Rely on excellence

Development and Testing of Dry Gas Seals for Turbomachinery in Multiphase CO2 Applications

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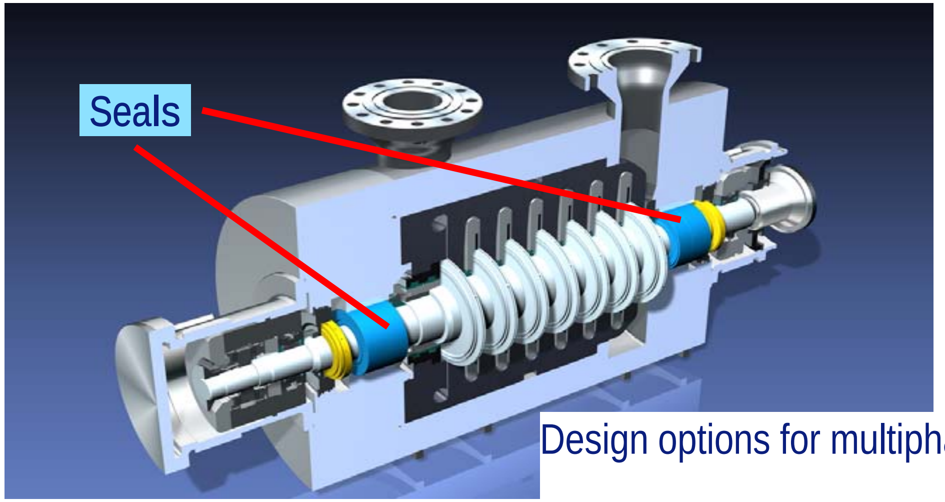
Multiphase Seals in Turbomachinery Applications

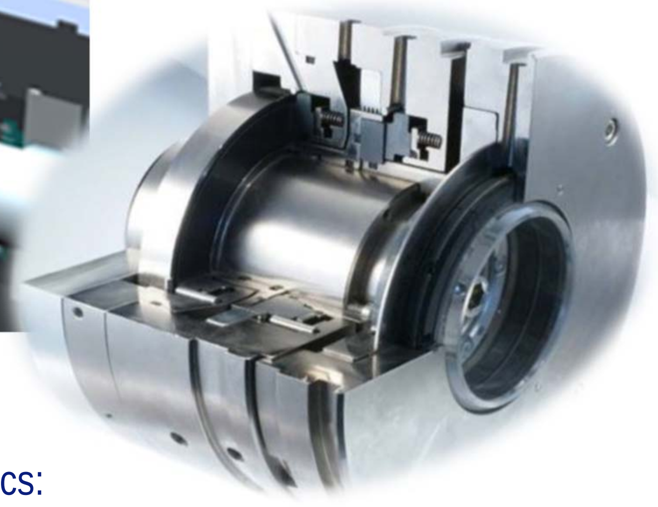


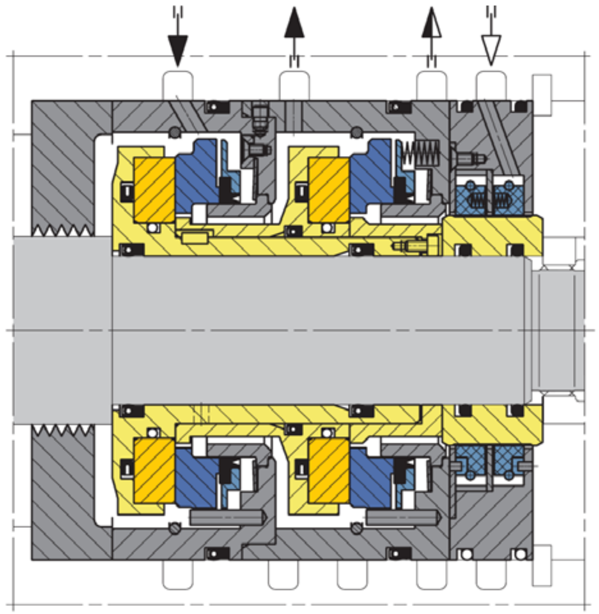
Low leakage demands require **mechanical seals**!

Design options for multiphase applications:

A)	Liquid Seal	contacting seal, small sealing width, low speed limits, low liquid leakage, cannot work with pure gas
B)	Dry Gas Seal	non-contacting, large sealing width, material determined speed limits, can work with liquids (in a limited range), very low gas leakage, high liquid leakage
C)	Liquid/Gas Seal	features of both seal designs are combined

Multiphase Seal

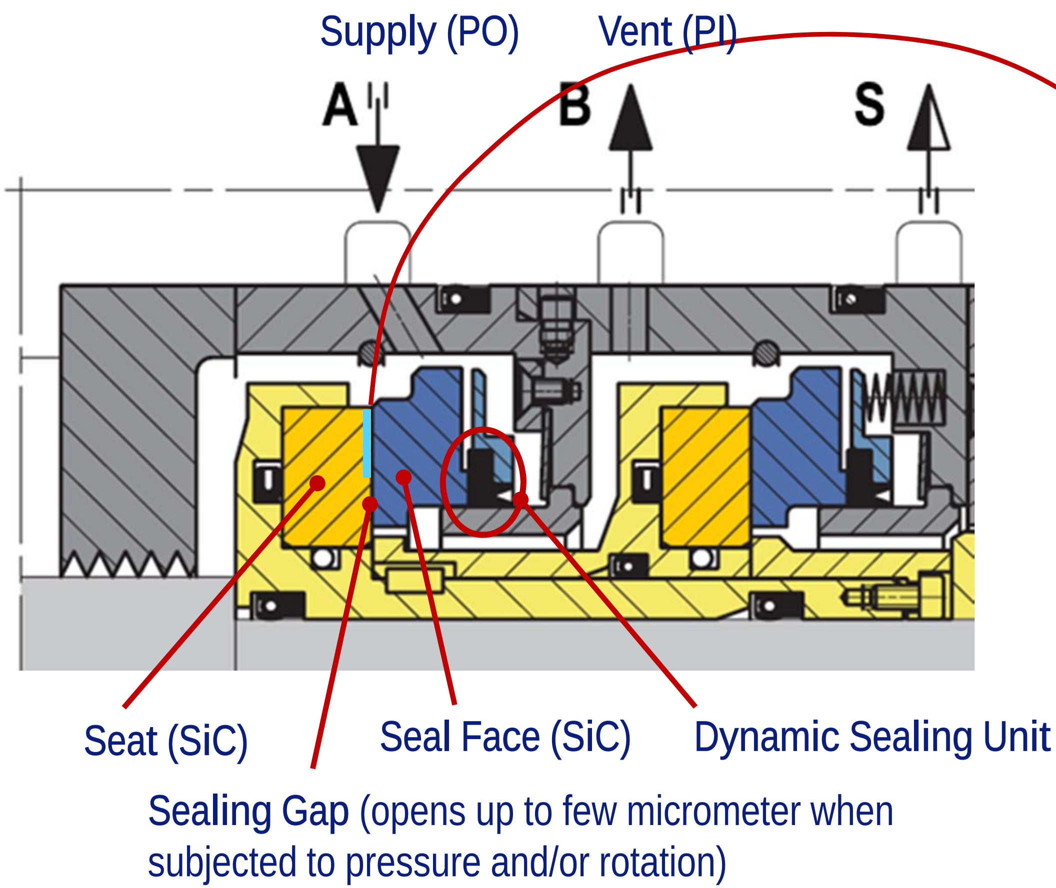


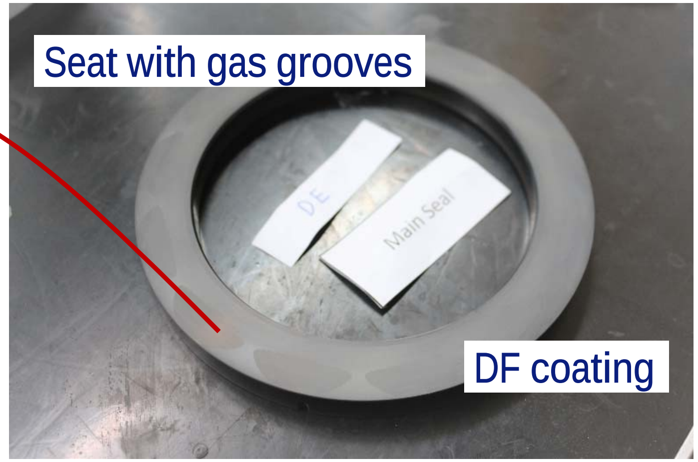


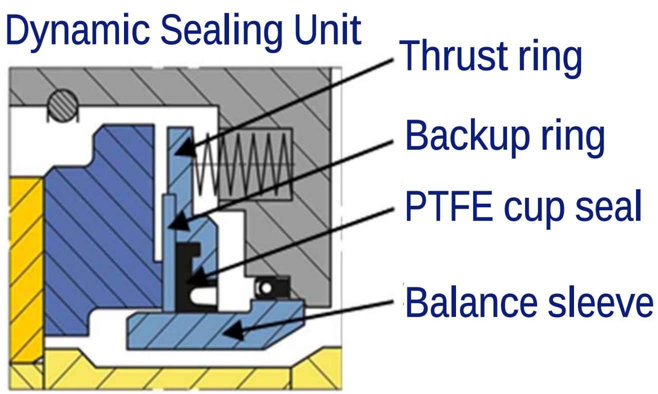
Dry Gas Seal Characteristics:

