Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Well integrity

Carbon dioxide effect on Portland cement estimated by Mercury Intrusion Porosimetry

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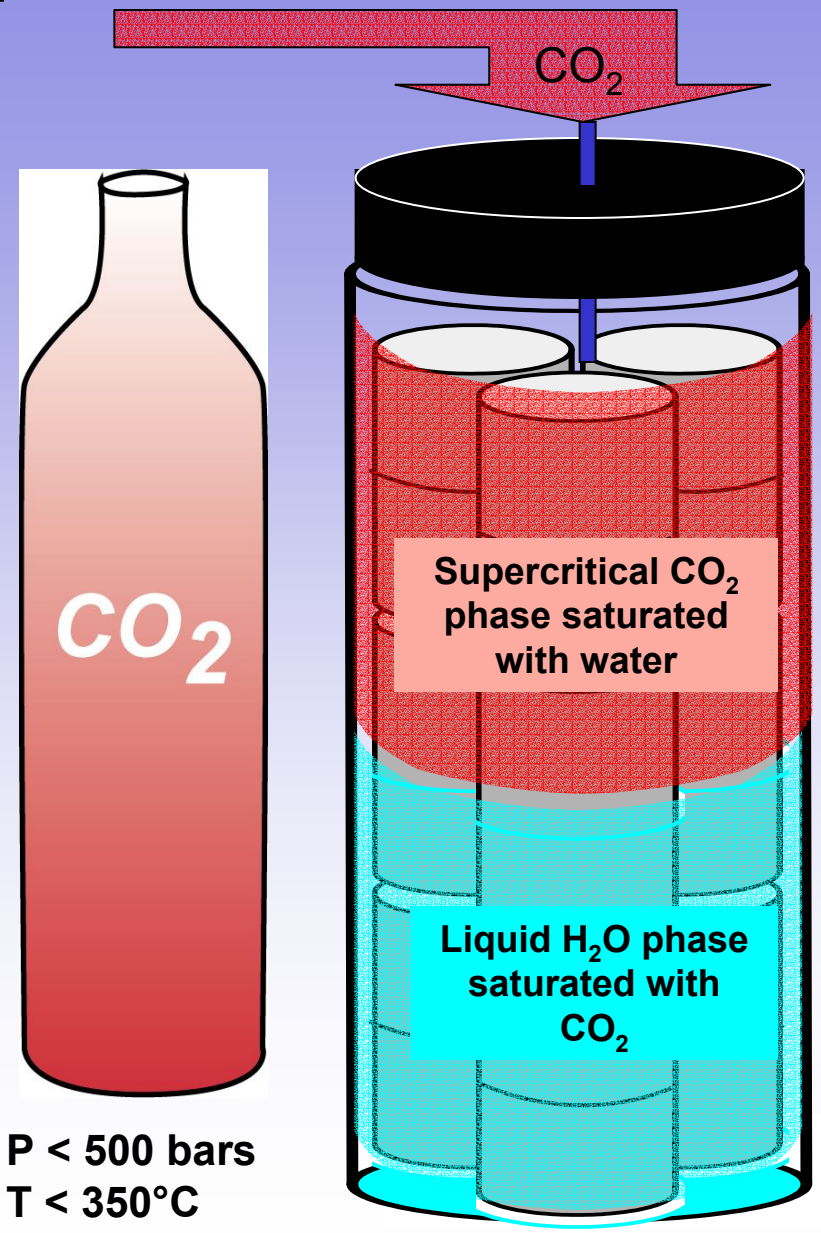
Introduction

- Carbon Capture and Storage application requires long-term well bore integrity
- Identified major risk: CO_2 leakage through the well bore annulus
- Experimental methodology simulating downhole conditions has been developed.

