Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Sequestering Carbon Dioxide by Accelerated Concrete Curing

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CO_2 Accelerated Concrete Curing

A Greenhouse Gas Mitigation Technology

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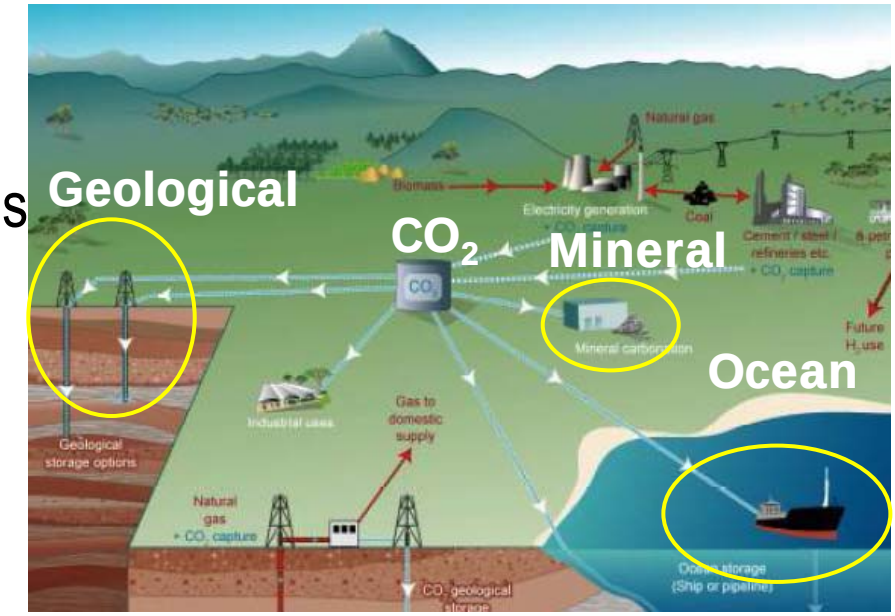
CO_2 Accelerated Concrete Curing

- Mineral carbonation
- Alternative concrete curing process
- Concrete masonry units
  - 4 Billion blocks/year in the US

    ≈ 10 Million tons CO_2/year
- Environmentally benign products
- Improved concrete physical properties
  - Higher compressive strength
  - Faster curing time
  - Reduced permeability



Courtesy of IPCC, 2005

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Conventional CMU Production Process

Concrete

cement, sand, aggregate, water

Steam Curing

Concrete Masonry Unit (CMU)

CO_2 Emissions from Steam Curing

12-24 hrs, 55-75ºC, 100% Humidity, atmospheric pressure

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CO_2 Accelerated Concrete Curing Process

Concrete

cement, sand, aggregate, water

CO_2 Curing

Concrete Masonry Unit (CMU)

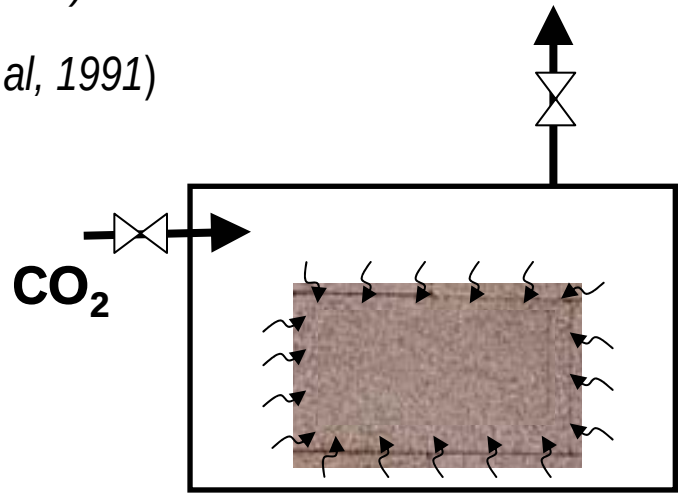
CO_2 Sequestered from the Accelerated Curing Process

500kg CO_2/ ton cement

1 hr, 20ºC, atmospheric pressure

Concrete Carbonation Literature

- Current areas of research:
  - Hazardous waste immobilization *(Bertos et al, 2004)*,
  - CO_2 injection well integrity *(Druckenmiller et al, 2005)*
  - Carbon dioxide accelerated curing (*Dewaele et al, 1991*)
- Carbonation in pressurized chambers



