EUROPEAN FORUM for RECIPROCATING COMPRESSORS

EFRC Training Workshop 2019

Critical Compressor Components

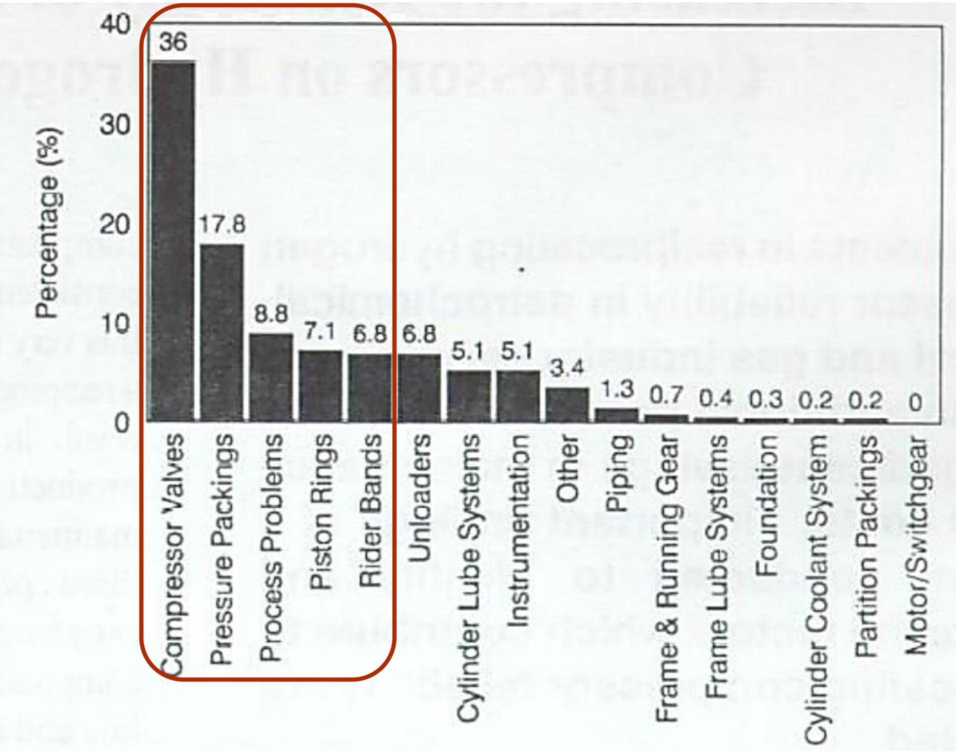
Paul Modern, Cook Compression

What are Critical Components?

- Compressor Valves
- Pressure Packing Cases
- Cylinder Rings – Piston and Rider

- Why are these critical? – Quantity of cycles
- Example 1 – a typical API 618 type compressor at low speed (400 RPM) – 210 million cycles per year
- Example 2 – a mid/high speed type compressor (1200 RPM) – 630 million cycles per year

Components causing unscheduled shutdown of recips compressing hydrogen (Dresser-Rand, 1995)



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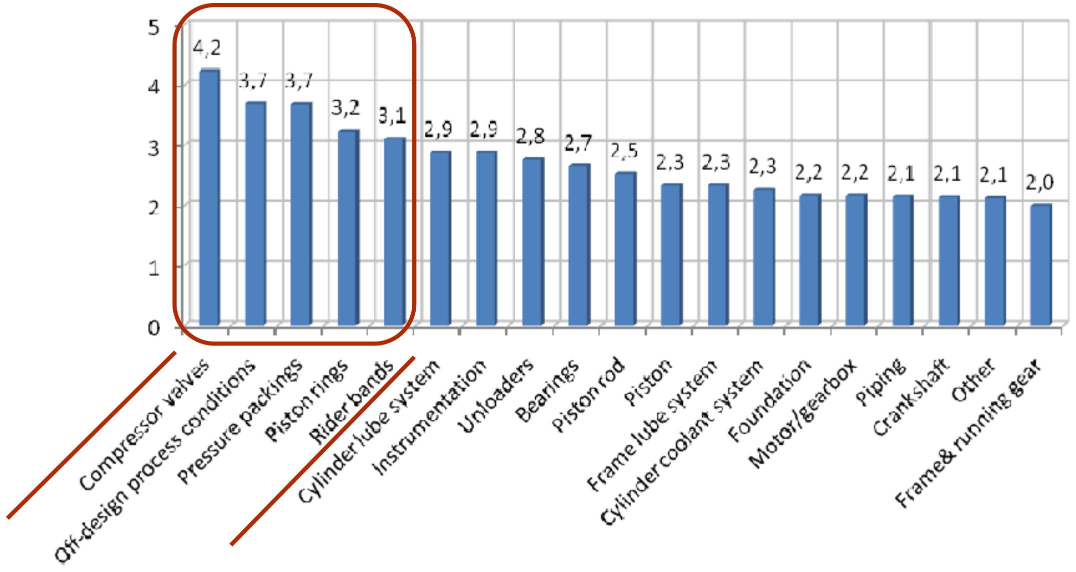
Criticality of components with respect to unscheduled shut down (1-not critical, 5-very critical) (EFRC, 2010)



Compressor Valves

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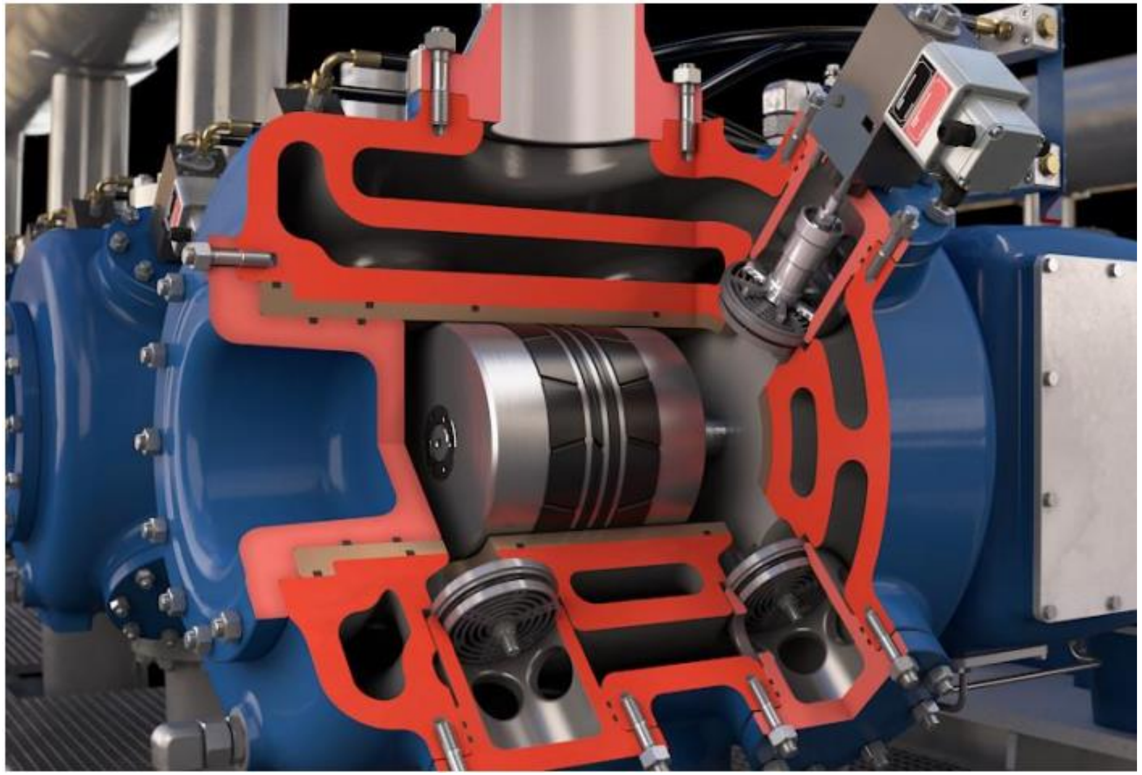
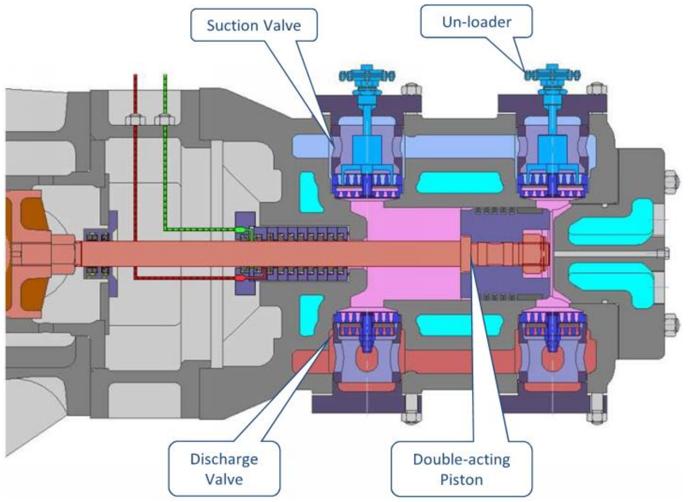
- Fundamental operating principles
- Overview of different valve types and designs
- Application
- Capacity control

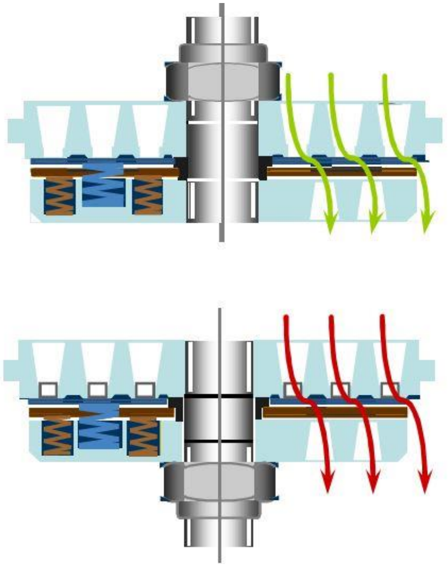


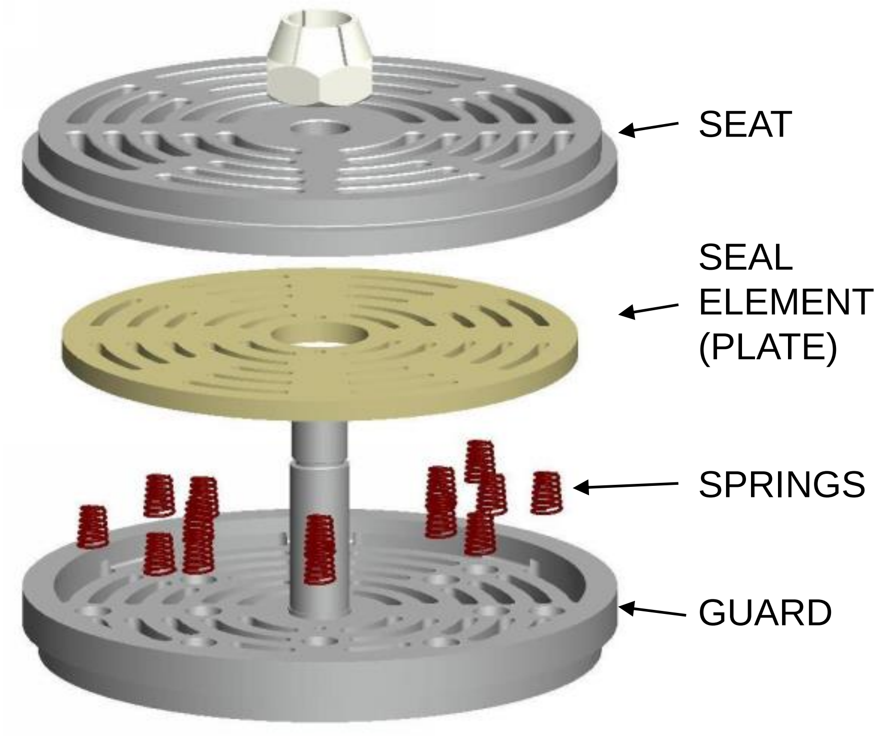
Picture Courtesy Hoerbiger

Compressor Valves – Fundamental Principles

- Valves rely solely on pressure differential and gas flow forces to operate
- Inlet (Suction), Outlet (Discharge) are one way valves
- Sealing element/s (plate / ring / poppet) move between a seat and a guard – seal against seat
- Valve closing is controlled by spring forces