Experimental procedure

➔ **Diphasic system**

TEST CONDITIONS:
P = 280 bars ; T = 90°C



P < 500 bars
T < 350°C

IADC/SPE 98624: Mitigation strategies for the risk of CO_2 migration through wellbore, V. Barlet-Gouédard and al., Schlumberger /ENS

Quantification of the cement alteration

- Chemical & mineral evolution of the matrix
  - Thickness of the alteration front
  - XRD analyses
  - SEM-EDS analyses
- Characterization and visualization of matrix porosity
  - Mercury Intrusion Porosimetry measurements
  - SEM-BSE image analyses
  - Water diffusion test
- Fluid analysis:
  - pH variation
  - Water production
- Evolution of physical properties
  - Weight and dimensions variation measurements
  - Compressive strength measurements

Carbonation of Portland cement

- Reactions involved

$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$

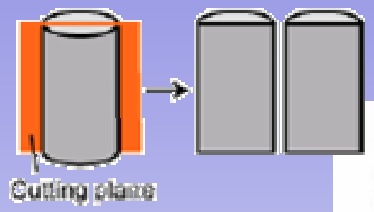
$Ca(OH)_2 + H^+ + HCO_3^- \rightarrow \mathbf{CaCO_3} + \mathbf{H_2O}$

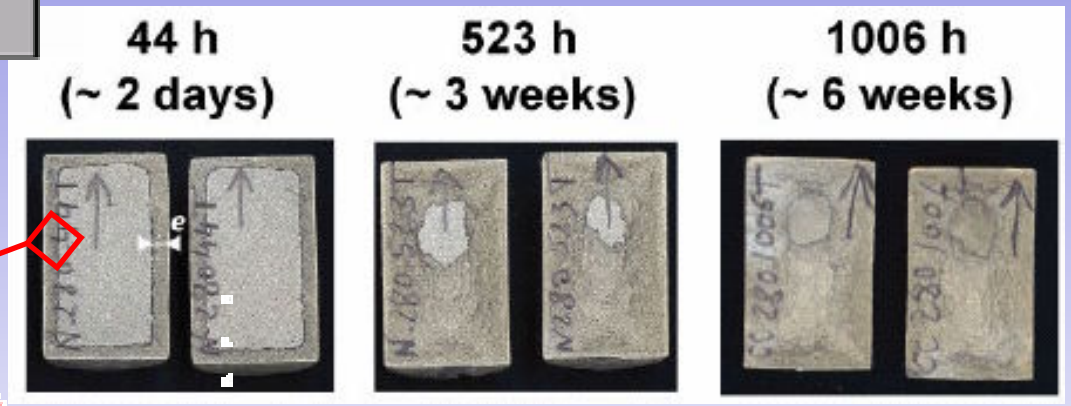
$CSH + H^+ + HCO_3^- \rightarrow \mathbf{CaCO_3}$ + silica gel

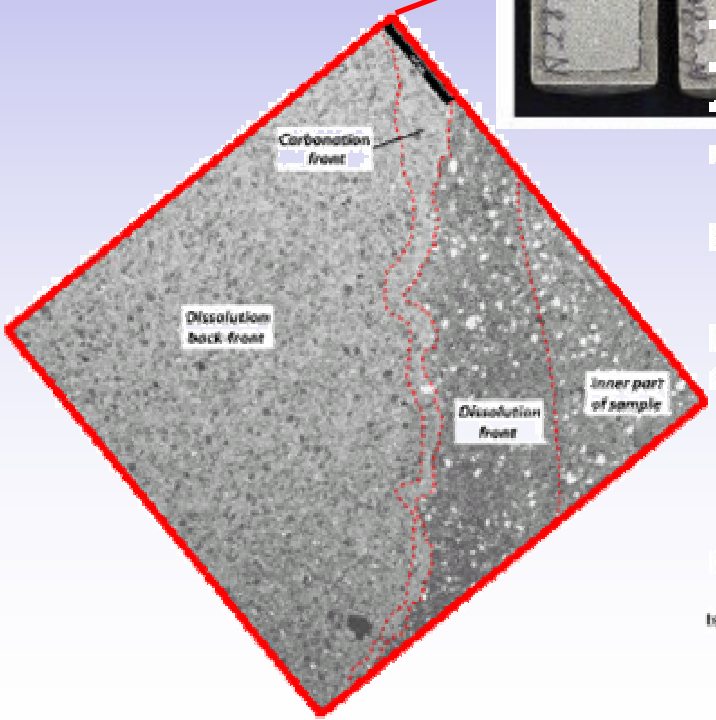
$\mathbf{CaCO_3} + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$

