanical action of the vanes

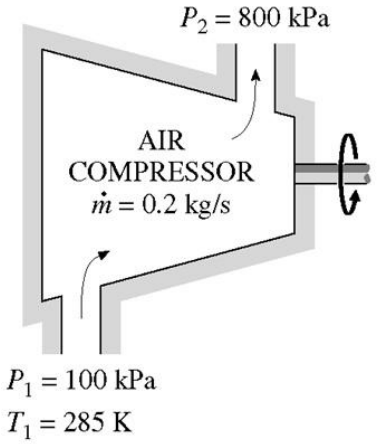
Centrifugal compressor

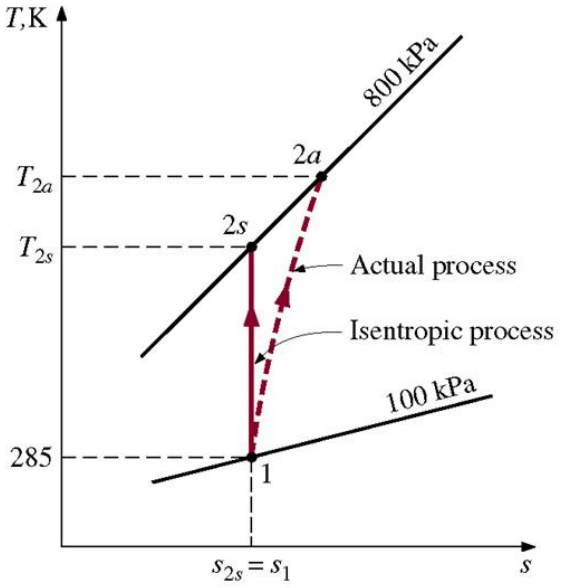
- The velocity generated is converted to pres, partially in the impeller and partially in the stationary diffusers immediately down stream of the impeller
- The amount of pressure increase in the impeller relative to the diffuser is a function of the compressor design
- Due to high mechanical stresses, the pres. ratio with a single stage 4:1 to 8:1, with higher ratios requiring expensive materials such as titanium
- Multi stage compressors are generally limited to 8 to 10 stages per casing

The isentropic and actual compression process

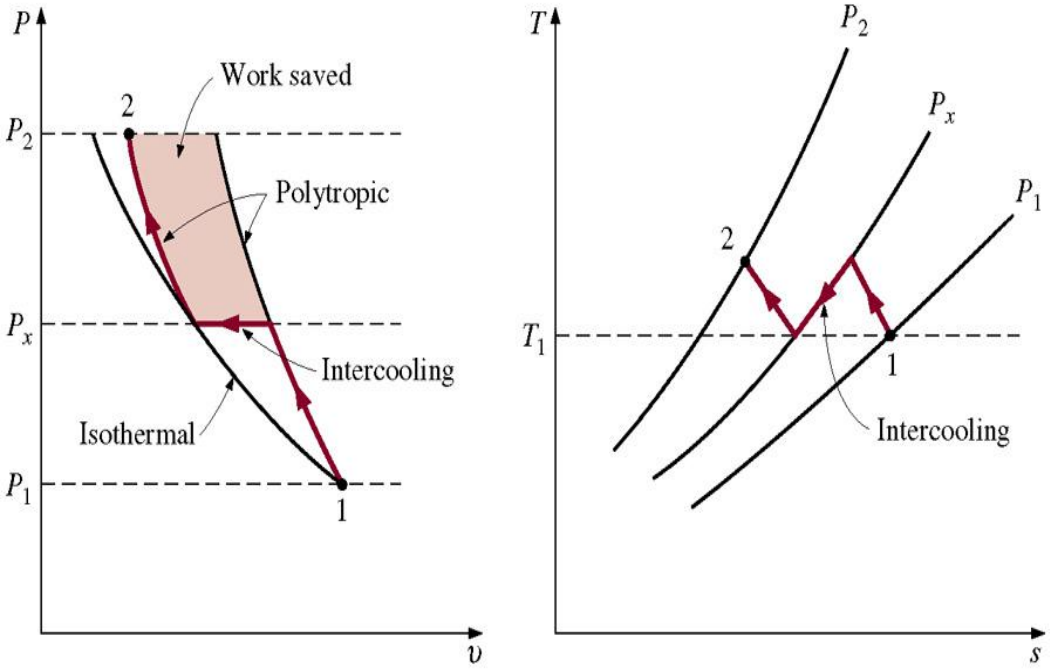


The isentropic and actual compression process

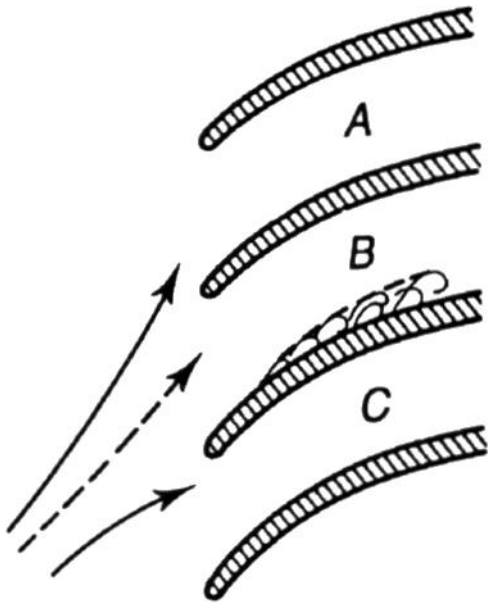




The compression process with intercooling



Rotating stall



Compressor problems

- Fouling
- Internal recirculation
- Mechanical damage
- Inlet filter fouling
- Flow path restriction