Conditions: P: 75-800 psi, T >25ºC

CO_2 uptake: 6.5 – 12 wt% cement

CO_2 uptake limit: 50 wt% cement

$CaCO_3$ crust formation limiting CO_2 penetration (2-10 mm)

Research Objectives

To understand the mineral carbonation fundamentals as applied to curing concrete products to thereby:

1. Identify causes of limited CO_2 uptake and penetration
2. Examine concrete carbonation in a 1-D flow-through reactor with constant P, T, RH, Q
3. Examine the effects of select process parameters and optimize CO_2 uptake and curing time

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Standard Experimental Sequence

Mixing

w/c	*0.26*
Cement	*160g*
Sand	*640g*

No Coarse Aggregates

Compaction

Pressure	*8 MPa*
Diameter	*127 mm*
Height	*25 mm*

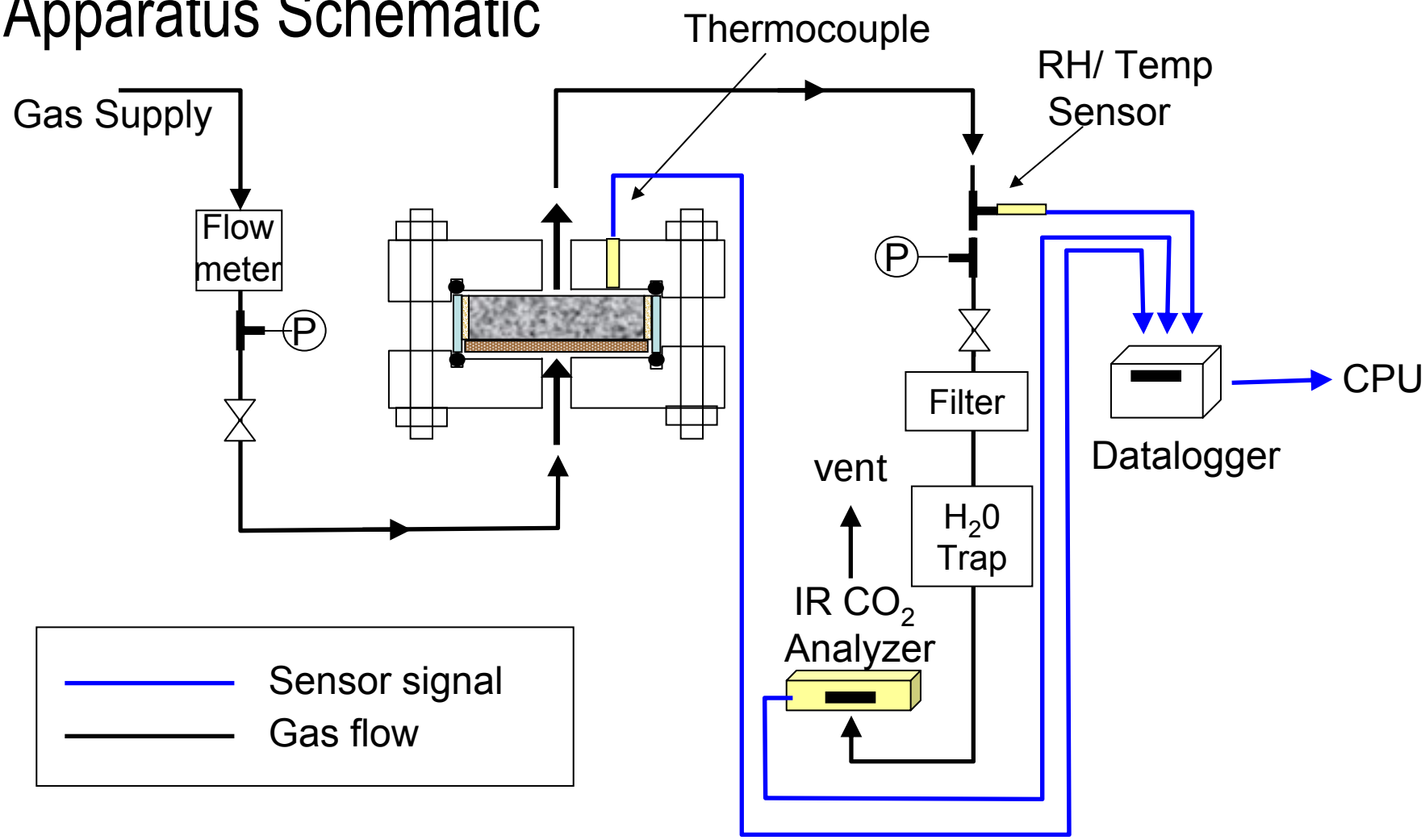
Casing

PVC Shell
Compacted grout mounted with 5 minute Epoxy

Carbonation

Pressure	*atm*
Flow	*1 Lpm*
Temp	*20ºC*
Gas Conc	*20%*
Hydration Time	*1- 480 hr*