$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ \mathbf{CaCO_3} + 2\ \mathbf{H_2O}$

Evolution of the alteration front in both fluids



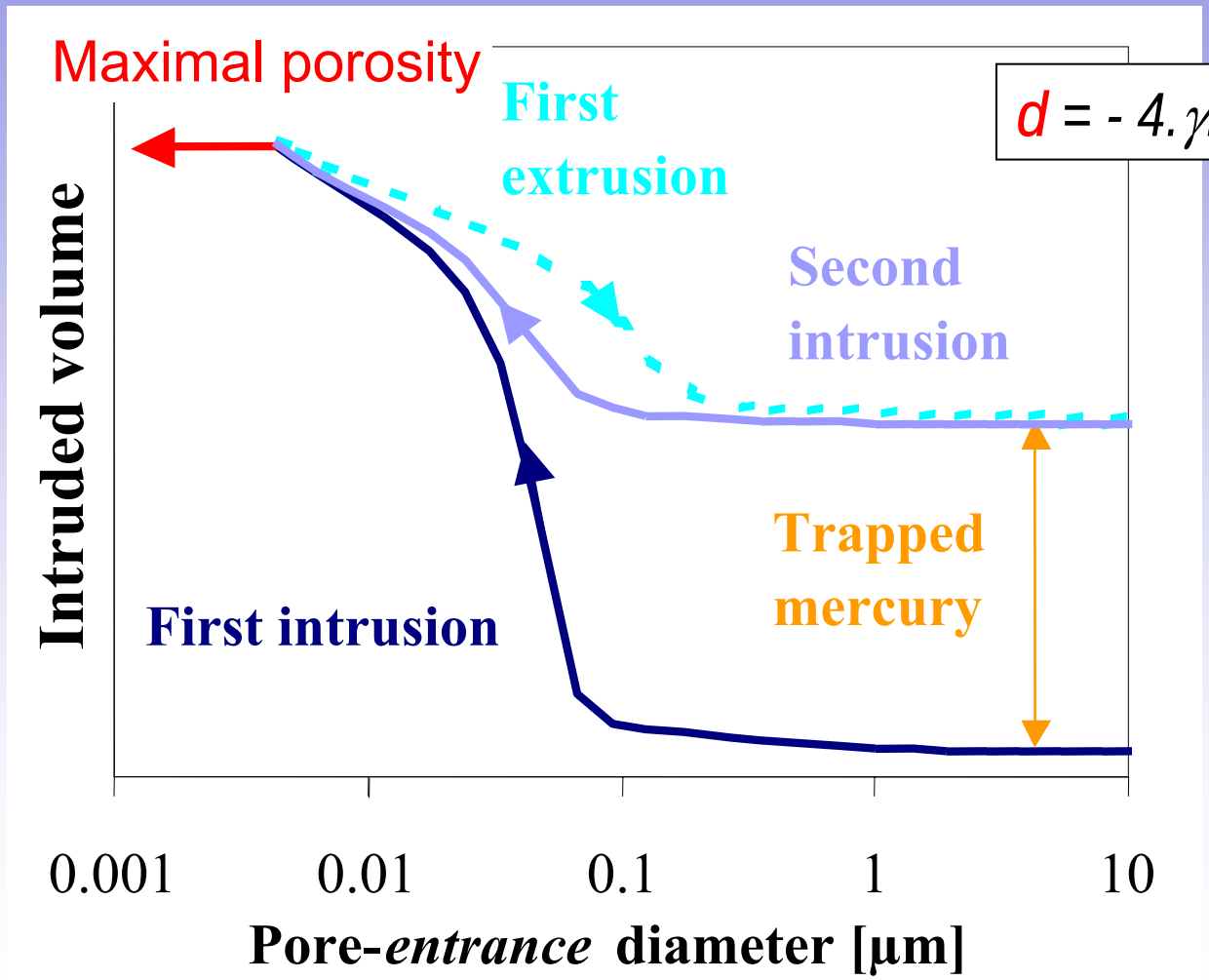




- Weak interface in a heterogeneous matrix

G. Rimmelé et al., Quantifying CO_2-related Alteration of Portland Cement: Experimental Approach and Microscopic Methodology. Second Well Bore Integrity Workshop, Princeton, 2006.

