# Analysis and testing of dry gas seals for turbomachinery in multiphase CO2 applications

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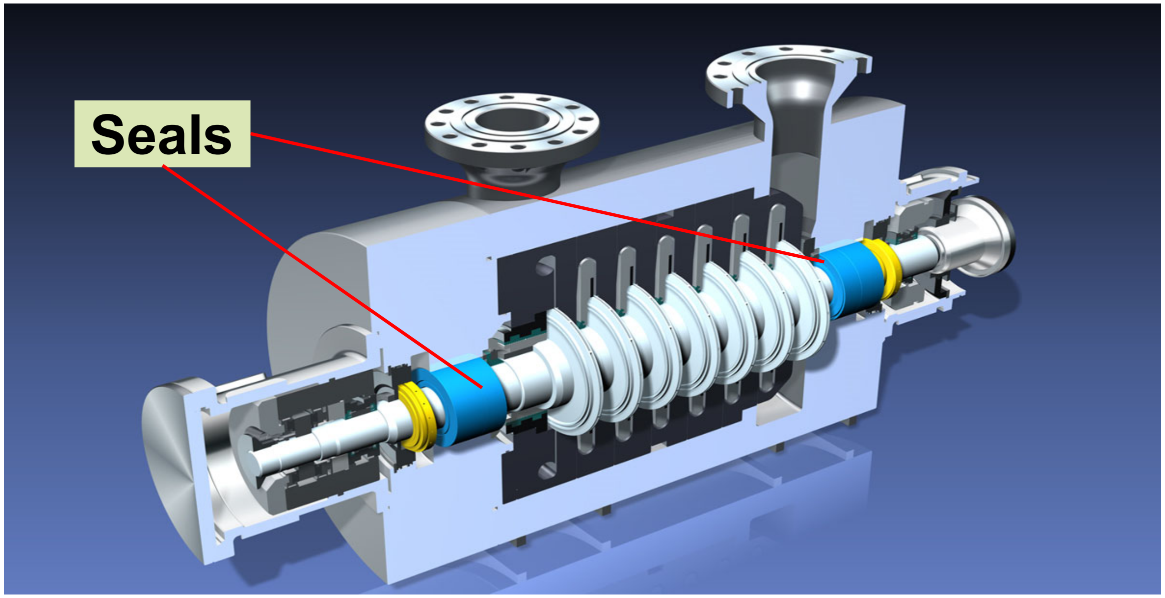
- $CO_2$ multiphase seal
- $CO_2$ special characteristics (seal related)
- Numerical analysis - seal performance
- Test Rig
- Test results and analysis - Low speed seal
- (Test results) and analysis - High speed seal
- Summary and conclusions

# CO2 multiphase seal

Rotating machinery requires shaft seals (e.g. labyrinths, carbon rings, mech. seals)

Low leakage demands mechanical seals

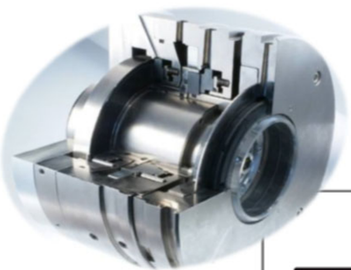


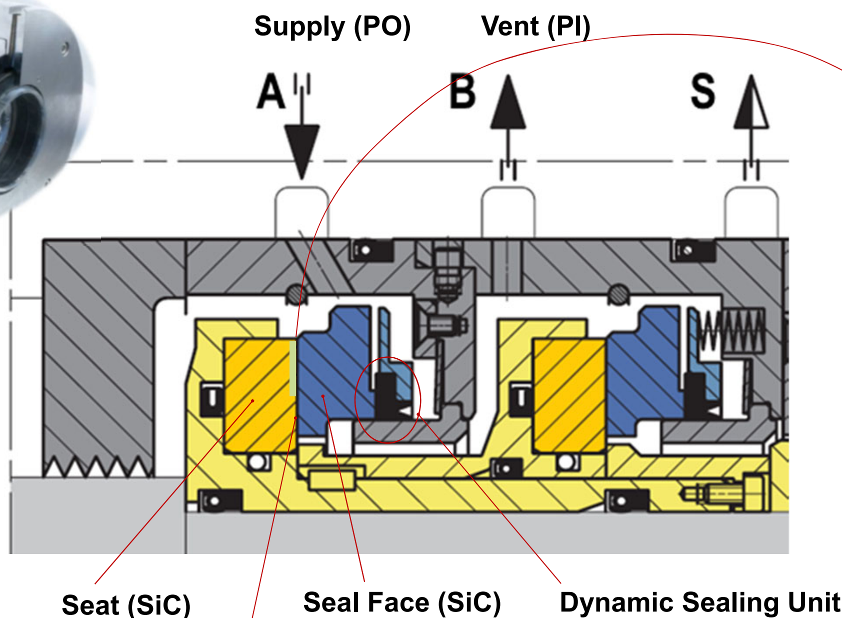
# CO2 multiphase seal

Mechanical seal options:

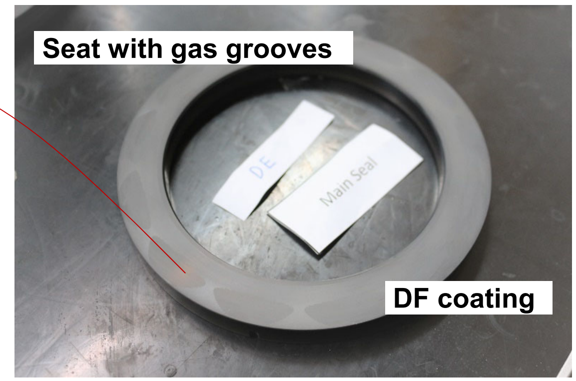
- Liquid Seal: contacting seal, small sealing width, low speed limits, low liquid leakage, cannot work with pure gas
- Dry Gas Seal: non-contacting, large sealing width, material determined speed limits, can work with liquids (in a limited range), very low gas leakage, high liquid leakage
- **Liquid/Gas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