- Low gas leakage
- Low friction losses
- No wear in sliding face

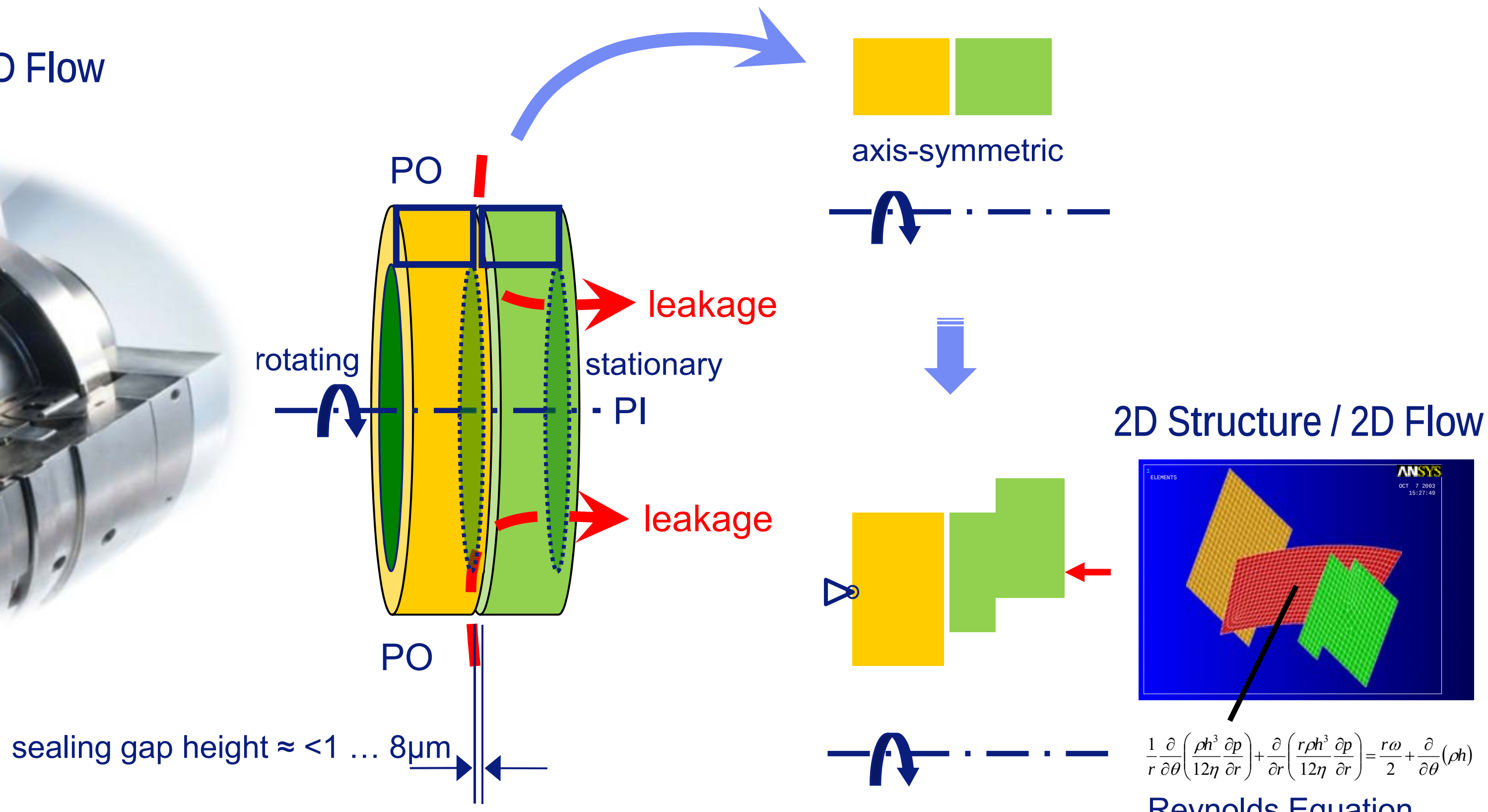
Dry Gas Seal (DGS) – Design







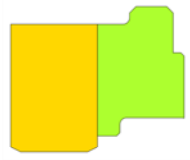
Dry Gas Seal – Analysis

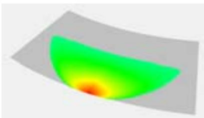


$$\frac{1}{r}\frac{\partial}{\partial\theta}\left(\frac{\rho h^3}{12\eta}\frac{\partial p}{\partial r}\right)+\frac{\partial}{\partial r}\left(\frac{r\rho h^3}{12\eta}\frac{\partial p}{\partial r}\right)=\frac{r\omega}{2}+\frac{\partial}{\partial\theta}(\rho h)$$

Reynolds Equation

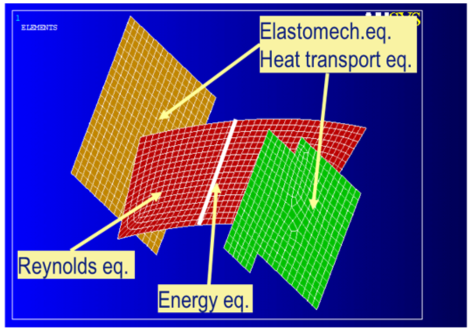
Sealanalysis – Coupled Fluid-Structure-Analysis





Design Data
Operating Data

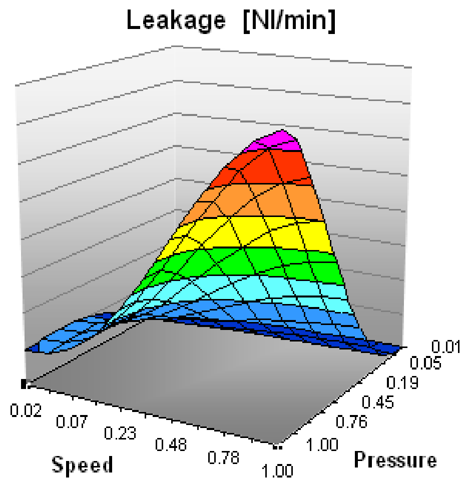
Fluid
Properties

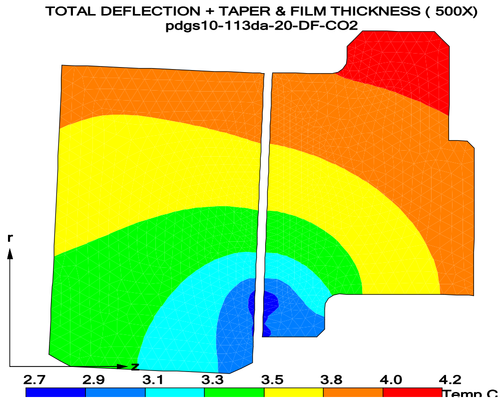


SEALANALYSIS

Addtional Calculational Design Tools

Gap flow: *p, h, v* cyclic symmetric, *f(r,θ)*
Interface: *T, q* *f(r)*
Ring System: *T, u, q* axis-symmetric, *f(r,z)*





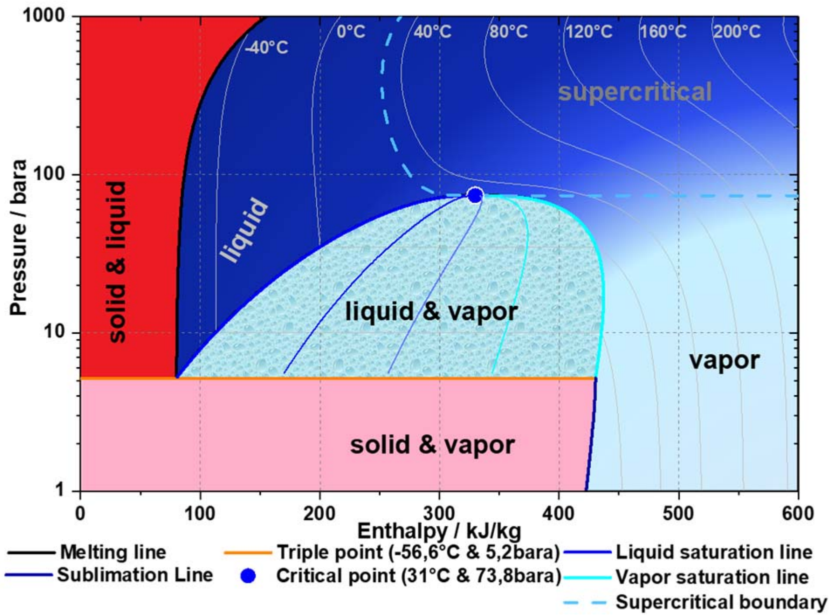
DGS for CO_2 Multiphase Applications

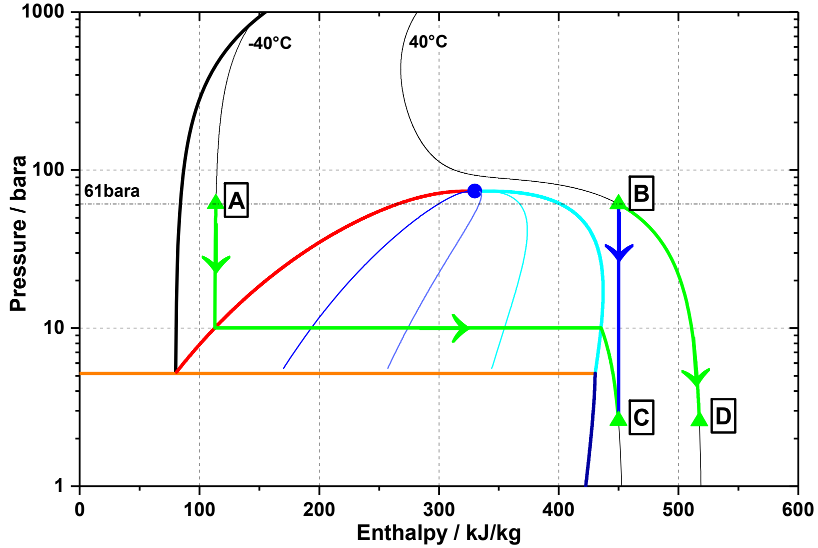
What‘s different with CO_2 compared to most other fluids?