Mercury Intrusion Porosimetry



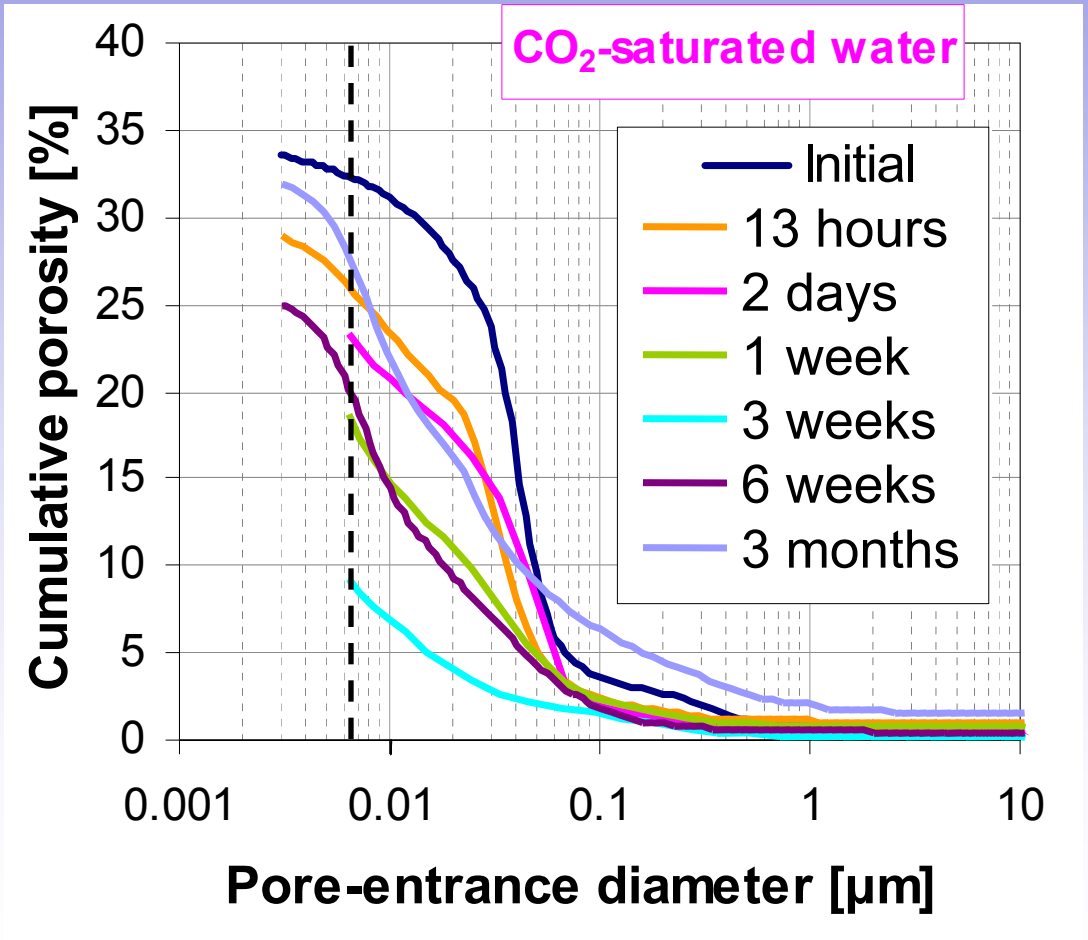
$$d = -4.\gamma.\cos\theta / P$$

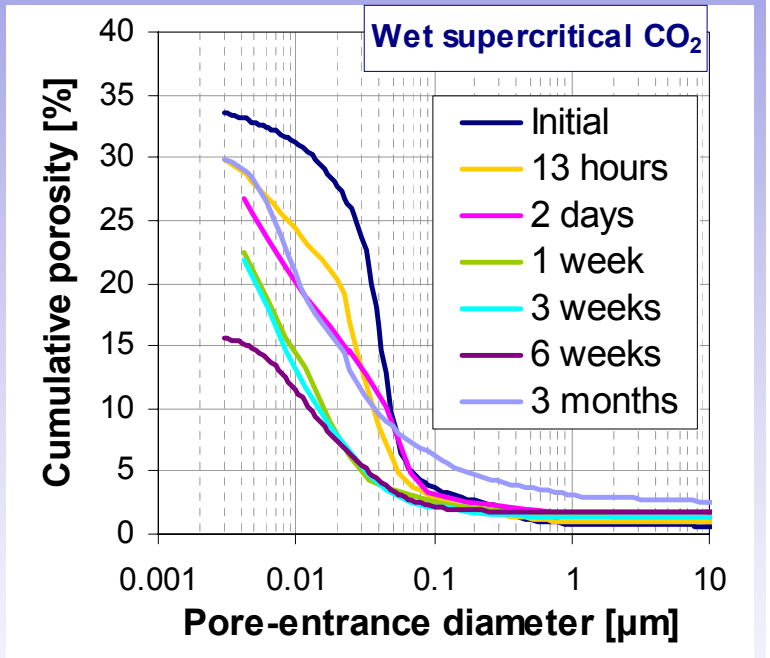
Experimental conditions

- Same drying conditions: 60 hrs at 100 deg.C