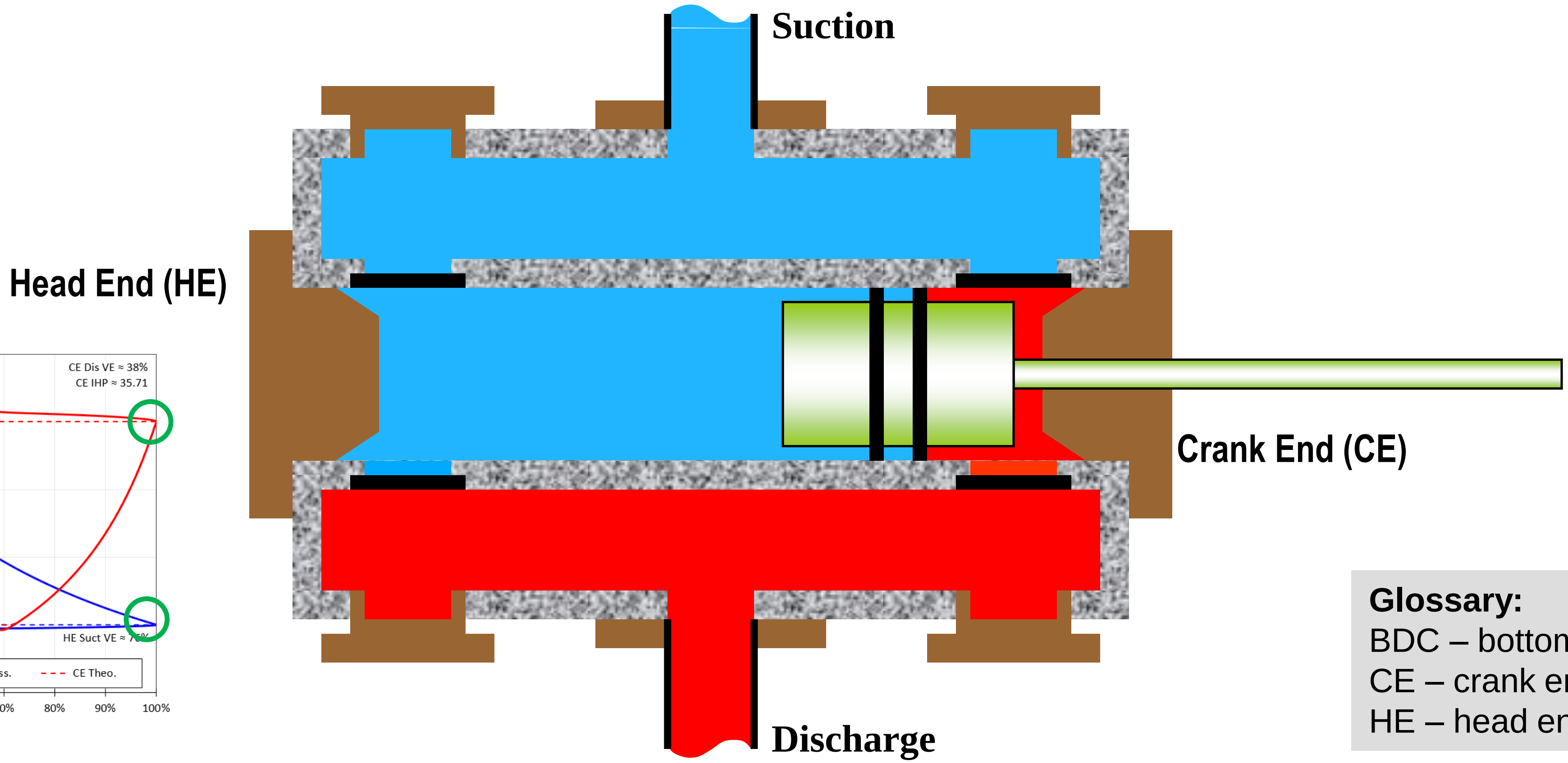


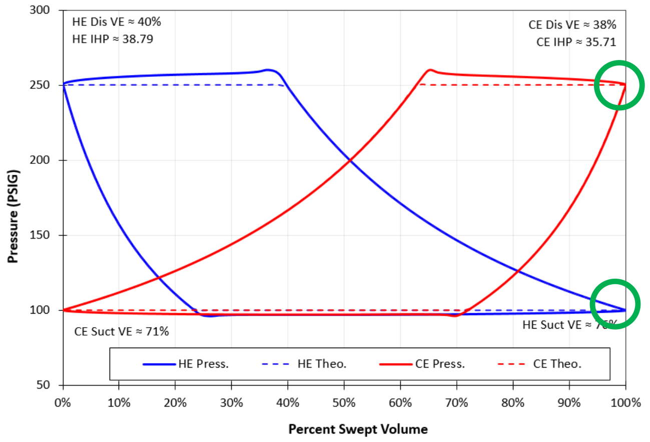




Compressor Valves – Fundamental Principles

- Start of piston motion at bottom dead center (BDC) – zero velocity





Glossary:
BDC – bottom dead center
CE – crank end
HE – head end

Compressor Valves – Fundamental Principles

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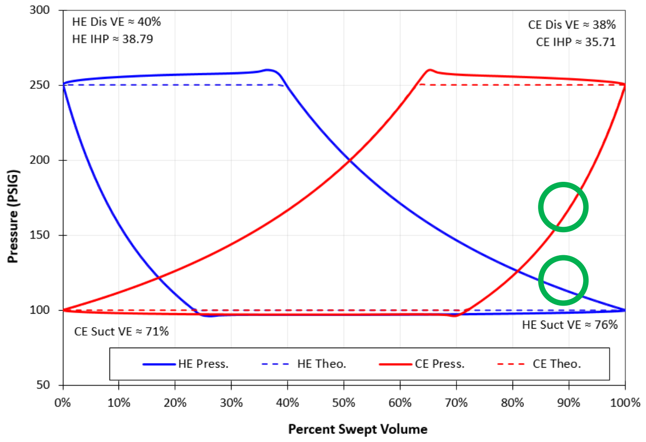
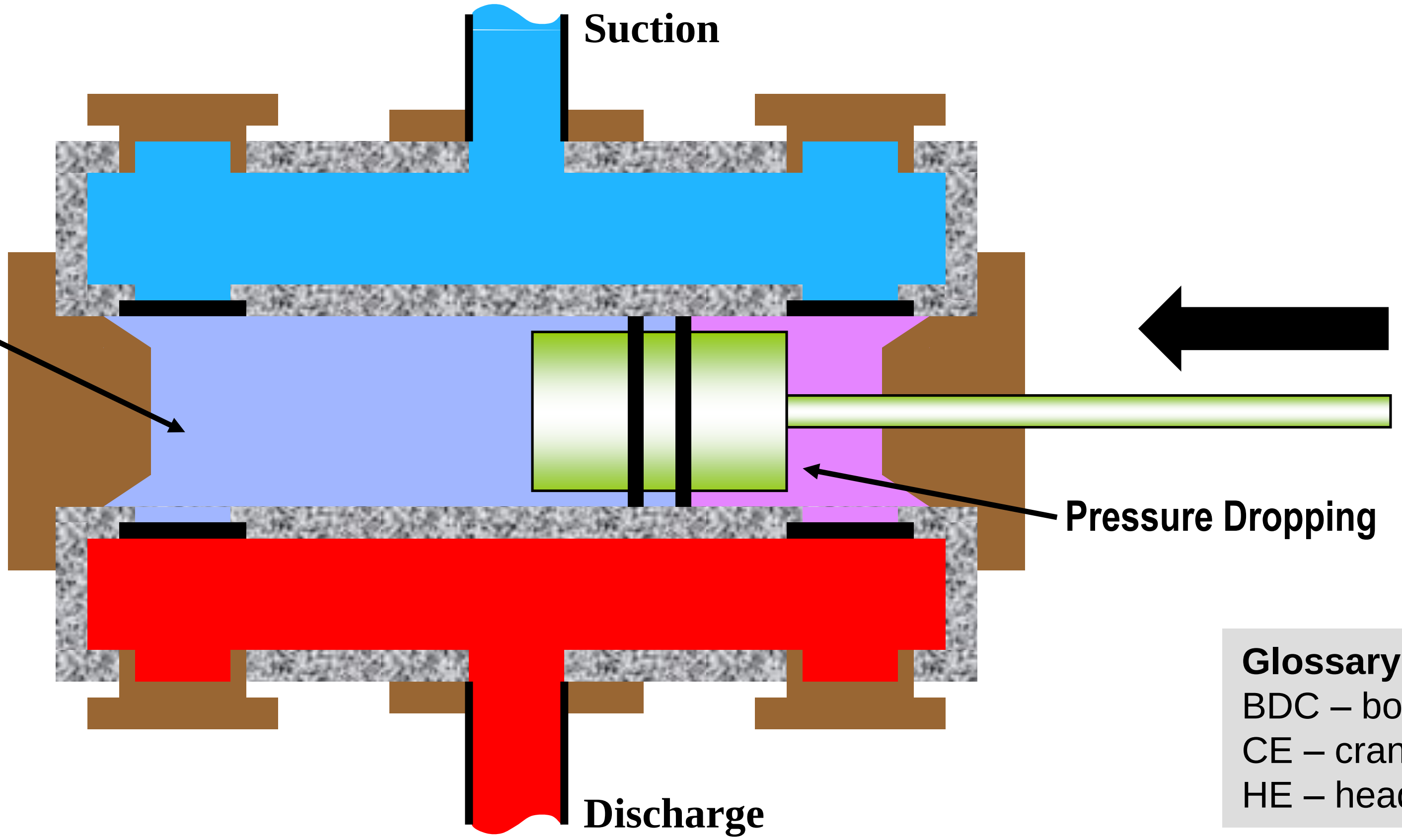
- Piston starts to travel – gas pressure changes due to expansion of volume below piston (CE), compression of volume above piston (HE)





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Compressor Valves – Fundamental Principles

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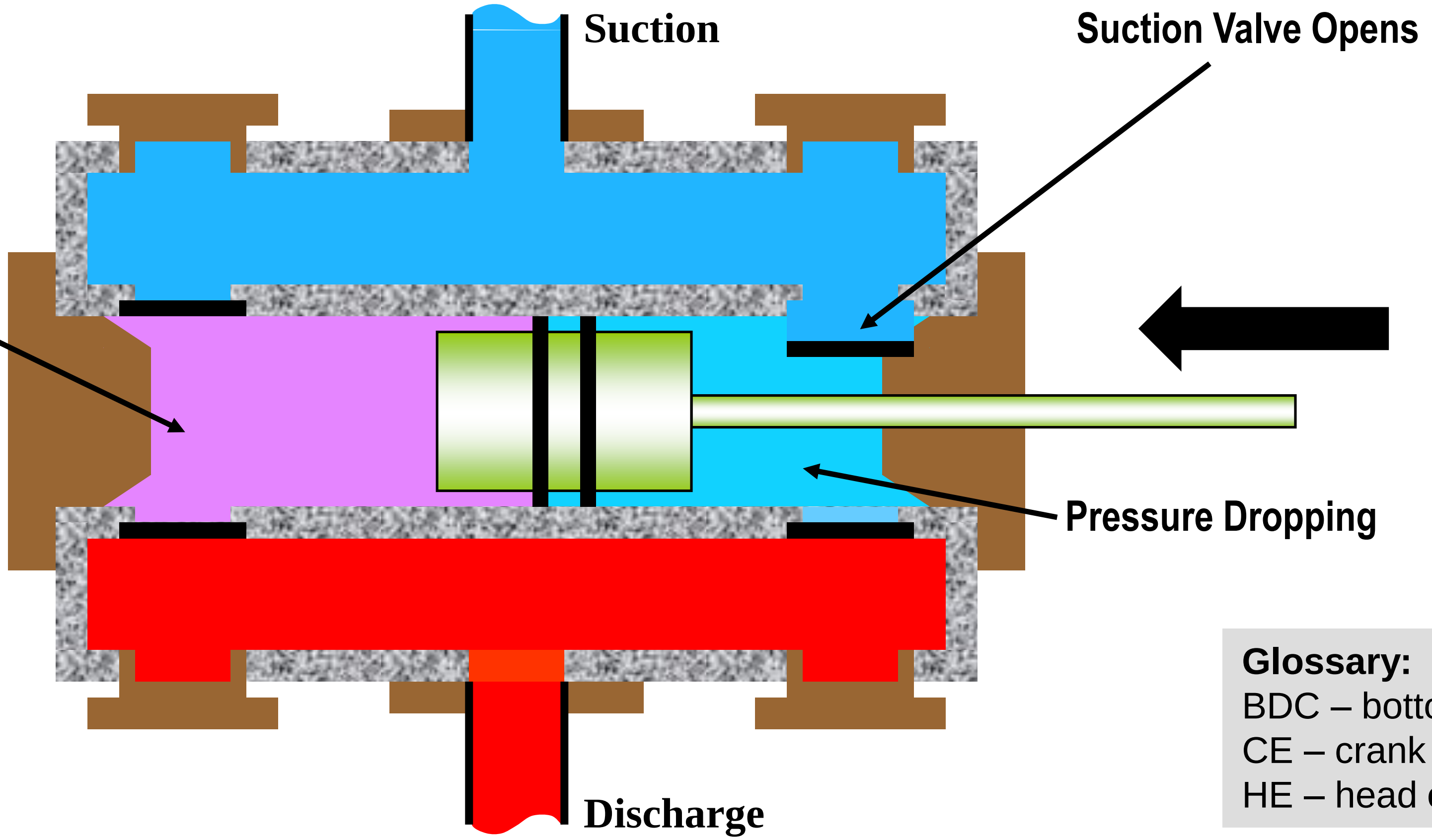
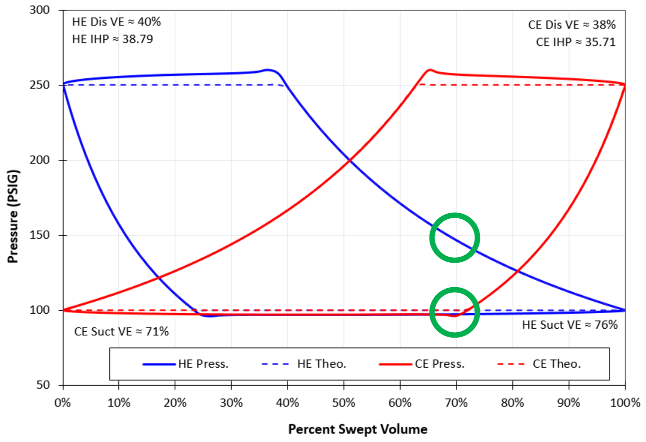
- Pressure differential opens suction valve against springs on CE





Glossary:
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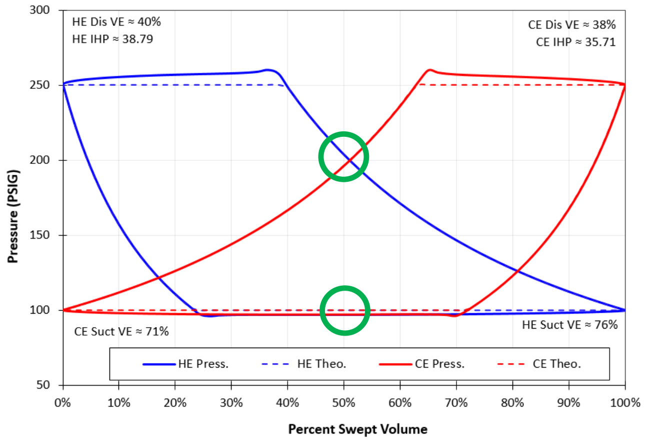
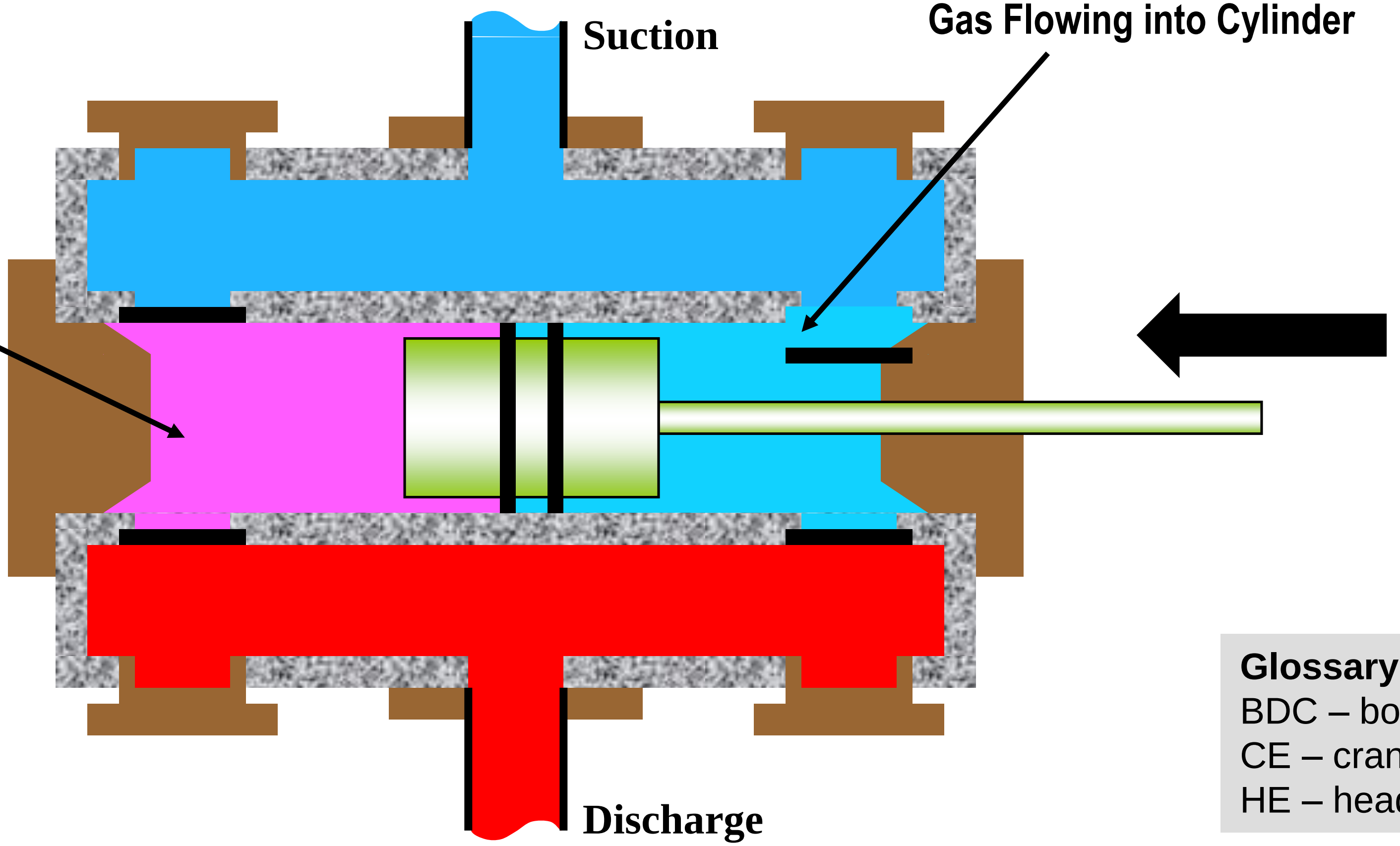
Compressor Valves – Fundamental Principles

- Flowing gas (drag forces) and differential pressure allow gas to flow into CE cylinder
- HE still compressing





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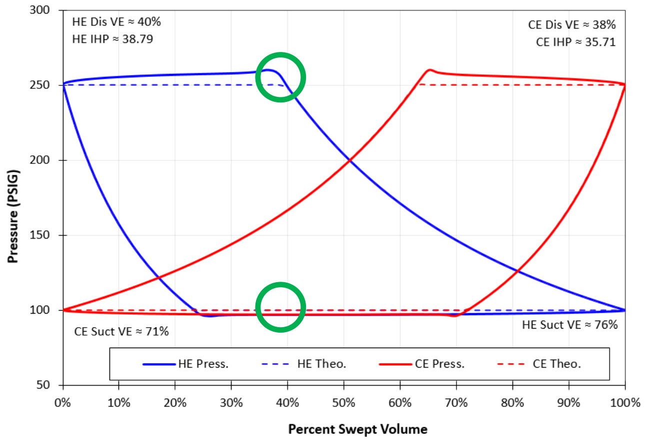
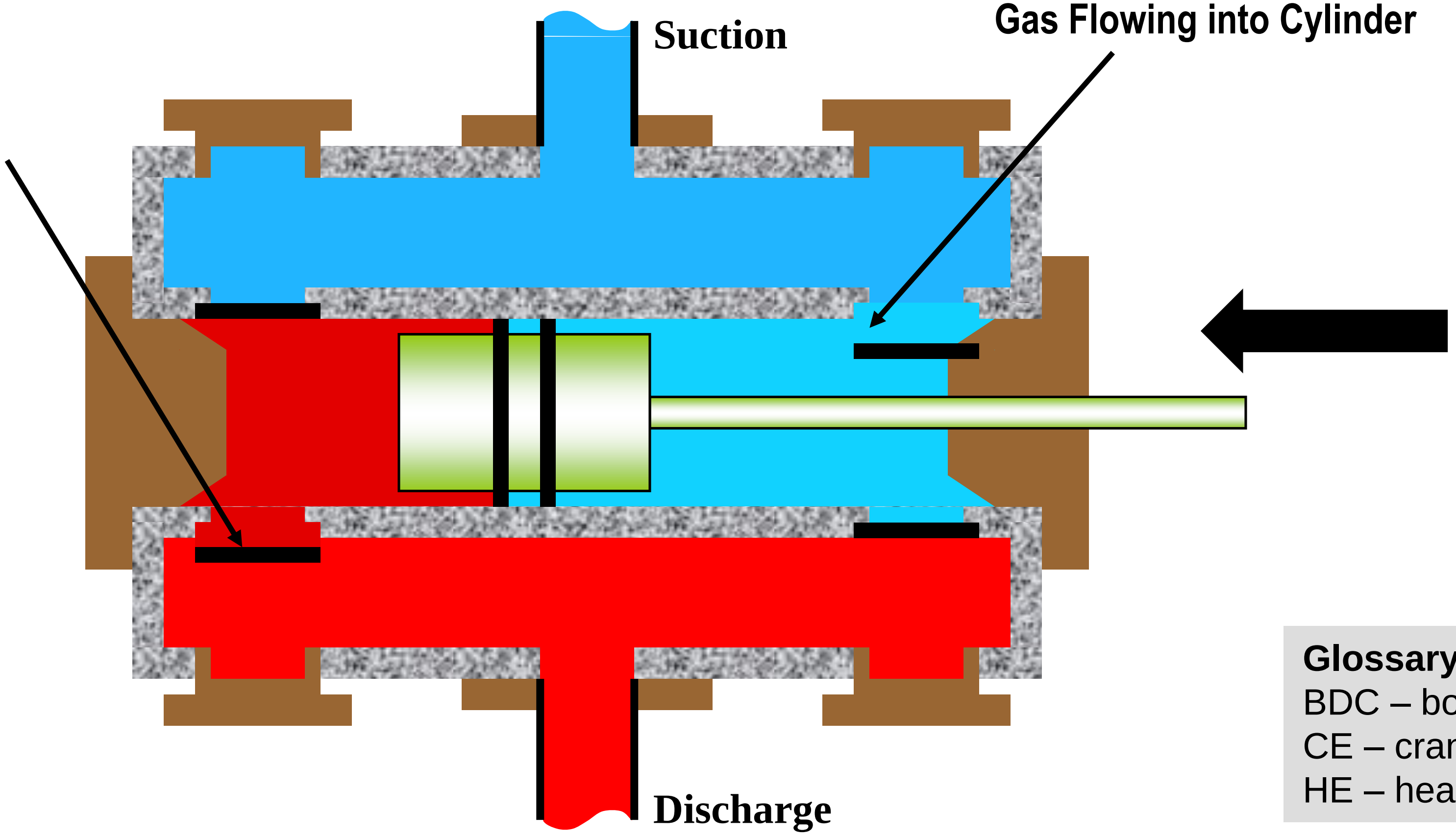
Compressor Valves – Fundamental Principles