# CO2 multiphase seal

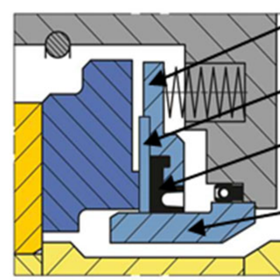




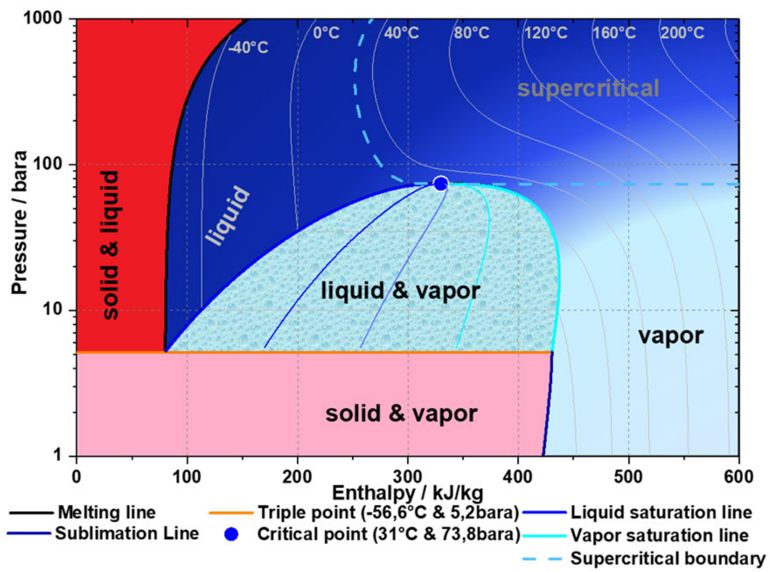

**Sealing Gap** (opens up to few micrometer when subjected to pressure and/or rotation)

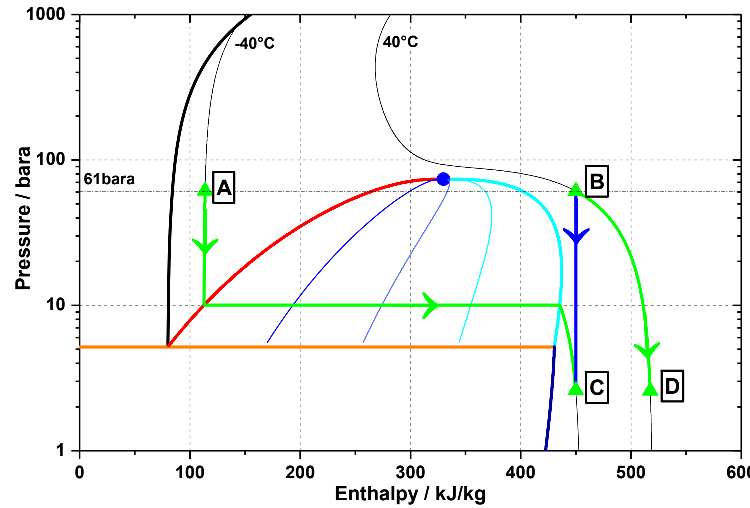



Dynamic Sealing Unit



# CO2 special characteristics (seal related)

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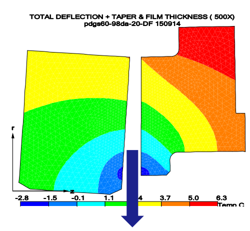


A → C … isothermal, ΔT = 0K

B → C … isenthalpic, ΔT = -80K

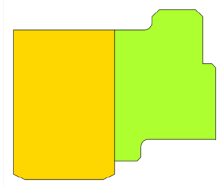
B → D … isothermal, ΔT = 0K

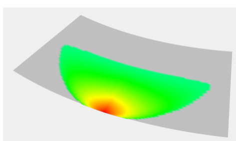
# $CO_2$ special characteristics (seal related)

- Operation without additional heater possible?
- Operation without cooling possible?
- Are numerical predictions correct?

→ Verification / validation of design by internal test campaign!

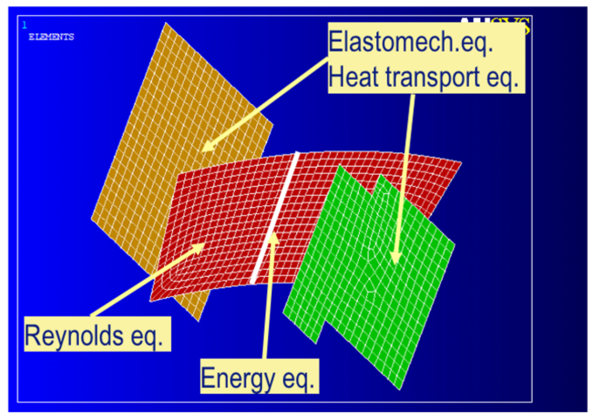
# Numerical analysis - seal performance



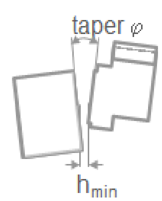


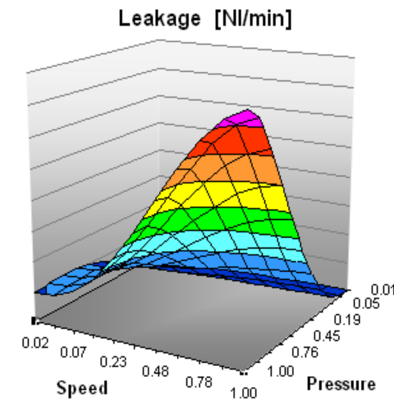
Design Data
Operating Data

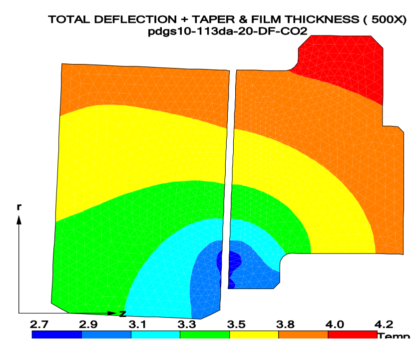
Fluid
Properties




Gap flow: $p$, $h$, $\boldsymbol{v}$ cyclic symmetric, $f(r,\theta)$
Interface: $T$, $\boldsymbol{q}$ $f(r)$
Ring System: $T$, $\boldsymbol{u}$, $\boldsymbol{q}$ axis-symmetric, $f(r,z)$