- Same core size (0.5”diameter x 1” length cylindrical core samples)
- Maximal intrusion pressure of 60,000 psi

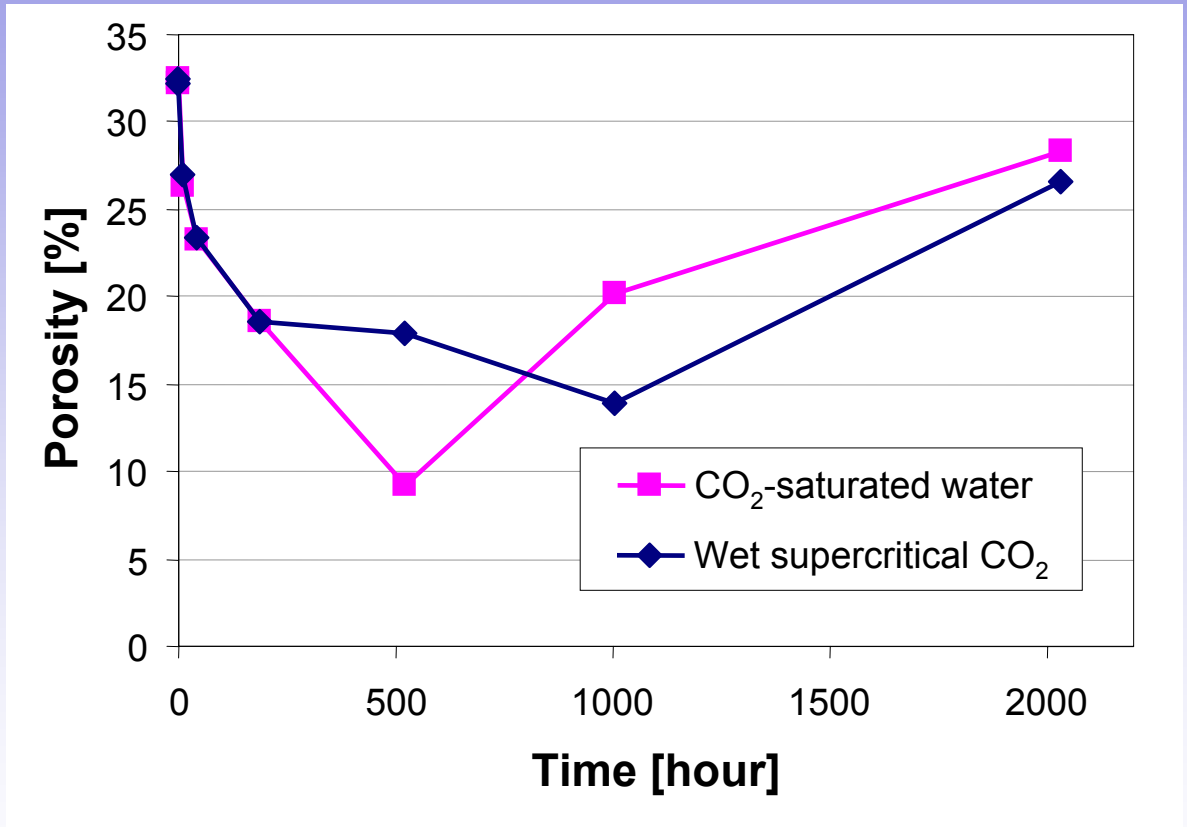
➪ Comparison of the measurements at each duration is significant