- HE pressure increases enough for differential pressure to open discharge valve





Glossary:
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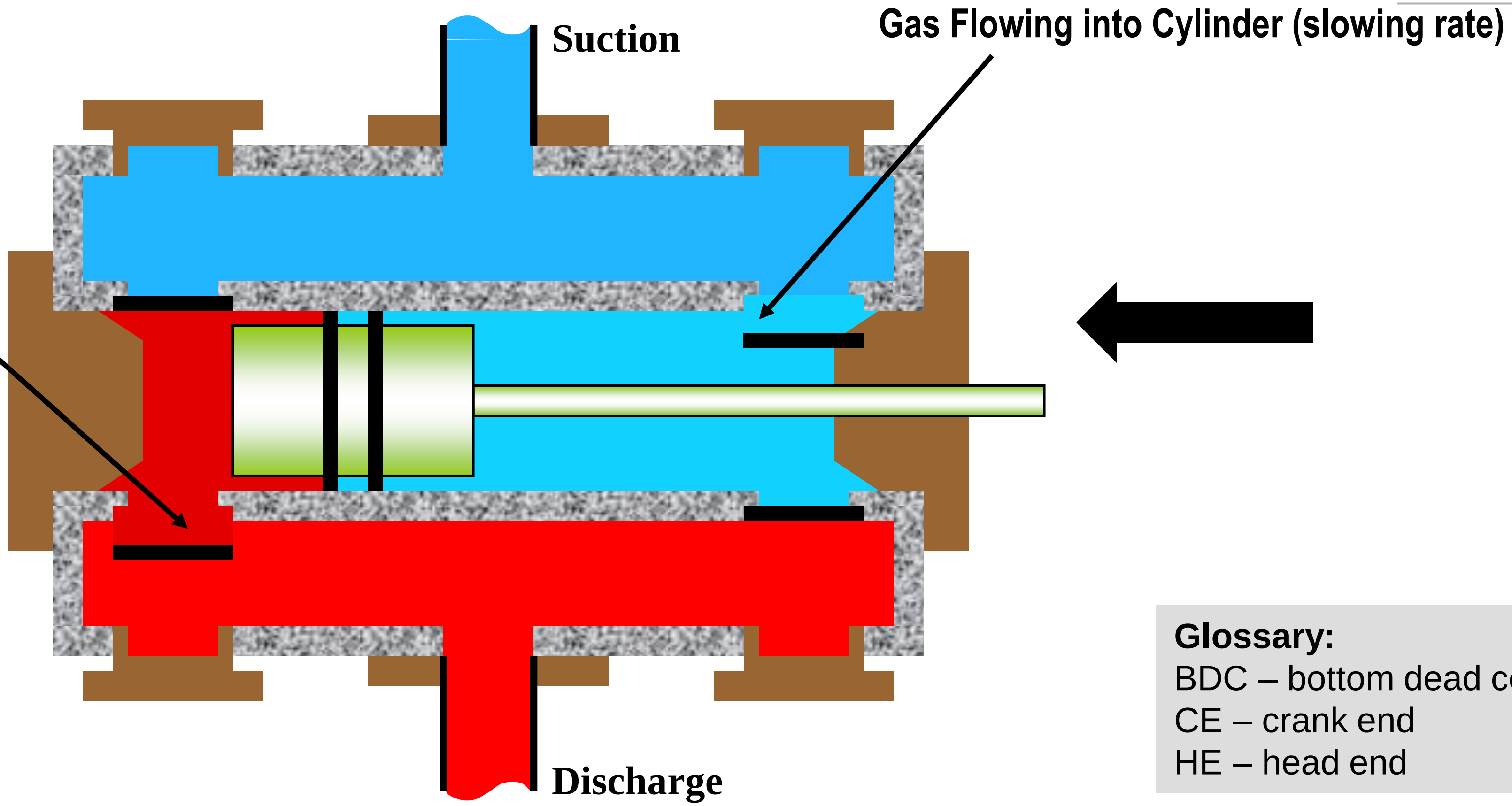
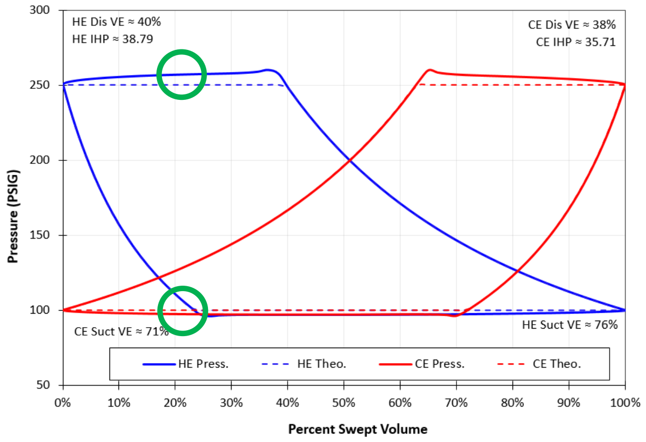
Compressor Valves – Fundamental Principles

- Gas flowing into CE at suction pressure, gas flowing out of HE at discharge
- Piston slowing = gas flow slowing

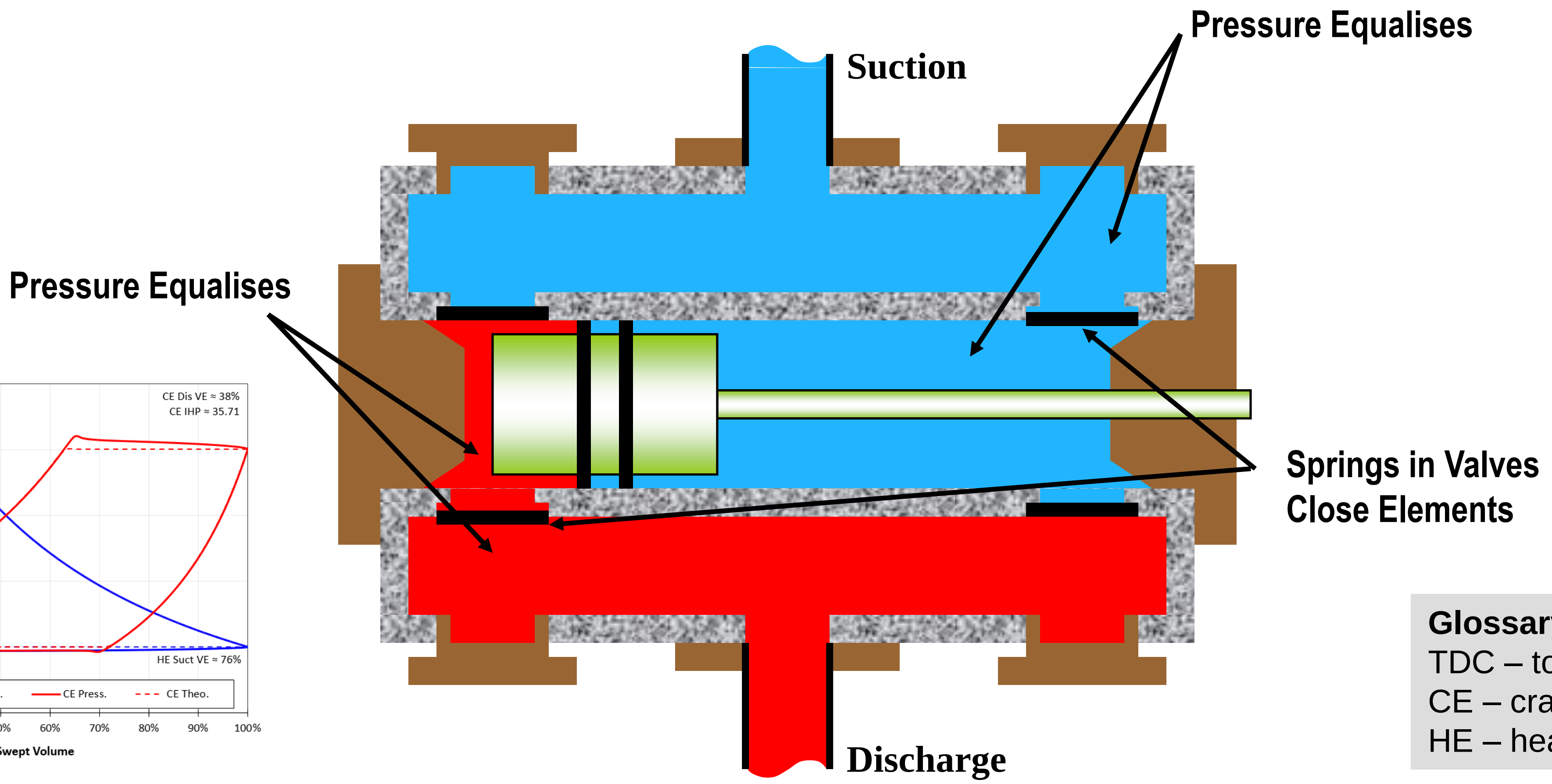


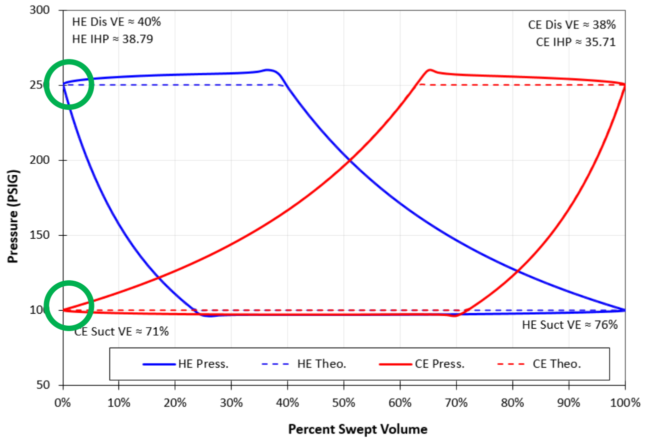


Glossary:
BDC – bottom dead center
CE – crank end
HE – head end

Compressor Valves – Fundamental Principles

- Near top dead centre (TDC), flow rates decrease, pressures equalise, valve springs overcome forces and close valves





Glossary:
TDC – top dead center
CE – crank end
HE – head end

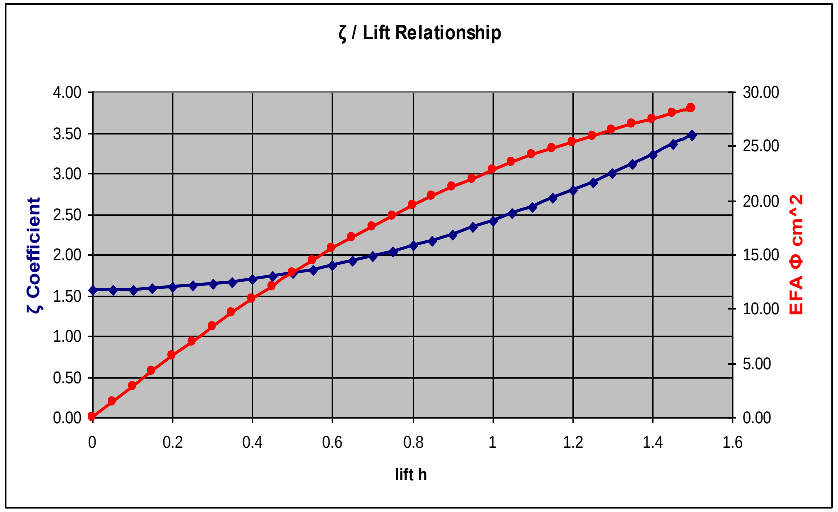
Compressor Valves – Design for Application

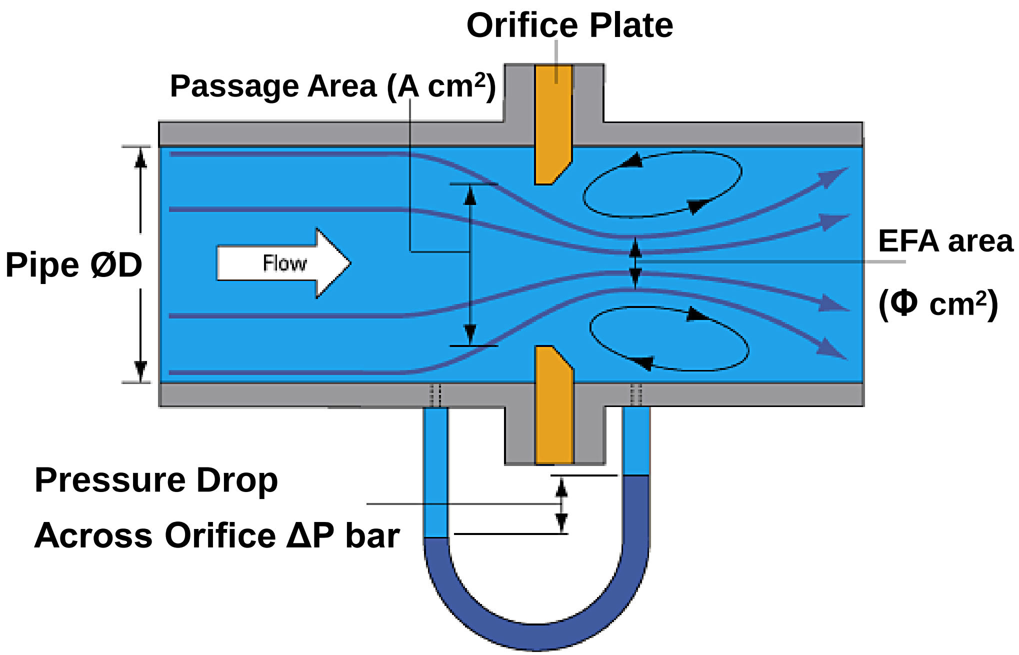
- Design for specific compressor applications requires three main considerations

- Valve flow area for good efficiency
- Correct valve spring loads for good closure timing (dynamics)
- Strength and material properties

Compressor Valves – Flow Area

- Passage or Lift Area is the full geometric flow area
- Effective Flow Area (EFA) is used to calculate pressure loss
- Based on pressure drop testing for valves
- Determine ζ for a range of valve lifts
- EFA = passage area / SQRT ζ





PRESSURE DROP $\Delta P = 0.5 \times \zeta \times \rho \times v^2$

PRESSURE DROP COEFFICIENT (ζ)

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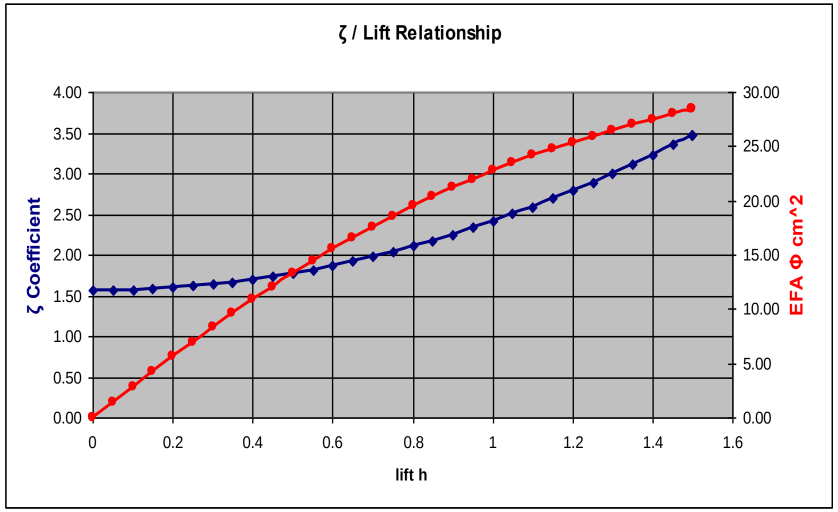
Compressor Valves – Q Coefficient

- Q coefficient is a valve flow adequacy measure
- Q indicates pressure drop as a percentage of suction pressure
- Ideally in the range 2 – 5 but higher up to 15 accepted

$$q_{sv} = \frac{\pi^2}{8} \cdot \frac{\rho_s}{P_s} \left(v_m \cdot \frac{f_e}{\varphi} \right)^2 = \frac{\Delta P}{P_s}$$

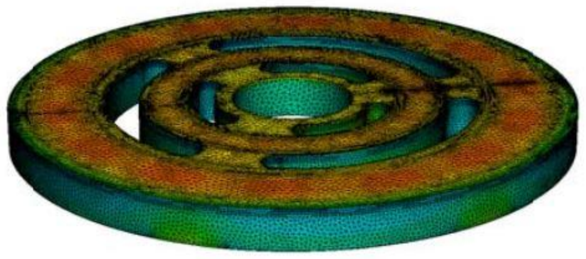


where:

Qsv	= Q at suction pressure
ρ s	= suction gas density
Ps	= suction pressure
Vm	= mean gas velocity (through lift area)
Fe	= passage (lift) area
Φ	= EFA

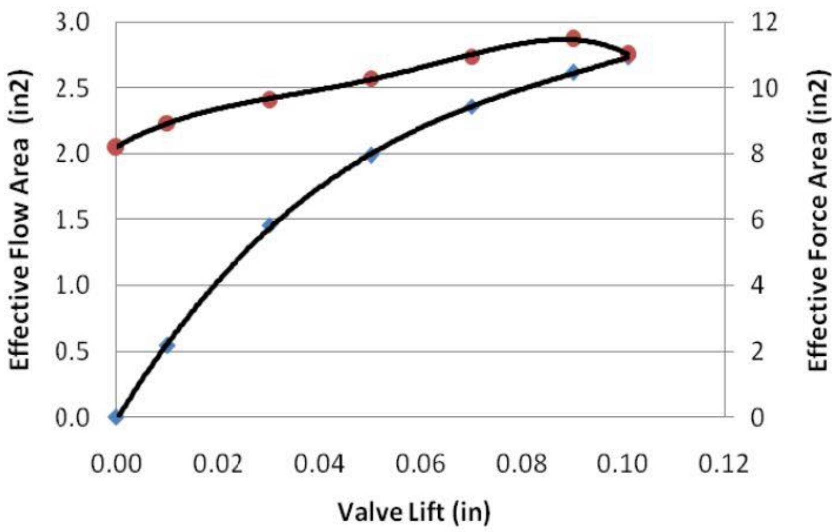
Compressor Valves – Flow Forces

- Mass flow of gas creates drag forces on seal element
- Experimental data or CFD data gives forces
- For any mass flow we can calculate force