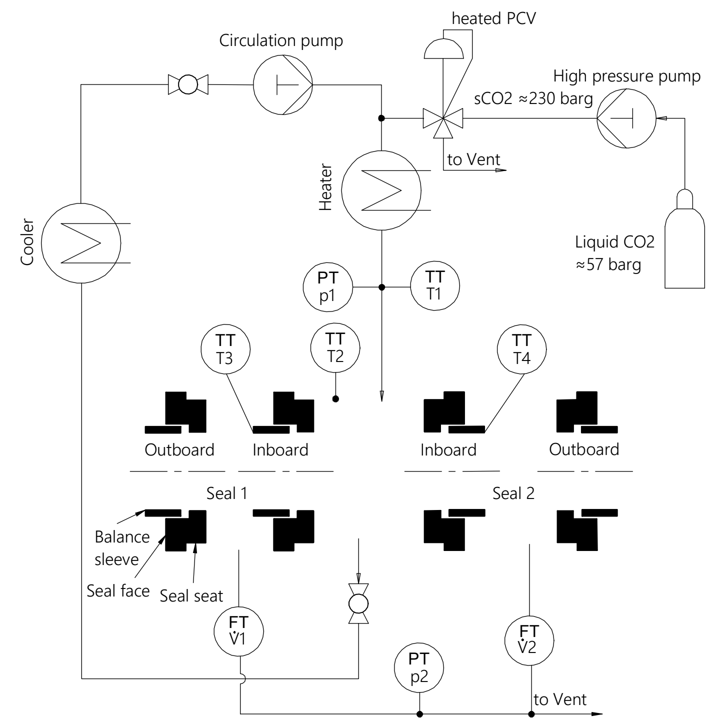


# Test rig

- Test gas: CO2, Air, N2, N2-He mix and He
- Shaft size: 50 … 300 mm
- Max speed: 20000 rpm
- CO2 heating/cooling and circulation as
- closed loop
- CO2 temperature control range: 20 ….120 °C
- CO2 supply (max): 1000 Nl/min
- CO2 max. testing pressure: 200 bar
- He max. supply pressure: 700 bar

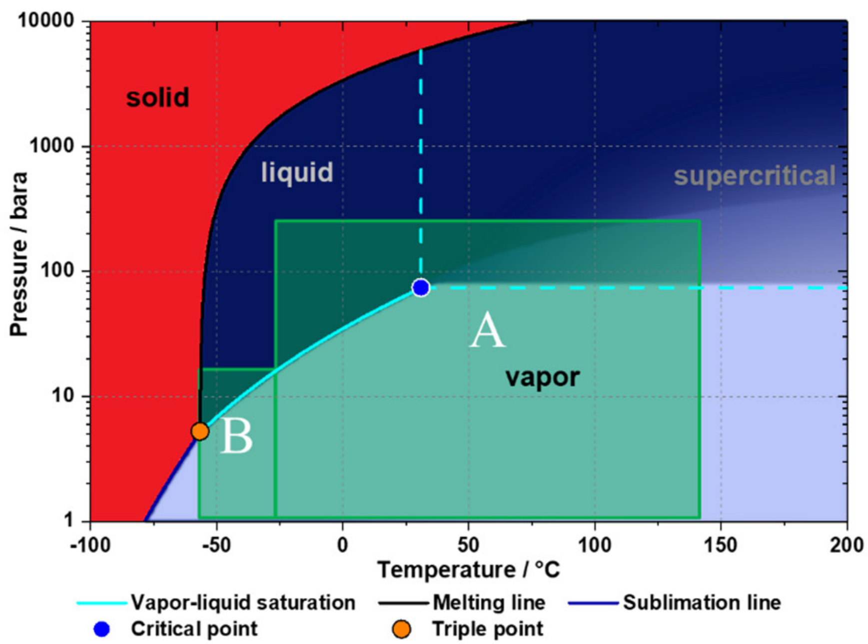


# Test rig

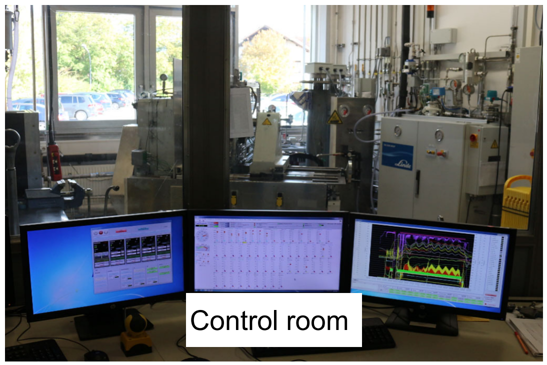
- Multiphase suitability:
  Seal can operate in liquid, two-phase, vapor and supercritical region without additional heater!

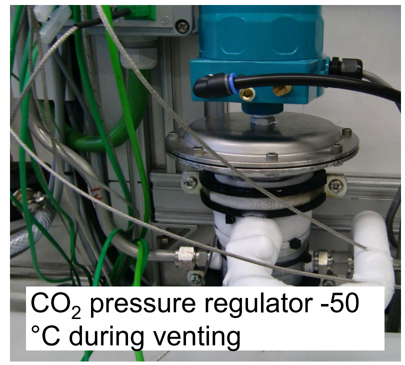
- A … normal operating range
- B … failure test