Evolution of the porosity after CO_2 attack at 90°C under 280 bars



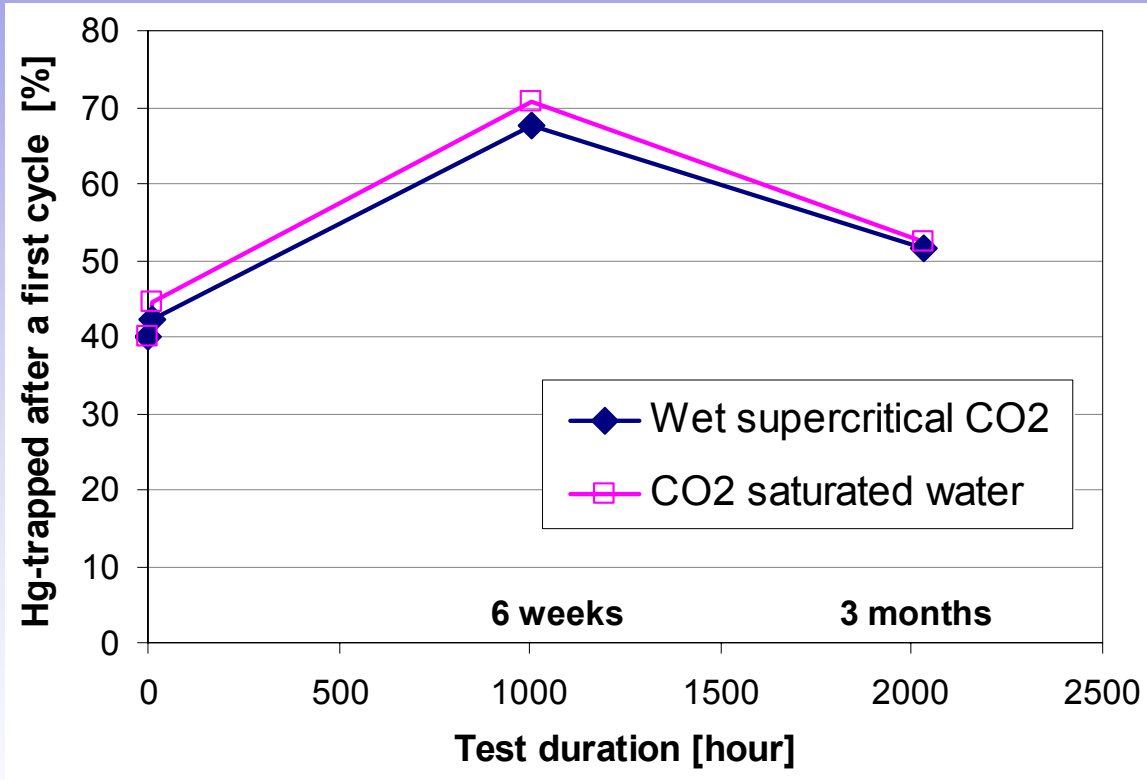


Evolution of the porosity after CO_2 attack at 90°C under 280 bars



Sealing stage Dissolution stage

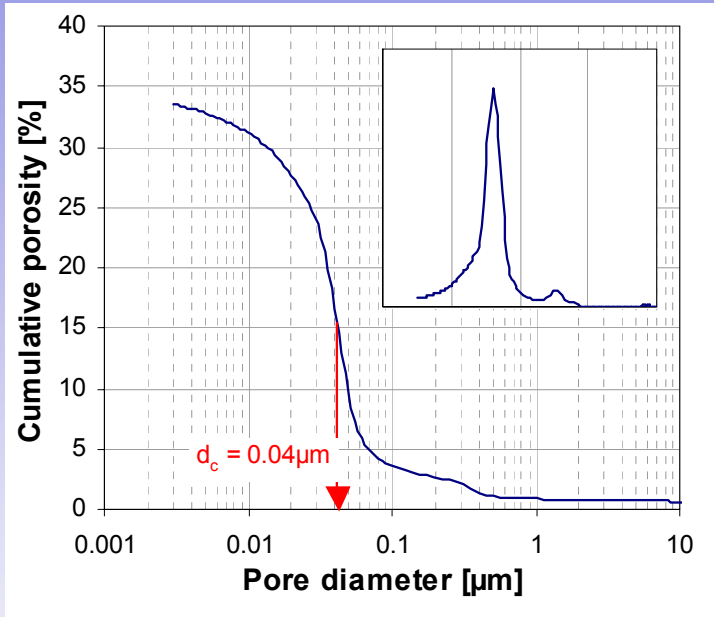
Evolution of the trapped mercury after CO_2 attack at 90°C under 280 bars



