COMPASS
SUMMER SCHOOL

Thermal and mechanical stress mitigation in geothermal wells with supercritical resources

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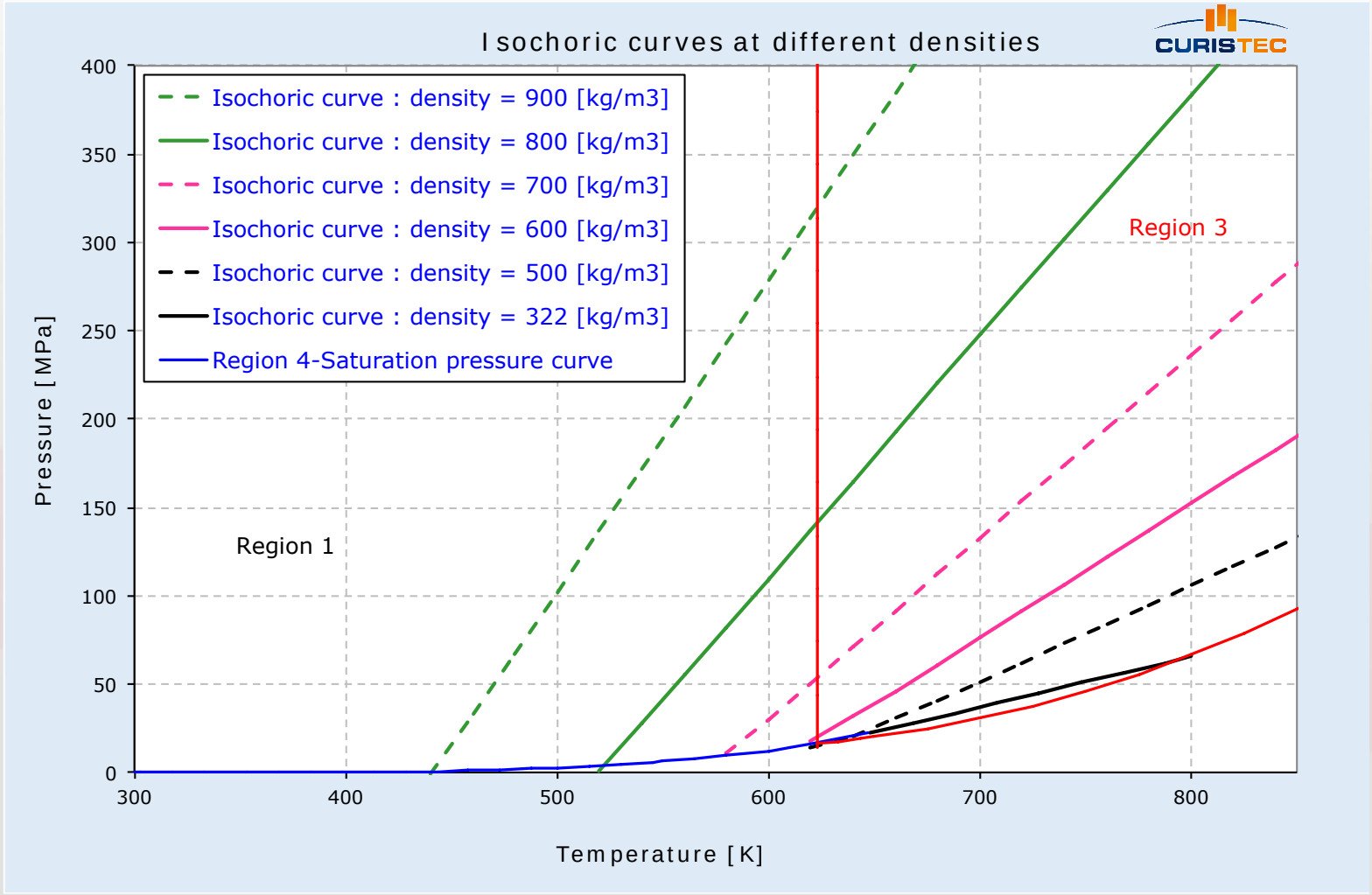
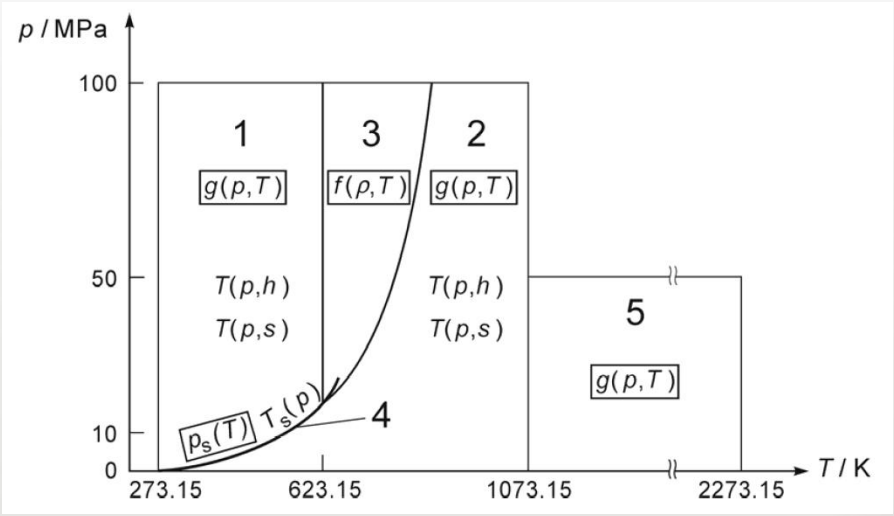
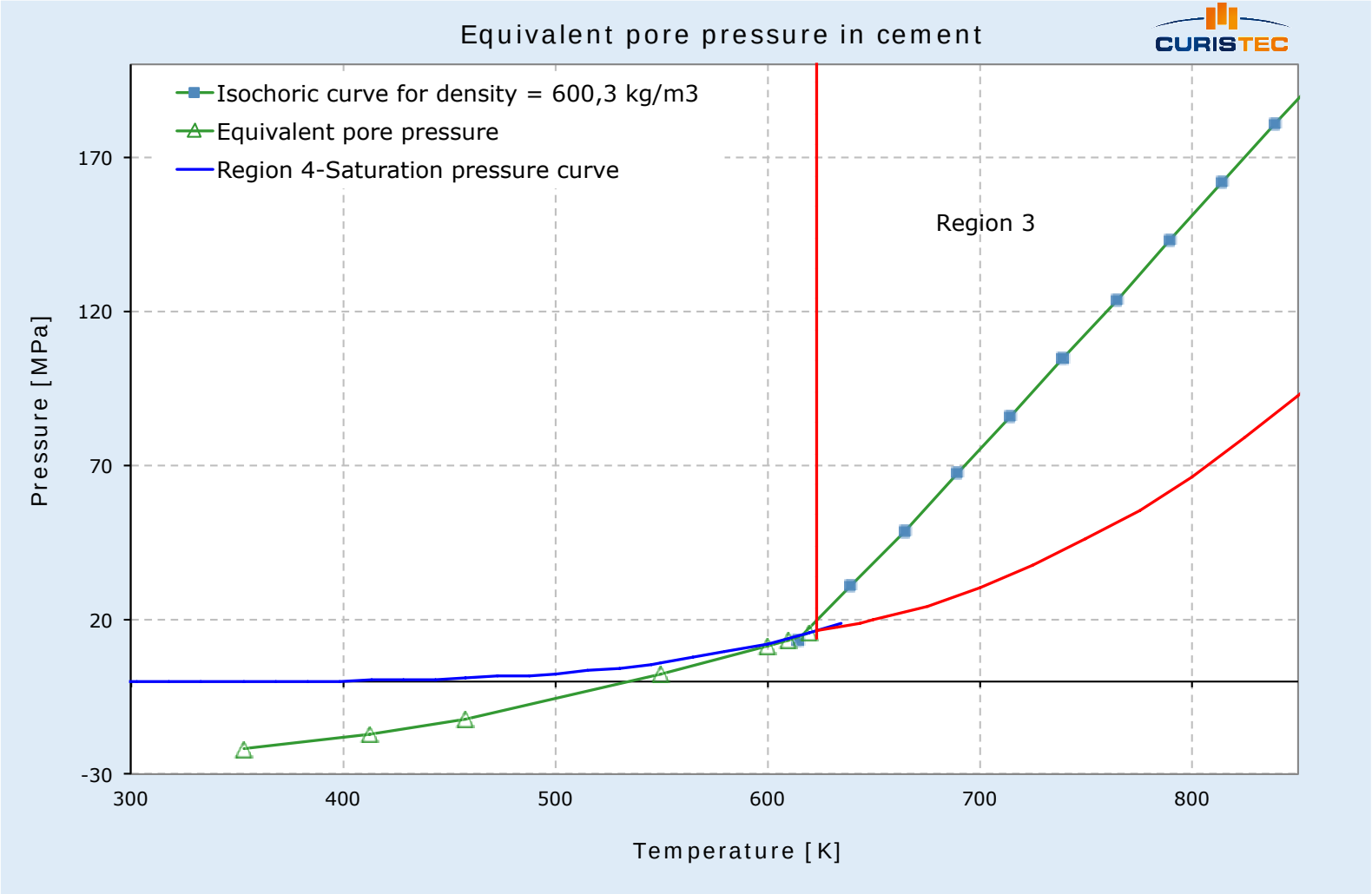
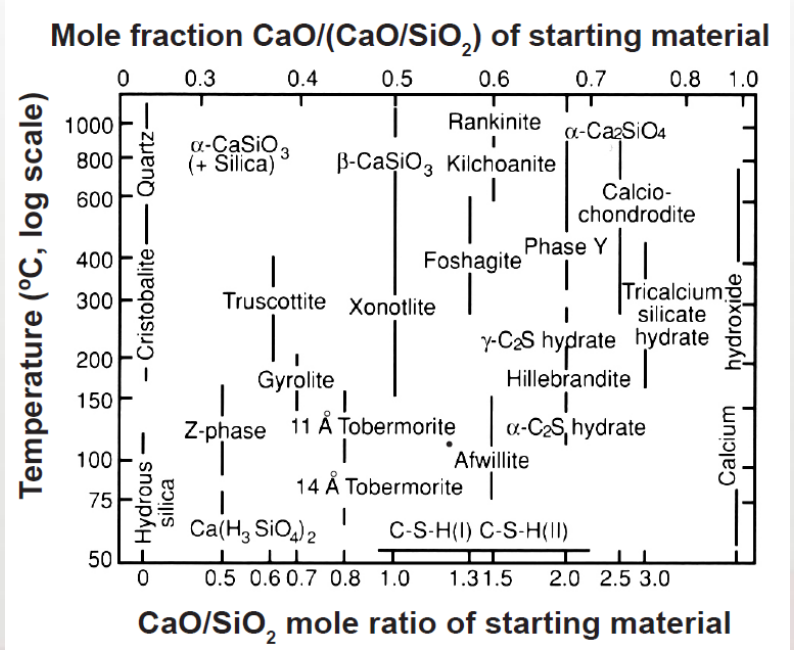
Isochoric water pressure can reach very high values when heated to supercritical conditions