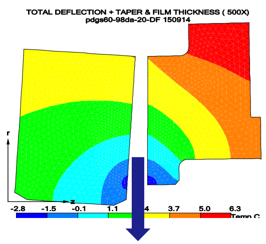
- Gas properties, in particular in transcritical region.
- Operation without additional heater possible?
- Are numerical predictions correct?

=> Verification / validation of design by internal test campaign!

Criticality of CO_2 Sealing Applications







A → C … isothermal, ΔT = 0K

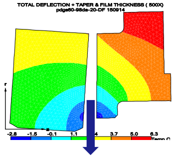
B → C … isenthalpic, ΔT = -80K

B → D … isothermal, ΔT = 0K

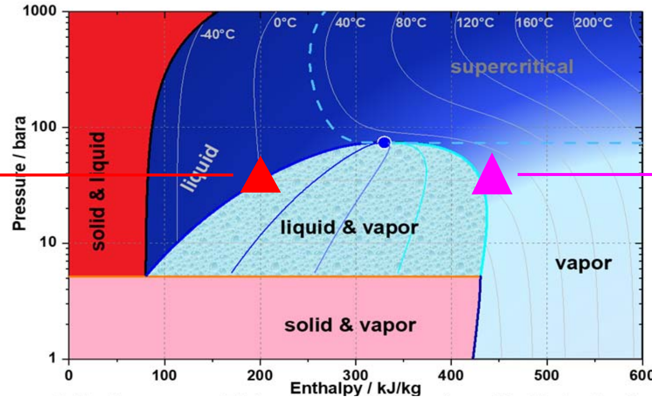
(Almost) Isothermal Expansion – What does it really mean?

PO = 40bar, PI = 1bar

CO_2, Static



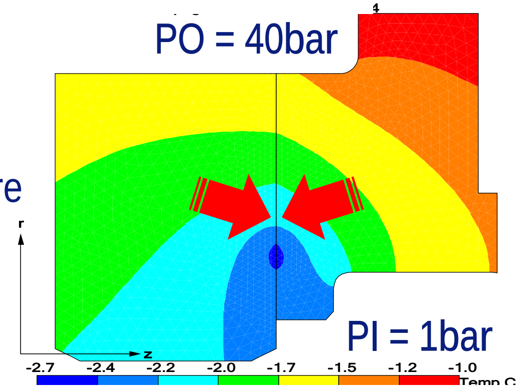
T = 0°C



T = 10°C

Constant ambient temperature

PO = 40bar

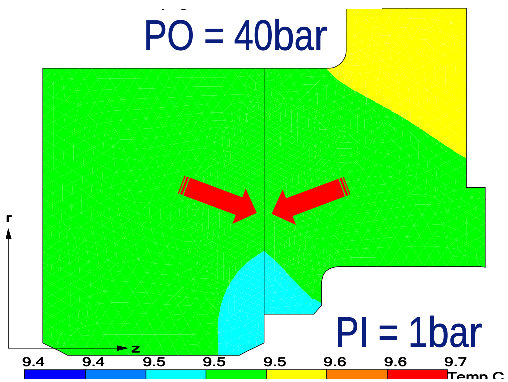


PI = 1bar

T >> -56.6°C !

Expansion with only little temperature drop in the ring system is referred to as **almost isothermal** or simply **isothermal**!

PO = 40bar



PI = 1bar

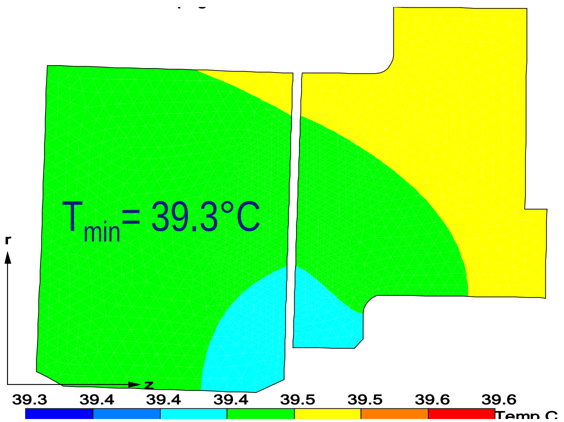
Constant ambient temperature

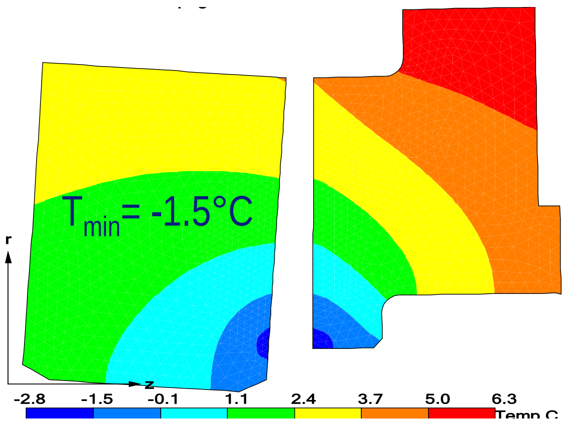
Criticality of CO_2 Sealing Applications

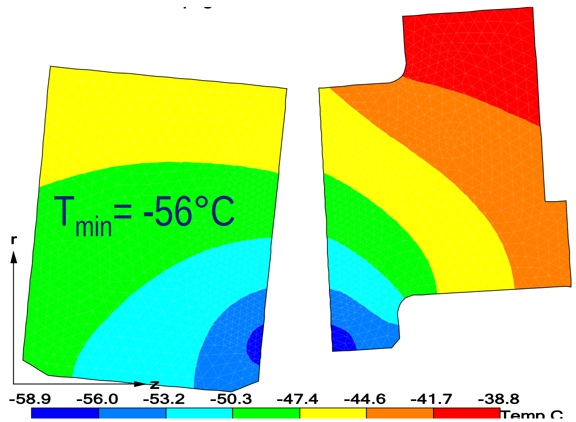
PO = 60barg, PI = 0barg, **T = 40°C**, CO_2, Static

Result plots: Total deflection and isotherms (scale 500X)

Reference | **Inappropriate gap design 1** | **Inappropriate gap design 2**





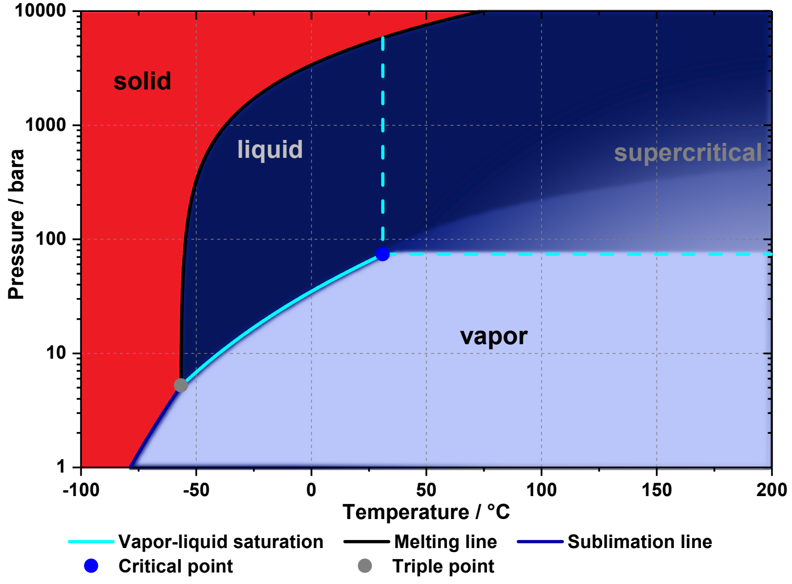


Leakage: 2.2 Nl/min | **107 Nl/min** | **260 Nl/min**

Avoiding adverse effects on seal performance requires extremely low leakage levels!

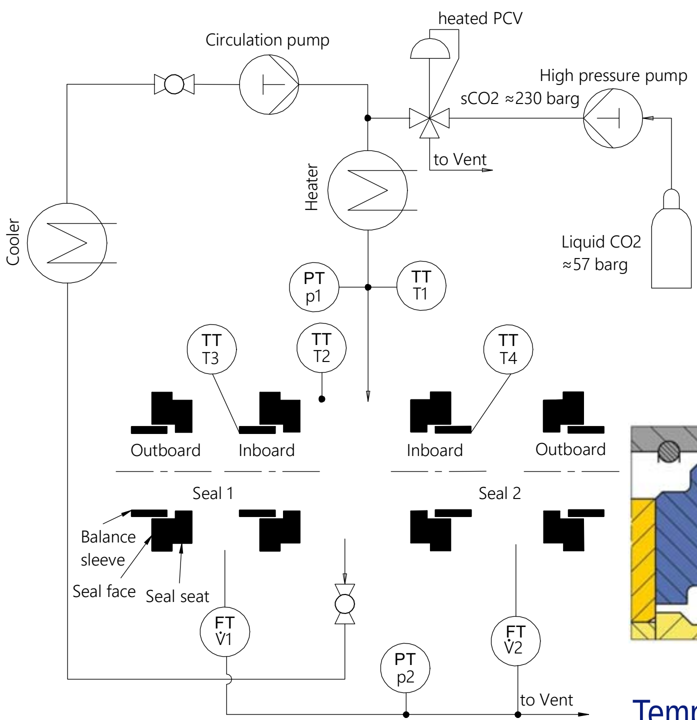
Test Set-up and Testing Range (Pressure/Temperature)

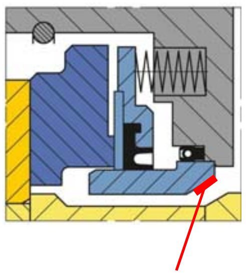
Multiphase suitability: Seal can operate in liquid, two-phase, vapor and supercritical region **without additional heater**!