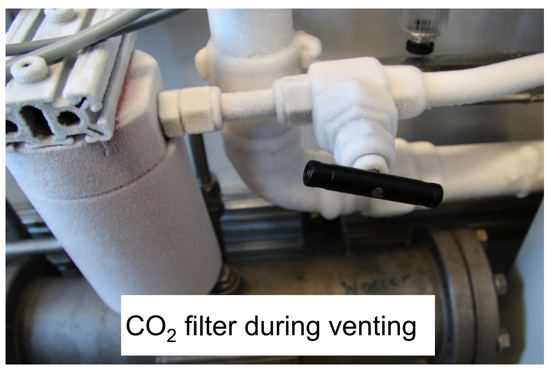
P-T Range of Testing

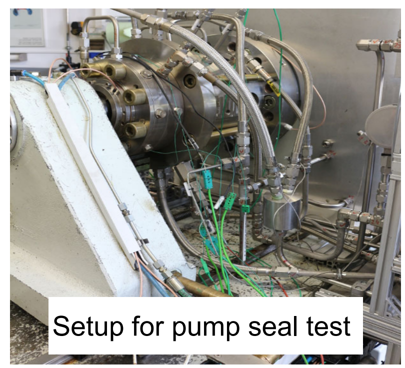


# Test rig


Control room


$CO_2$ pressure regulator -50 °C during venting


$CO_2$ filter during venting


Setup for pump seal test

# Test results and analysis - Low speed seal

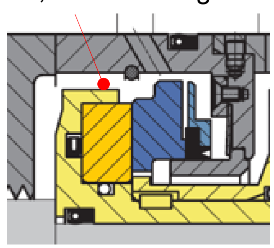
**Test section:**

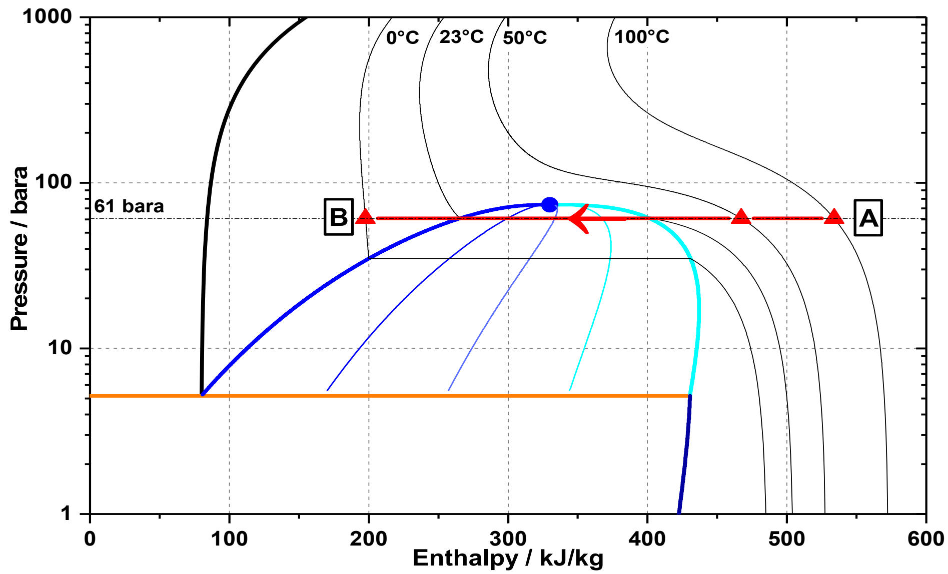
**Cool down phase (18h)**
**after dynamic run with hot $CO_2$**