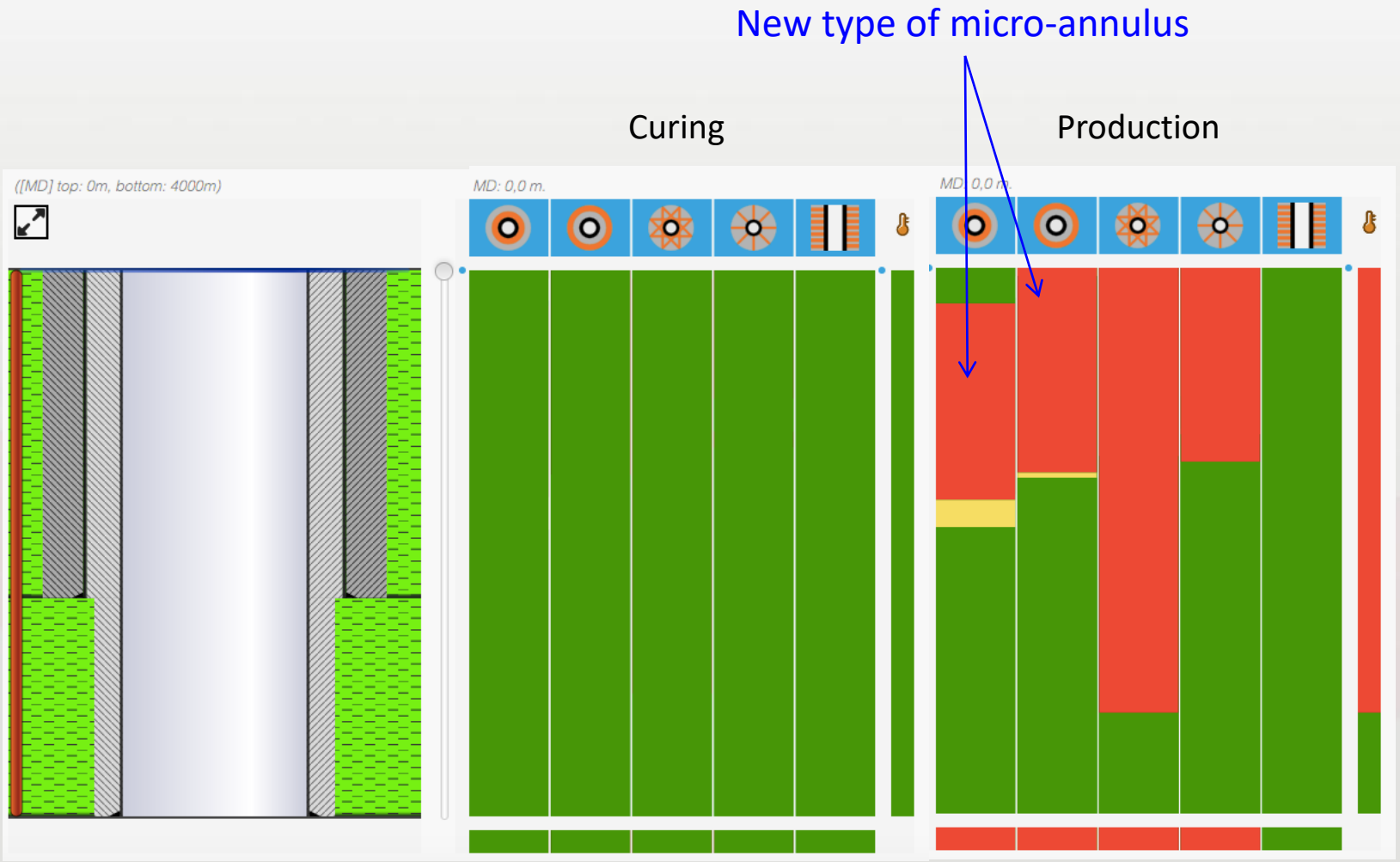
Isochoric pore pressure in cement can reach very high values when heated to supercritical conditions





$$C_{1.7}\text{-}S\text{-}H_4 + 1.3\ CH + 2\ S \rightarrow 0.5\ C_6\text{-}S_6\text{-}H + 4.8\ H$$

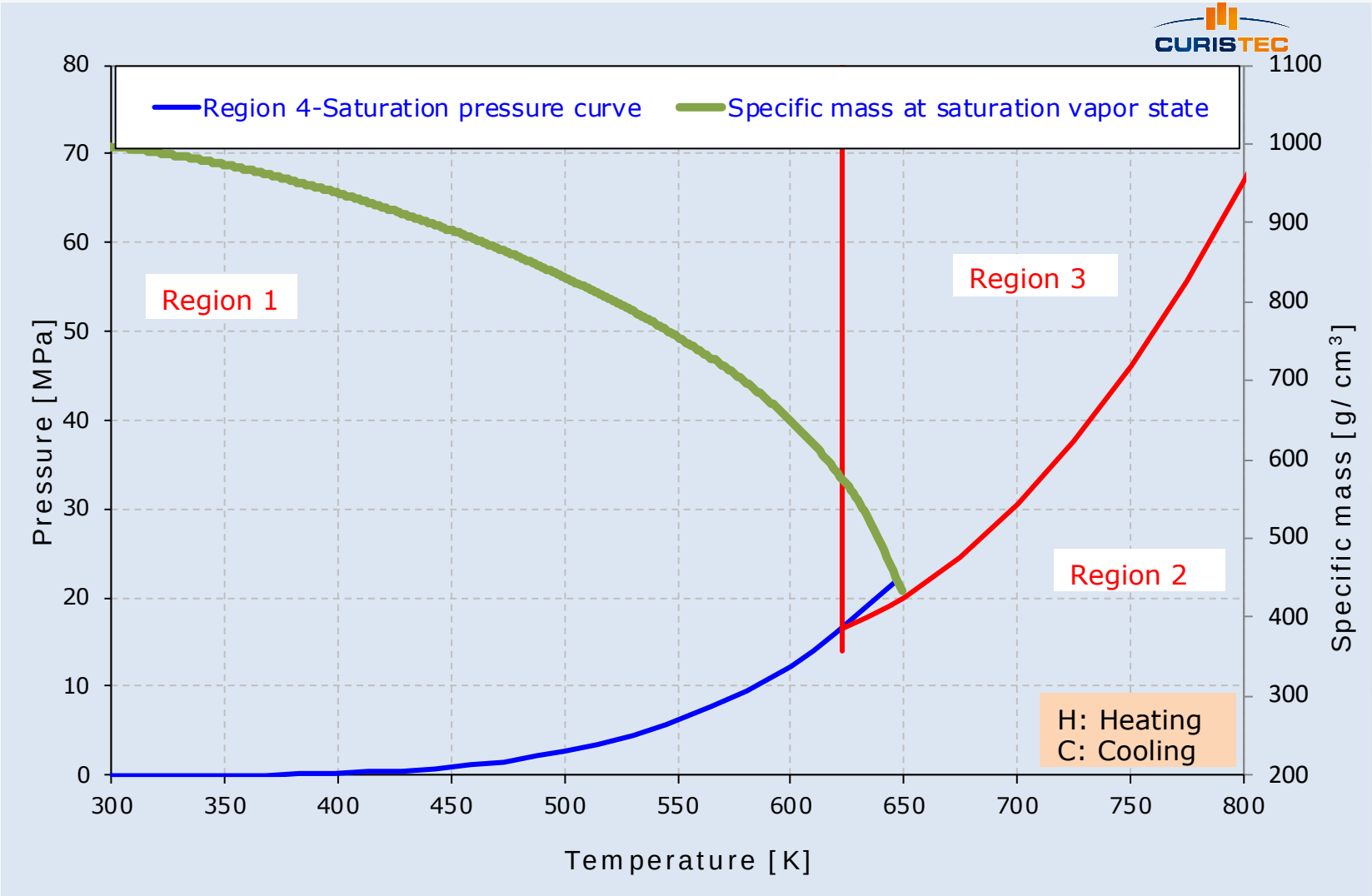
A cement sheath becomes damaged and μ-annuli are created by when heating it to supercritical conditions



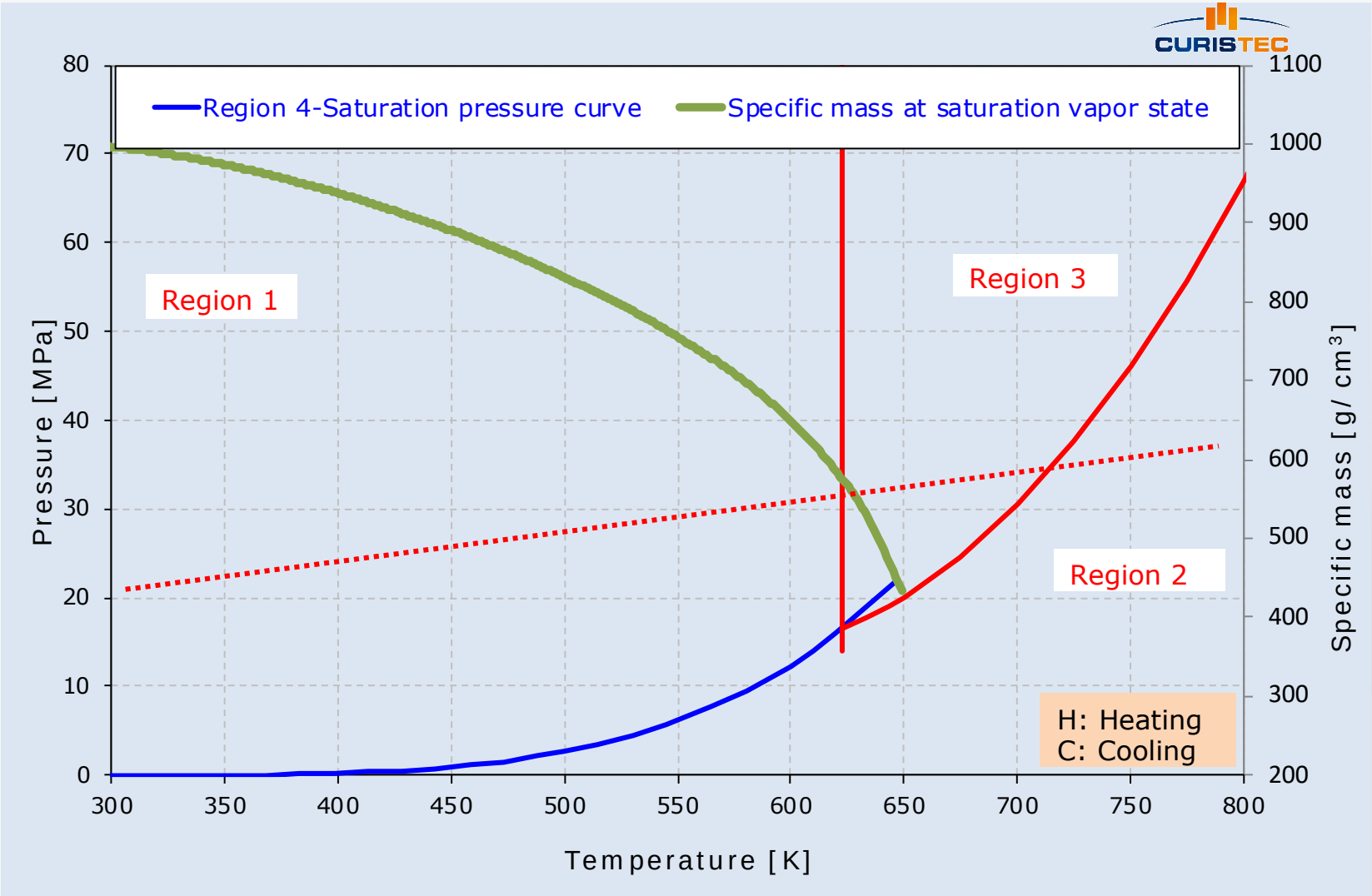
IDDP-1

To decrease the pore pressures, one should remove the isochoric conditions: Fluid is vented to the atmosphere or to reservoirs