Test Set-up and Testing Range (Pressure/Temperature)

Simplified PID

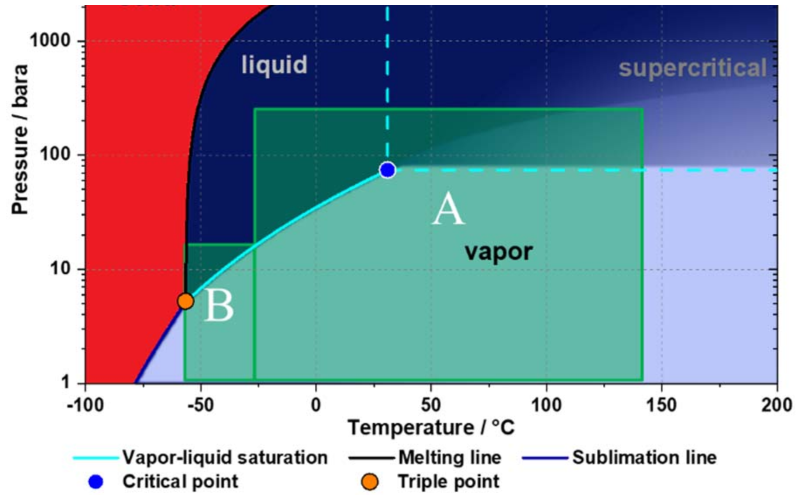




Temperature probes

Multiphase suitability: Seal can operate in liquid, two-phase, vapor and supercritical region **without additional heater**!

P-T Range of Testing

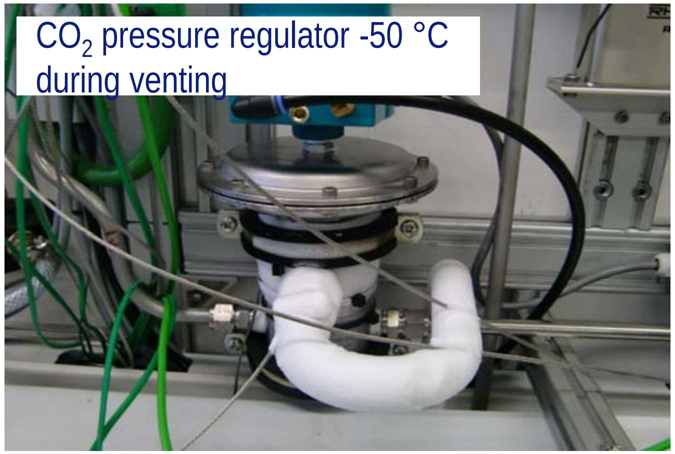


A … normal operating range

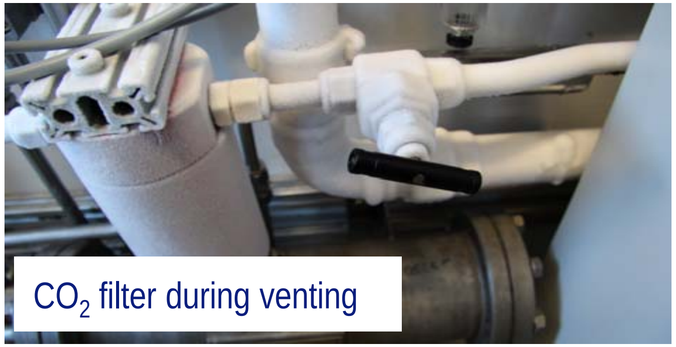
B … failure test

CO_2 Test Facility


Control room

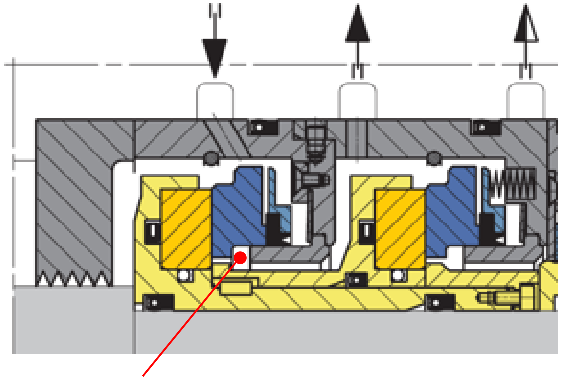

CO_2 pressure regulator -50 °C during venting


Setup for pump seal test


CO_2 filter during venting

Test Program

		Pressure	Speed	Temperature	Time
		barg	rpm	°C	h
Tandem seal	static	60 / 80 / 200	-	0 … 120	
	static	60	-	0 … 100	18
	dynamic	60 / 80 / 180	3600	0 … 120	
Single seal	static	60	-	ambient	48
	static	200	-	ambient	14



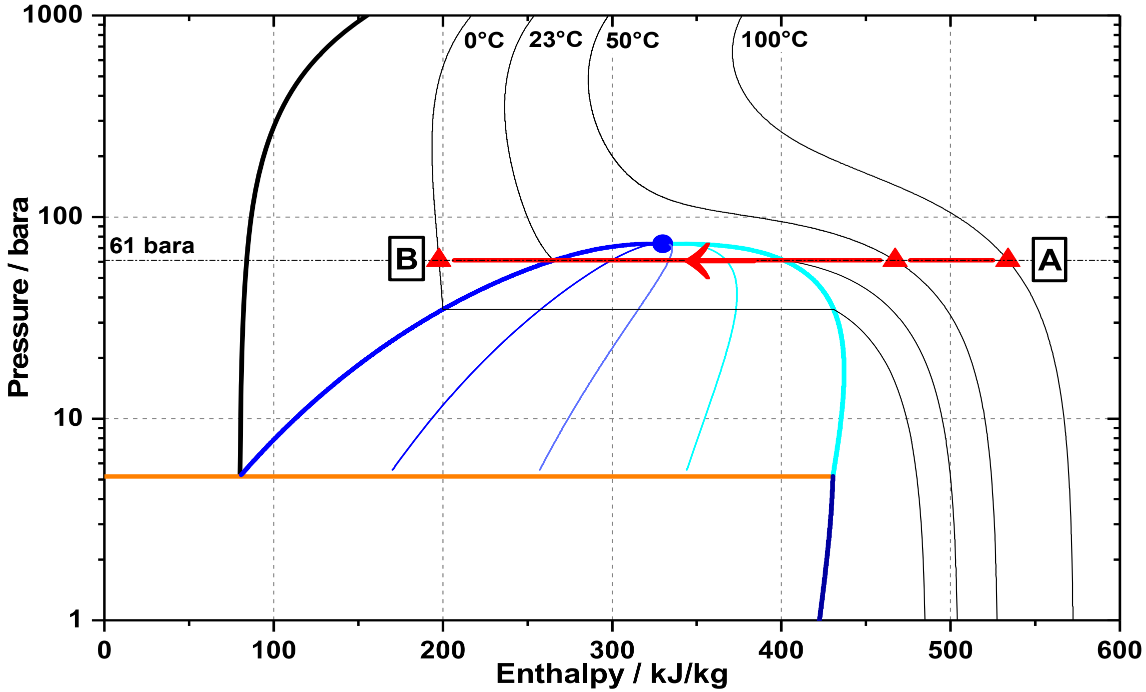
Low pressure area:

- optional protected by N2 (tandem seal)
- exposed to ambient conditions (single seal)