A … Start in gaseous region 60barg/100°C

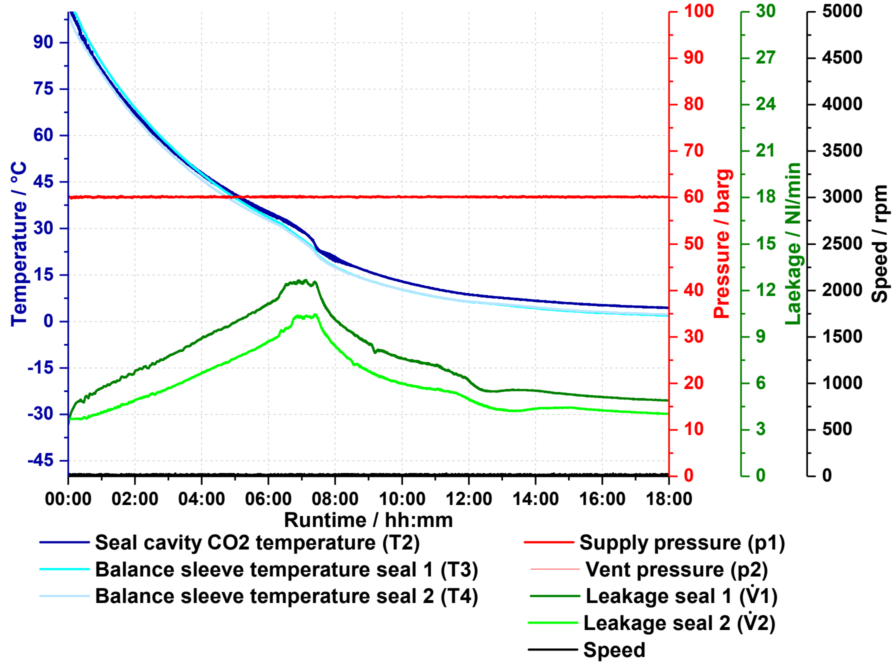
B … End in liquid region 60barg/0°C

P const., T decreasing

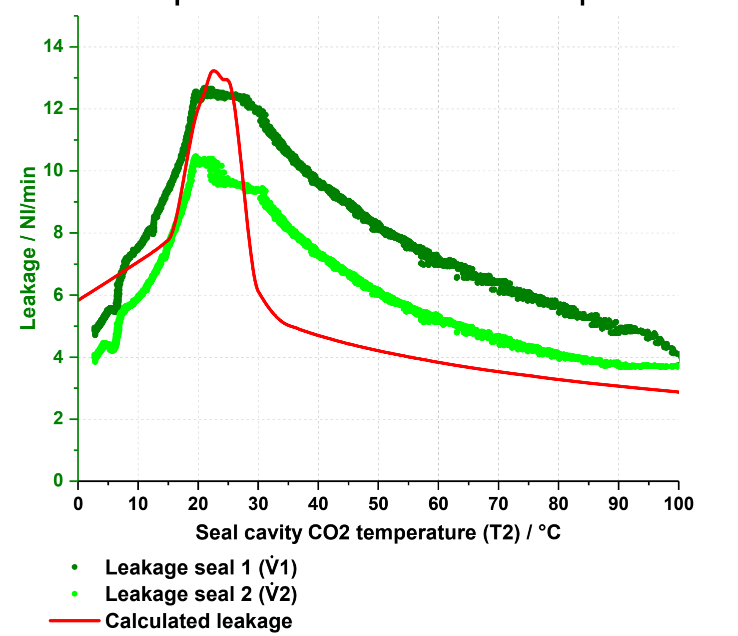




# Test results and analysis - Low speed seal



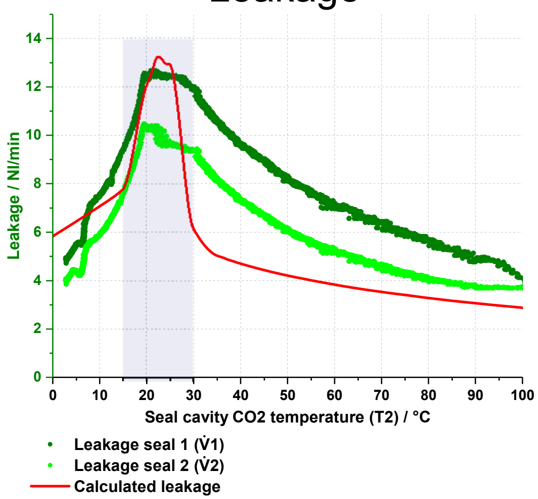

Comparison with numerical prediction



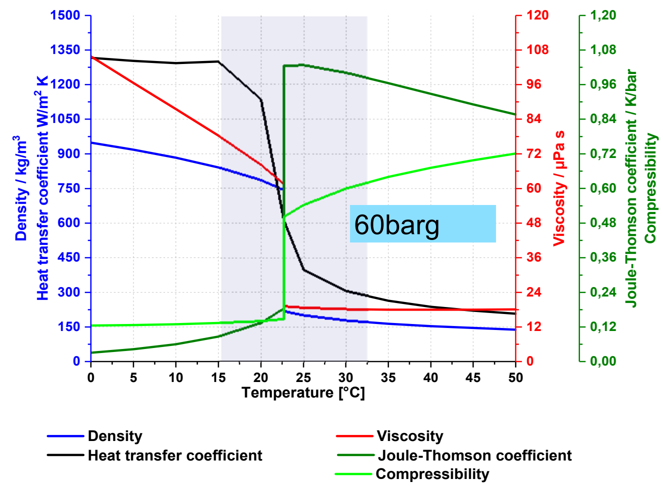
# Test results and analysis - Low speed seal

## Changing properties during CO2 phase change can explain leakage curves

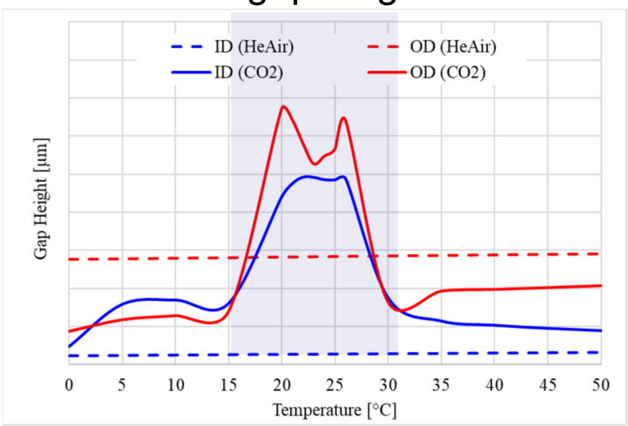
### Leakage




### CO2 Properties




### Seal gap height



# Test results and analysis - Low speed seal

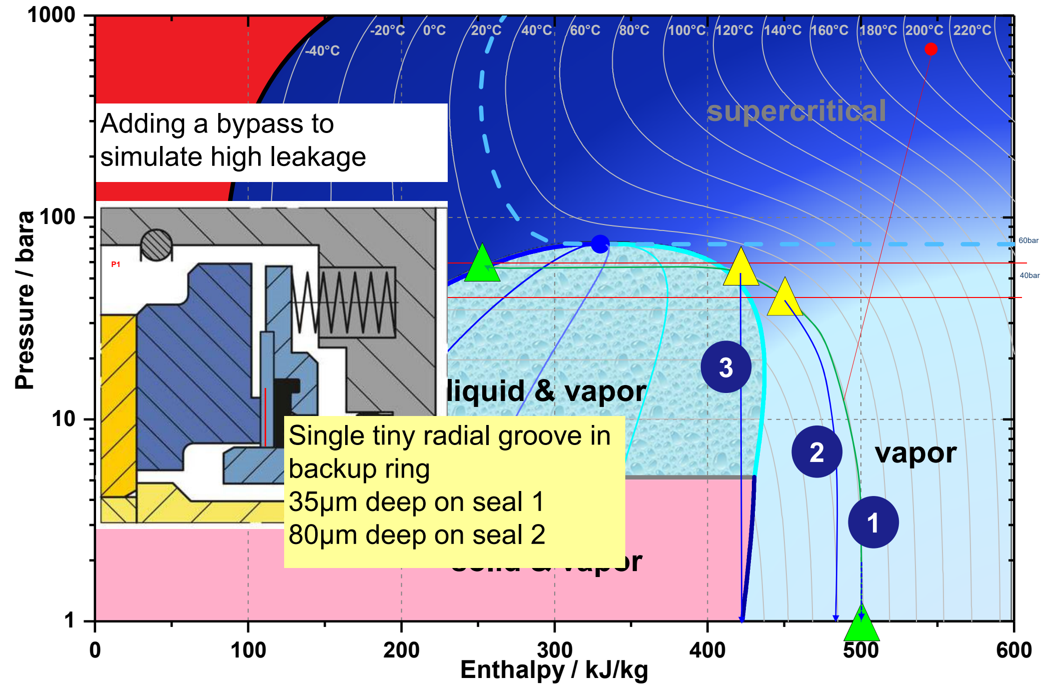
**Test section:**

**Static test simulating a seal failure/high leakage**

1 … Sealing cavity pressure increase at constant temperature 20°C

2 … At about 40bar remarkable deviations from isothermal expansion. Seal temperature about 0°C