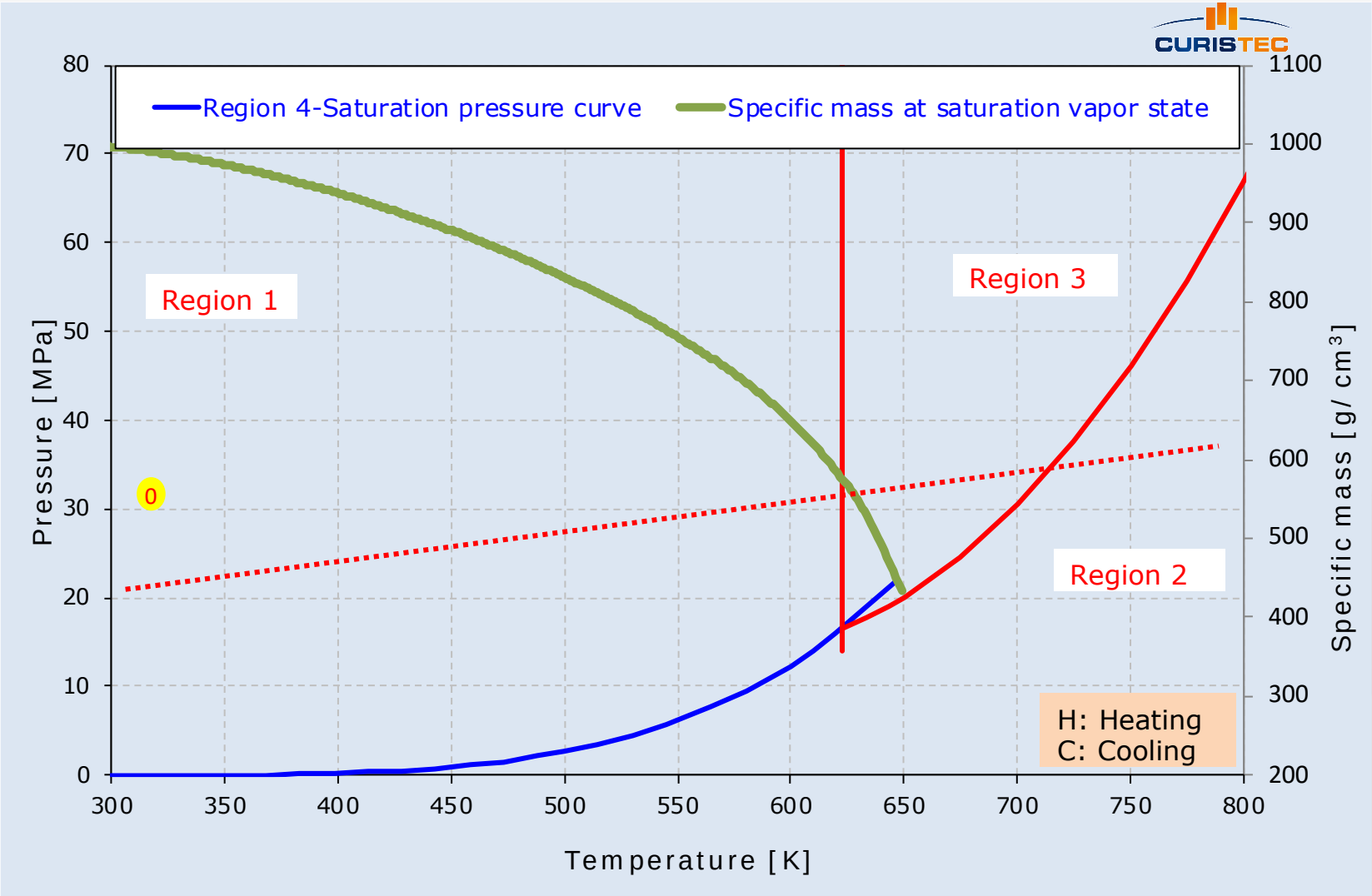
Loss of cement integrity



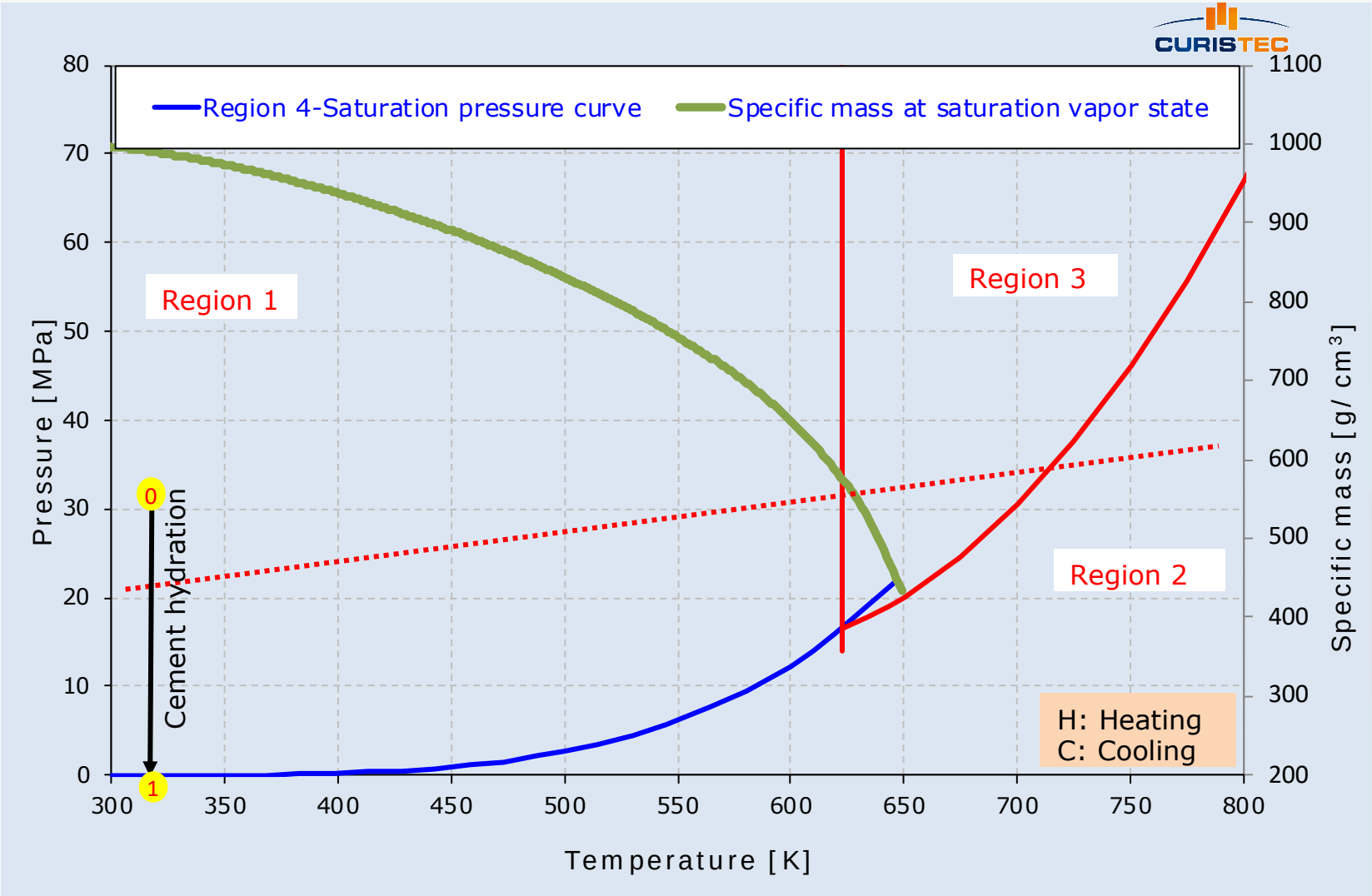
Loss of cement integrity: Micro-annulus threshold