Apparatus Schematic



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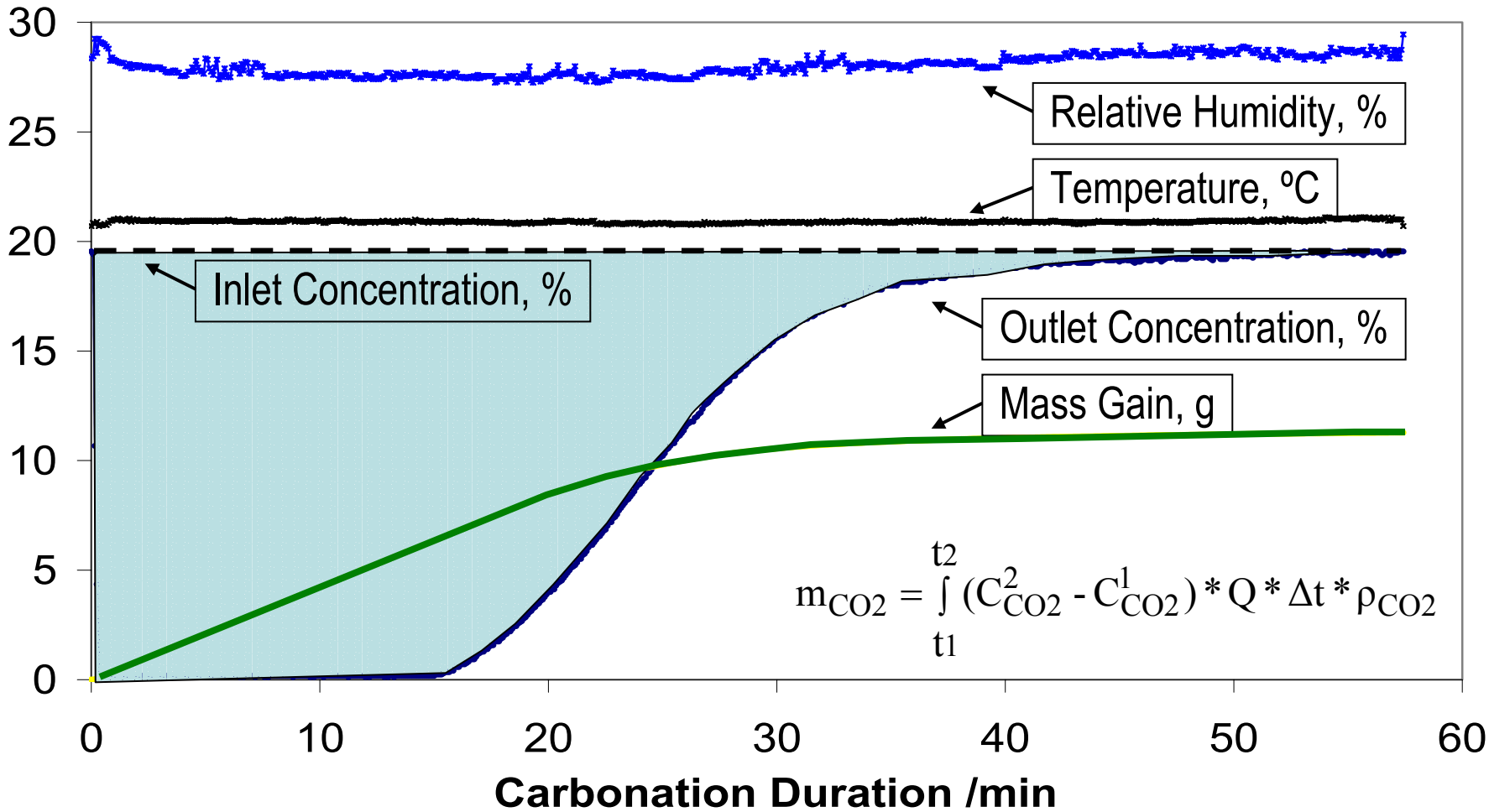


m_{CO2} = mass of CO_2 uptake [g]

