EFRC Training Workshop
State-of-the-art Design of Reciprocating Compressor Systems

Options for Compressor Sizing

Niek Albers – Howden Thomassen Compressors B.V.

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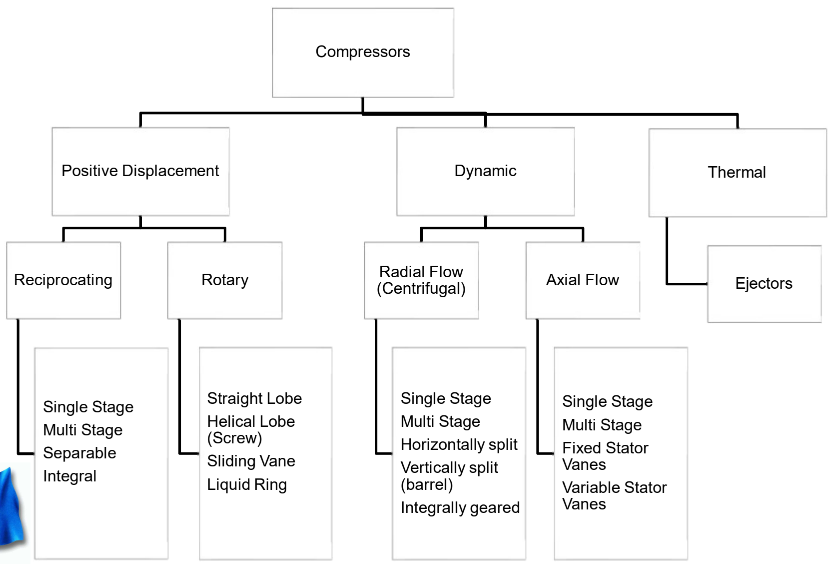
September 13th 2018

Compressor types



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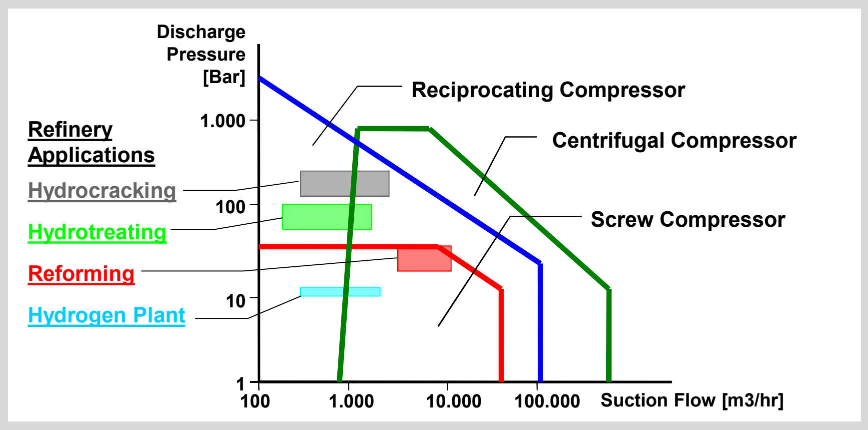
Compressor applications



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Why use a piston compressor?

- **High efficiency**

- **High flexibility**
- Variable process conditions (gas composition, pressure)
- Capacity control (flow)

- **High pressure ratio for low molecular mass gas**

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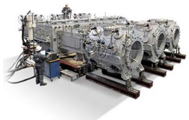
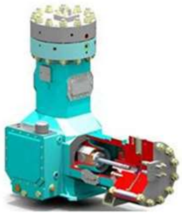
Compressor configurations

Horizontal



Vertical

L-type



V-type

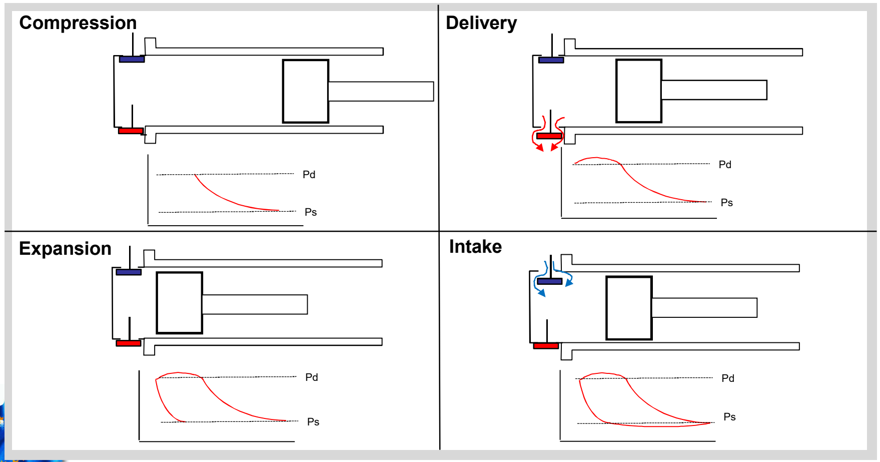
W-type

Image source: Howden, SIAD MI (V), GEA Grasso (W)