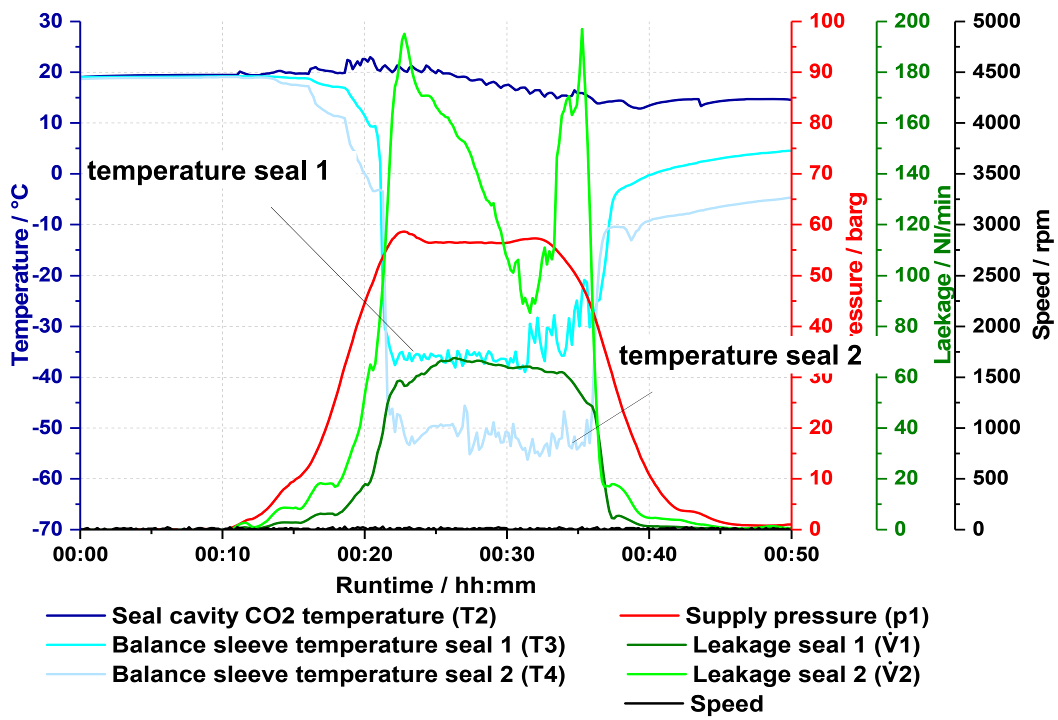
3…Beyond 55bar isenthalpic expansion down to triple point




Sealing cavity pressure PO

Expansion through sealing gap & bypass

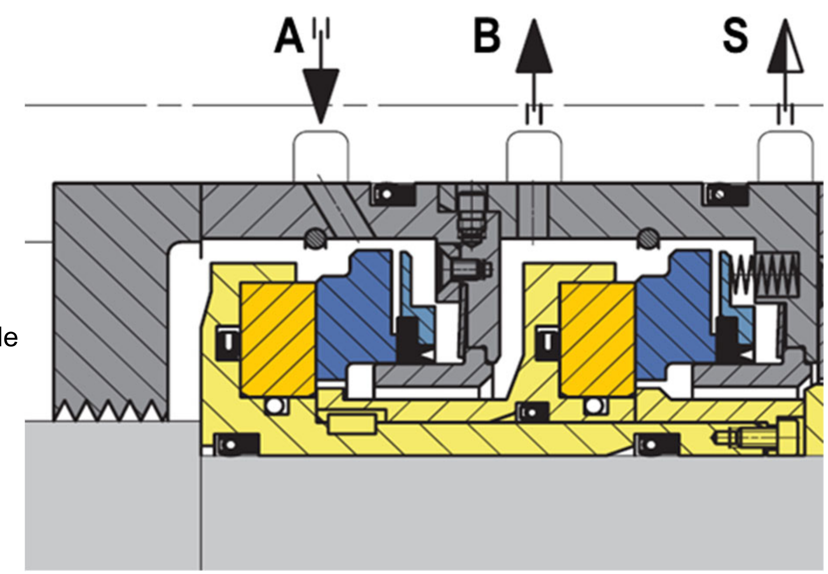
# Test results and analysis - Low speed seal




# Analysis - High speed seal

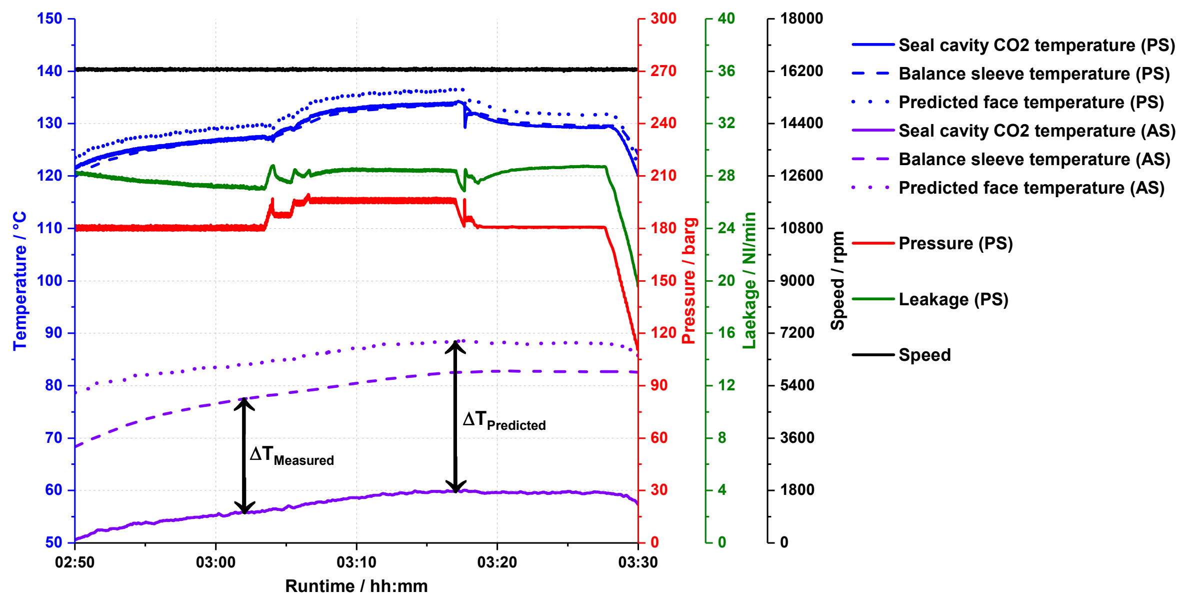
**Atmosphere side (AS) seals are critical in high speed $CO_2$ applications**

- Less gas pressure/density
- Less Joule Thomson cooling
- Less leakage
- No seal gas cross flow
- → High temperatures possible