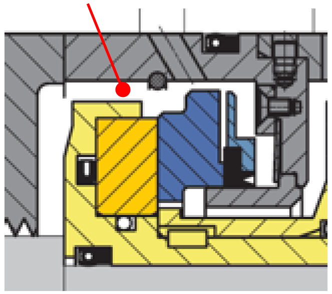
Additional: **Seal failure simulation**

60barg CO_2 Static Test, Decreasing Temperature

Test section: Cool down phase (18h) after dynamic run with hot CO_2



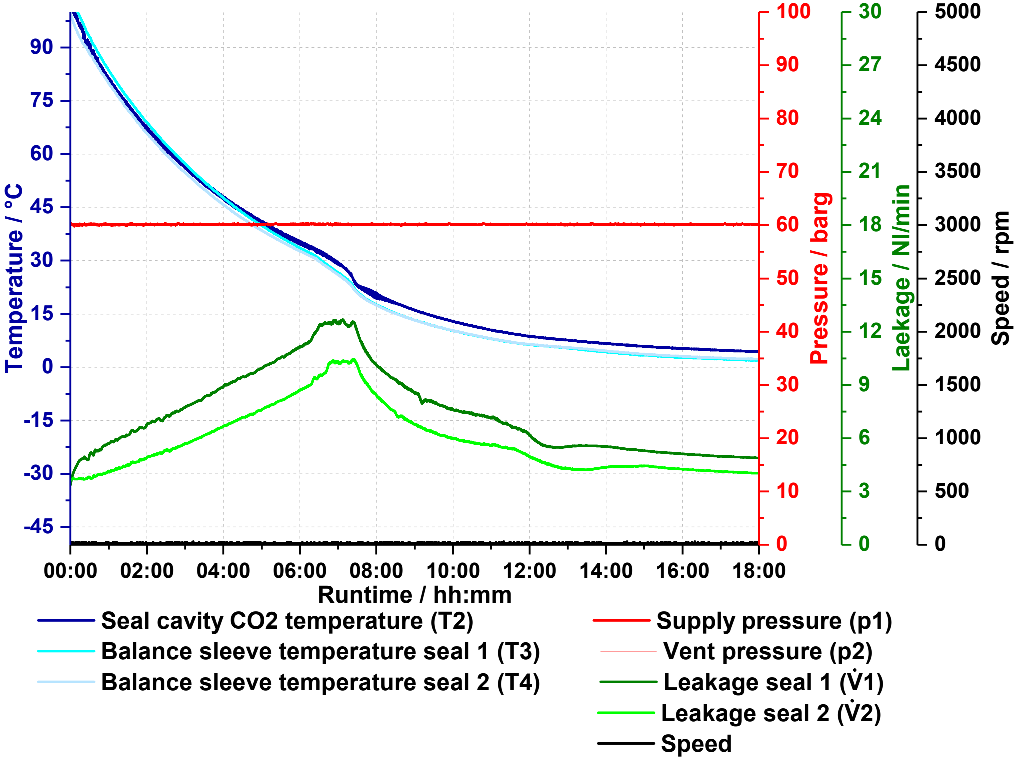
P const., T decreasing

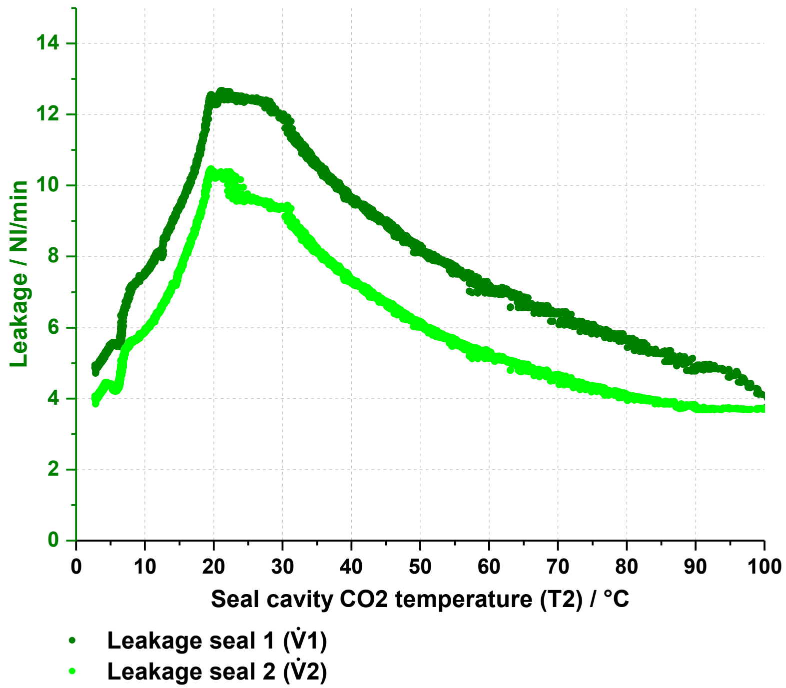


- A Start in gaseous region 60barg/100°C
- B End in liquid region 60barg/0°C

60barg CO_2 Static Test, Decreasing Temperature

Test section: Cool down phase (18h) after dynamic run with hot CO_2





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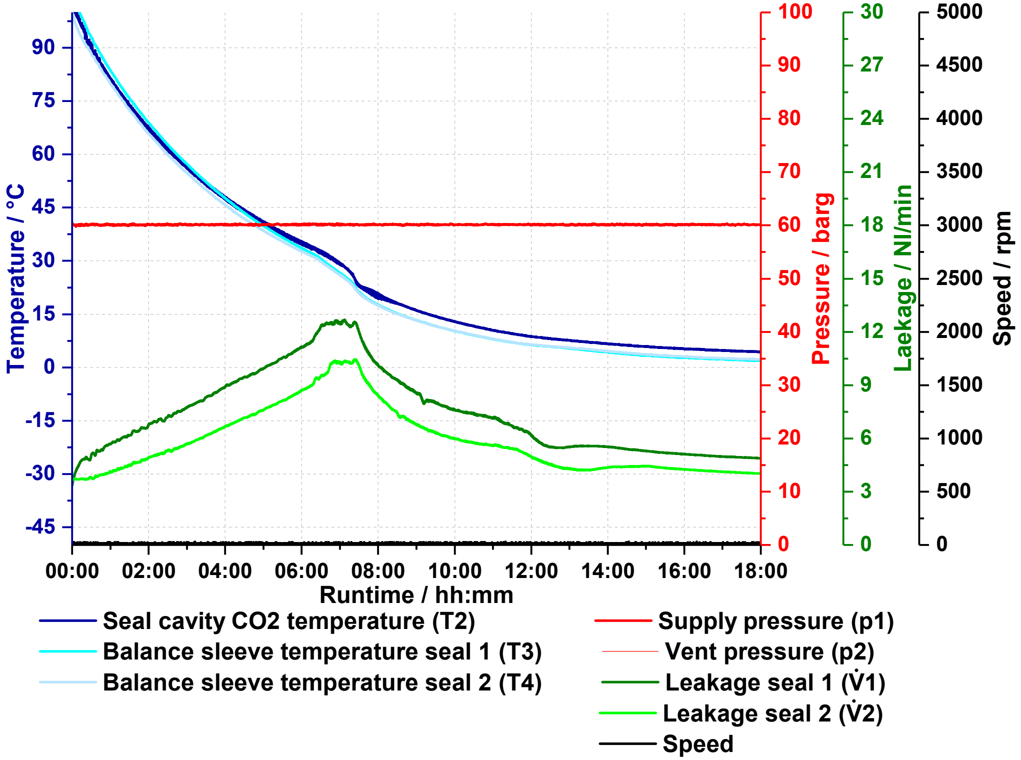
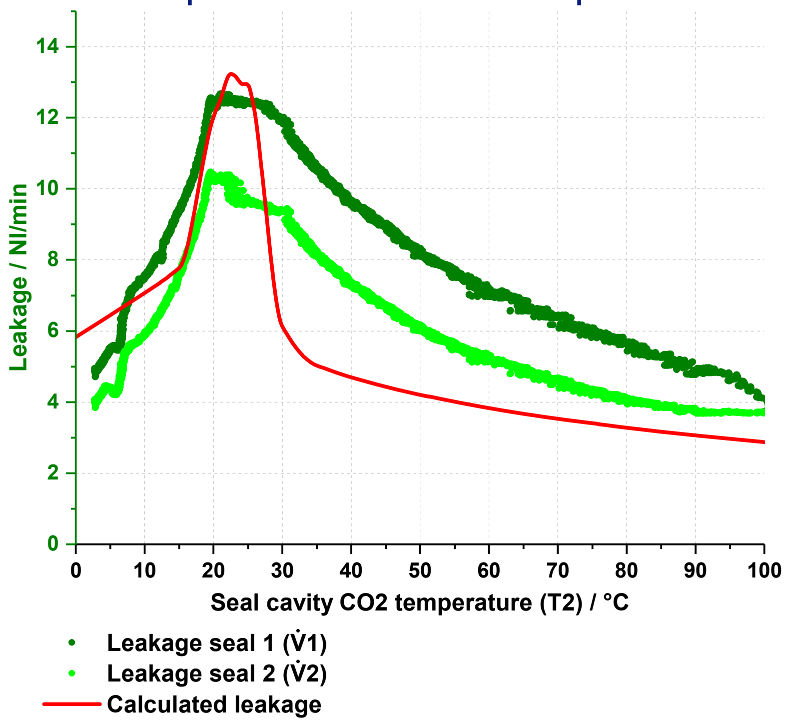