Loss of cement integrity: 0. Slurry after placement

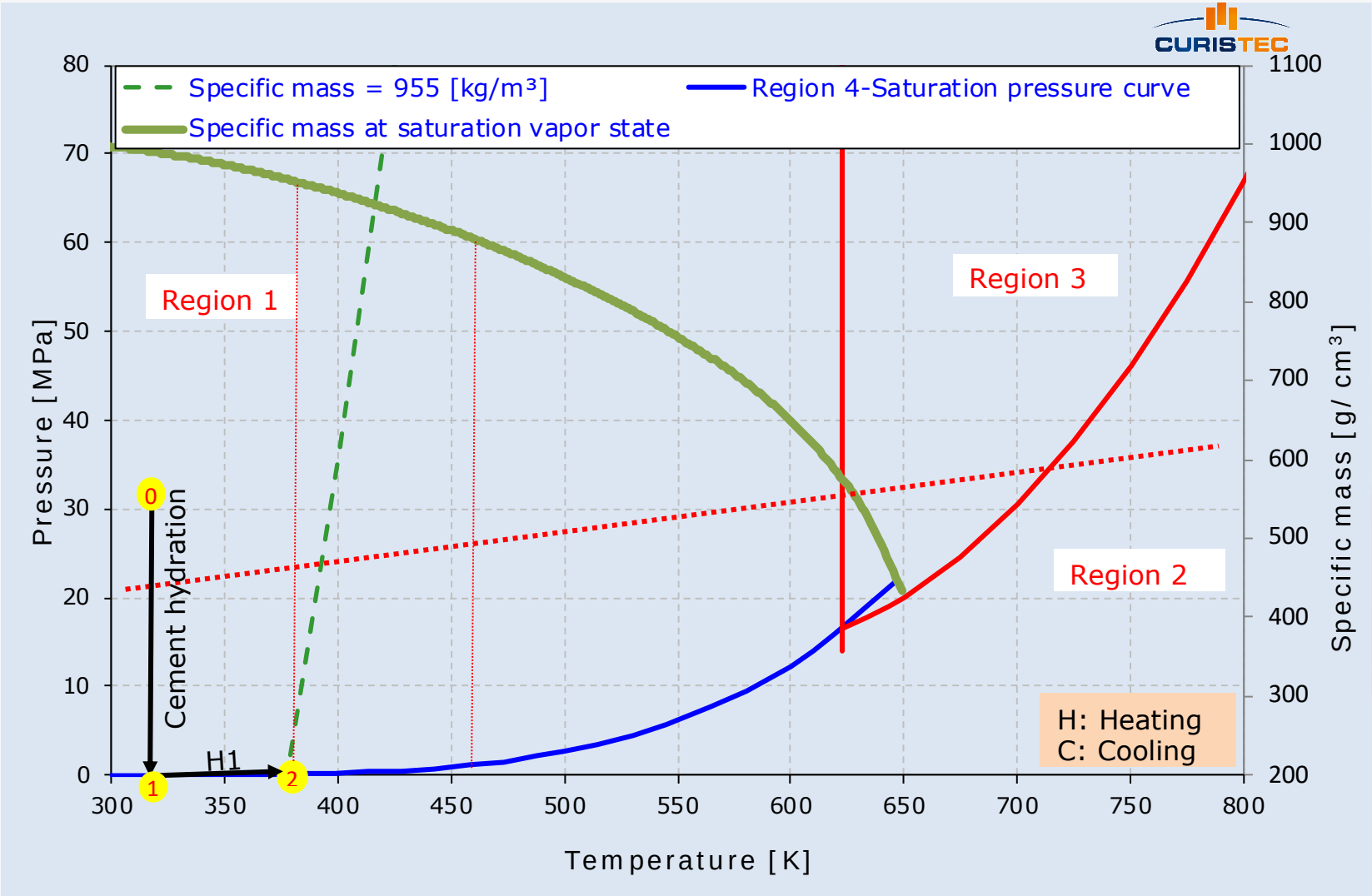


Loss of cement integrity: 1. Saturated cement after hydration



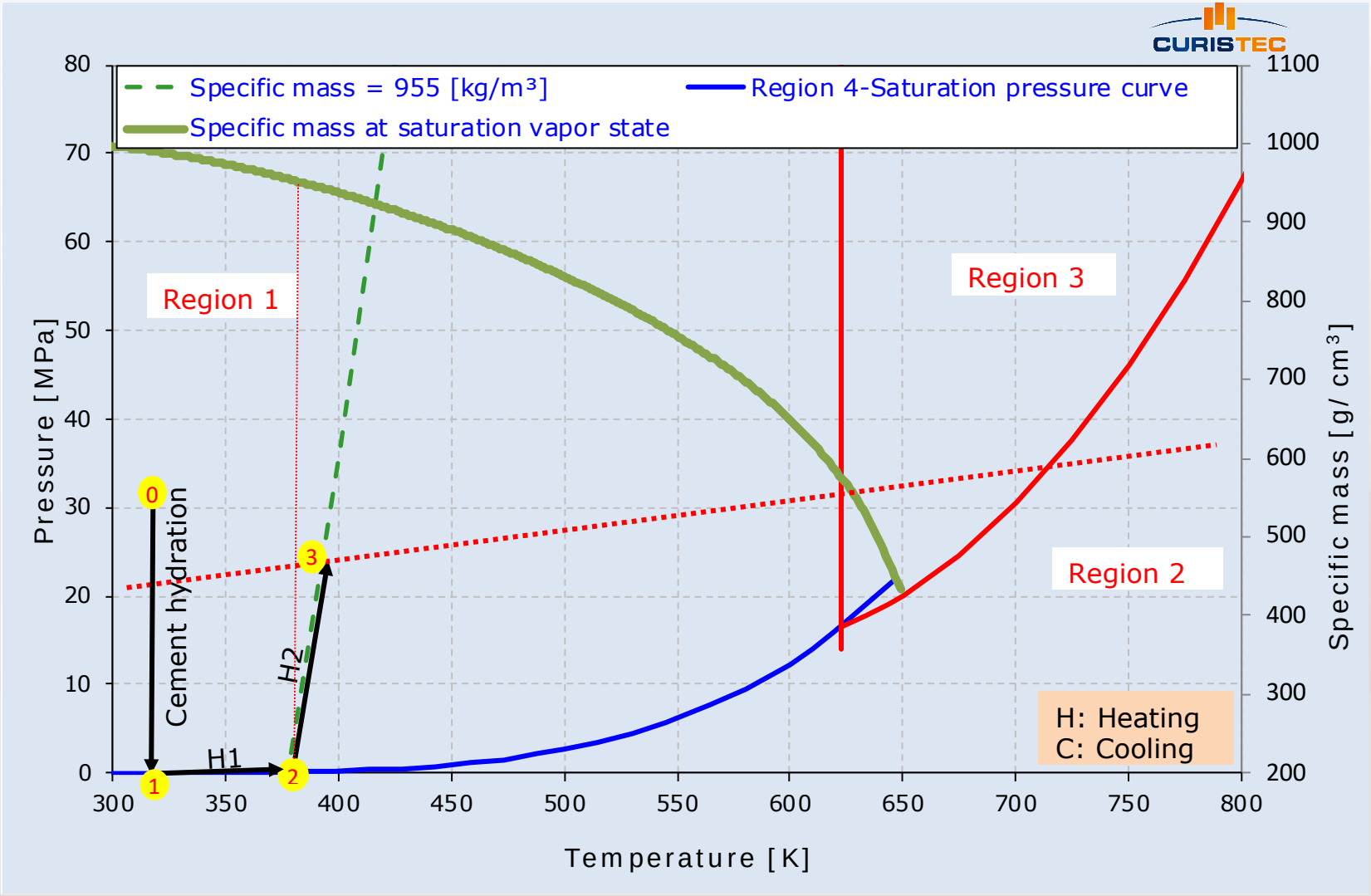
d = 991 kg/m³
m = 0 kg/m³

Loss of cement integrity: 2. Closed system heating



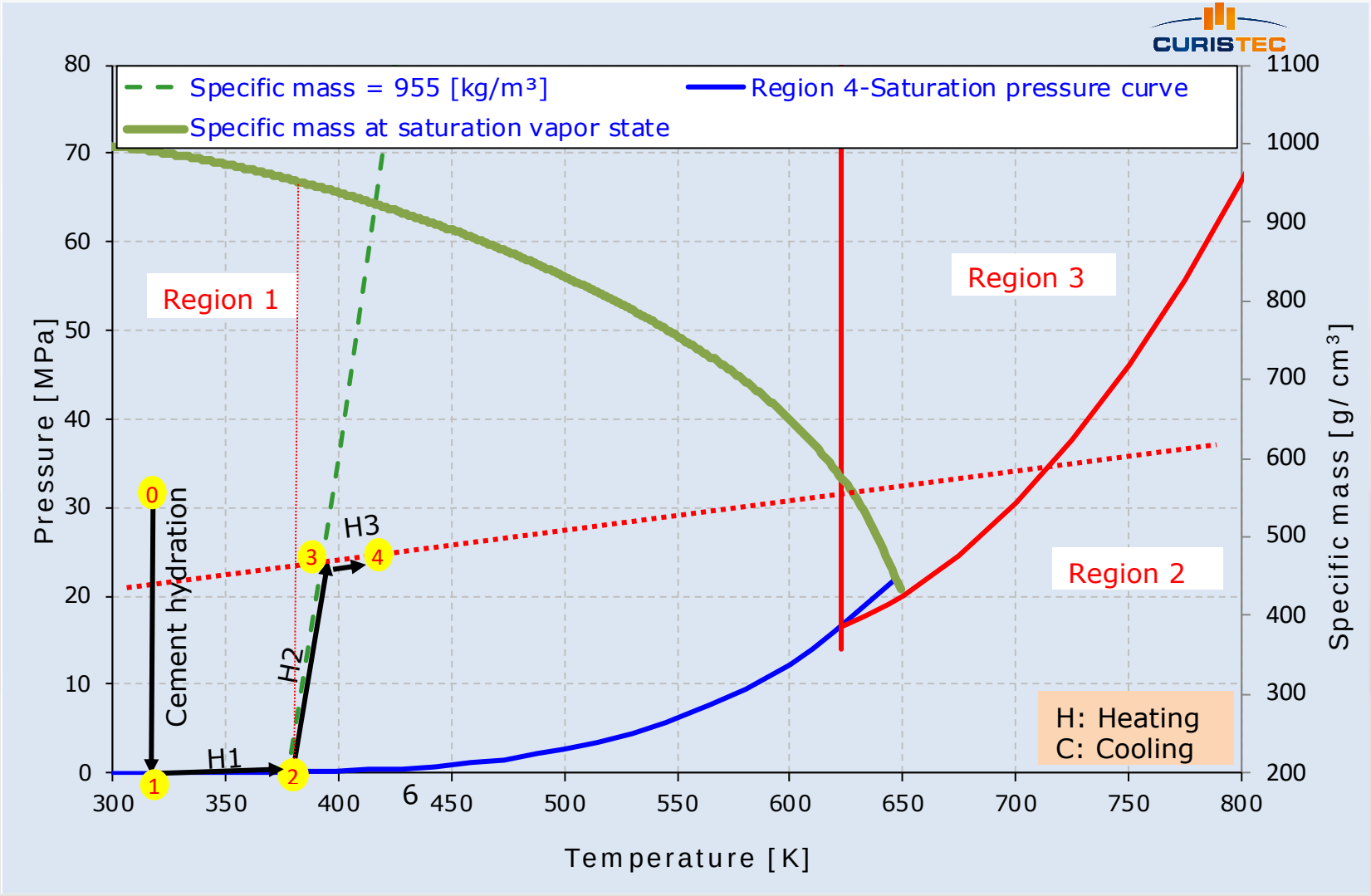
d = 955 kg/m³
m = 0 kg/m³

Loss of cement integrity 3. Closed system heating



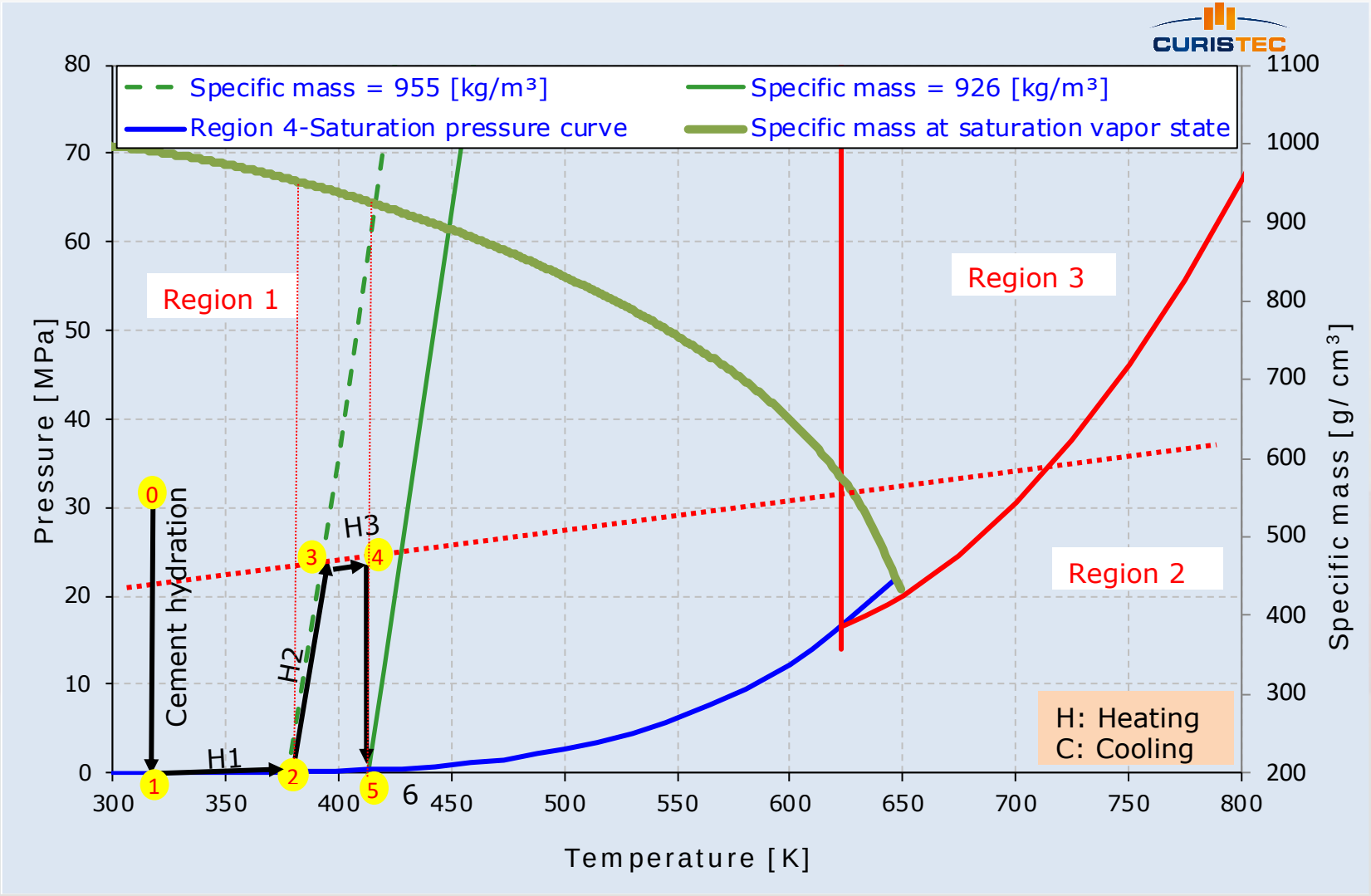
d = 955 kg/m³
m = 0 kg/m³

Loss of cement integrity: 4. Open system heating



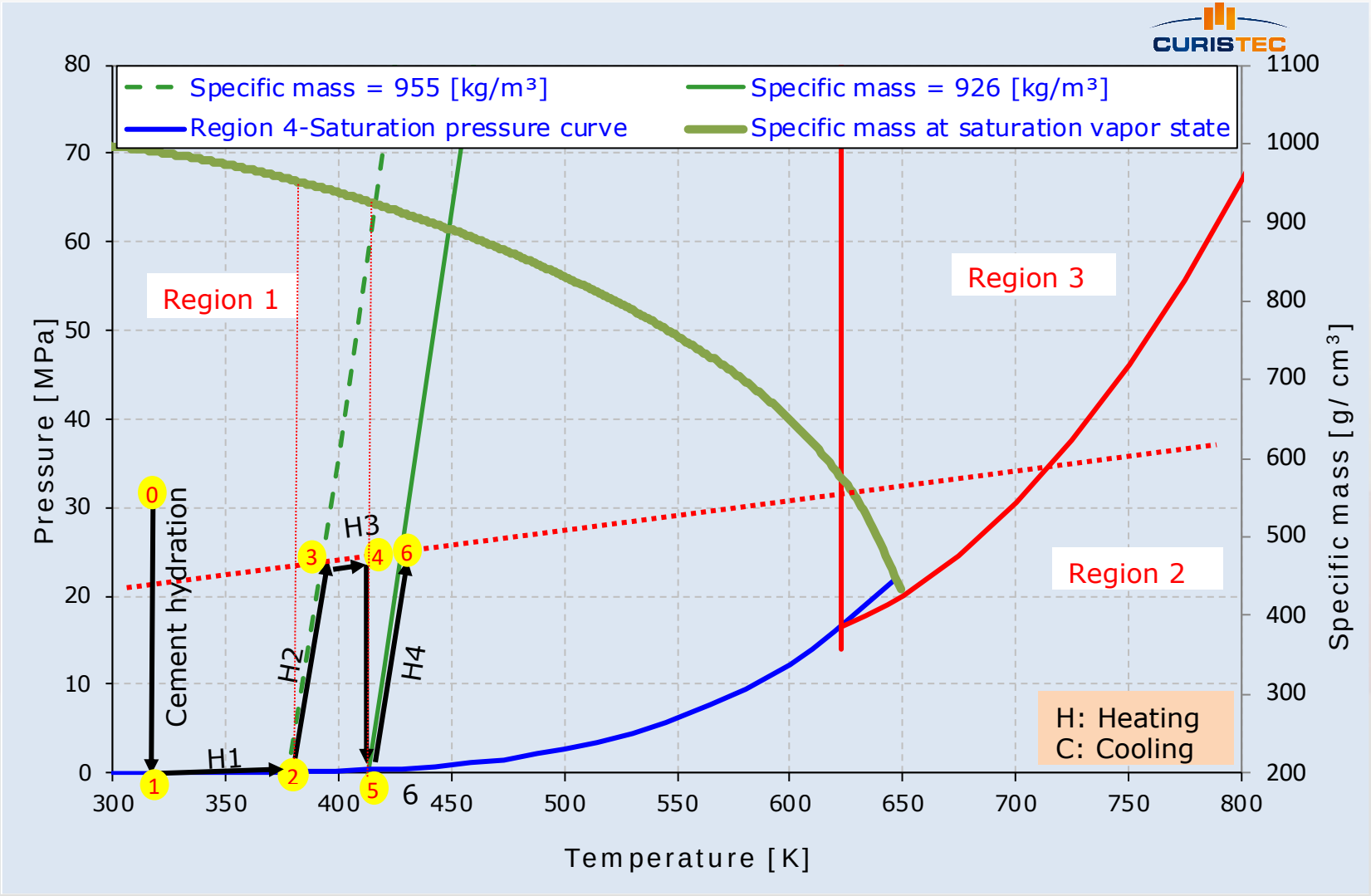
d = 938 kg/m³
m = 6 kg/m³

Loss of cement integrity: 5. Phase transformation



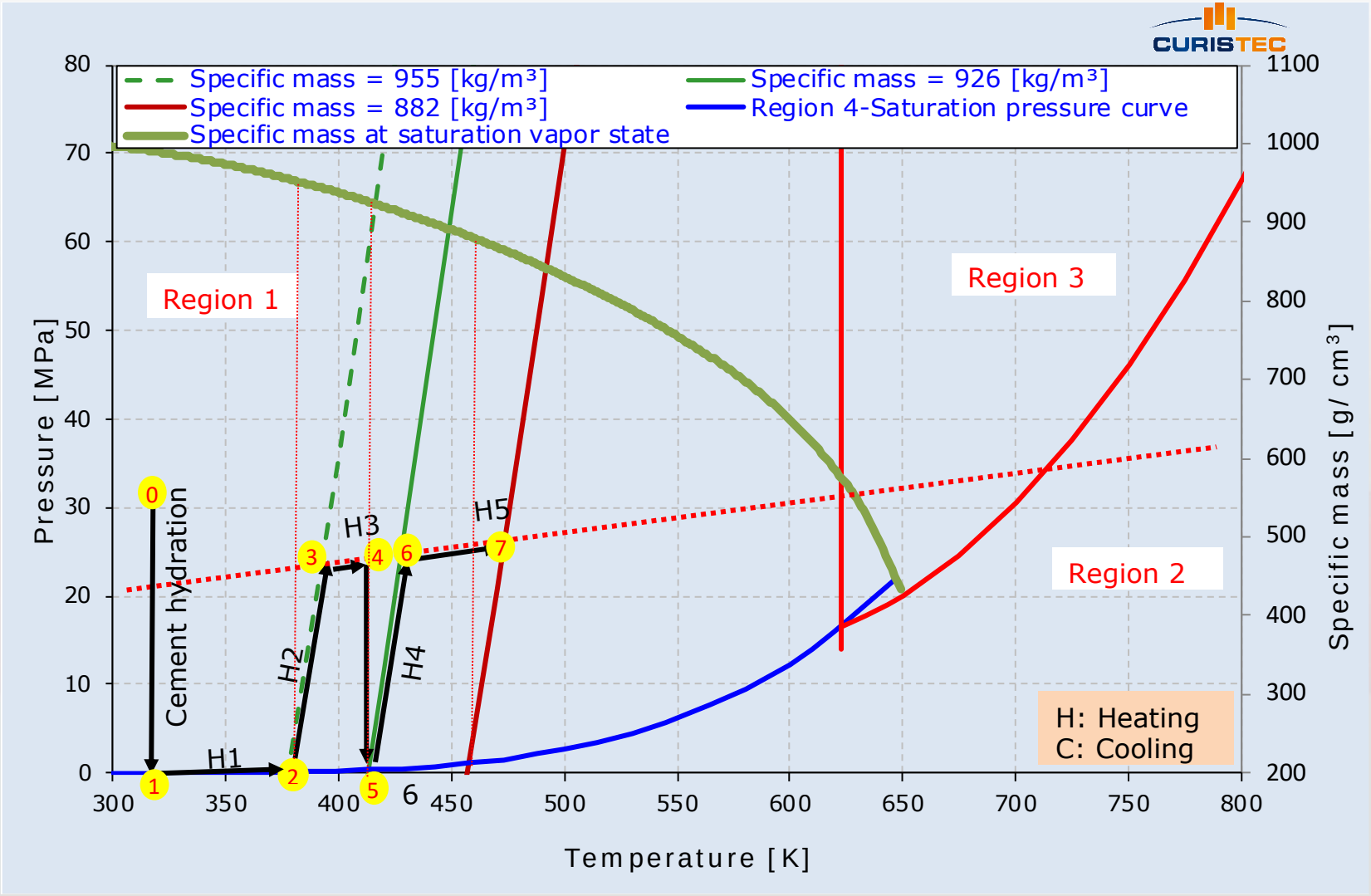
d = 926 kg/m³