CFD Generated Plate Pressure Profile

EFA and Force Area



Compressor Valves – Dynamic Model

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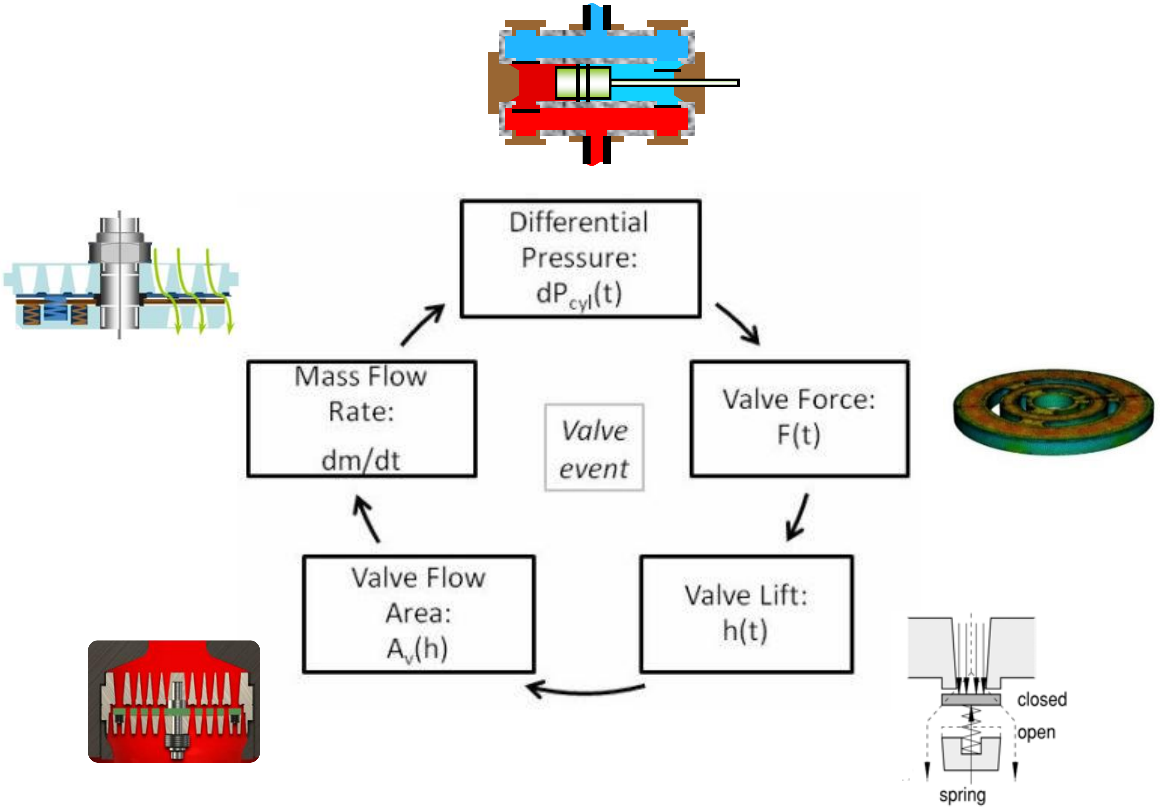
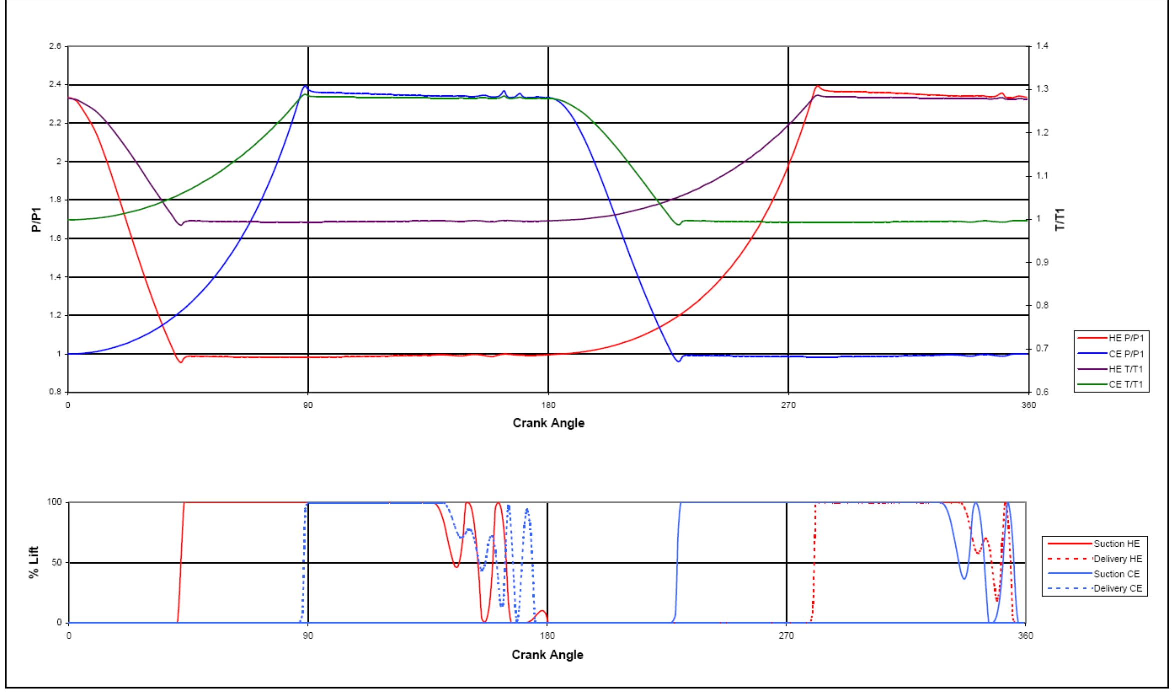
- Modelling a valve event requires an iterative cycle through the stroke of the piston



SAMPLE													
p1 (bara)	p2 (bara)	T1 (°C)	T2 (°C)	mT (-)	Z1 (-)	Z2 (-)	Mol. Wt. (g/mol)	Speed (RPM)	Bore (mm)	Stroke (mm)	Rod dia. (mm)	Cl. Vol. HE (%)	Cl. Vol. CE (%)
15.50	36.15	40.00	125.72	1.400	1.010	1.020	3.170	355.00	290.00	300.00	75.00	16.80	15.70



Compressor Valves – Dynamic Model

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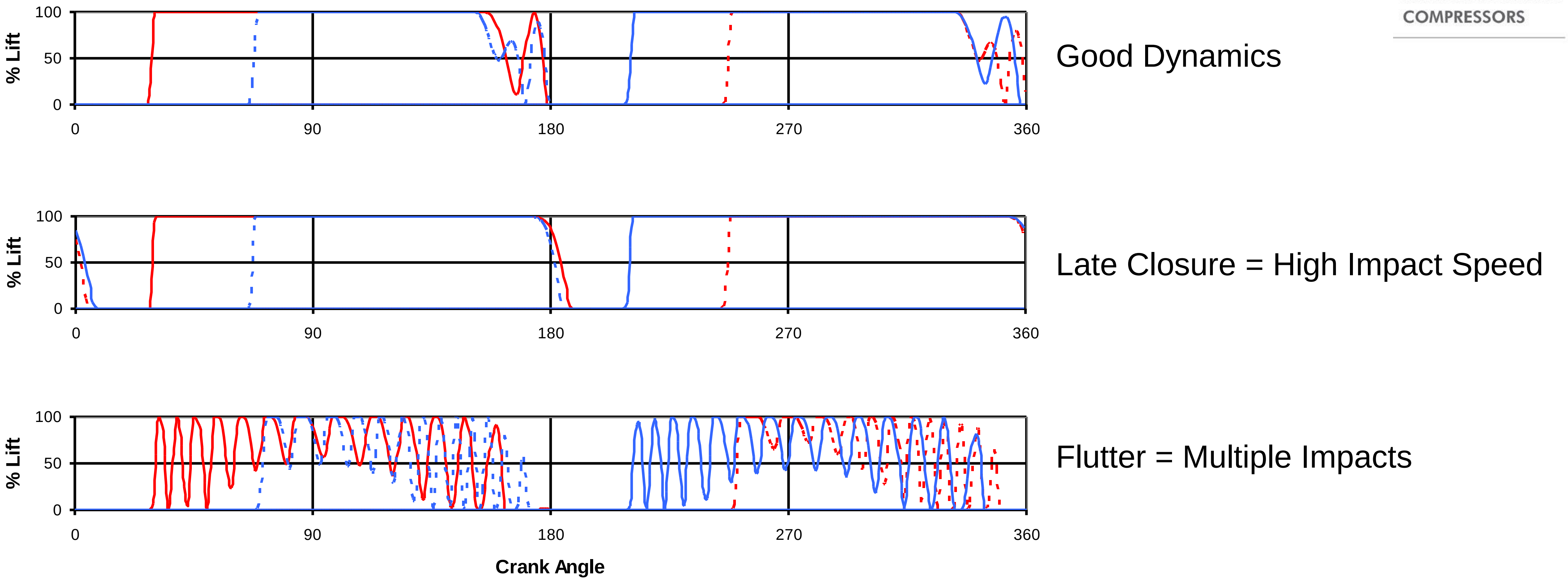
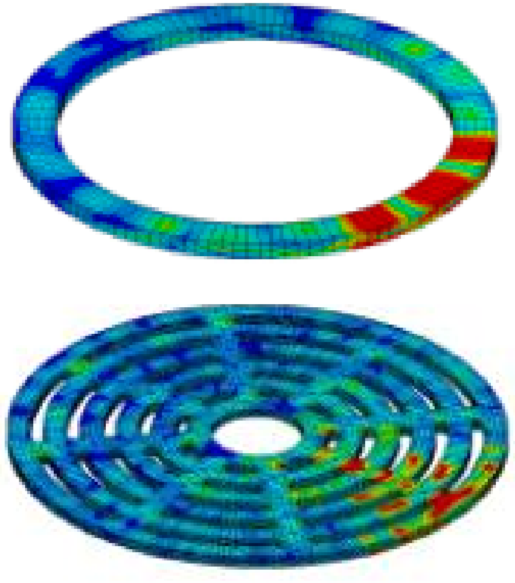
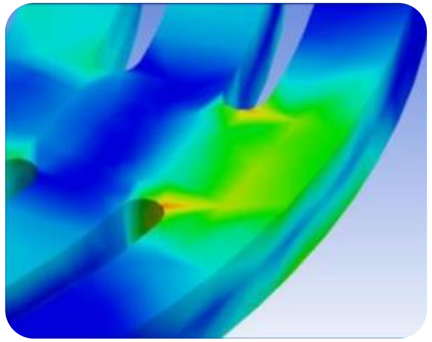
- Dynamics show timing and velocity of closure events

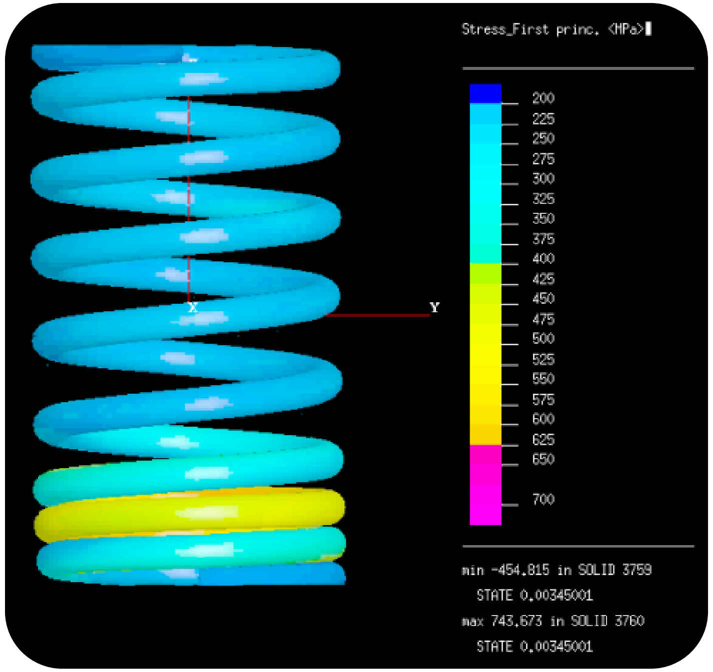


Compressor Valves – Dynamic Model

- Sealing element impact velocity is a critical design criteria
- Sealing element stresses are proportional to the impact speed
- Closing spring stress and wear are also affected by impact speed







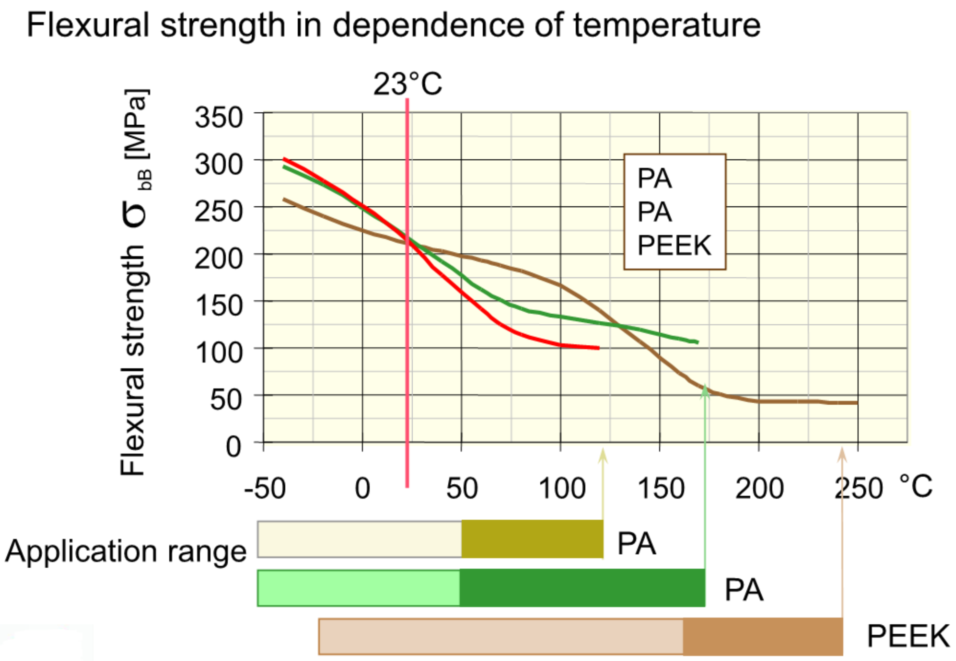
Picture Courtesy Hoerbiger

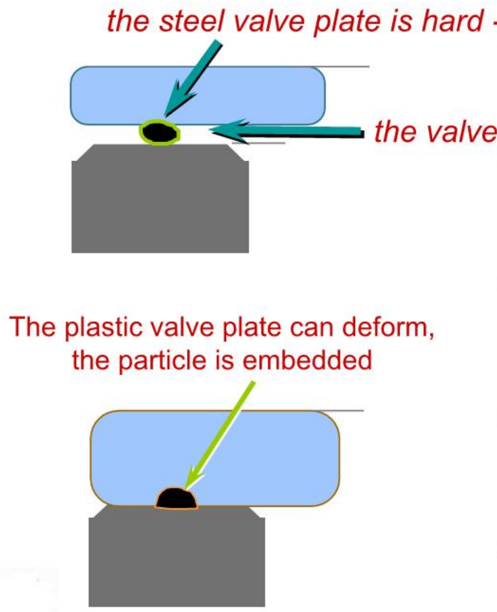
Compressor Valves – Material Considerations

- Conflicting requirements – pressure loads, fatigue, impact toughness
- Seats generally steel grades for strength
- Seal elements often polymer materials for combination of strength, low mass and impact toughness
- Selection of polymer is dependant on temperature, chemical compatibility and strength

Compressor Valves – Material Considerations

- Polymer selection based on strength at elevated temperatures during working conditions
- Polymer sealing elements can resist debris better





Plastic valve plate with embedded particles

Compressor Valves – Basic Types

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- All principles mentioned apply to any type of valve
- Plate valves – Single flat sealing element, may be damped
- Ring valves – Concentric ring shaped seal elements
- Poppet – Multi element valves

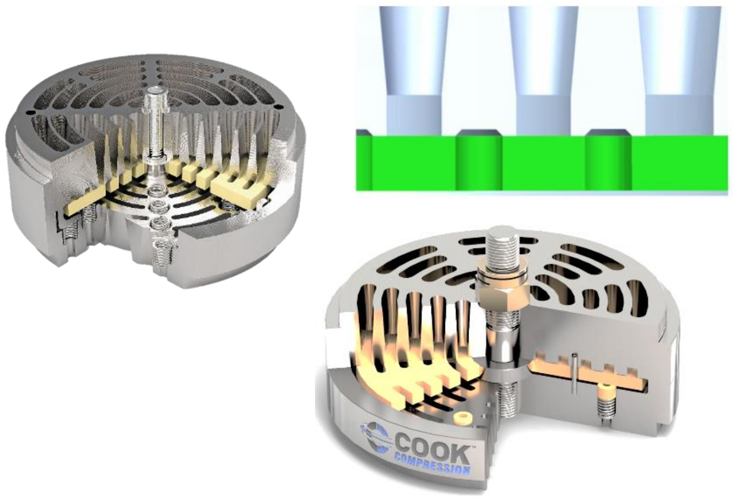
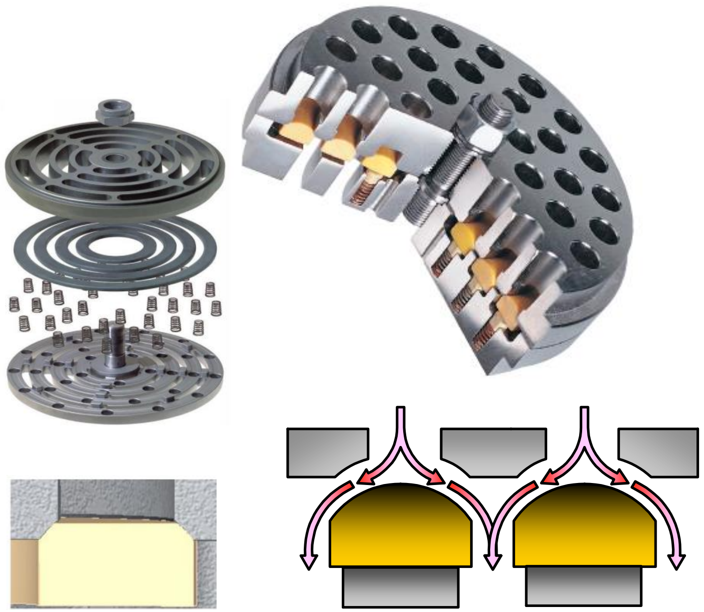


Plate Type Valves

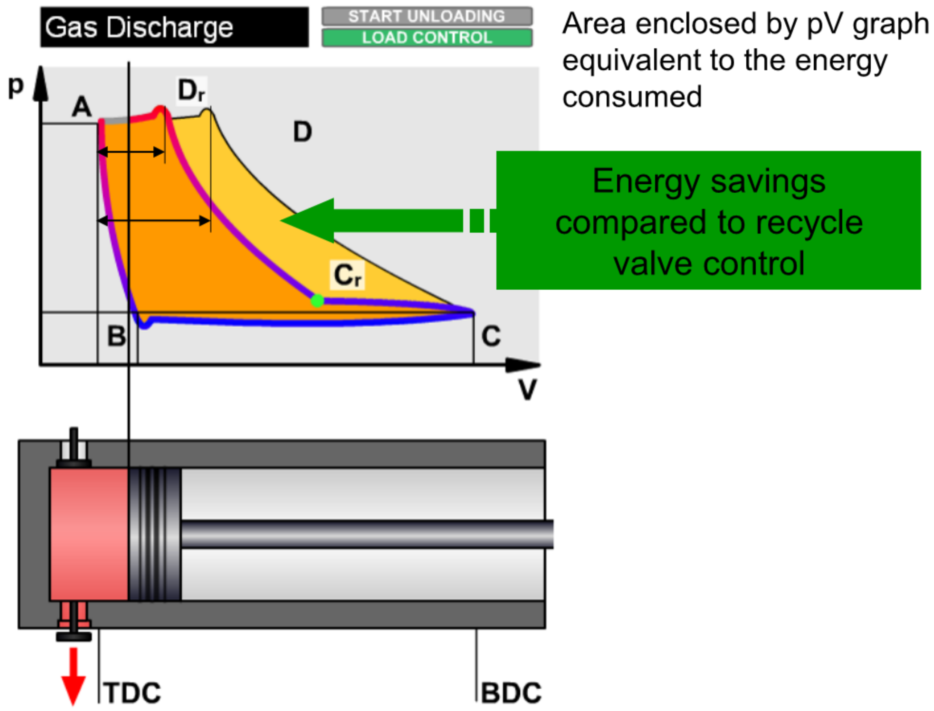


Ring Type Valves

Poppet Type Valves

Compressor Valves – Capacity Control / Unloading

- Unloading refers to holding open suction valves
- Step unloading switches off one cylinder end
- Step-less reverse flow (SRF) unloading uses timed opening of suction valves to control capacity