Compressor configurations

	Horizontal	Vertical	L-type	V-type
Footprint	--	++	+	+
Maintenance	+	-	-	-
Scalability	++	+	-	-
Capacity	++	+	-	-

Operating Principle



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Basis of design for sizing

Client has to specify:

- Gas composition
- Environmental conditions (ambient temp, cooling water)
- Suction pressure P_s
- Suction temperature T_s
- Discharge pressure P_d
- Required normal flow Q_0 [Nm3/hr] or mass flow [kg/hr]
- Capacity control requirements
- Power frequency in case of E-motor driver

For design case and alternative operating cases (if any), such as starting, nitrogen case etc.

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How many compression stages?

No. of stages typically determined by temperature limit (client, API 618).
Calculation of (adiabatic) discharge temperature:

$$T_d = T_s \cdot r_p^{\frac{k-1}{k}}$$

Where $r_p = p_d / p_s$ = pressure ratio
k = specific heat ratio

If $T_d > T_{d,\,max}$ (client, API 618) then increase number of stages

$$r_{p\_stage} = \sqrt[x]{r_p}$$

Where x = number of stages

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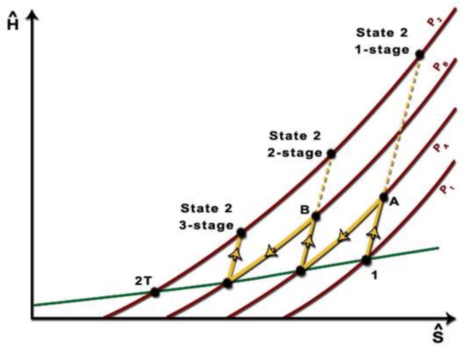
How many compression stages?



- Effluent from a single stage compressor has a high enthalpy
- This energy is provided by the compressor – extra work!
- Isothermal compression is by definition most efficient process
- Would require an infinite number of stages

Image source: www.learnthermo.com

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Design iterations

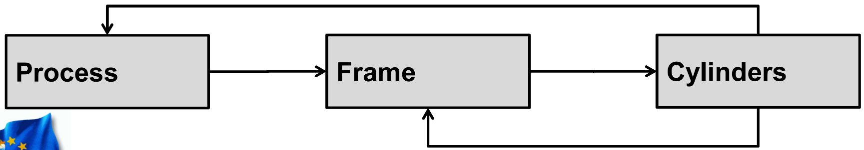
In case discharge temperature is too high:

•Increase number of compression stages: allows interstage cooling, compression cycle closer to isothermal process so more efficient

•Cooling: Apply pre-cooler at suction, increase interstage cooling (watch out for liquids, use properly sized separators)

•In case of multi-stage compressors: change pressure differential for relevant stage (other stage discharge temperature will increase).

General: Design optimization is iterative!



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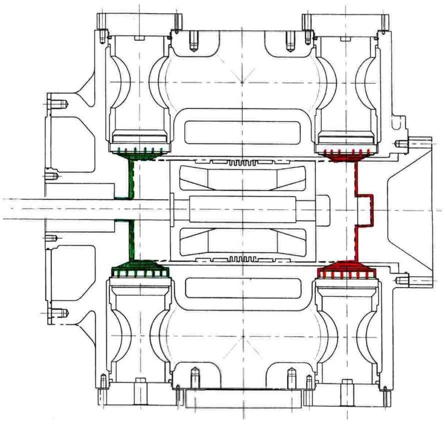
Clearance Volume

1. Clearance between piston and end of cylinder
2. Volume in the suction and discharge valves
3. Volume between the suction and discharge valves and the cylinder
4. Possible dead spaces

Clearance volume normal range

10~20% of swept volume



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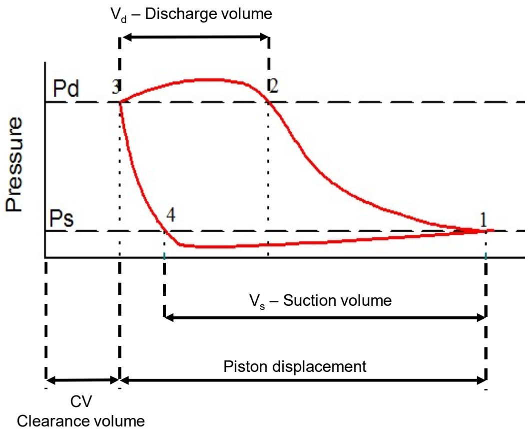
Volumetric Efficiency

$$\eta_v = \frac{\text{intake volume}}{\text{piston displacement}}$$

$$\eta_v = 1 - CV(\varepsilon - 1)$$

$$\varepsilon = \frac{V_s}{V_d} = \left(\frac{p_d}{p_s}\right)^{\frac{1}{k}} \cdot \left(\frac{Z_s}{Z_d}\right)$$