m = 6 kg/m³

Loss of cement integrity: 6. Closed system heating



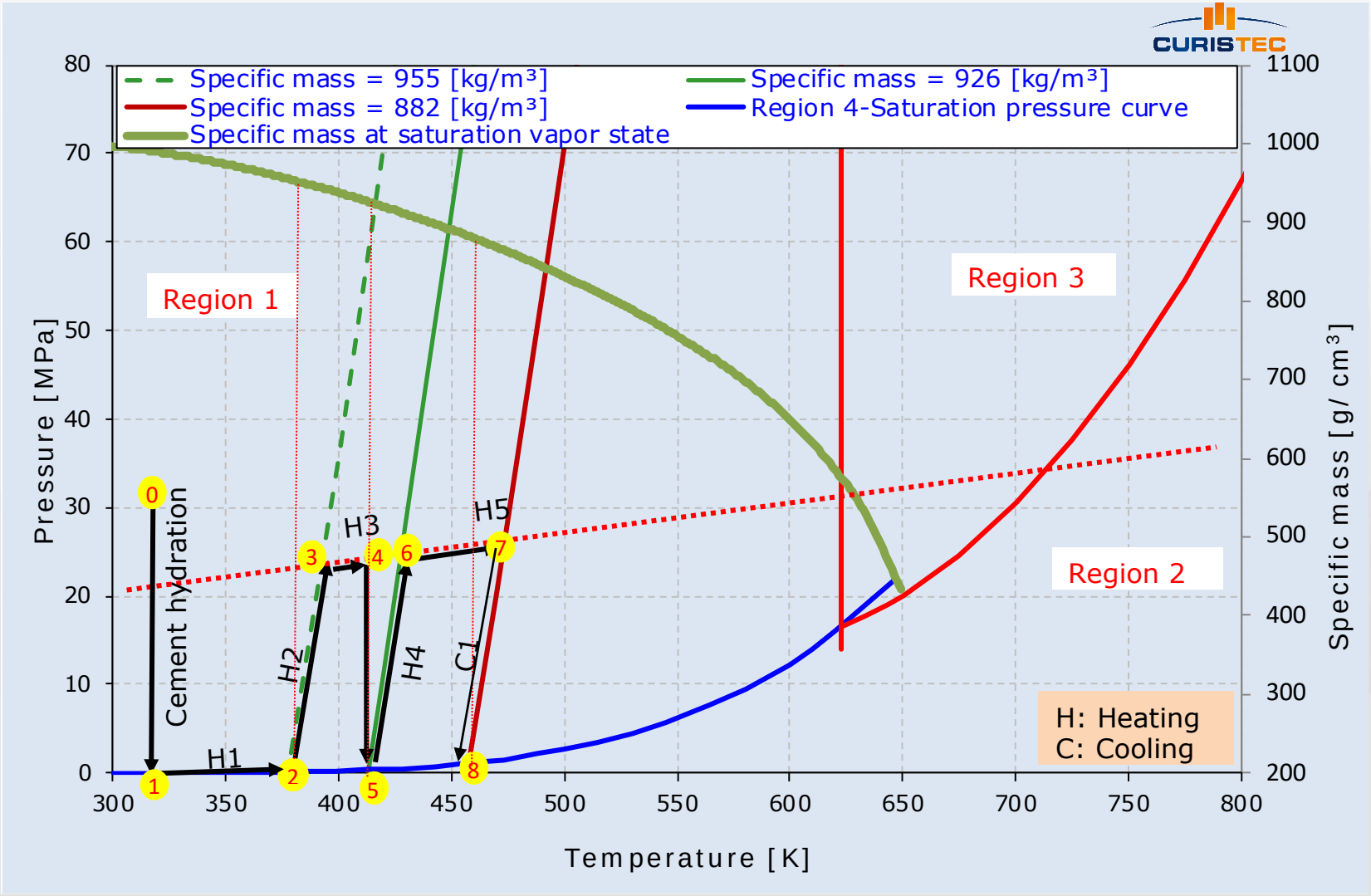
d = 926 kg/m³
m = 6 kg/m³

Loss of cement integrity: 7. Open system heating



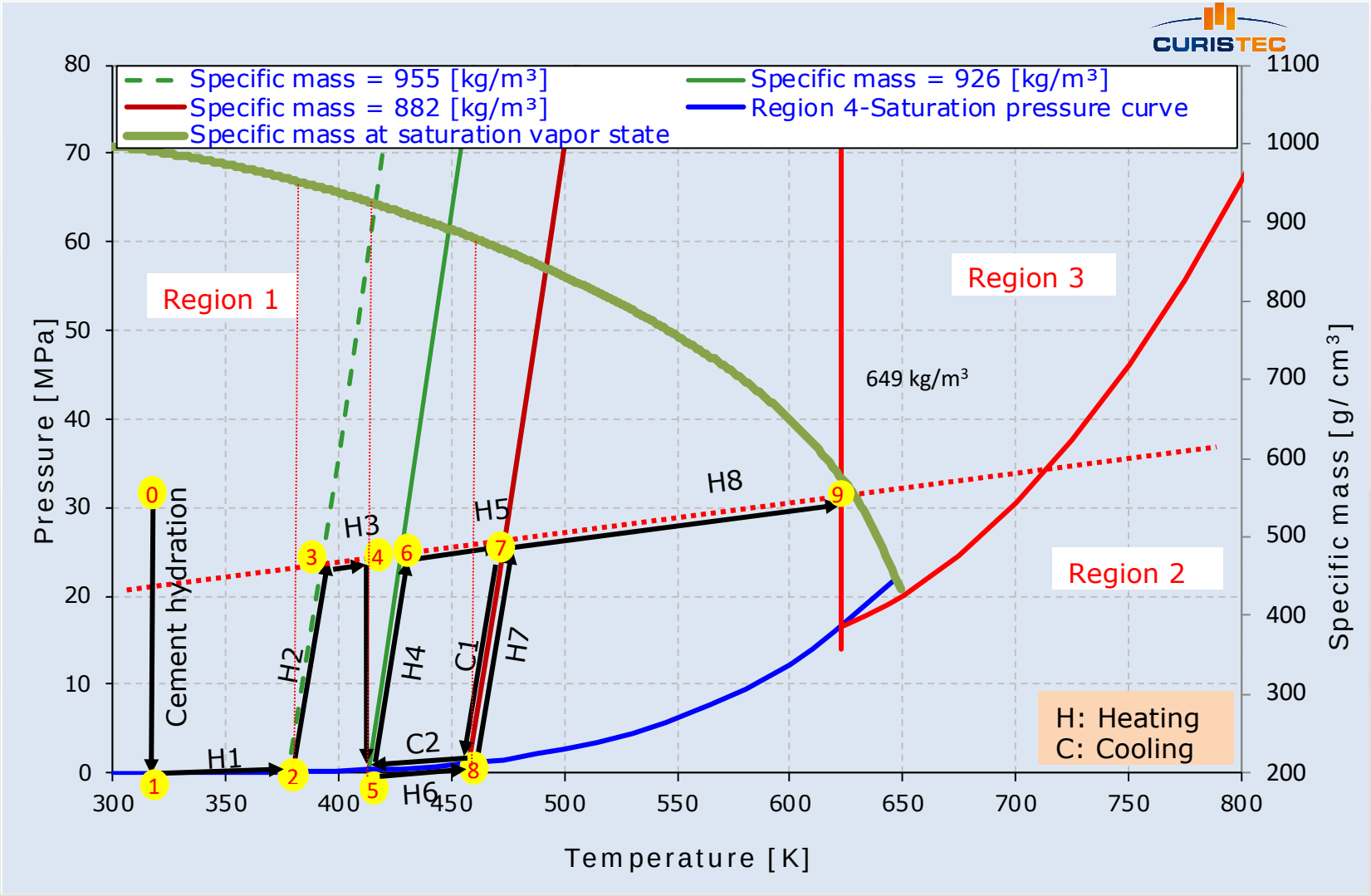
d = 882 kg/m³
m = 21 kg/m³

Loss of cement integrity: 8. Closed system cooling



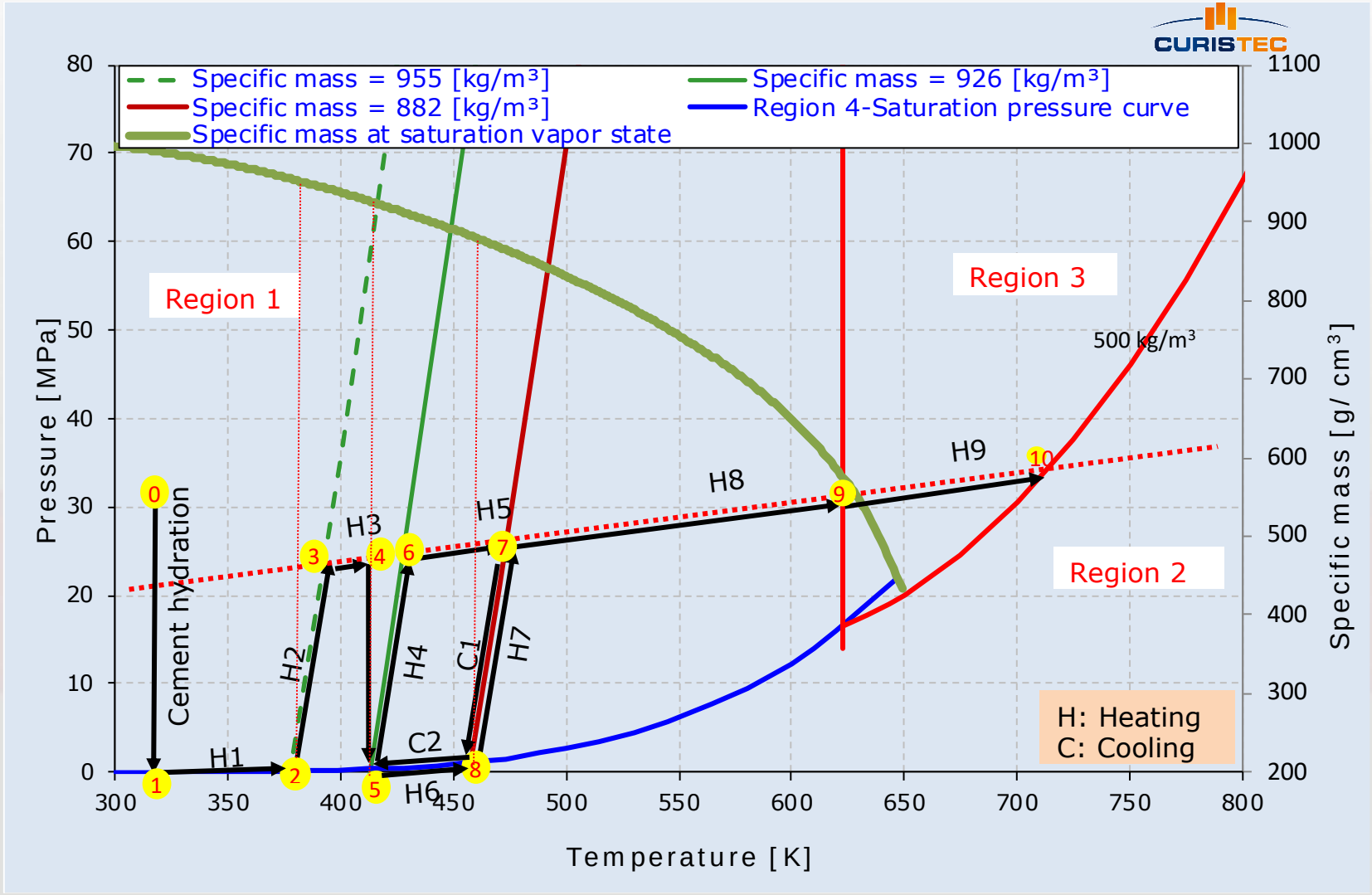
d = 882 kg/m³
m = 21 kg/m³

Loss of cement integrity:9. Open system heating



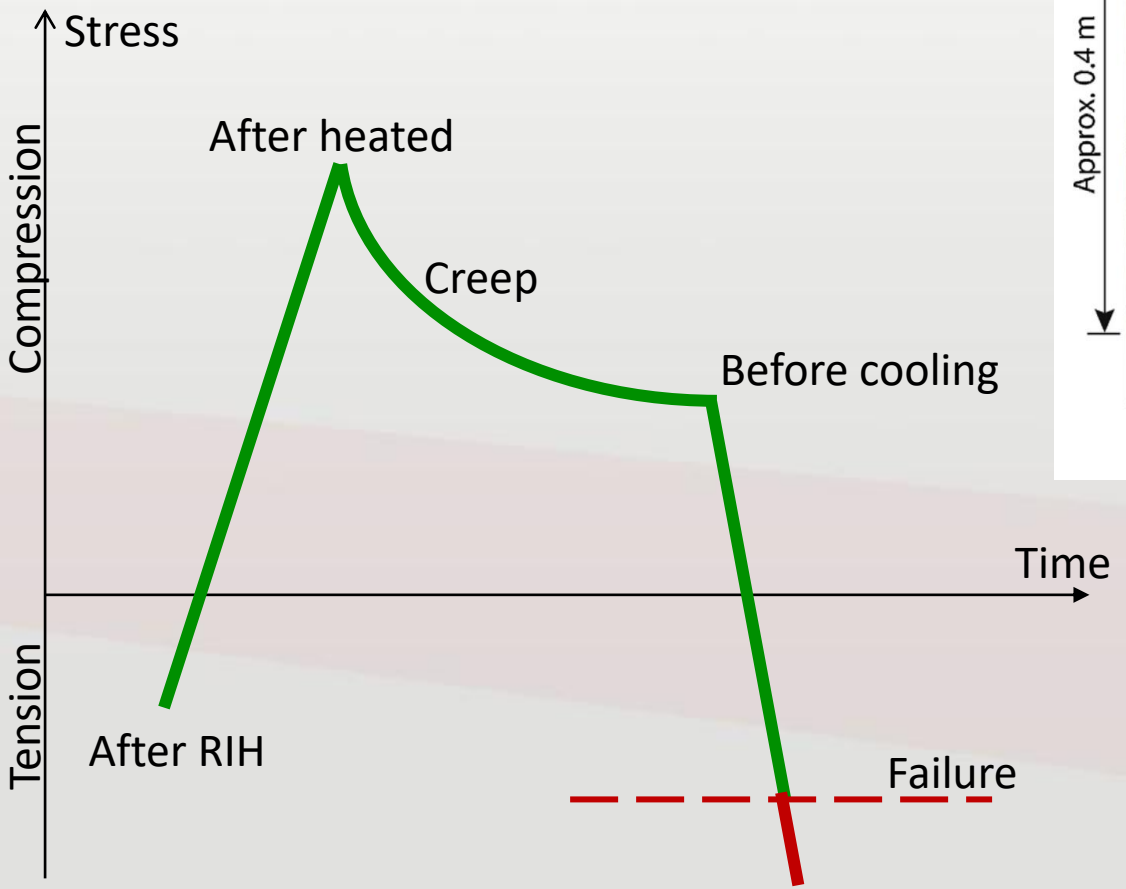
d = 649 kg/m³
m = 103 kg/m³

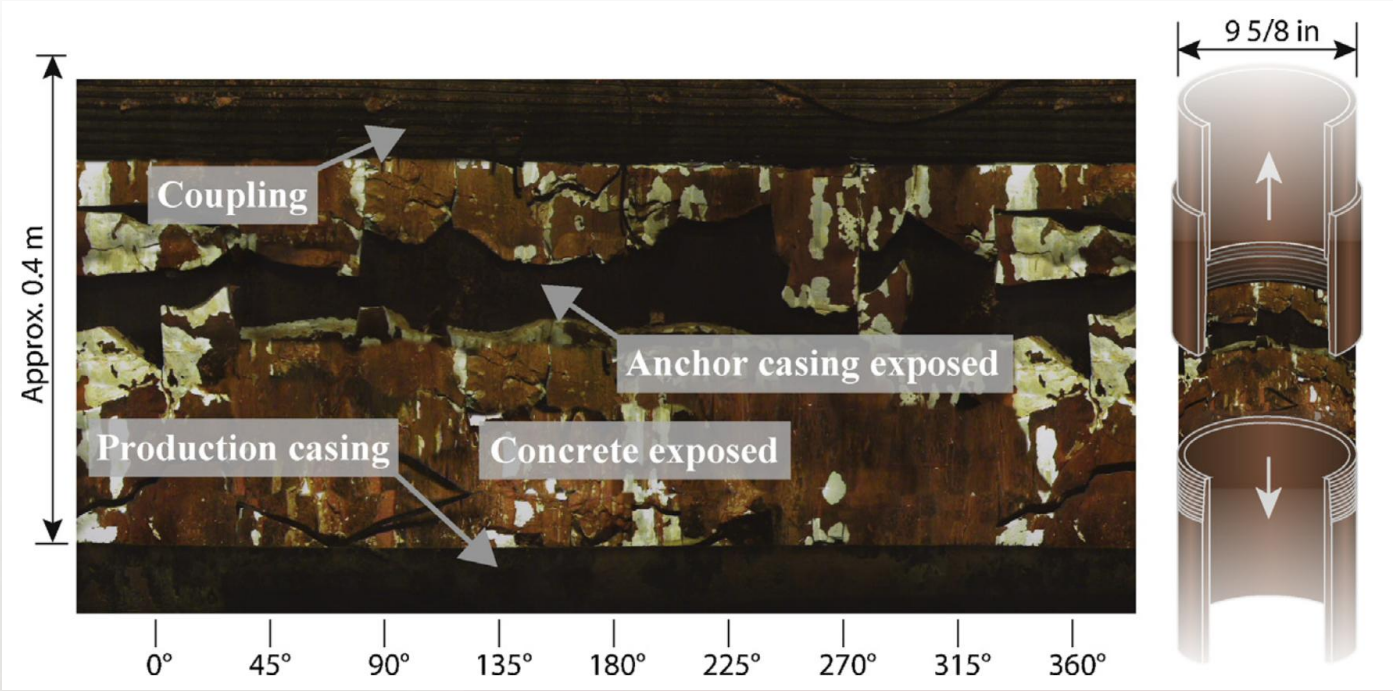
Loss of cement integrity: 10. Open system heating



d = 500 kg/m³
m = 155 kg/m³

Loss of casing integrity: Need flexible coupling