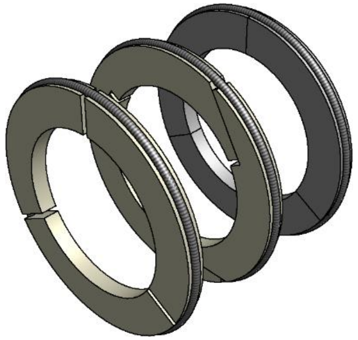


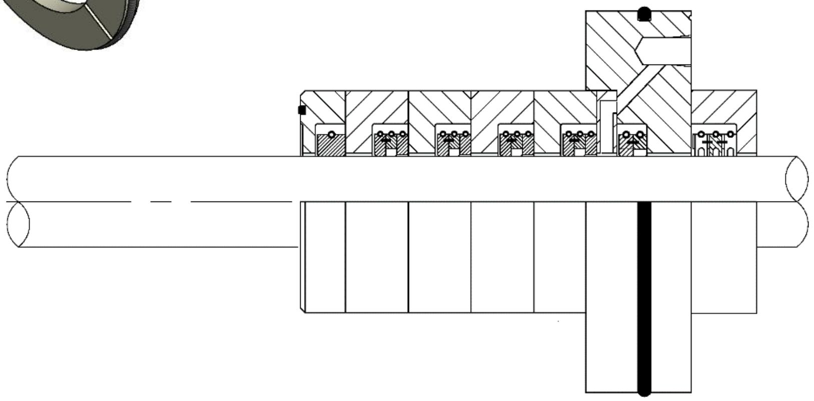
Area enclosed by pV graph is equivalent to the energy consumed

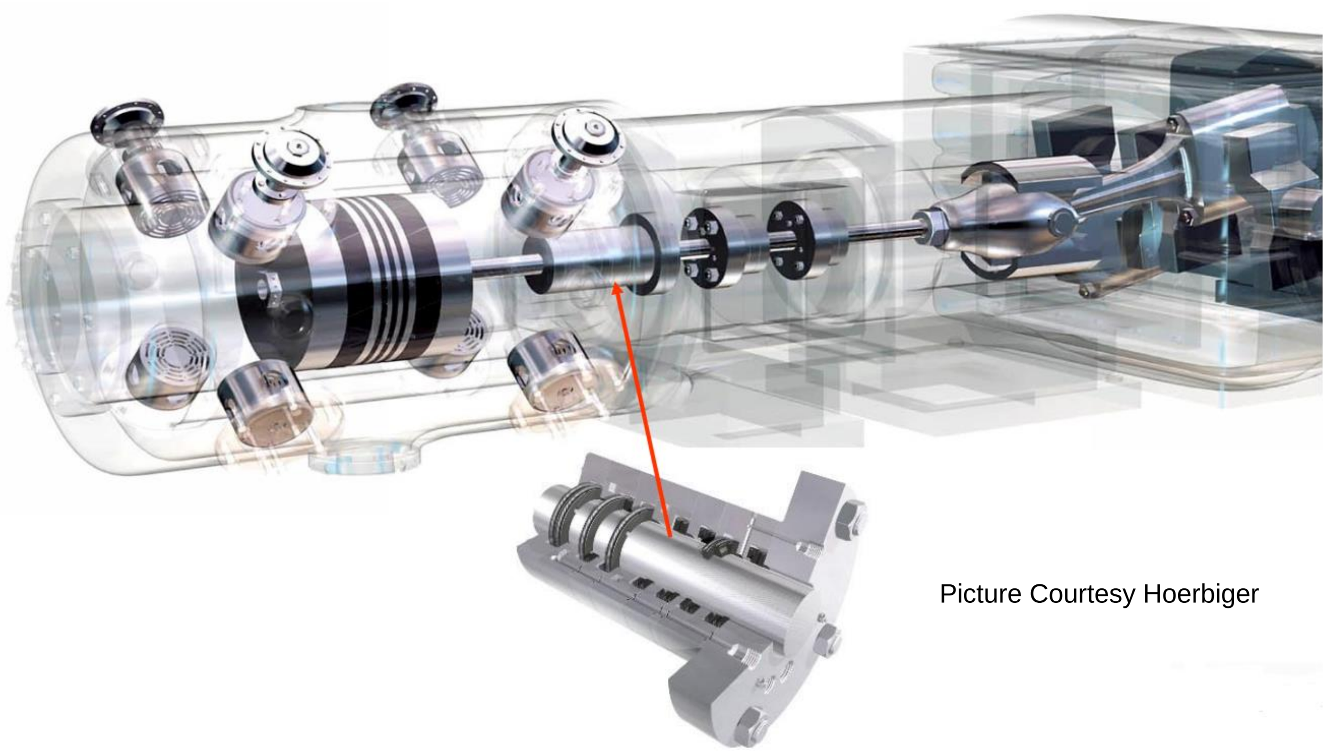
Picture Courtesy Hoerbiger

Pressure Packing Cases

- Fundamental operating principles
- Overview of different seal types and designs
- Applications







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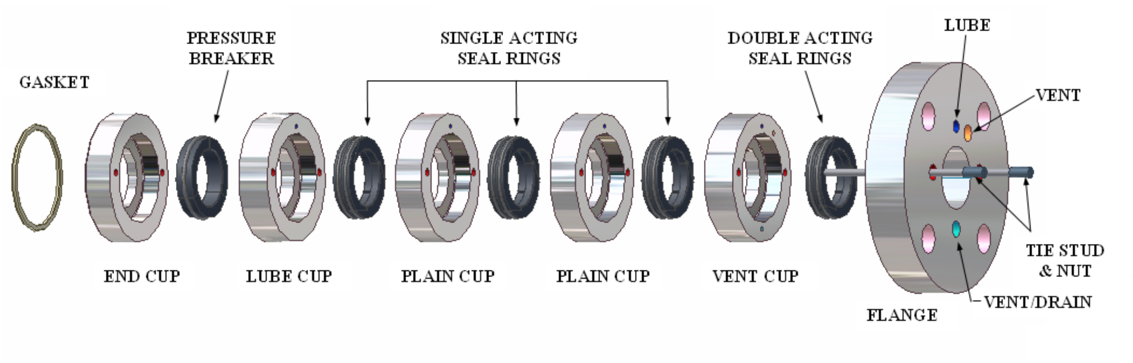
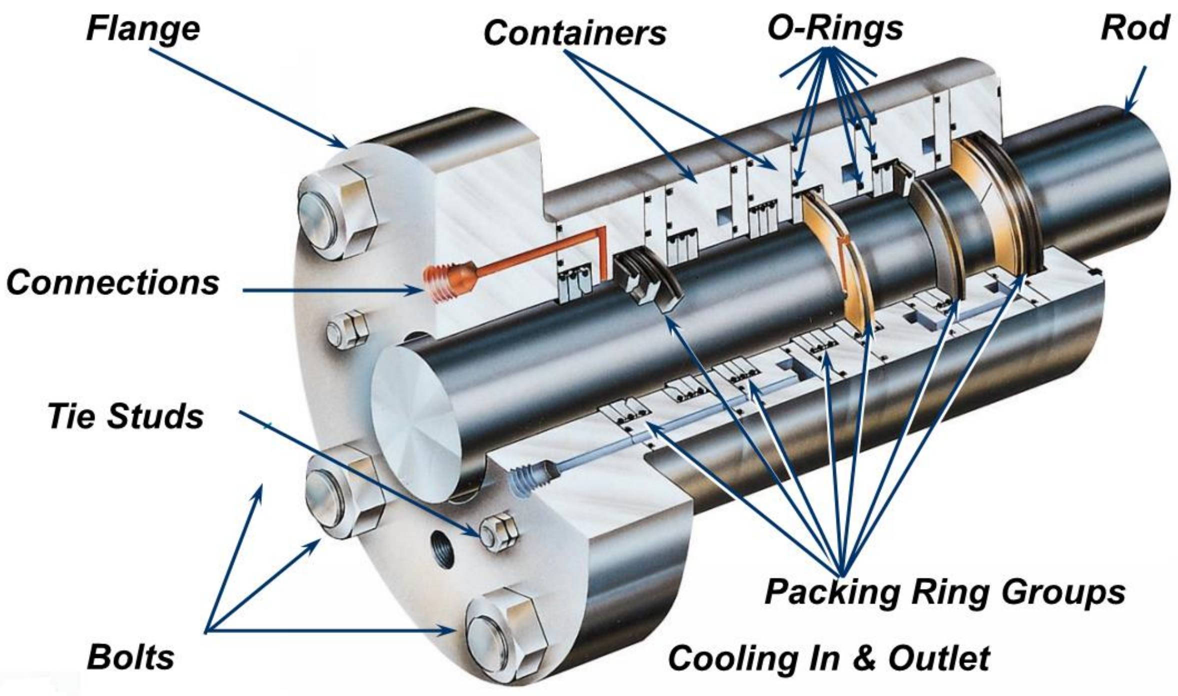
Pressure Packing Cases

- Case made up of pressure containing cups and a flange
- Multiple seal ring sets fitted
- Various connections for lube / cooling / vent etc





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Pressure Packing Cases - Fundamental

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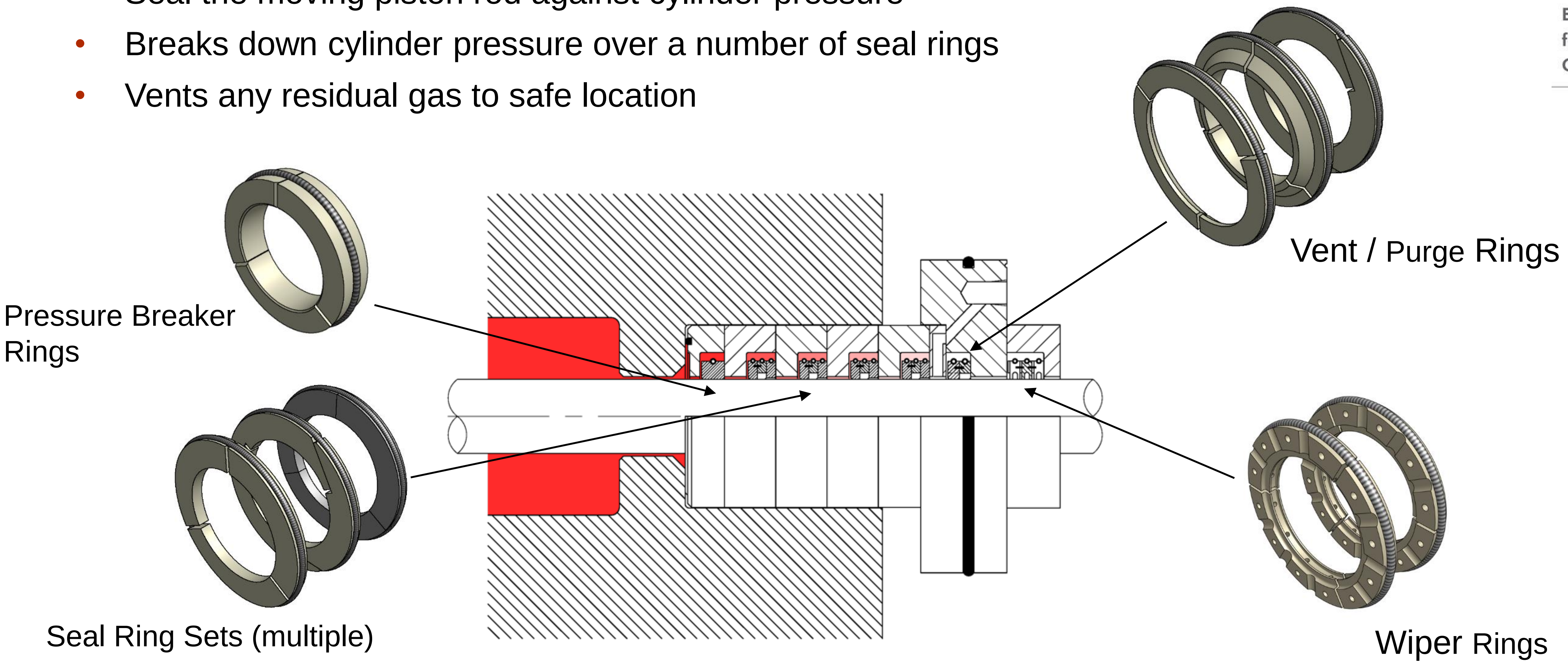
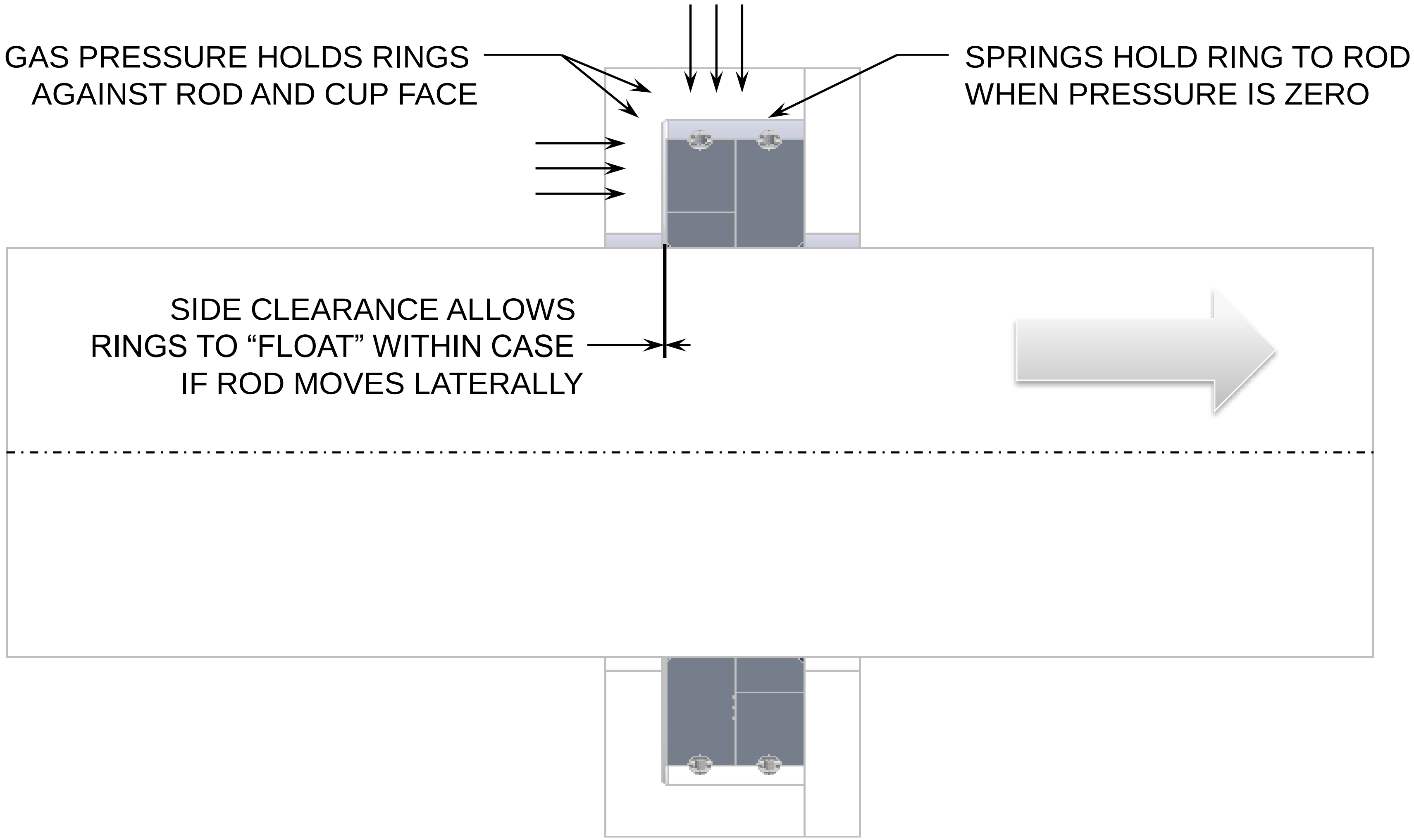
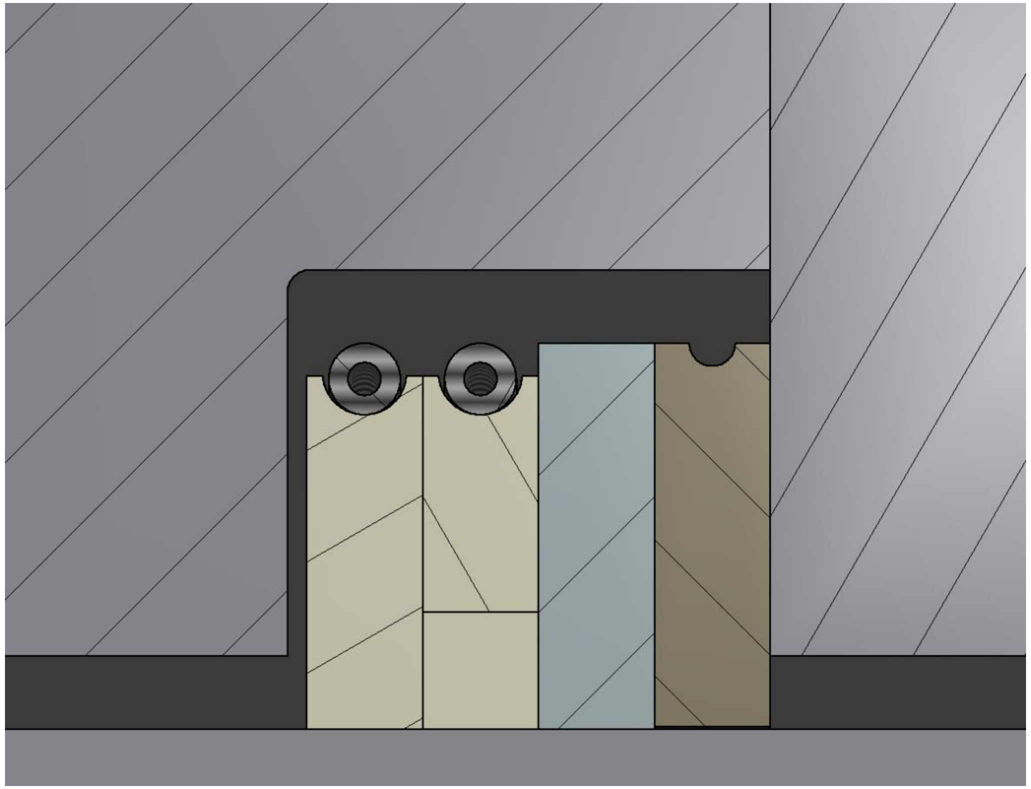
- Seal the moving piston rod against cylinder pressure
- Breaks down cylinder pressure over a number of seal rings
- Vents any residual gas to safe location