Comparison with numerical prediction



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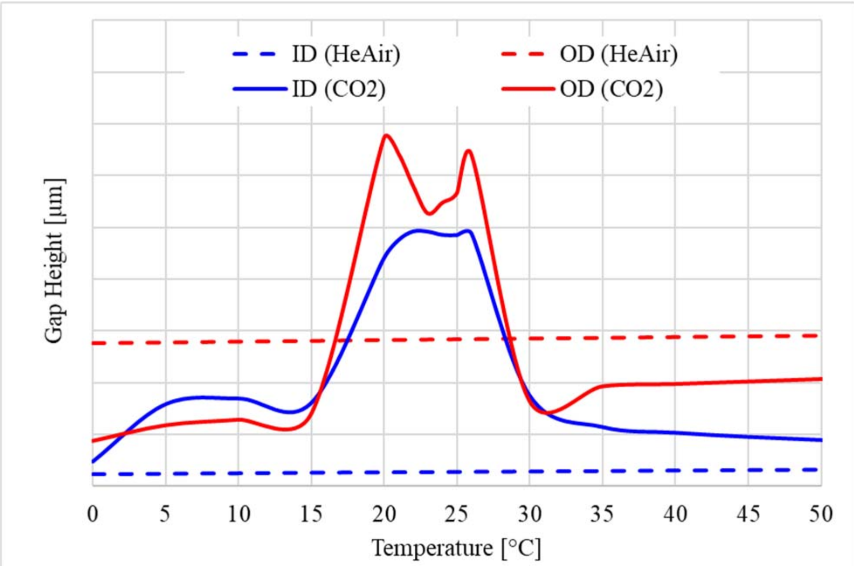
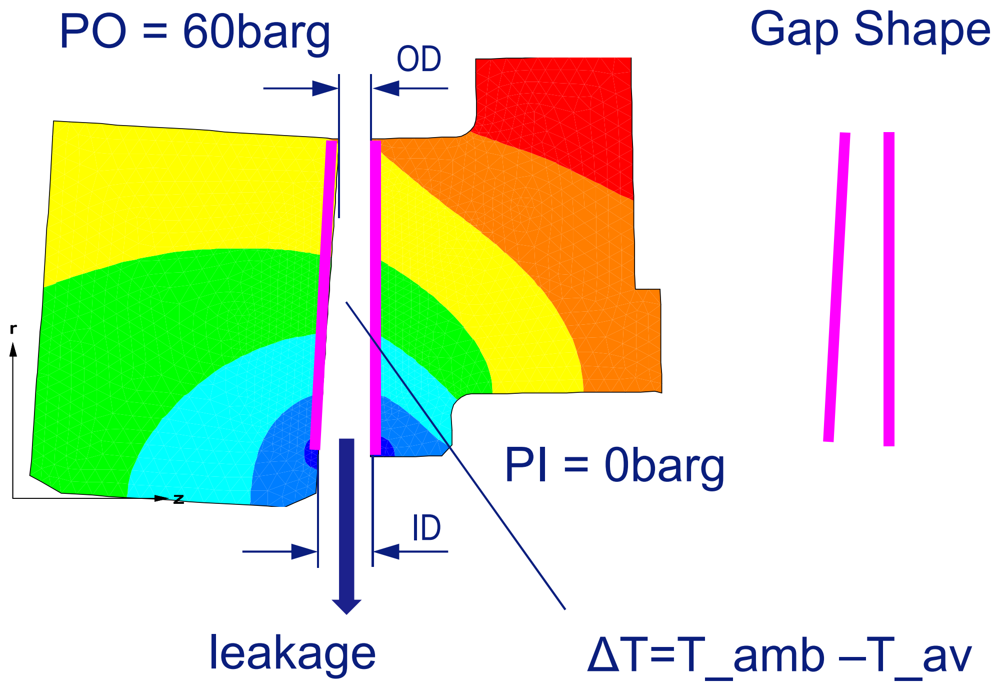
60barg CO_2 Static Test, Decreasing Temperature – Analysis

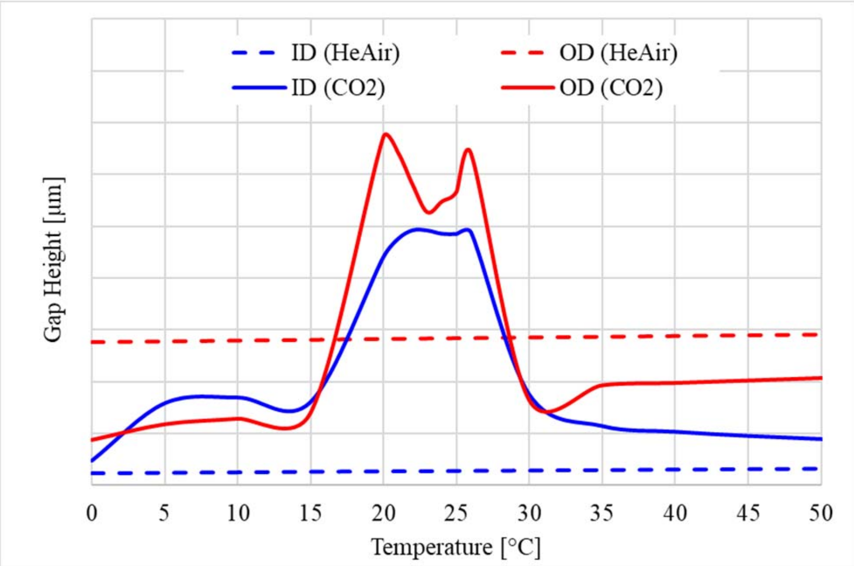
Numerical prediction of gap shape, leakage and temperature

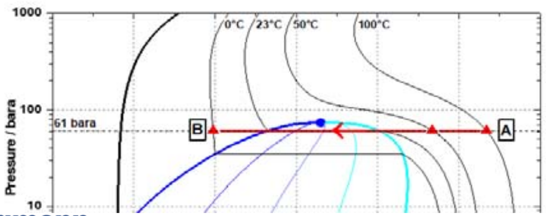




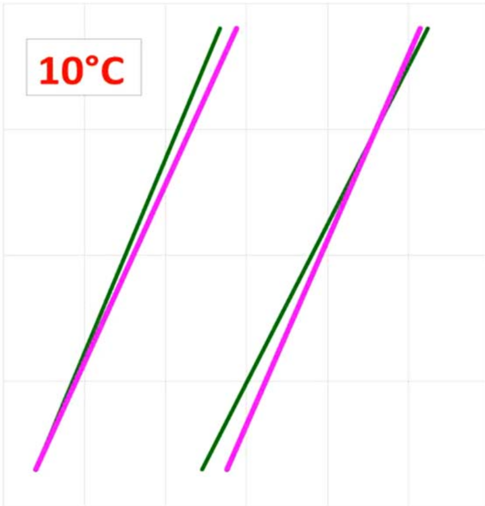
60barg CO_2 Static Test, Decreasing Temperature – Analysis

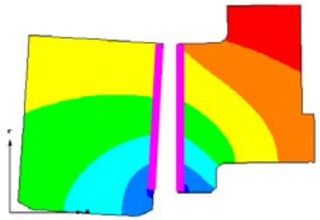
Inner/outer height of sealing gap





Gap shape





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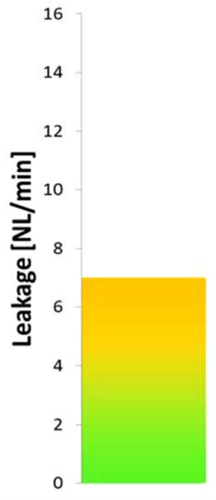
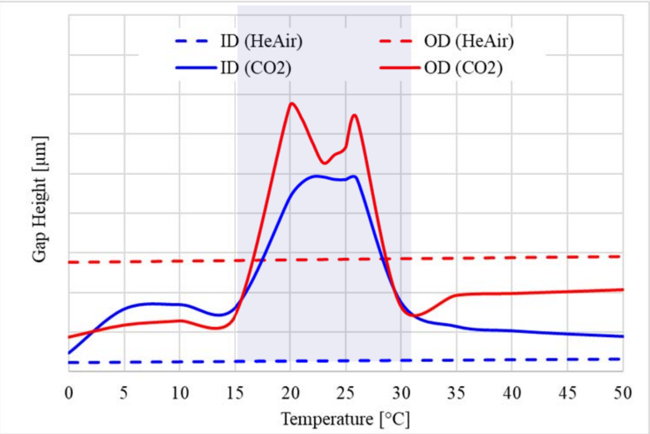
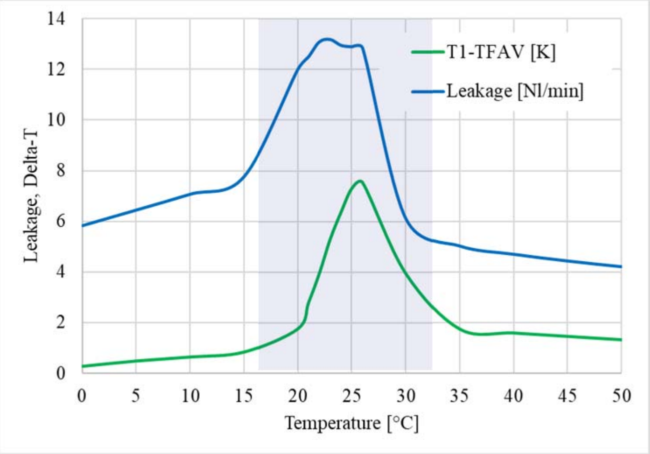
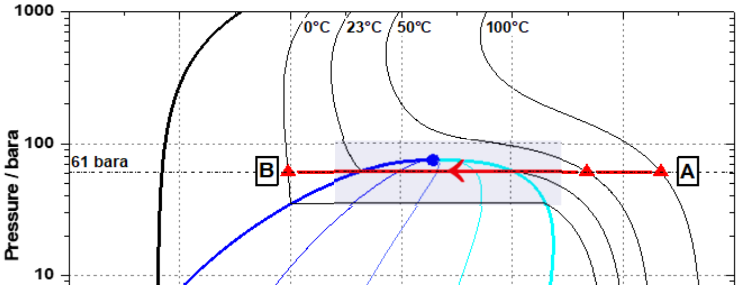