The use of flexible couplings requires sliding to occur between the casing and the cement → Development of a foam cement system at very high temperature

Why foam cement for geothermal wells?

Challenges with Conventional Cements

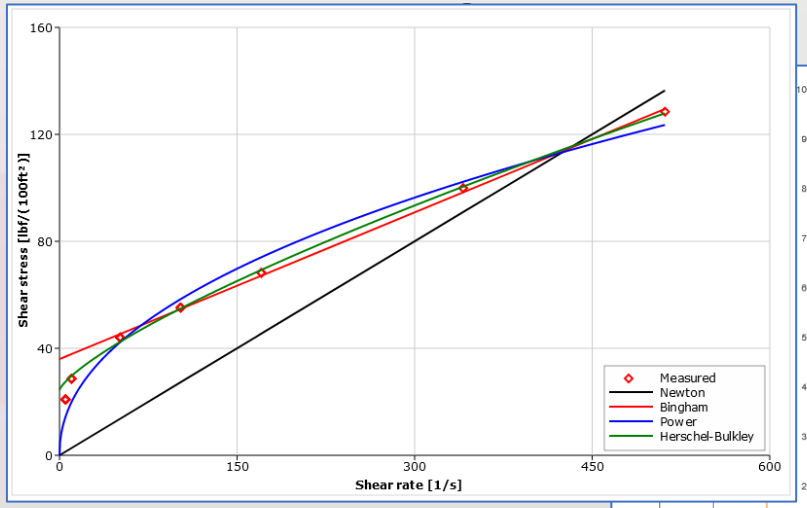
- Stiff and not very compressible
- Restrains casing expansion, leading to **high thermal stresses in the casing**
- Risk of **casing failure** in high-temperature wells

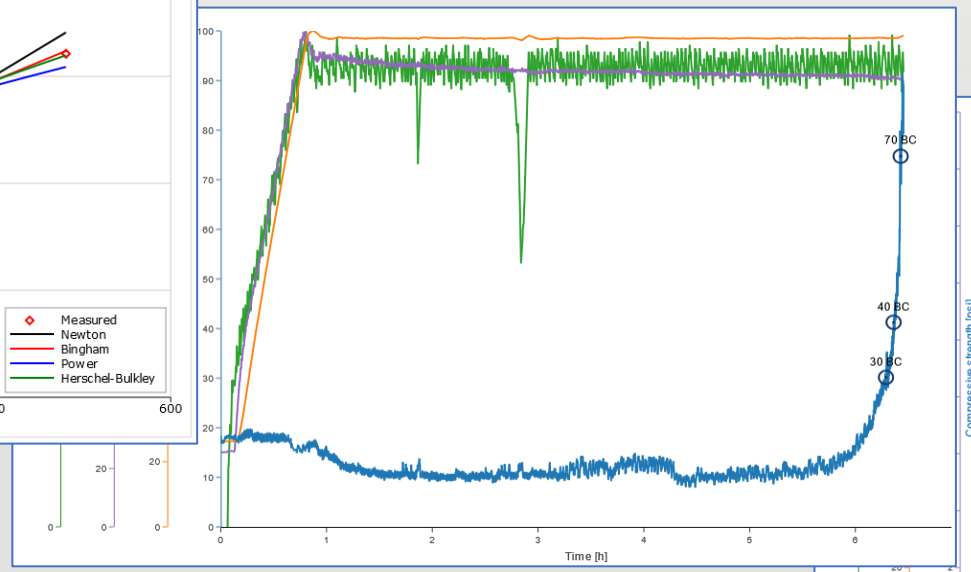
Foam cement – A flexible alternative

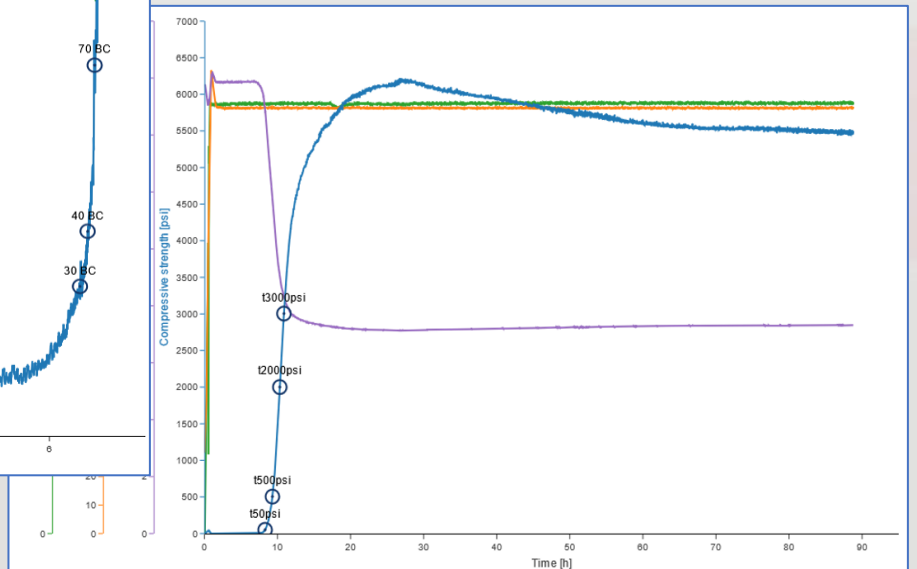
- **Lower density & higher flexibility**→ Allows casing expansion, reducing thermal stress
- **Improved compressibility** → Adapts better to well deformations
- **Lightweight & adaptable** → Prevents fluid losses during placement
- **Low thermal conductivity** → Reduces heat dissipation and improves energy efficiency

Foam cement developed in COMPASS

- **Base Cement:** API Class G
- **Thickening Time:** 6 hours at 150°C
- **Stability:** Bubbles preserved even after curing at 150°C







Standard protocol for mechanical testing

Cure under HTHP conditions
with access to water

Cooling
unloading

Ambient condition

Coring

Cutting

Grinding

Testing

Conditions	Bottom-hole	Test
Curing with access to water	Yes/No	Yes
Curing under effective stress	Yes	No
Loading disruption	No	Yes
Level of cement hydration	High/Low	High/Low