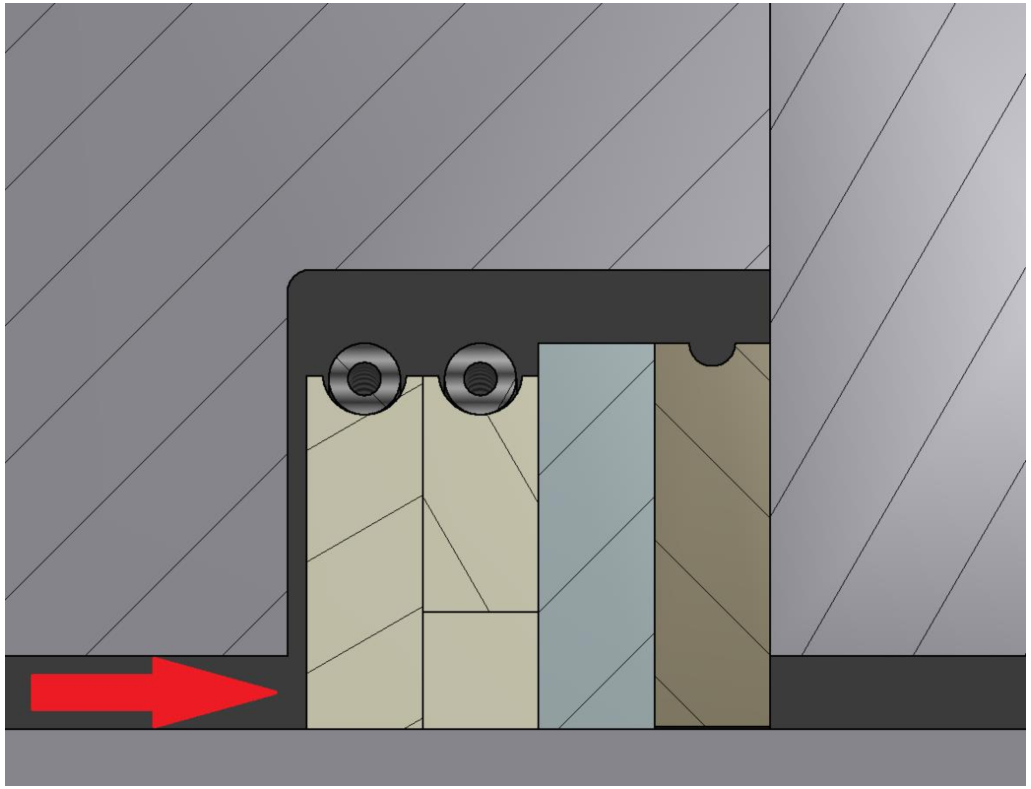
Pressure Packing Cases - Fundamental



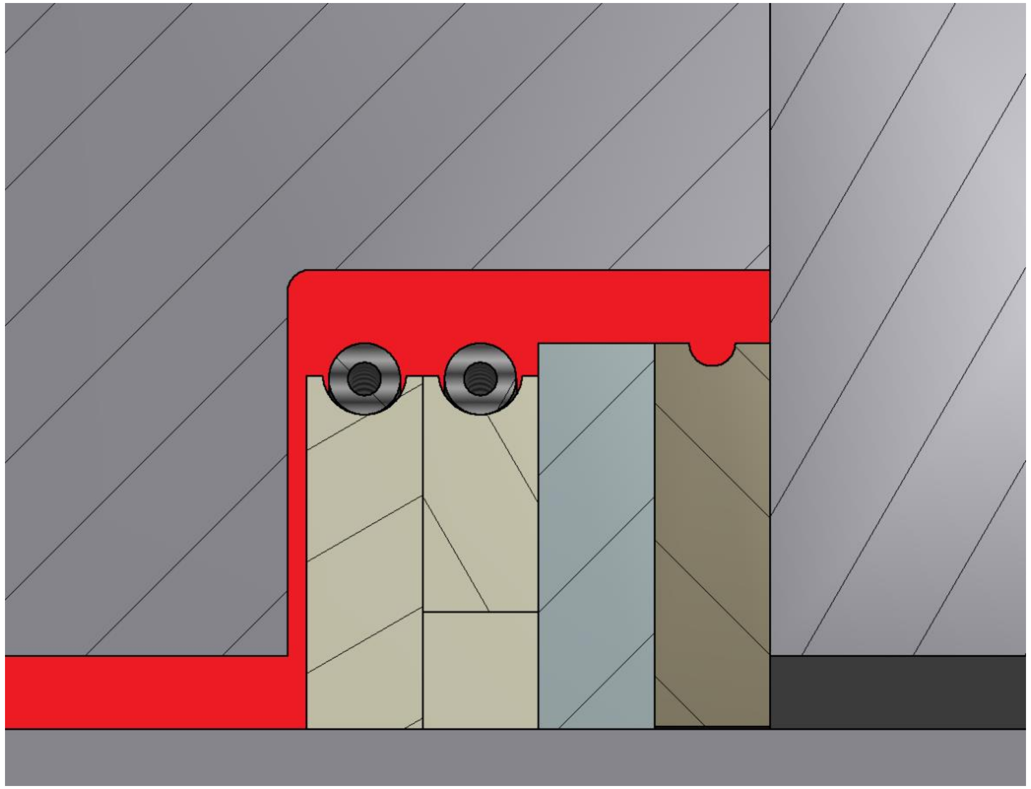
Pressure Packing Cases - Fundamental



Pressure Packing Cases - Fundamental



Pressure Packing Cases - Fundamental



Pressure Packing Cases - Fundamental

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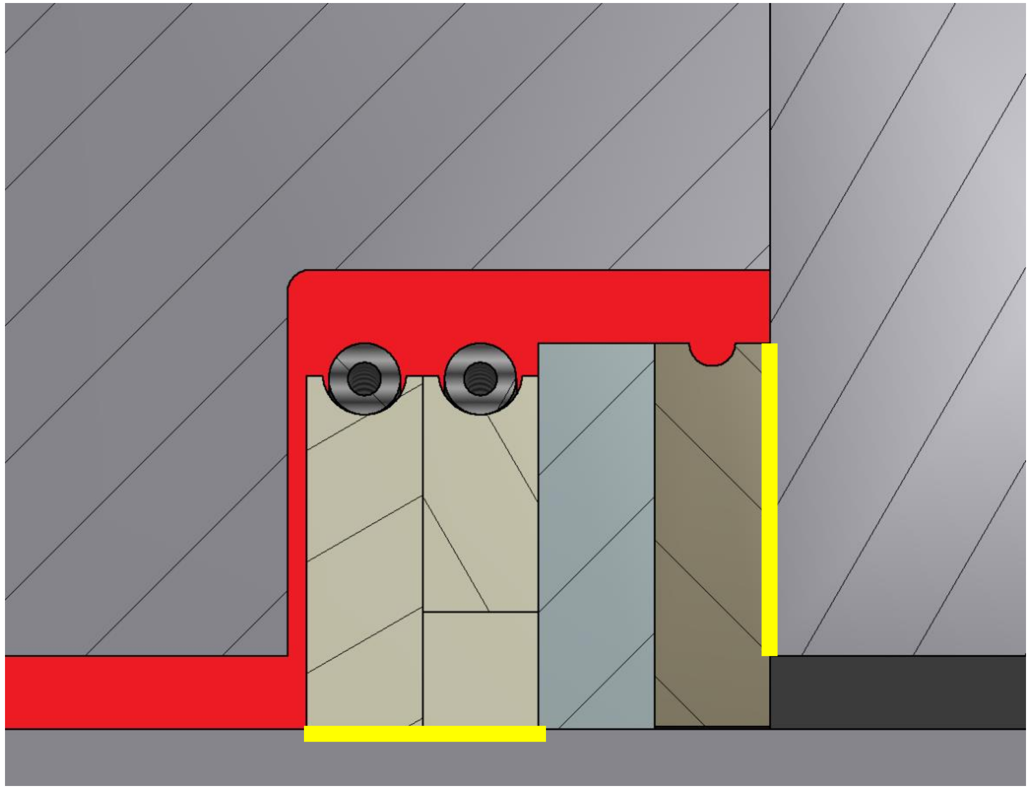
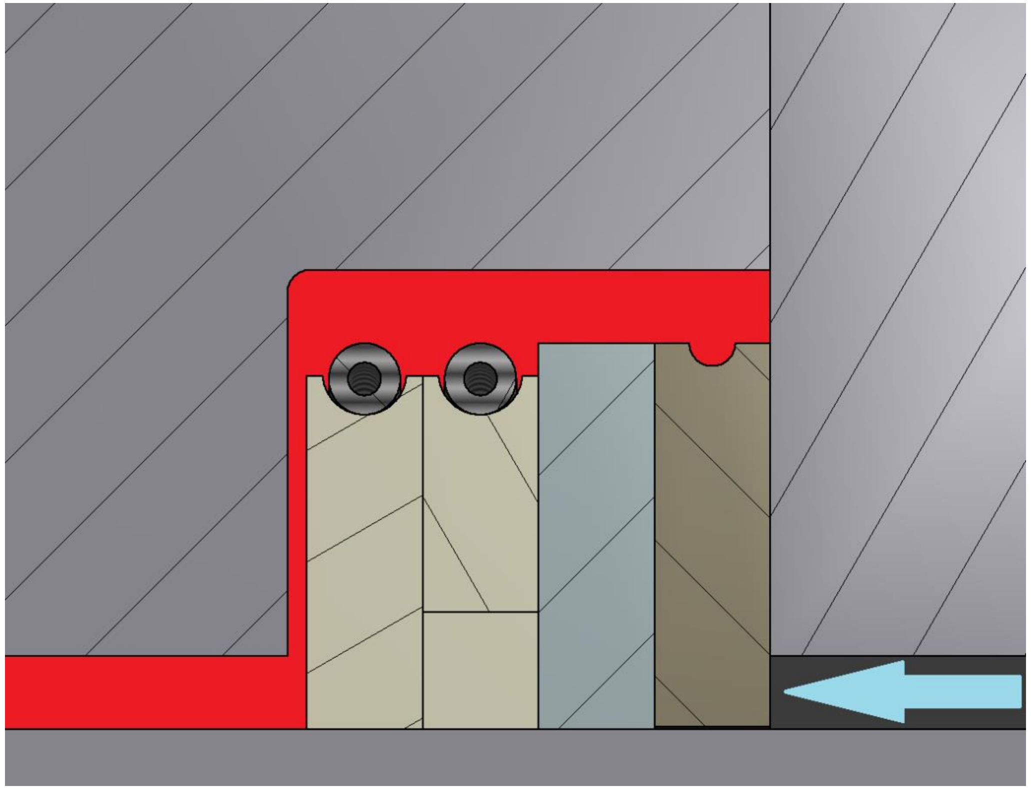


Pressure Packing Cases - Fundamental



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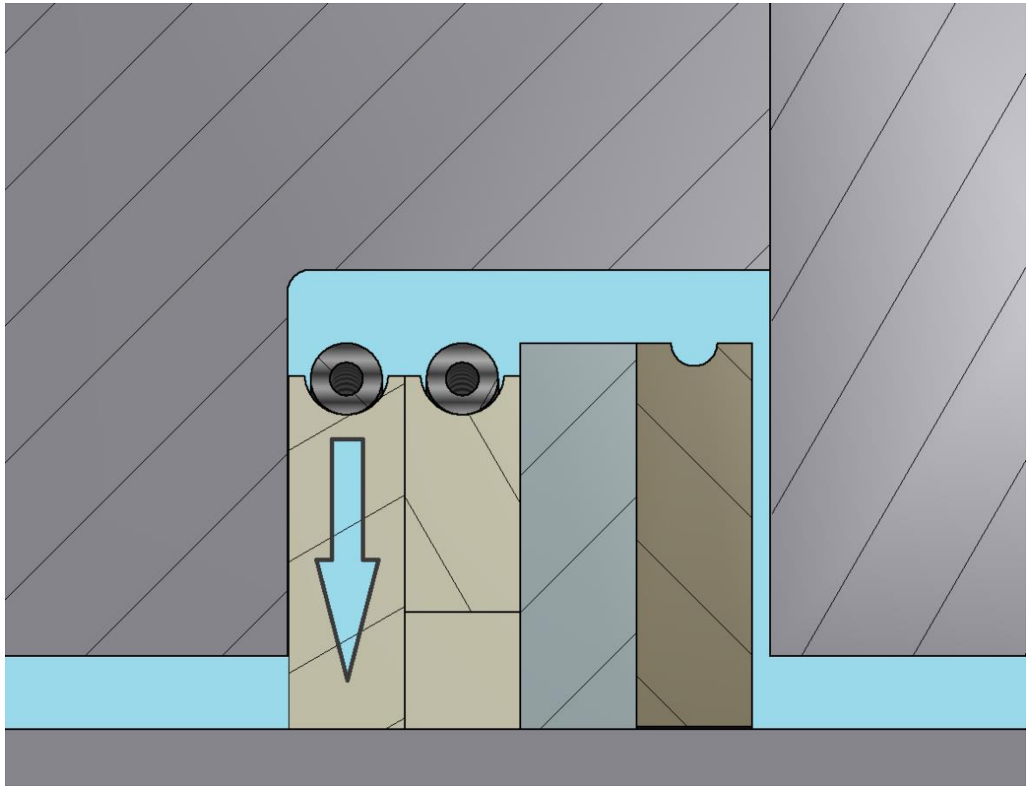
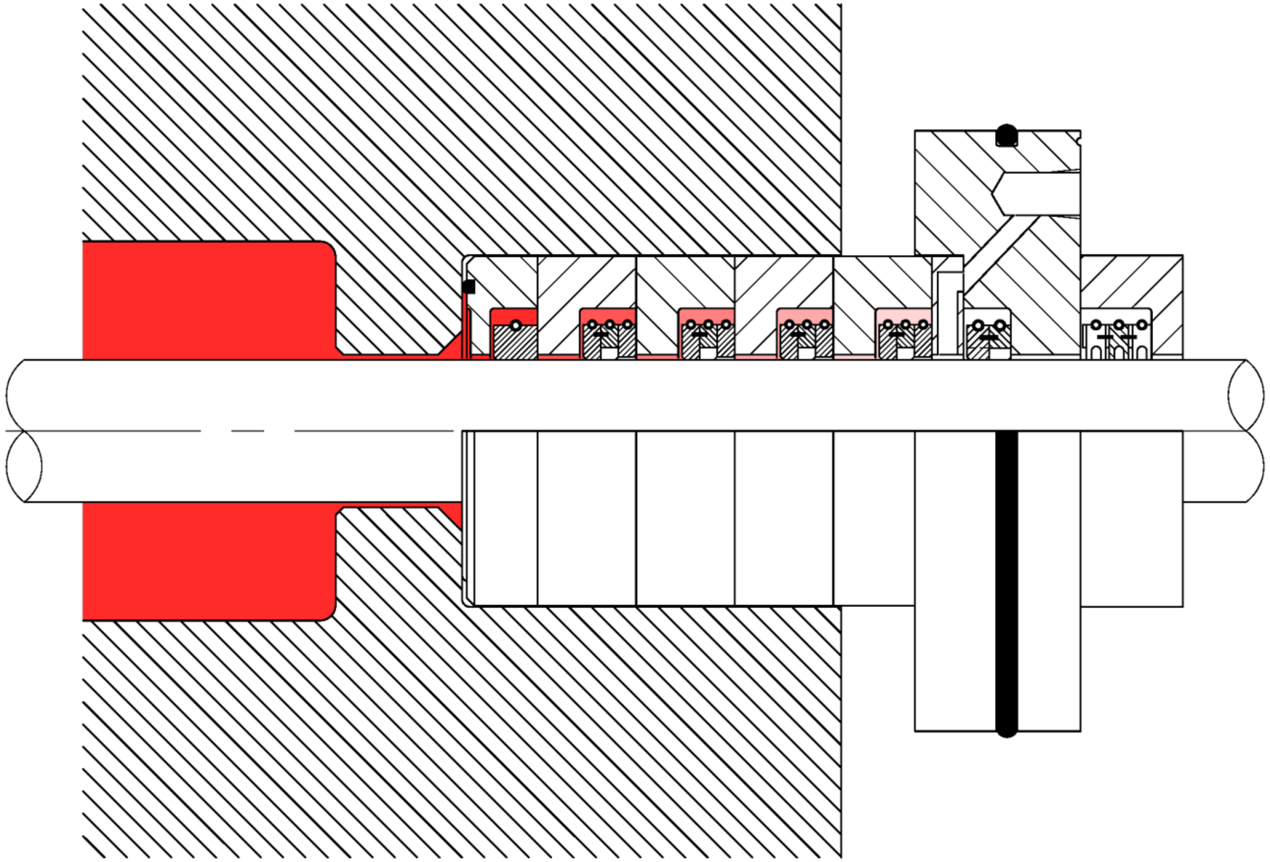
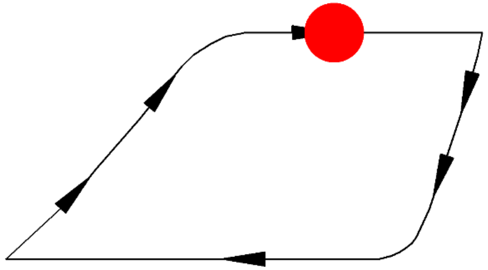