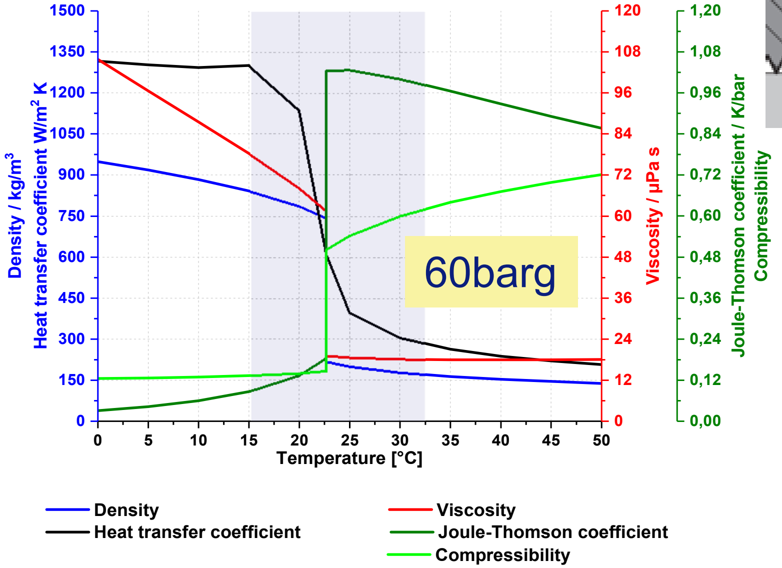
ΔT

60barg CO_2 Static Test, Decreasing Temperature – Analysis

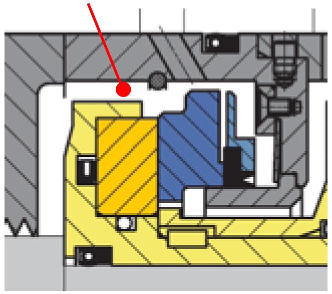






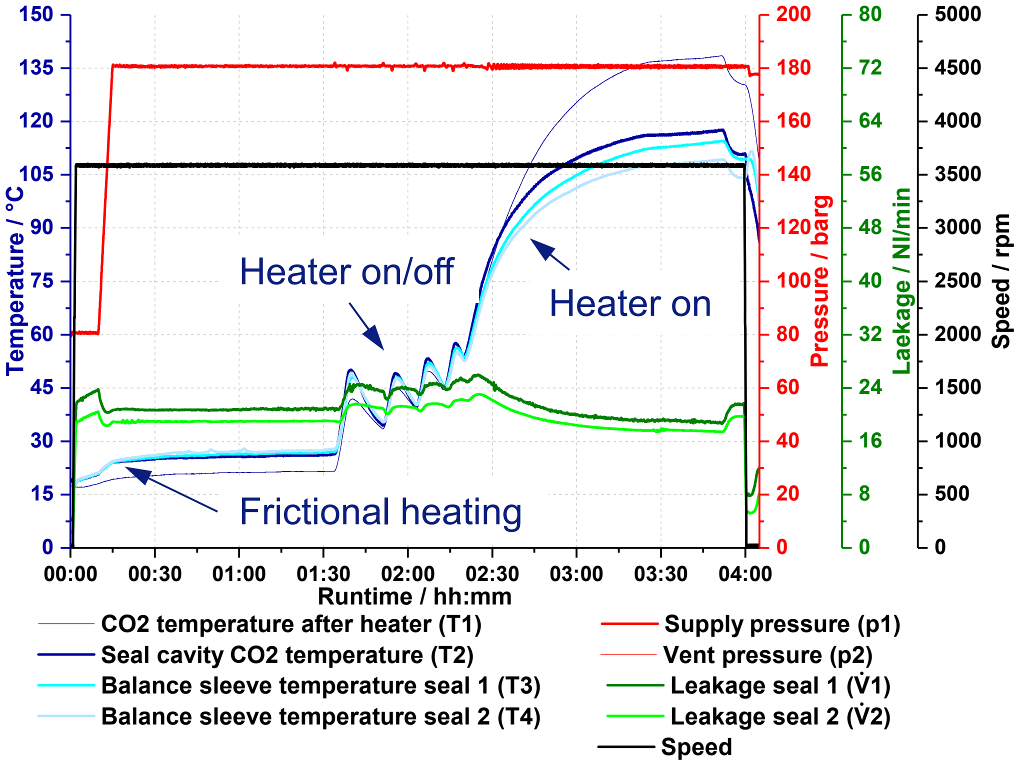


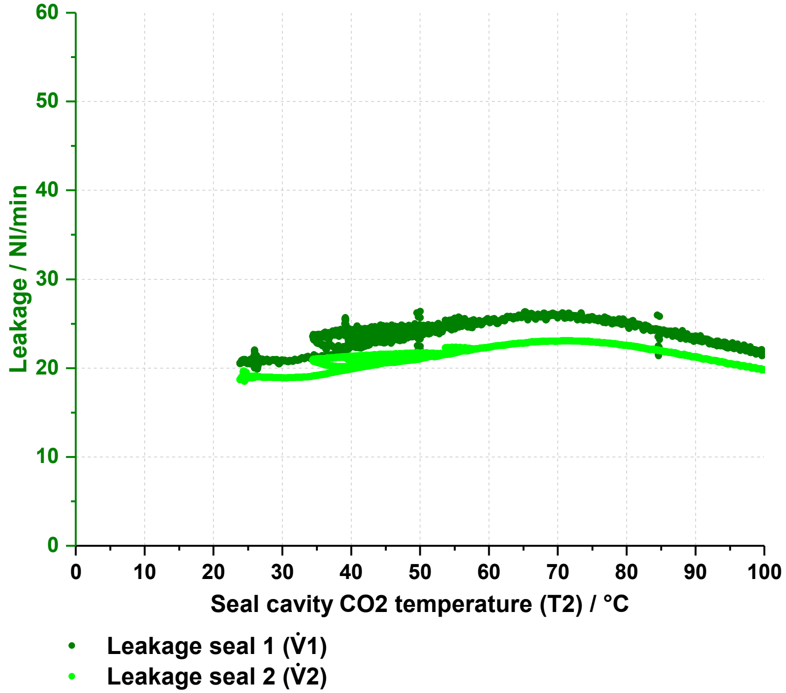
P constant
Par = F(T)



180barg CO_2 Dynamic Test, Increasing Temperature

Test section: Dynamic run (180barg/3600rpm), CO_2 temperature control: 20°C / 50°C / 120°C





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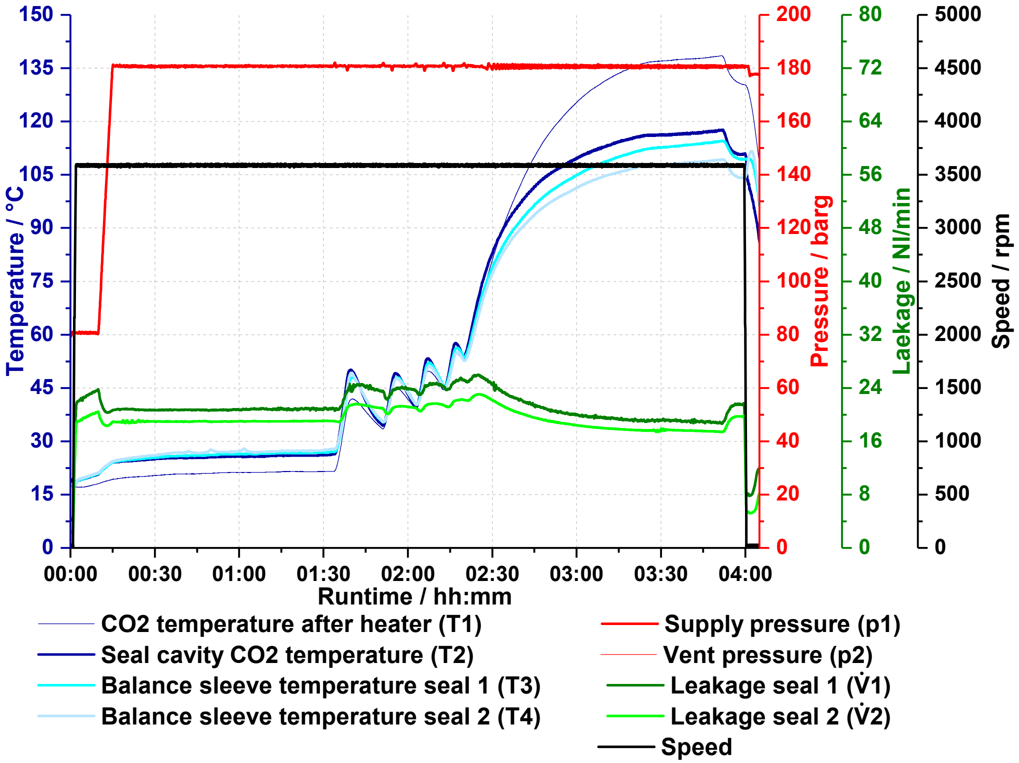