# Analysis - High speed seal

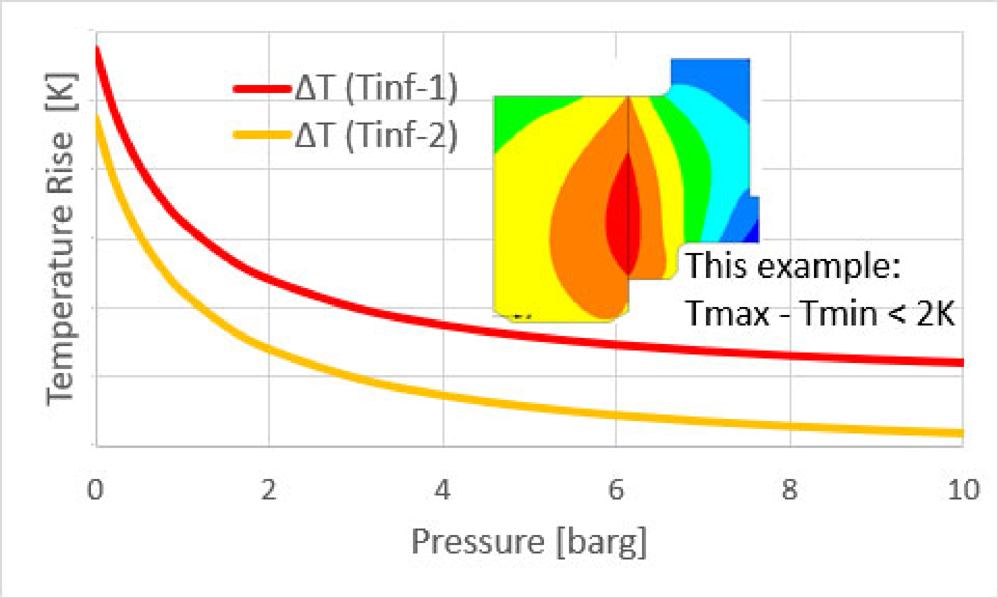
**Seal test results confirm higher temperature rise of AS seal compared to PS seal.**



# Analysis - High speed seal

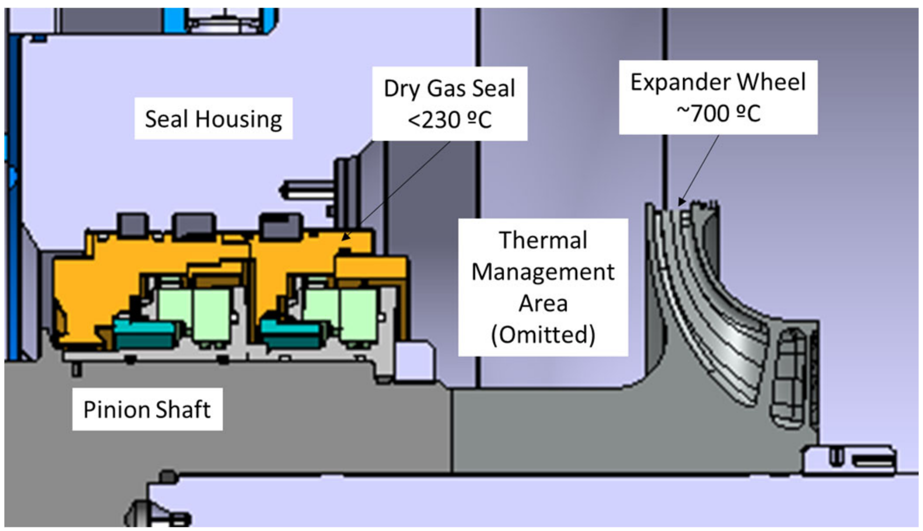
**Recipe to decrease AS seal temperature**

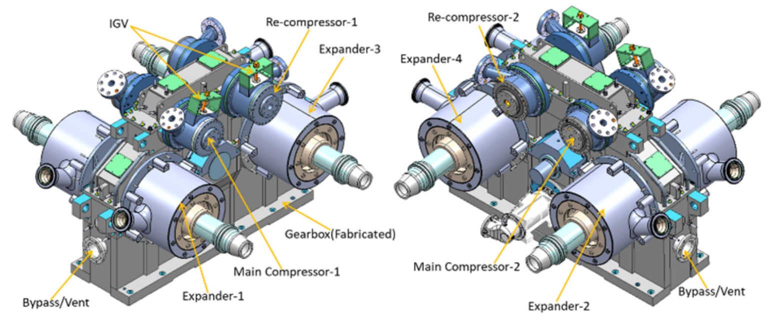
- Increase pressure/density
- → Better cooling of AS seal