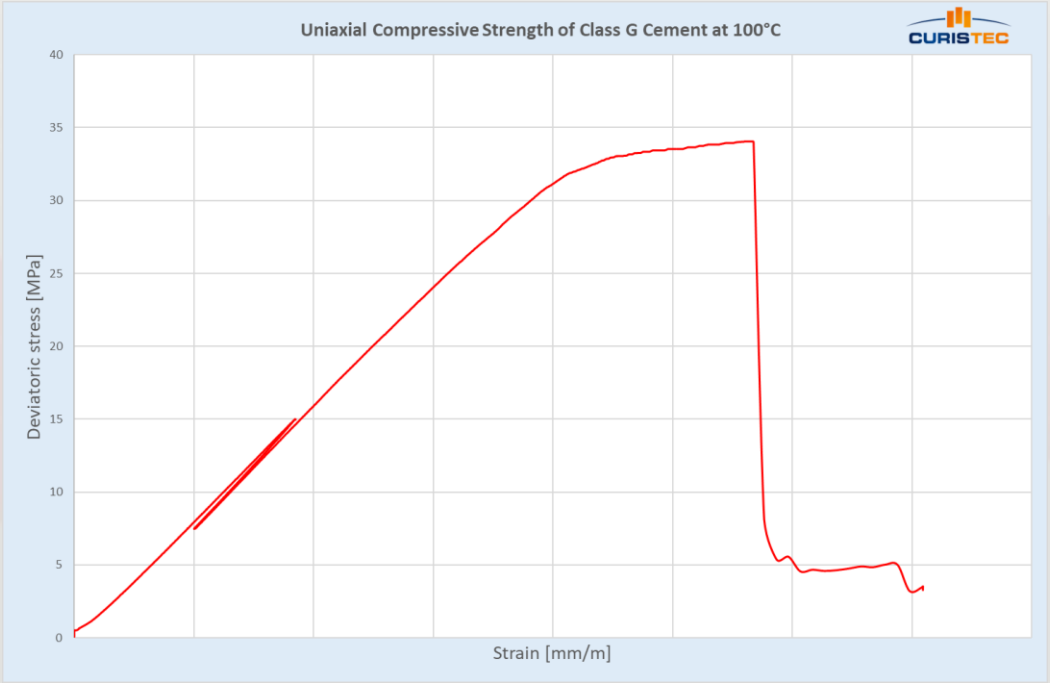
→ **Is the standard protocol truly representative of downhole conditions?**

→ **How does this impact test results and material behavior?**

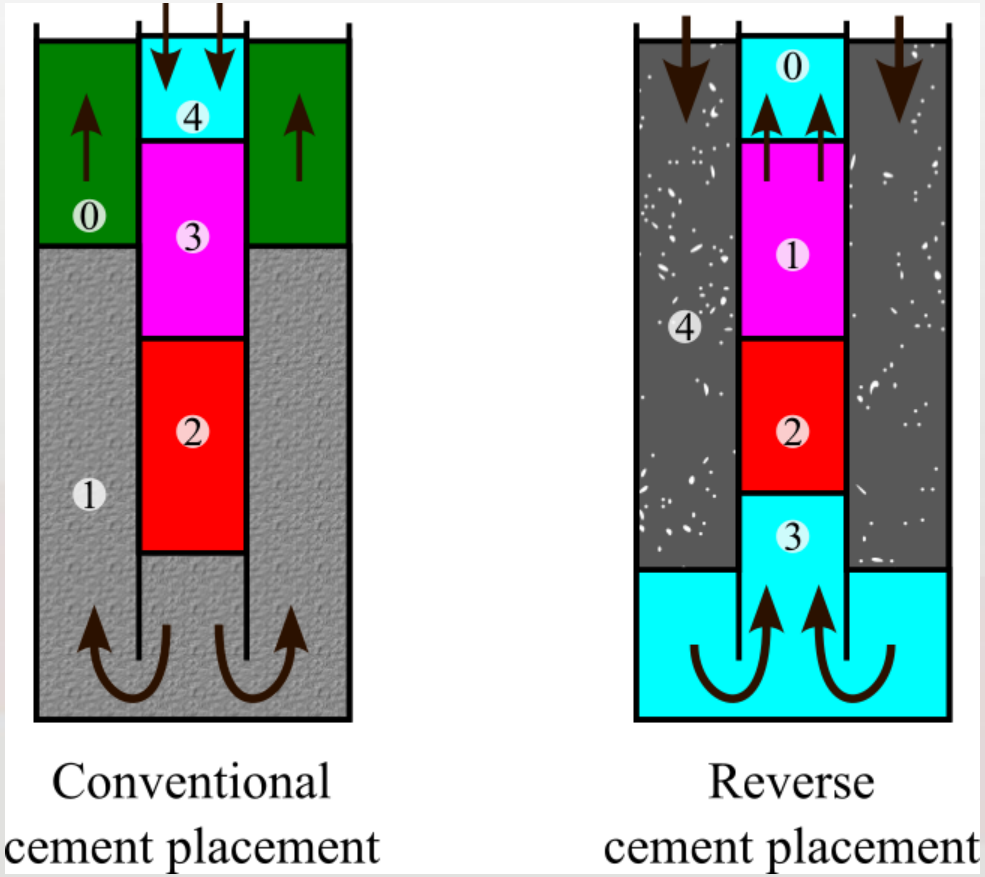
The C36 testing cell – A new approach

Key features and advantages:

- **Curing without access to water** → More representative of downhole conditions
- **Integrated curing & testing** → Avoids unloading cycles of temperature and pressure
- **High-Temperature testing** → Validated at **200°C**, target **300°C**



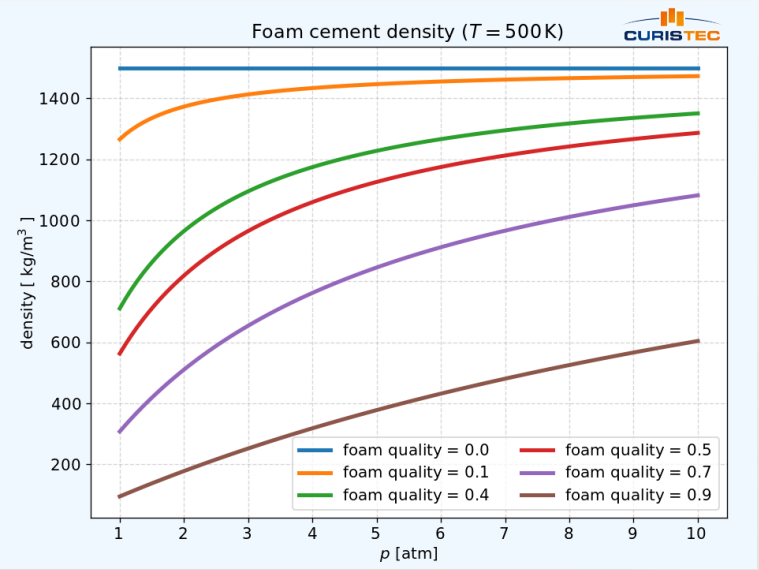
Conventional vs reversed cement placement



Advantages of reverse foamed-cement placement:

- Reduced ECD's
- Deal with large temperature differential from top to bottom of long strings of cemented casing. Get strength at TOC
- Good for large surface casing strings with stab-in DP
- Shorter job times
- Less excess / wasted cement
- With reverse circulation of foamed cement, less risk of trapped water and cement gaps at loss zones

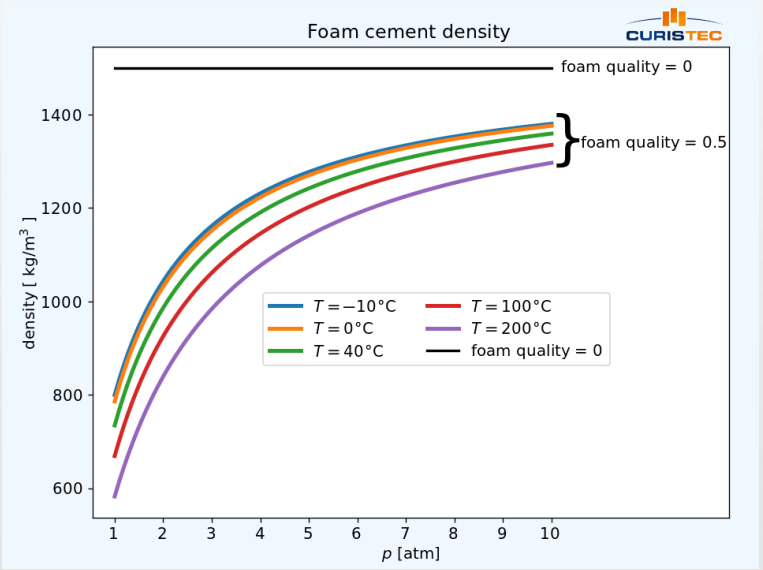
Foam cement density calculation



Density vs initial foam quality

$$\rho[p,T] = \frac{\rho_L \cdot (1-\Gamma_1) + \frac{p_1 \cdot m}{T_1 \cdot R} \cdot \Gamma_1}{1-\Gamma_1 \cdot \left(1 - \frac{T \cdot p_1}{p \cdot T_1}\right)}$$

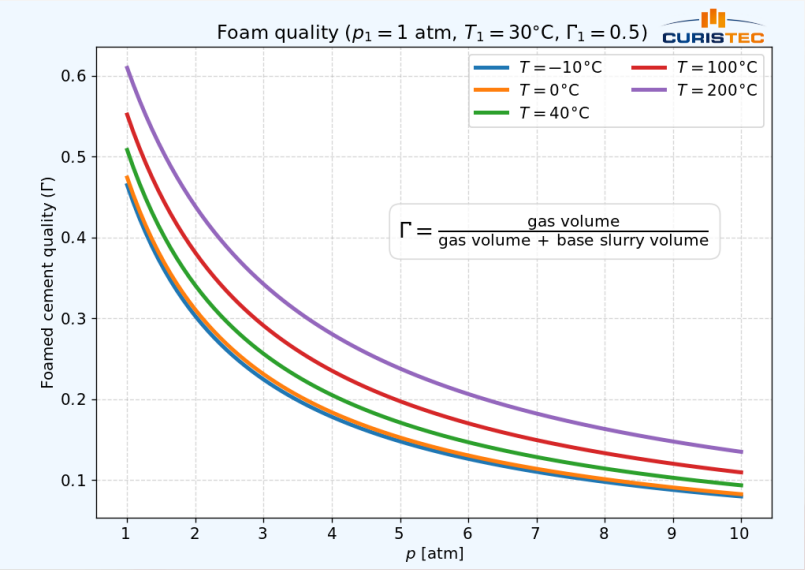
Density increases with increasing pressure, approaching the density of cement (i.e., zero foam quality)



Density vs temperature

$$\rho[p,T] = \frac{\rho_L \cdot (1-\Gamma_1) + \frac{p_1 \cdot m}{T_1 \cdot R} \cdot \Gamma_1}{1-\Gamma_1 \cdot \left(1 - \frac{T \cdot p_1}{p \cdot T_1}\right)}$$

Foam cement is denser at lower temperatures



Foam quality vs temperature

$$\Gamma[p,T] = \frac{\Gamma_1}{(1-\Gamma_1) \cdot \frac{p \cdot T_1}{T \cdot p_1} + \Gamma_1}$$

Local foam quality increases with pressure

Conclusions

- **Thermal stresses** → Casing integrity challenged

- **Current technologies & standards** → Insufficient

→**COMPASS: Thermal Stress Mitigation Solutions** :
  - High-temp. foam cement → Mechanical adaptability
  - High-temp. testing cell → Mechanical properties measurement @ HT
  - Cement placement & hydration models → Prediction of cement behavior & stress evolution
  - APB mitigation (ISOR)

- Technologies validated independently

- Next steps → Combined assessment: Flexible Foam Cement + APB

Thank you!

Axel-Pierre Bois

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