$\rho CO2$ = density of CO2 [g/L]

C_{CO2} = Concentration of CO_2 [%]

Q = Flow [L/s]

Aquatic Chemistry Fundamentals

$C3S_{(alite)} + 3H^+ \leftrightarrow \mathbf{3Ca^{2+}} + SiO_2^0 + 3OH^-$

$C2S_{(belite)} + 2H^+ \leftrightarrow \mathbf{2Ca^{2+}} + SiO_2^0 + 2OH^-$

$Ca(OH)_{(2)(s)} \leftrightarrow \mathbf{Ca^{2+}} + 2OH^-$

Dissolution
(Ca Supply)

+

$CO_{2\,(g)} \leftrightarrow CO_{2\,(aq)}$

$CO_{2\,(aq)} + H_2O \leftrightarrow H_2CO_{3\,(aq)}$

$H_2CO_{3\,(aq)} \leftrightarrow HCO_3^-{}_{(aq)} + H^+$

$HCO_{3-\,(aq)} \leftrightarrow \mathbf{CO_3^{-2}}_{\mathbf{(aq)}} + H^+$

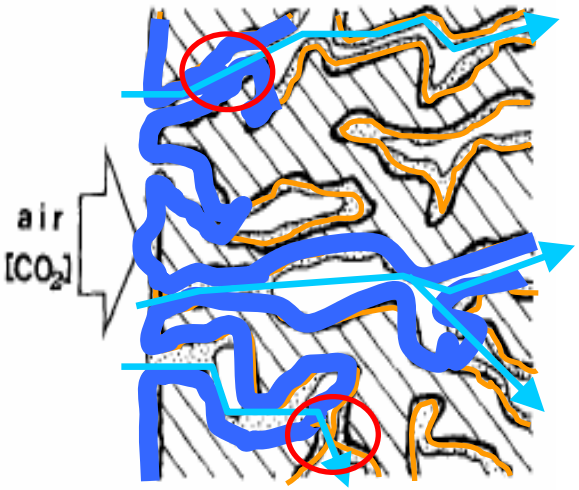
Carbonate Dissociation
(CO_3 Supply)

=

$\mathbf{Ca^{+2}_{(aq)} + CO_3^{-2}{}_{(aq)} \leftrightarrow CaCO_{3\,(s)}}$

Precipitation
(CO_2 Storage)

Microstructure Considerations



- Reaction products
  - Hydration product: Portlandite, $Ca(OH)_2$
  - Carbonation product: Calcite, $CaCO_3$
- Microstructure *(Shih et al, 1999; Dewaele et al, 1991)*
  - Heterogeneous infilling and blockage of meso pores by reaction products