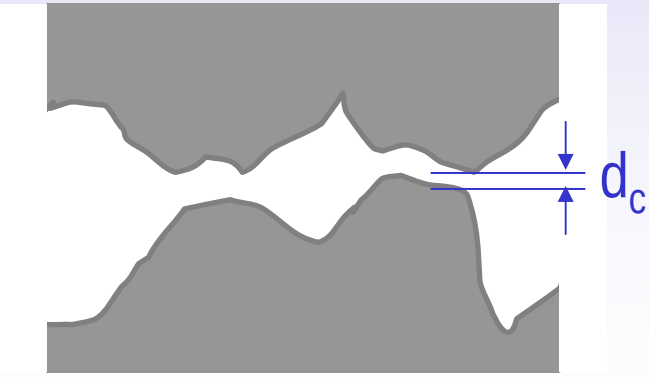
Sealing stage → Dissolution stage

Determination of the threshold diameter

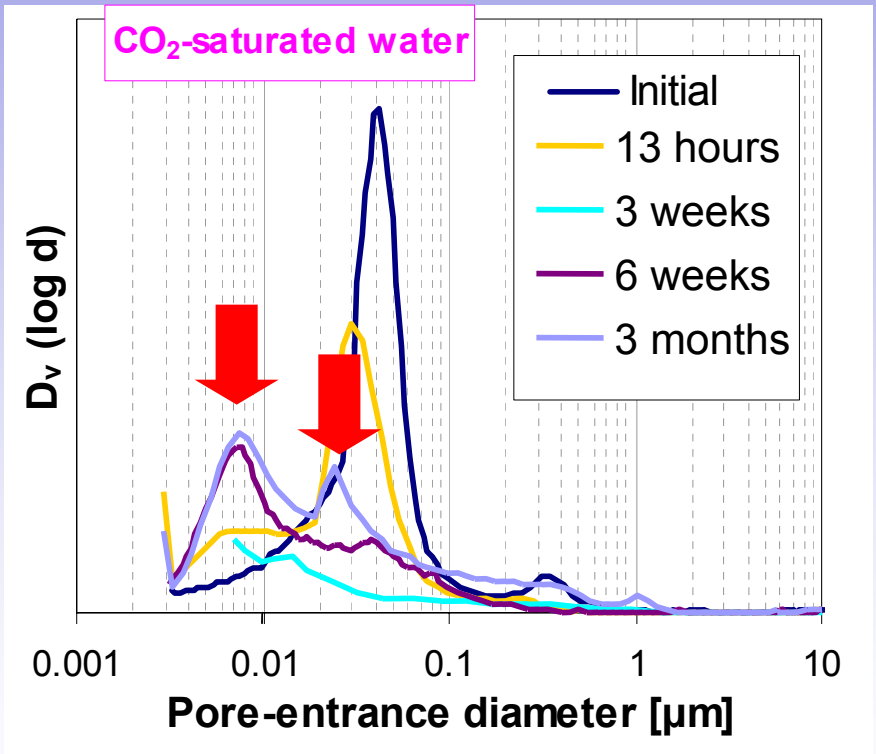
- Minimum diameter of pores, which are geometrically continuous throughout the whole region of the hydrated cement paste.

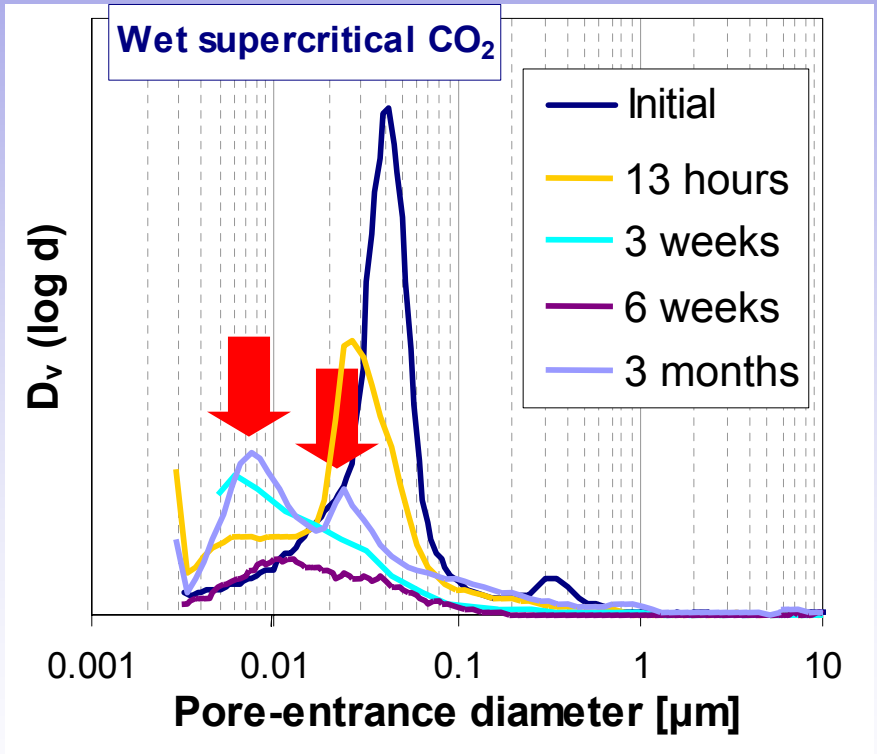


- Associated to the comparative size of "choke points" between percolative steps during the intrusion



Evolution of the threshold diameter after CO_2 attack at 90°C under 280 bars





Conclusion

- Porous network characterisation by MIP
  - Porosity
  - Network connectivity
  - Threshold diameter

- Evolution of the porous network under chemical attack
  - sealing stage by carbonation
  - dissolution stage

➪ Carbonation does not continuously plug Portland cement