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Required Piston Area

Calculation of required piston area:

$$\eta_v = 1 - CV(\varepsilon - 1)$$

$$A_{HE} + A_{CE} = \frac{Q_s}{n \cdot s \cdot \eta_v \cdot \lambda}$$

$$\varepsilon = \frac{V_s}{V_d} = \left(\frac{p_d}{p_s}\right)^{\frac{1}{k}} \cdot \left(\frac{Z_s}{Z_d}\right)$$

A_{HE} = Piston area Head End = $\pi/4 \cdot D^2$
A_{CE} = Piston area Crank End = $\pi/4 \cdot (D^2 - d^2)$
Q_s = Suction volume flow
D = Cylinder diameter
d = Piston rod diameter
s = Stroke
n = Compressor speed
η_v = Volumetric efficiency
λ = Factor for leakage (approx. 0.95)

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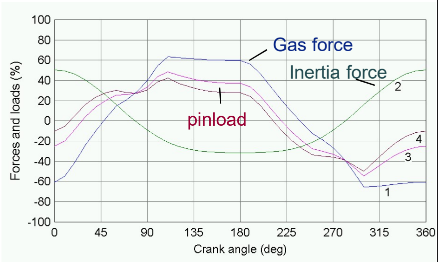
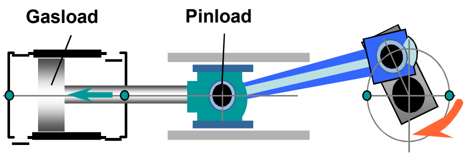
Load Constraints

Preliminary frame and cylinder selection is checked for:
•Maximum pinload
•Pinload reversal



Pinload (rodload): resulting load acting on crosshead pin,
•Summation of gas- and inertia forces
•Gas force: resulting force of pressure on piston area at HE and CE.
•Inertia force: resulting force of the reciprocating masses of piston, piston rod and crosshead.



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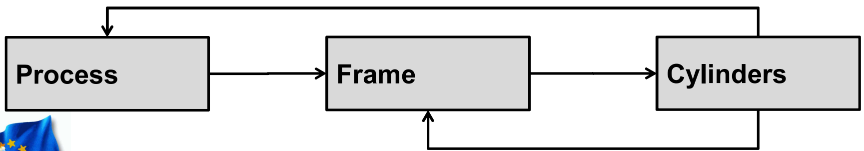
Design iterations

In case pinload is too high, reversal is too low:
•Increase frame size: increased allowable pin/rod/gasload
•Increase no. of cylinders: smaller piston area per cylinder and thus reduced loads
•In case of multi-stage compressors: change pressure difference for relevant stage (other stage loading will increase)

General: Design optimization is iterative!



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Large or small?

	Small	Large
CAPEX	-	+
Maintenance	-	+
Footprint	-	+
Redundancy	+	-

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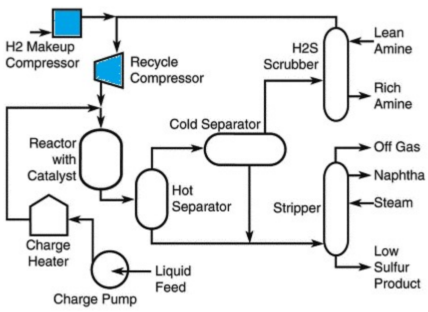
Image source: Ingersoll Rand (small air compressor)

Separate units or multiservice?



	Separate	Multiservice
CAPEX	-	+
OPEX	+	-
Footprint	-	+
Capacity	+	-
Availability	+	-

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Additional Sizing Considerations

- Compressor speed & driver
  - High or low speed?
  - Which driver type?
  - → Low speed vs. high speed compressors, Roberto Ravasio
  - → Options for driver design, Greg Phillippi
- Capacity control
  - Required control range?
  - Stepped or stepless
  - → Options for capacity control, Klaus Stachel

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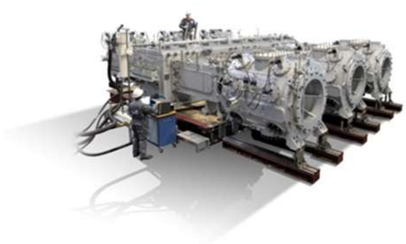
Conclusion

- Compressor sizing is an iterative process
- A solid understanding of operational requirements, constraints and customer requirements is required to achieve an optimal compressor sizing



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