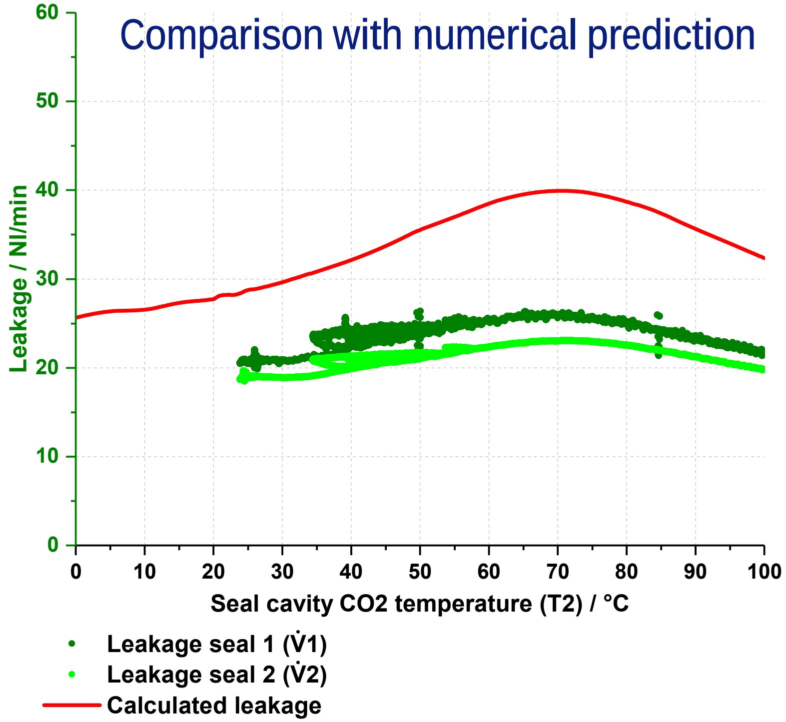

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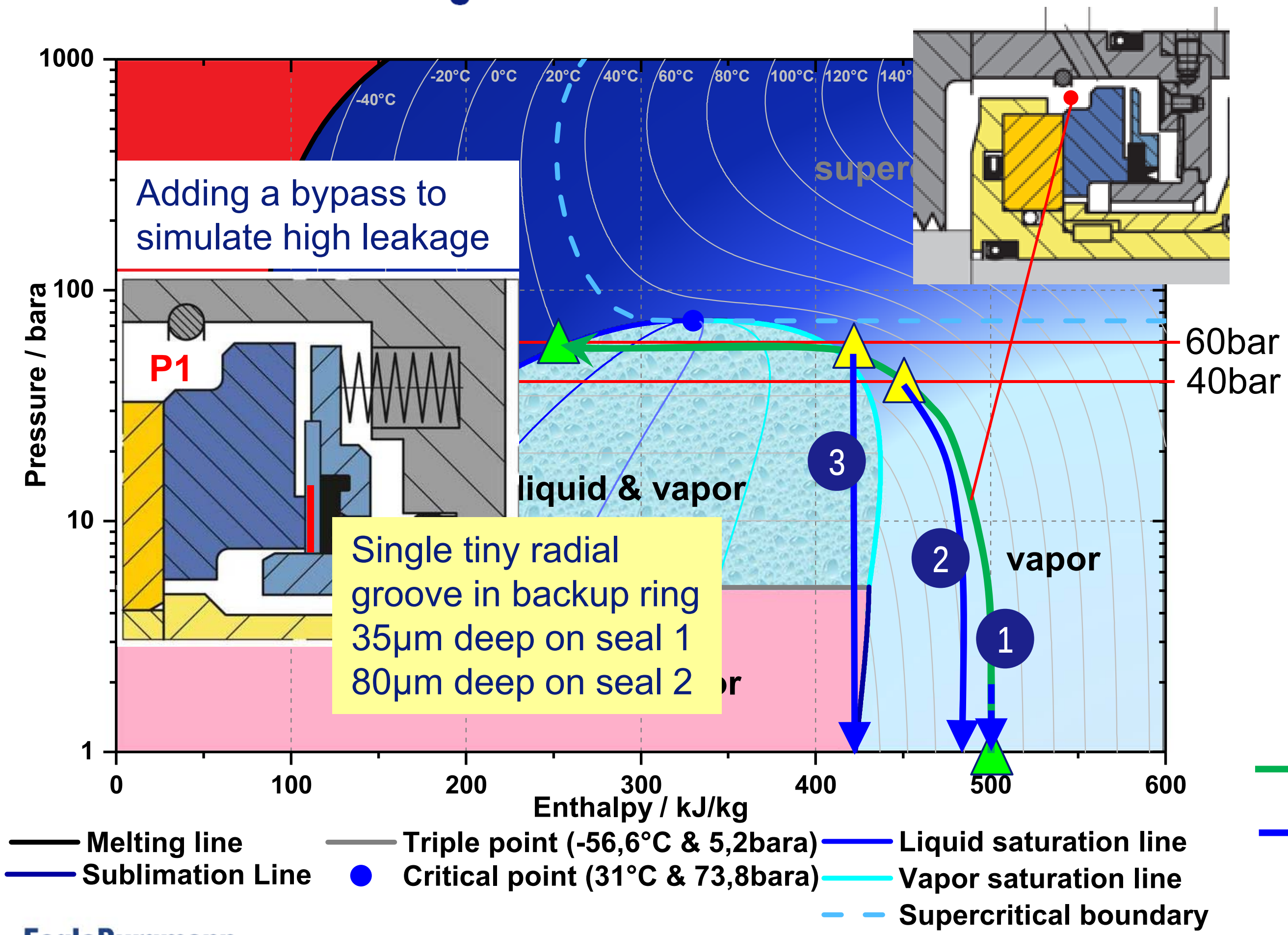
Static Test Simulating a Seal Failure



1. Sealing cavity pressure increase at constant temperature 20°C
2. At about 40bar remarkable deviations from isothermal expansion. Seal temperature about 0°C
3. Beyond 55bar isenthalpic expansion down to triple point

→ Sealing cavity pressure PO

→ Expansion through sealing gap & bypass

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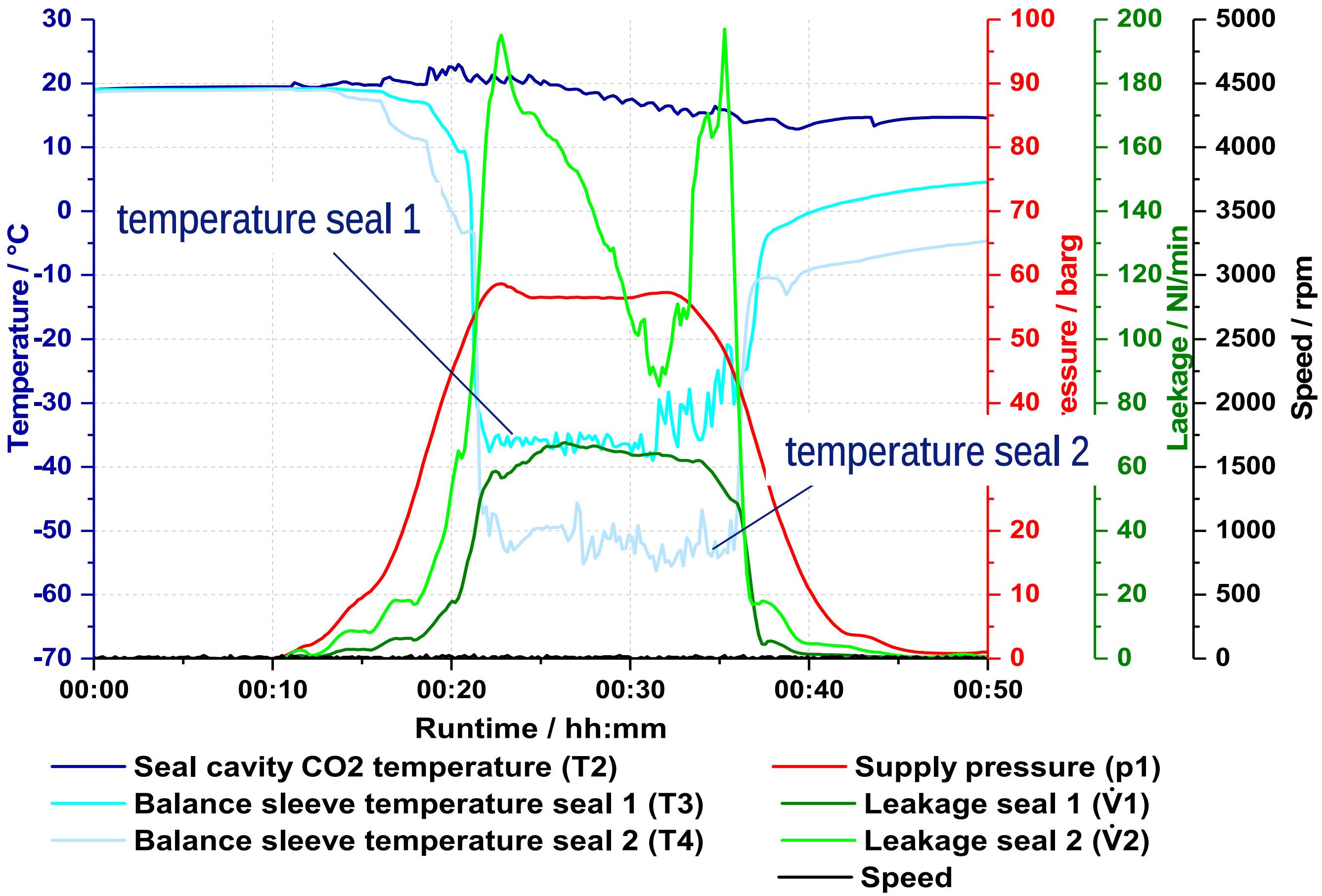
Static Test Simulating a Seal Failure – Results



Summary

- Dry Gas Seal design
  - large seal width provides good lift-off capability and thus wear-free operation
  - Safe non-contacting dynamic operation
  - Offers modification for compressor applications
- Virtually isothermal expansion due to extremely low leakage
- Works with liquid, two-phase, gaseous and supercritical CO_2 without the need for additional heating of the high-pressure sealing cavity
- Sound numerical predictive capability even close to critical CO_2 conditions and phase transitions

Thank you
for your attention!
Questions?

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82515 Wolfratshausen
Germany

Learn more
about EagleBurgmann

Dry Gas Seal (DGS) – Basic Components