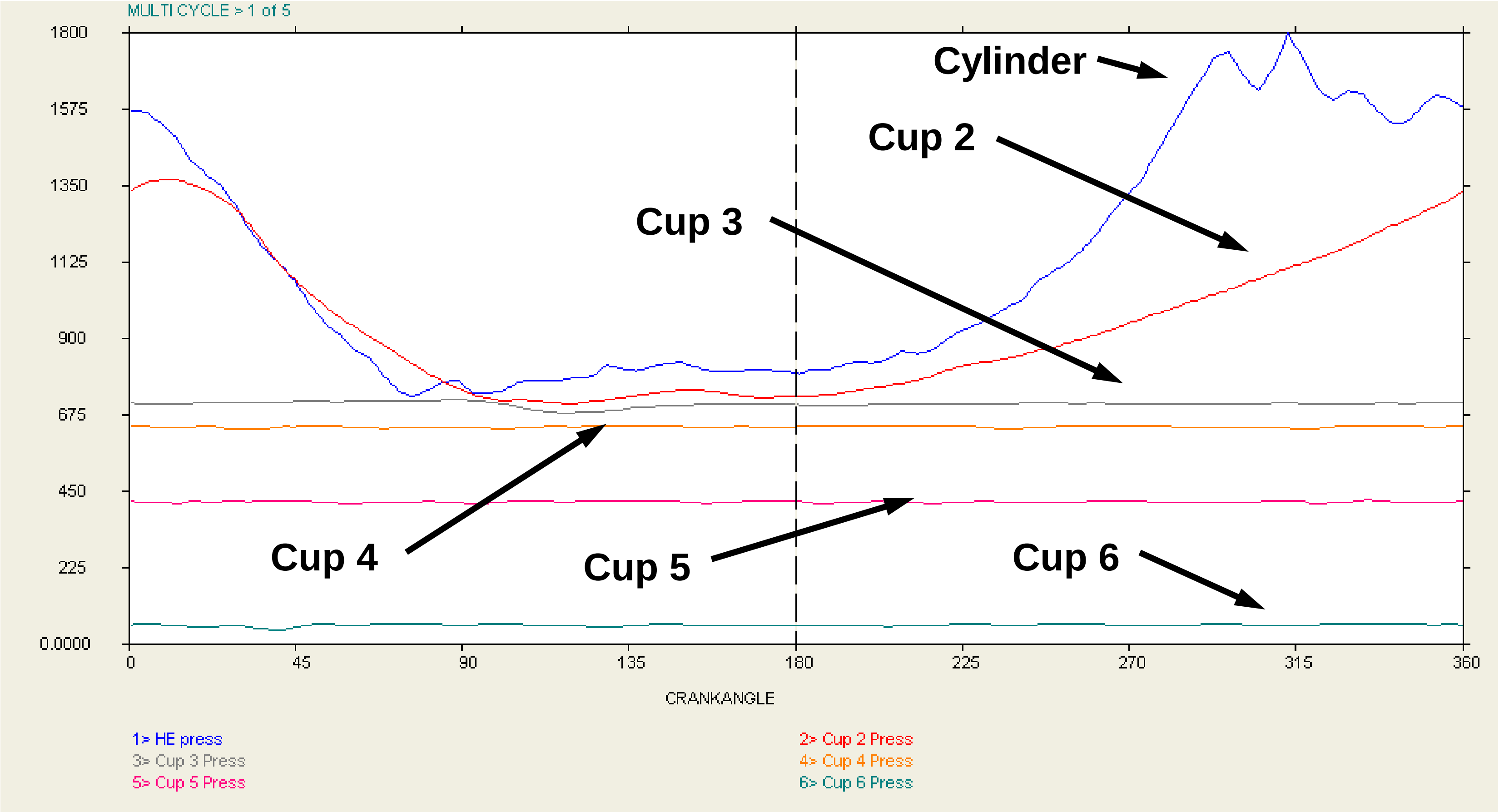
Pressure Packing Cases - Fundamental





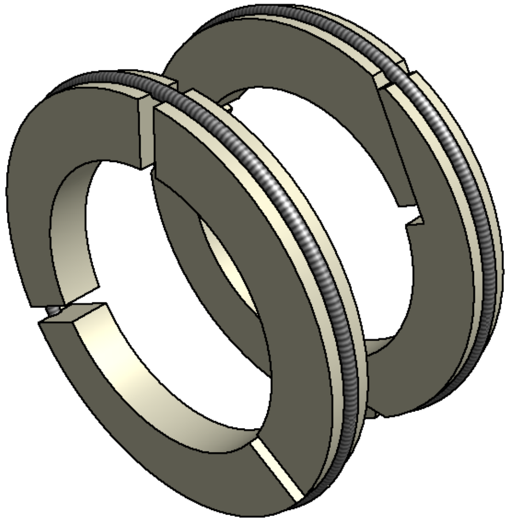
Pressure Packing Cases - Fundamental

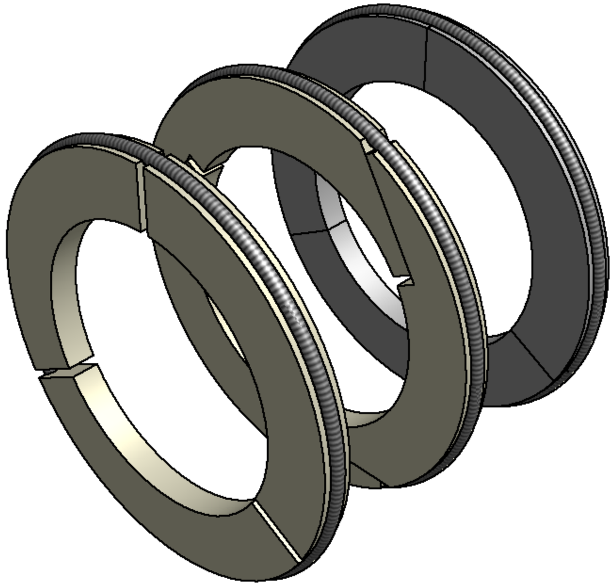
- Each cup and seal ring breaks down pressure



Pressure Packing Cases – Standard Seal Rings

- Standard floating mechanical packing seal design has been around for 100 years +
- Gaps for wear compensation covered by the adjacent ring
- Backup rings do not seal on the rod but reduce clearance to prevent extrusion





Pressure Packing Cases - Considerations

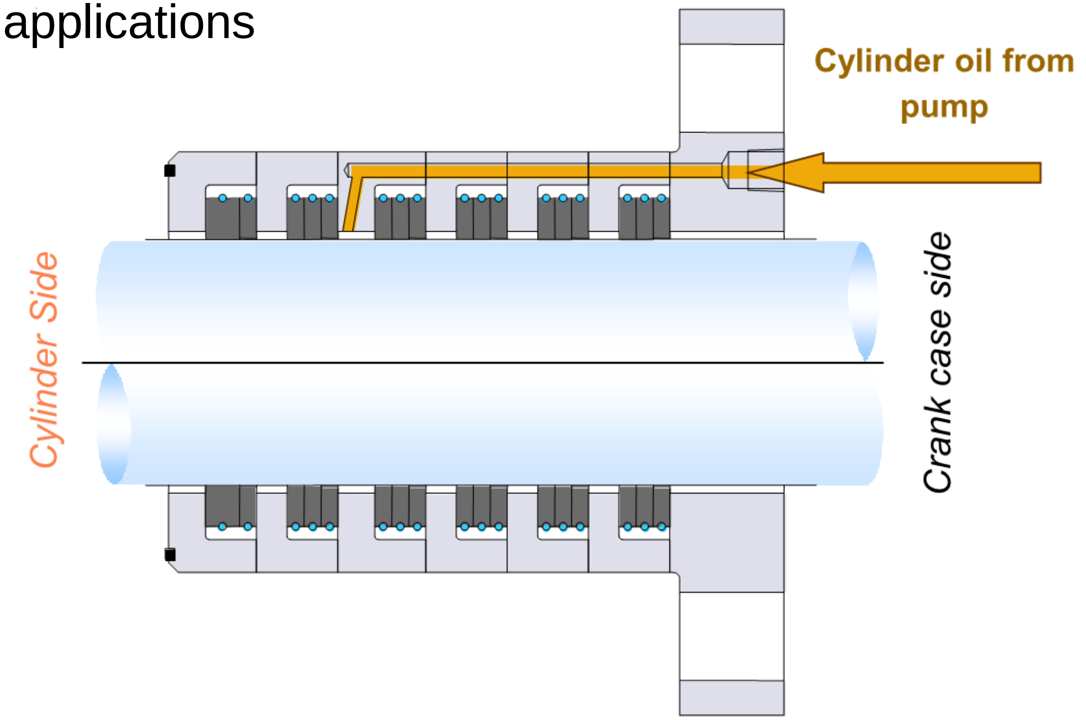
- Gas Pressure
- Gas Temperature
- Speed (sliding speed)
- Lube or non-lube
- With or without cooling
- With or without purge / buffer gas
- Gas type and dewpoint

- The types and numbers of ring styles and groups within a packing are dependant on all these considerations!

- Material selections are equally driven by all these considerations!

Pressure Packing Cases - Lubrication

- Forced lubrication applied via injection on top of rod
- Reduced friction and heat
- Increased cost of operation
- Necessary for high pressure & high speed applications



Pressure Packing Cases – Non Lube

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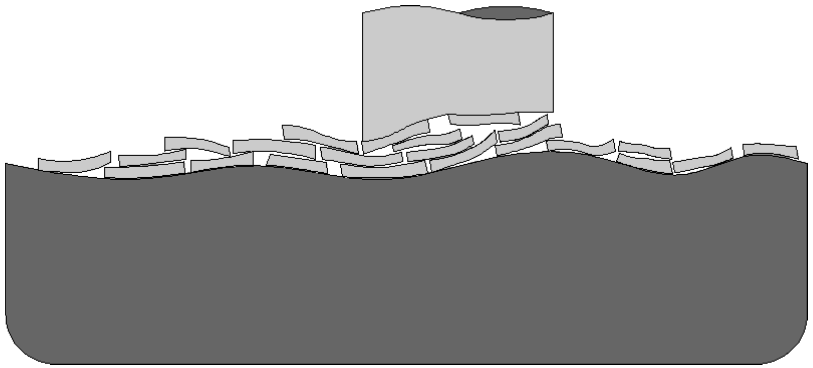
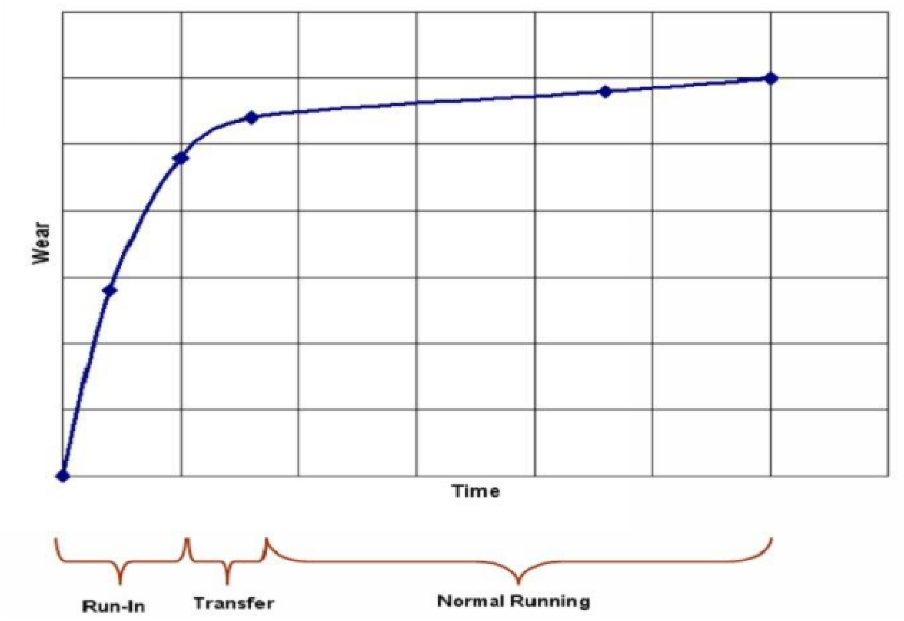
- Requires special material grades (PTFE based)
- Requires a transfer film of polymer onto metal rod
- Mechanical depostion requires proper surface finish
    - Induction hardened 0.2 – 0.3 Ra
    - TC coated 0.15 – 0.2 Ra
- Chemical reaction at interface depends on temperature & environment

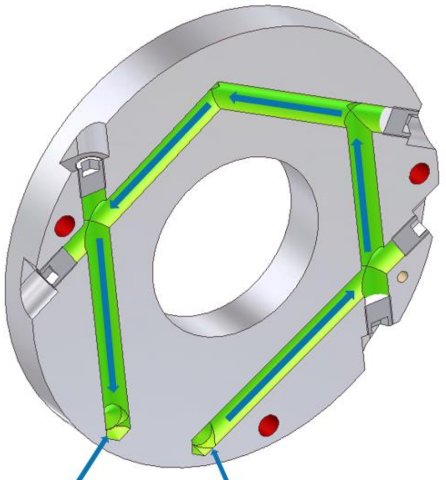


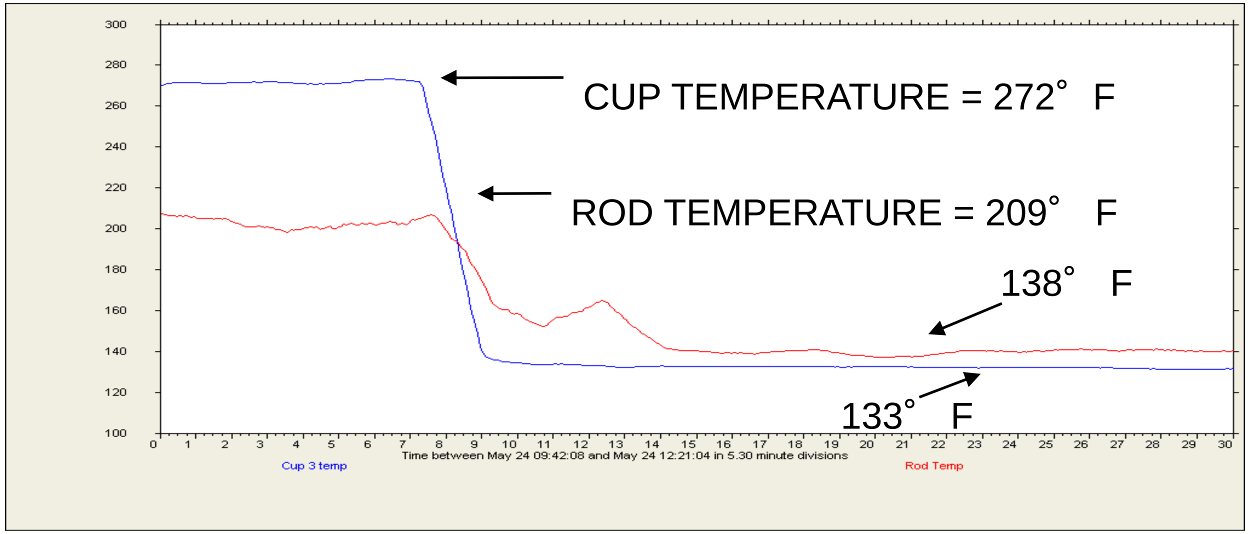
Wear over Time due to Transfer Deposition



Pressure Packing Cases – Cooling

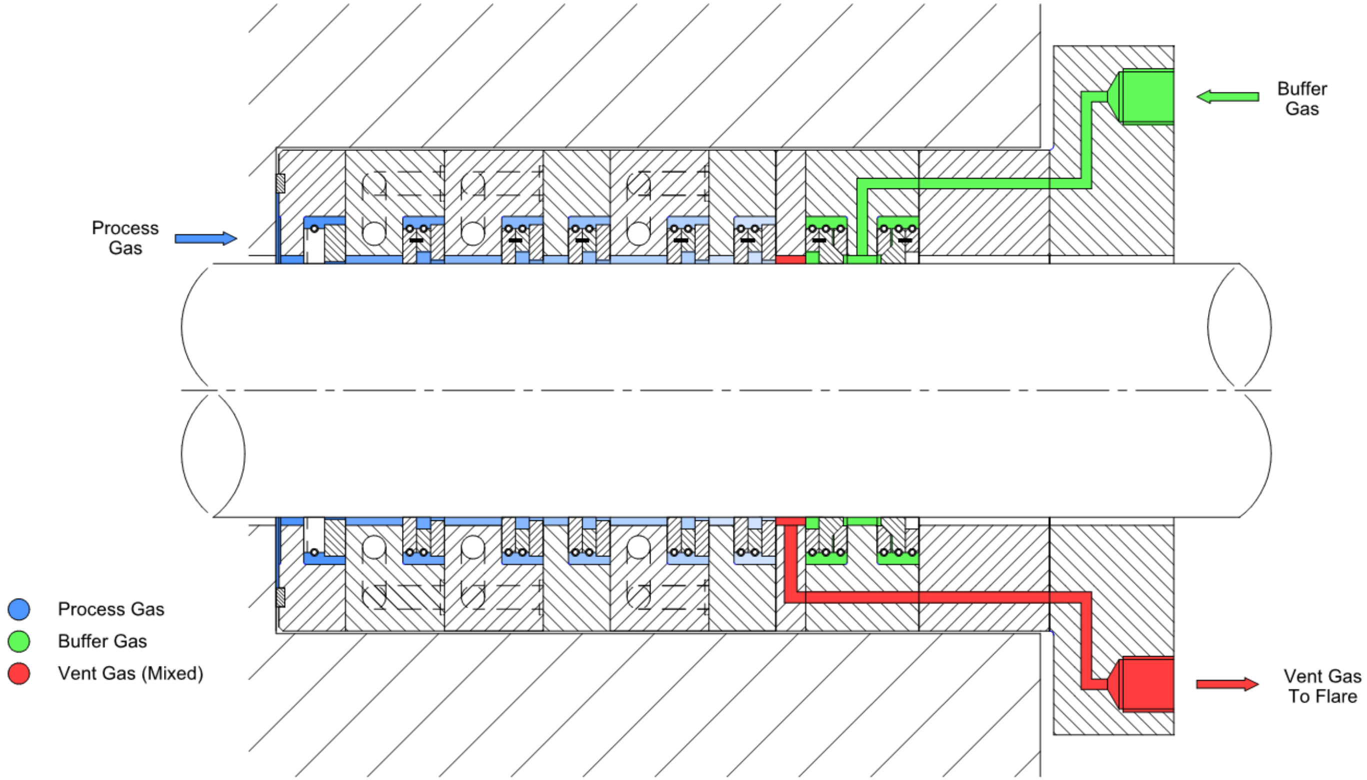
- API 618 states cooling is required for -
  - All non-lubed cases
  - Lube cases with non-metallic rings above 500 psi
  - All cases, lube or non-lube above 1500 psi
- Cooling reduces running temperature and extends wear life of polymer materials