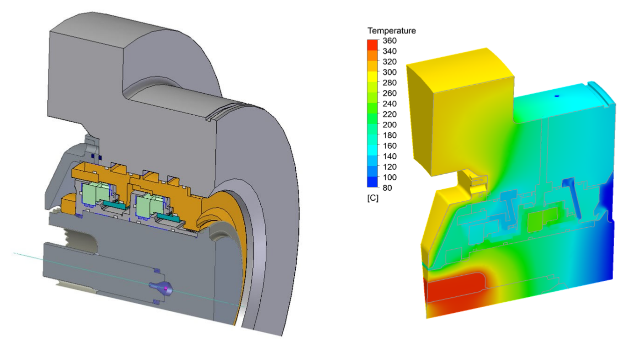


# Analysis - High speed seal

**A CHT calculation was conducted for a Hanwha $CO_2$ compander at SwRI with $CO_2$ inlet temperature of 700°C**

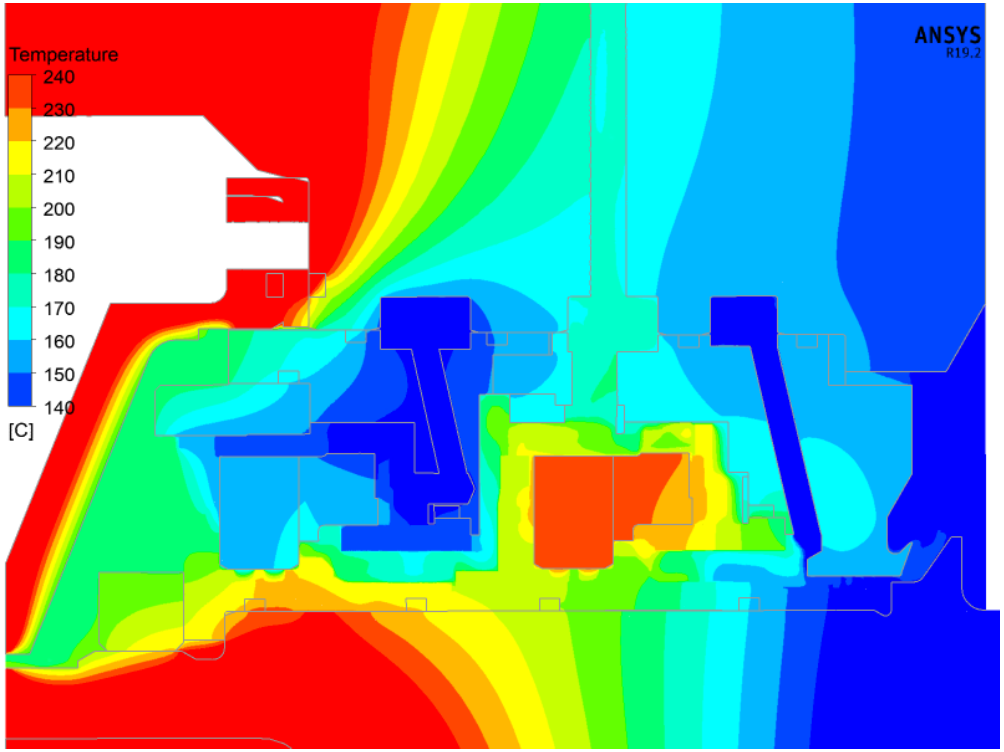


# Analysis - High speed seal

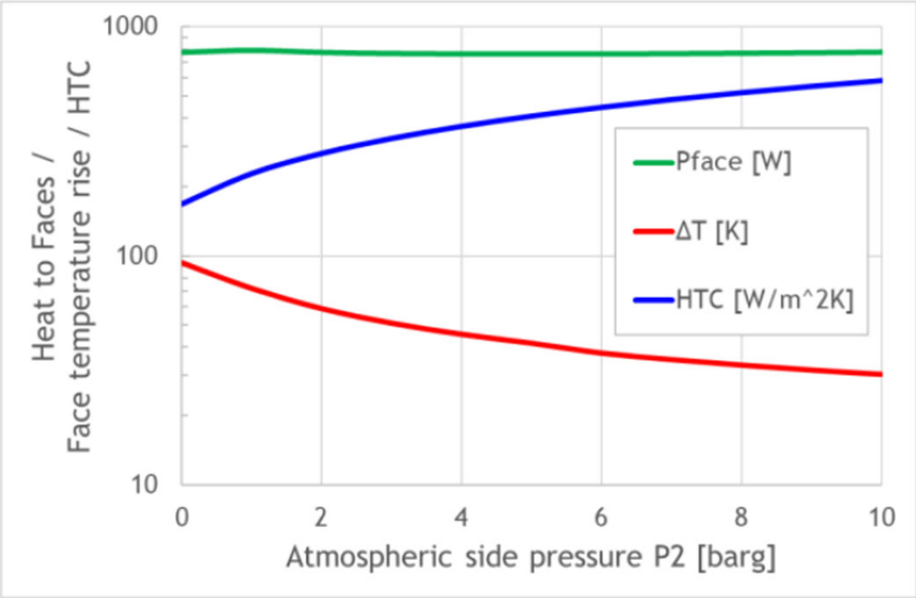
**The CHT calculation confirmed that a pressure of 1 barg is resulting in 240°C at seal faces and would especially affect secondary sealing elements.**



# Analysis - High speed seal

**Previous calculation was used to decide the input for the CHT calculation**

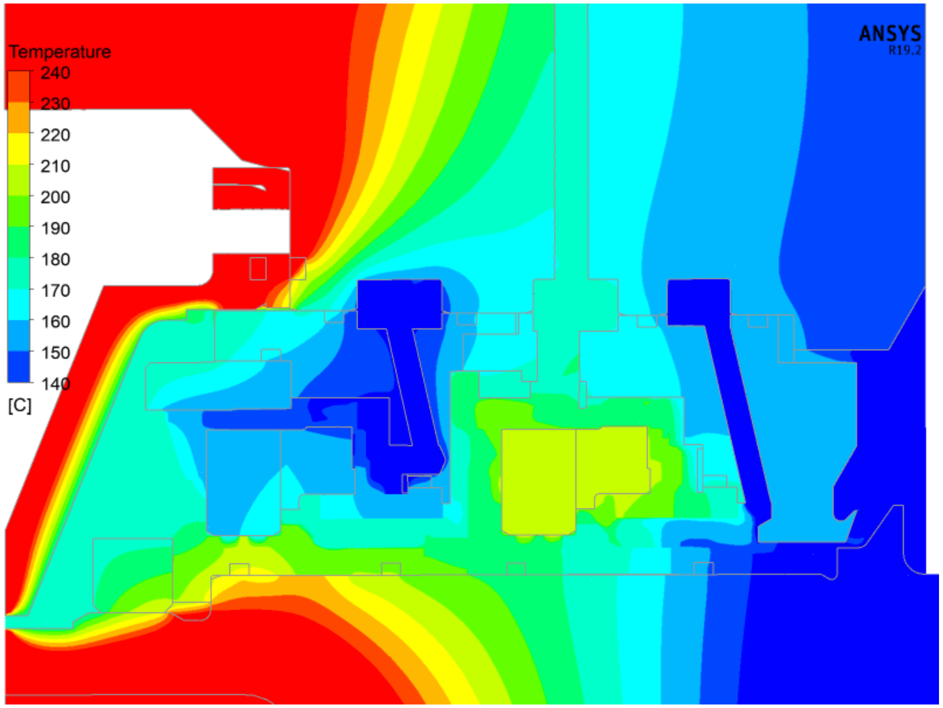
- **9 barg AS pressure seemed to be a good starting point**
- **HTC nearly triples from atm. to 9 barg**



# Analysis - High speed seal

**The CHT calculation confirmed that a pressure of 9 barg is enough to limit the temperature rise in the AS seal to an acceptable level of 210°C. A temp. decrease of 30K is achieved.**

**Testing also confirmed successful operation at 9 barg. Exact results to be analysed.**



# Summary

- Sealing CO2 is a special task due to CO2 properties
- Dry gas seals have been proven to be suitable for sealing various CO2 applications
- In low speed (pump) applications dry gas seals must work with different phases of CO2 and extremely low leakage rates are required to avoid icing
- In high speed applications (compressors/expanders/turbines) the temperature rise in the dry gas seal must be carefully considered additionally

# Thank You!