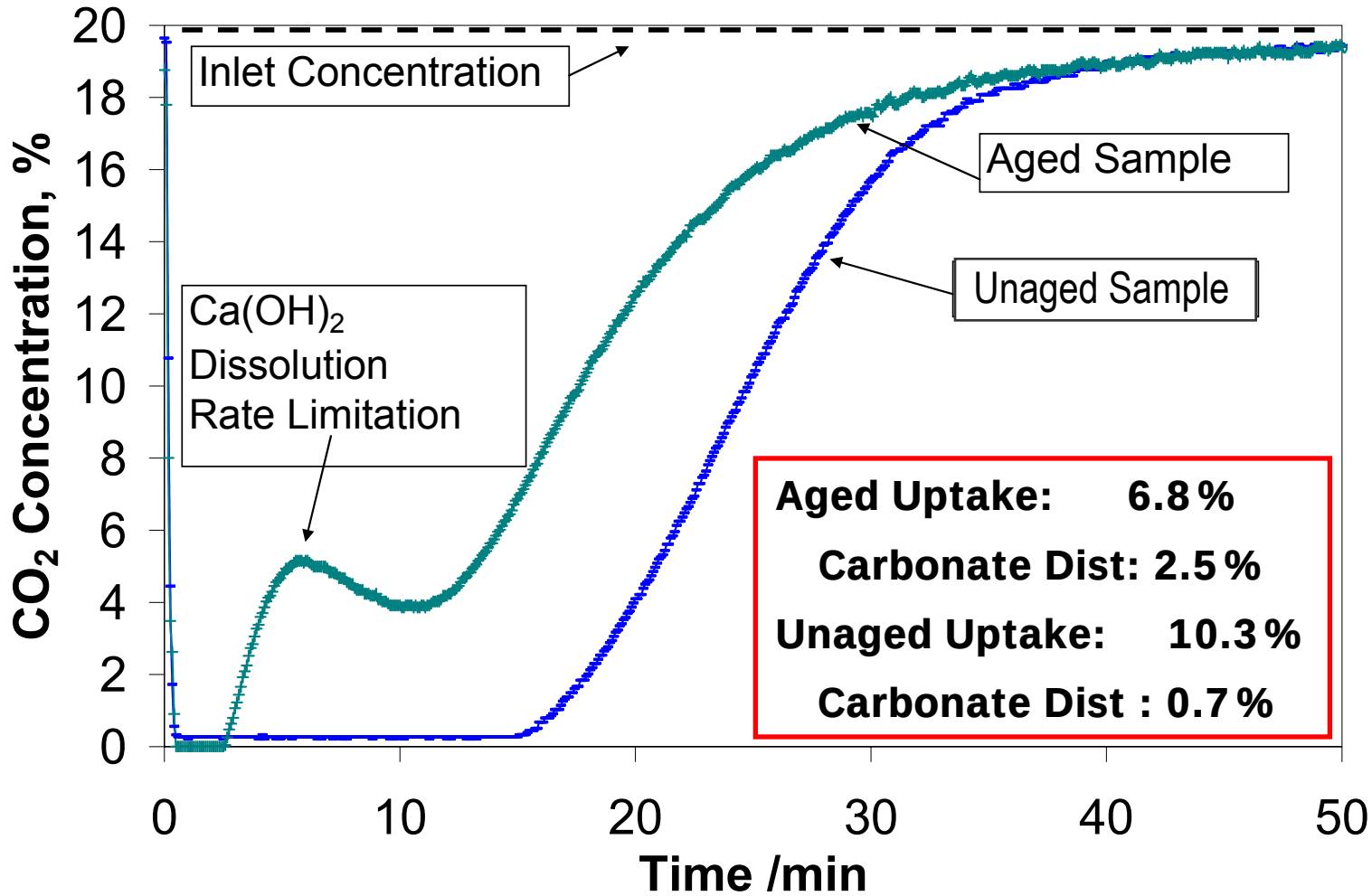
    → CO_2 starved zones within porous matrix

    → Reduced permeability and porosity by 3 to 5 orders of magnitude
  - $CaCO_3$ plating of exposed pore surface area

    → Ca^{2+} starved aqueous solution

    → Reaction severly retarded (diffusion kinetics)

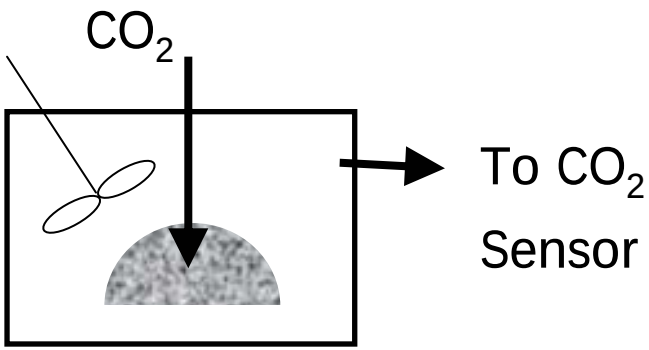
Age Effects on Carbonation



Permeability Effects on Carbonation

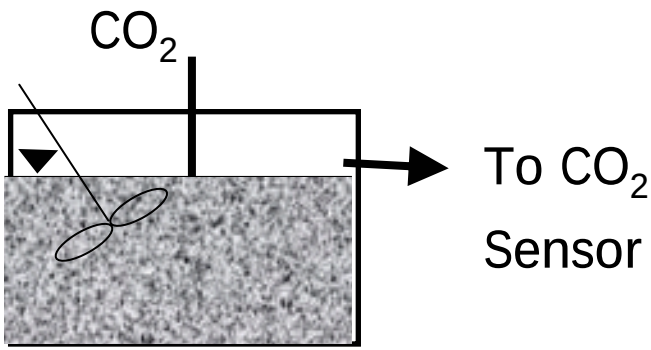
Loose Grout Experiment

- **Minimal permeability constraint**
- No compaction, loose grout
- Identical carbonating conditions and grout mixture