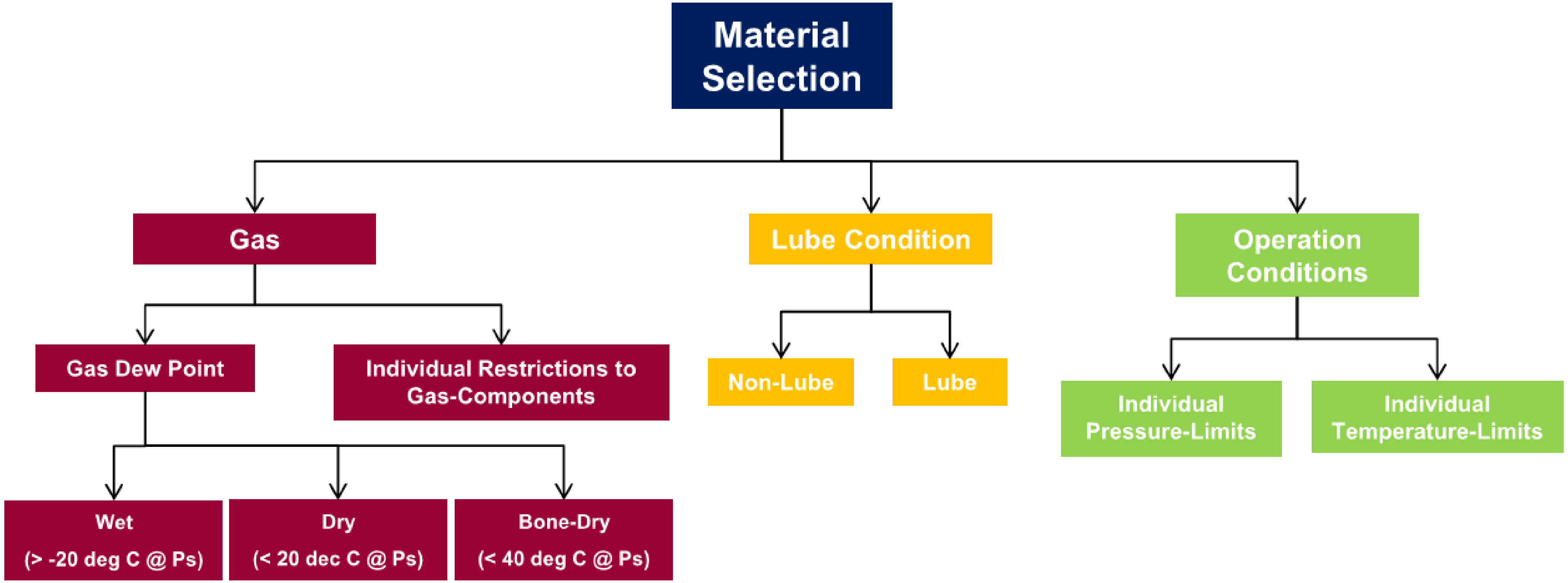
Pressure Packing Cases – Purge / Buffer

- Ensures residual gasses travel to the vent line rather than atmosphere
- Buffer pressure set to vent line pressure + 1 bar



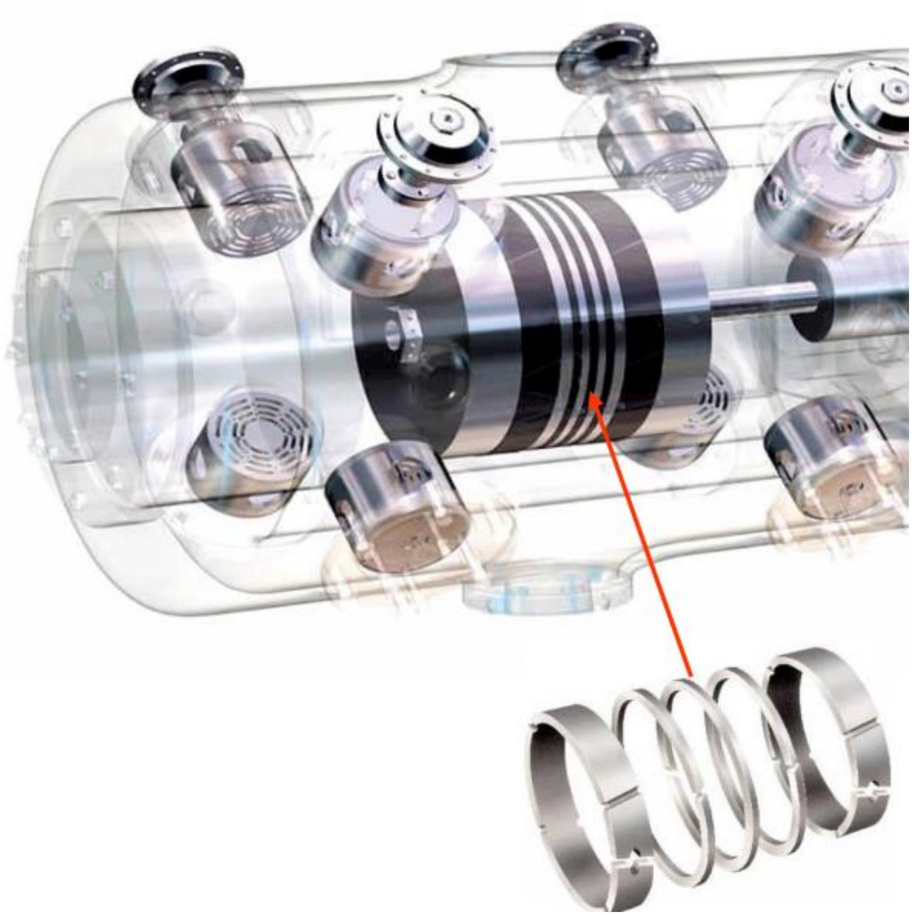
Pressure Packing Cases – Material Considerations

- Material selection for the application is critical



Cylinder Rings

- Fundamental operating principles
- Piston Rings
- Rider Rings



Picture Courtesy Hoerbiger

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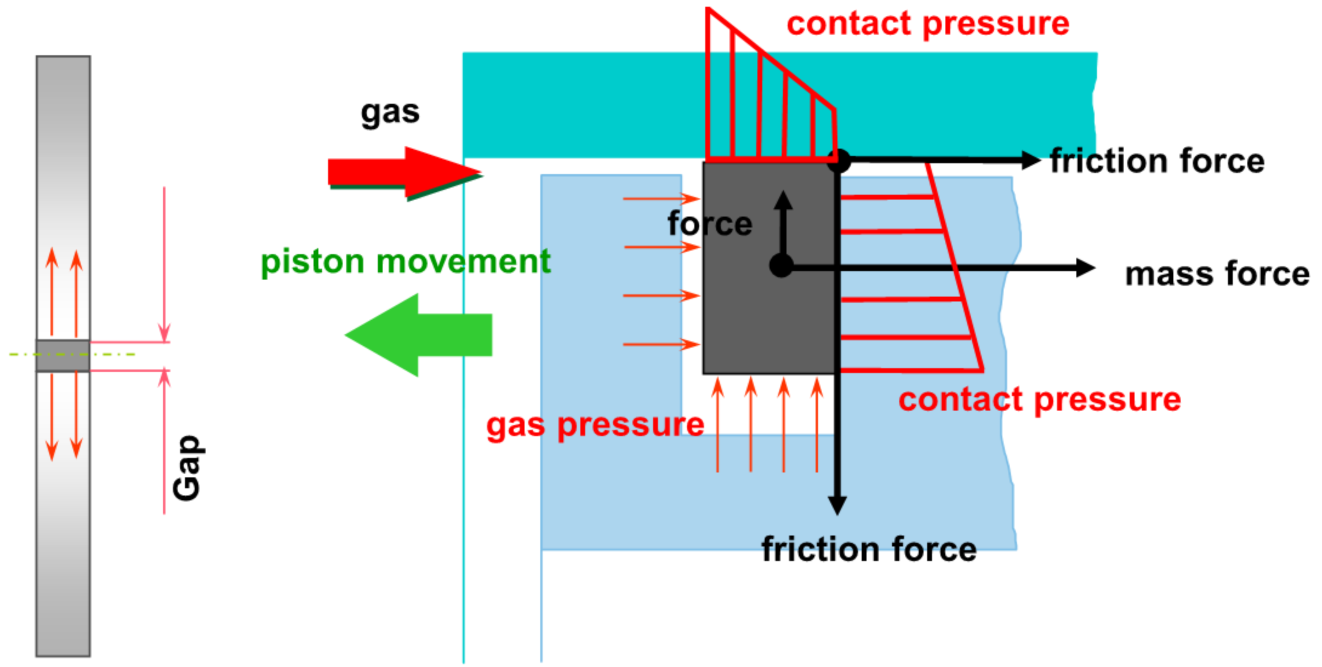
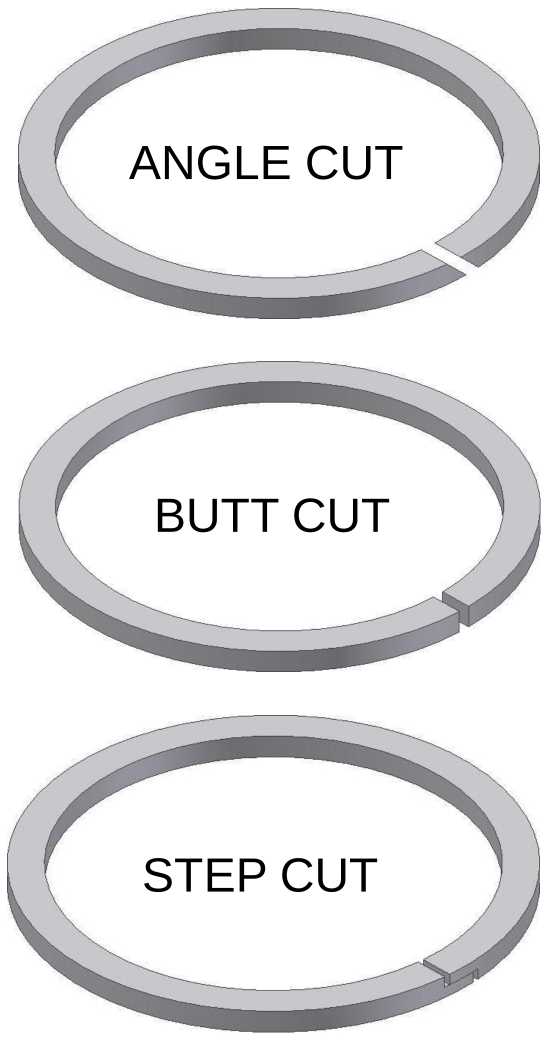
Cylinder Rings – Piston Rings

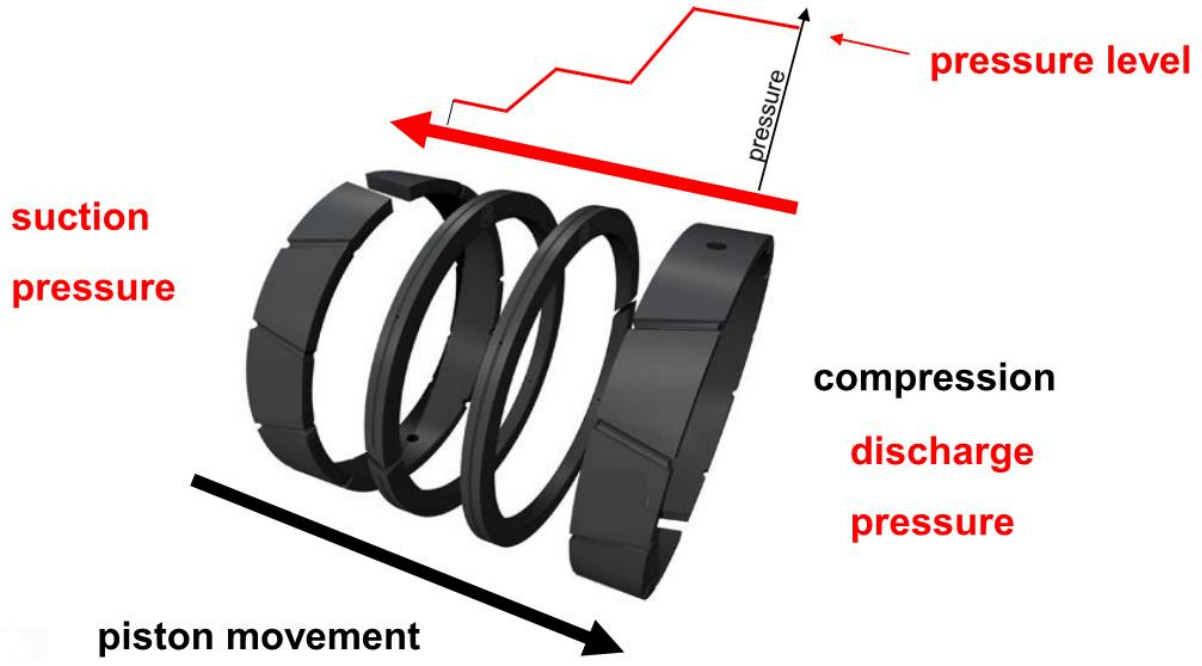
- End gap and axial gap critical
- End gap compensates for expansion due to temperature
- Pressure actuated against cylinder wall





Cylinder Rings – Piston Rings

- Number of piston rings determined by pressure difference



Pressure Differential	Number of Rings
Below 300 psi	2 – 4
300 – 800 psi	3 – 5
800 – 2000 psi	4 – 6
2000 – 3500 psi	5 – 7
Over 3500 psi	6 – 8

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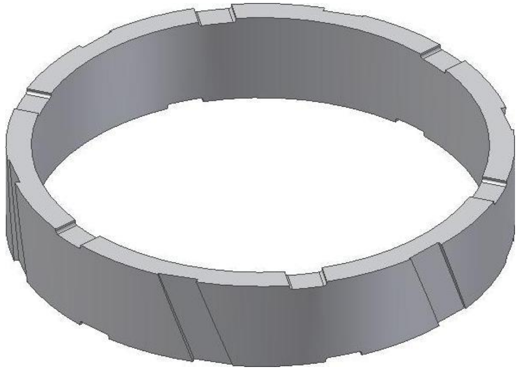
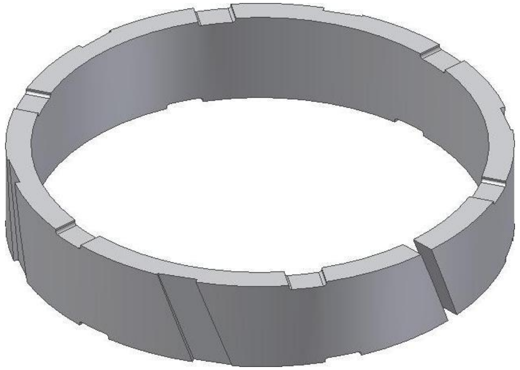
Cylinder Rings – Rider Rings

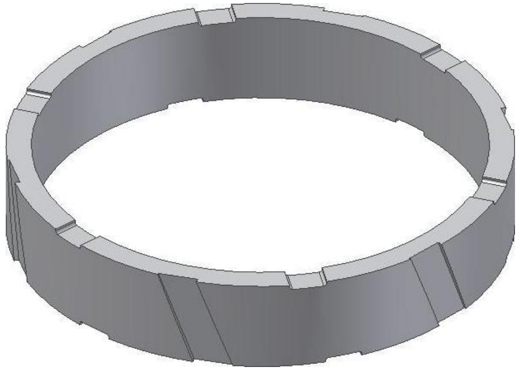
- Support the mass of the piston
- Must Not seal gas!
- Face flutes or grooves allow gas passage past the ring
- Side notches prevent seal against groove sides
- May be uncut inteference fit on piston or with end cut

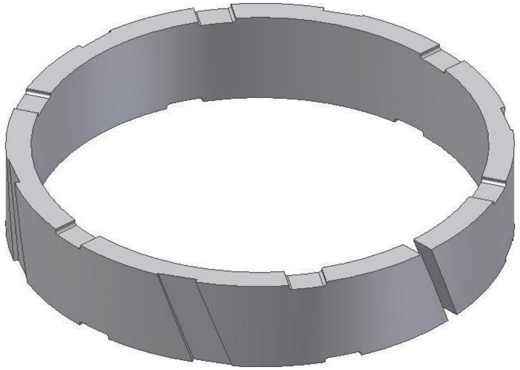




Cylinder Rings – Rider Rings

- Mass must be supported along full stroke
- Accounting for cylinder cutout overun
- Mass of piston + ½ rod = effective mass
- Assuming 1/3 circumference for load calculation
- Minimum width = effective mass / (0.866 x σ x Cyl Dia)
  - Target loadings
  - σ = < 5 psi for non-lube service
  - σ = < 10 psi for lubricated service





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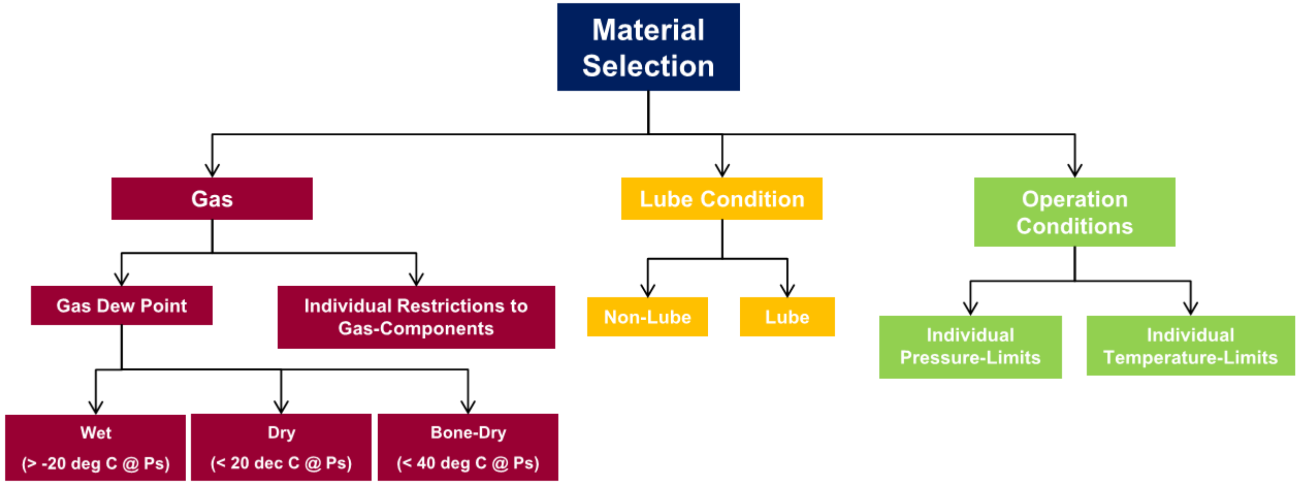
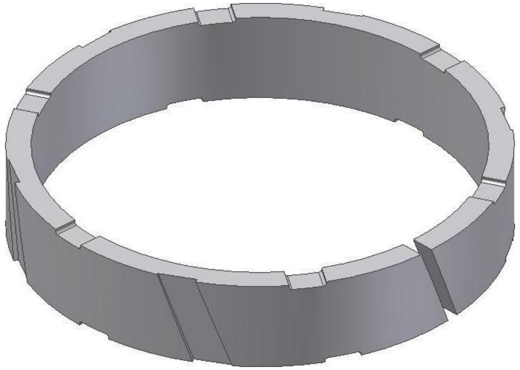
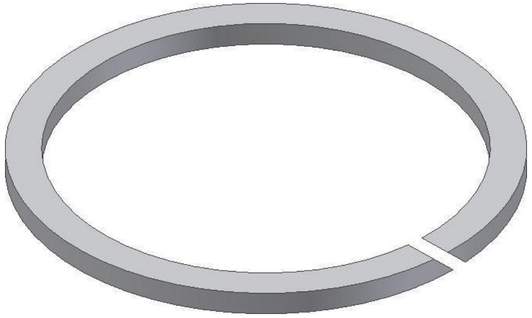
Cylinder Rings – Materials

- Material considerations for cylinder rings are similar to packing case seal materials
- Lube or non-lube
- Gas type and dewpoint







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EFRC Training Workshop 2019

Critical Compressor Components

Questions?