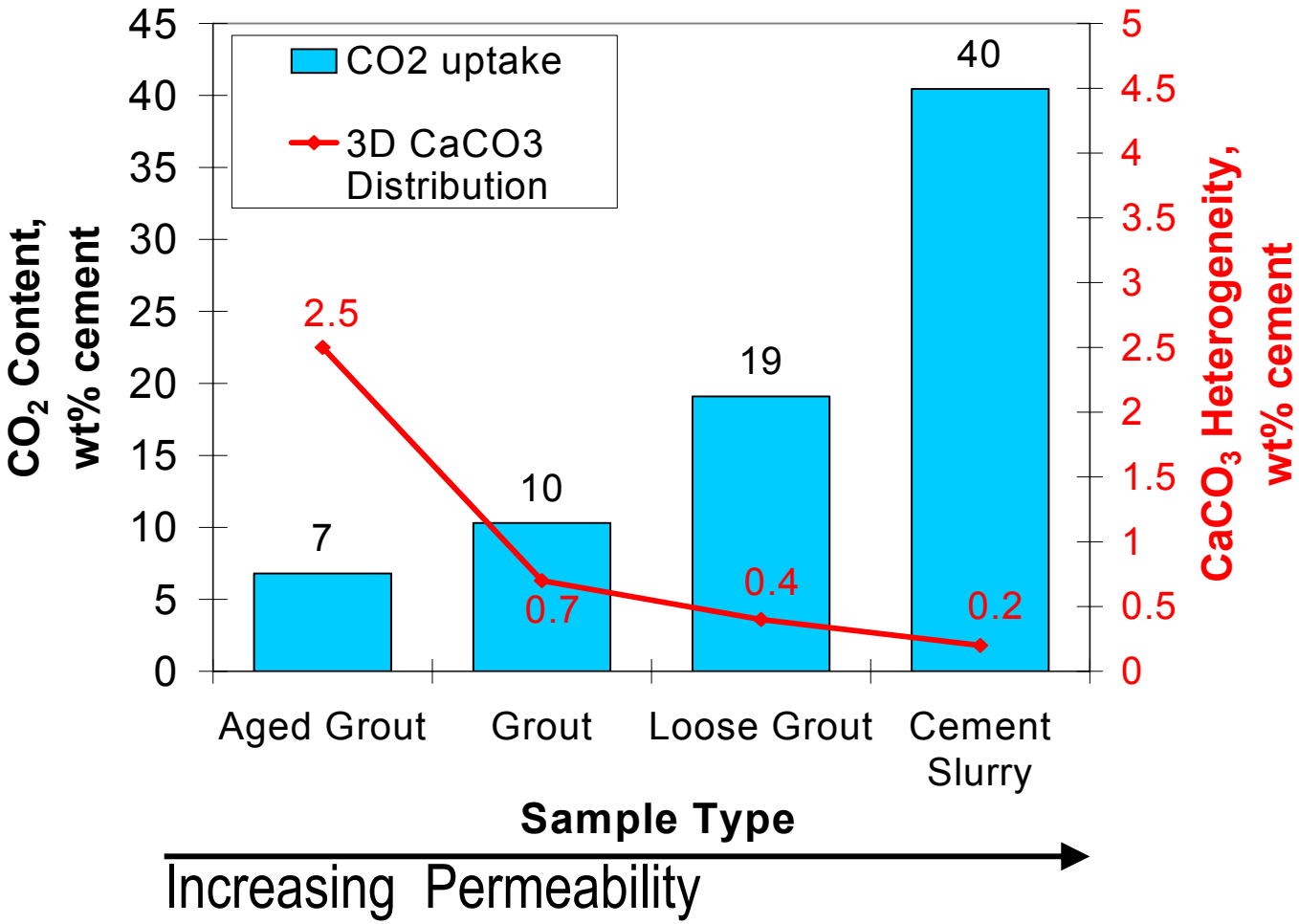


Cement Slurry Experiment

- **No permeability constraint**
- Increased moisture content w/c = 10
- Identical carbonating conditions, OPC only



Permeability Conclusions



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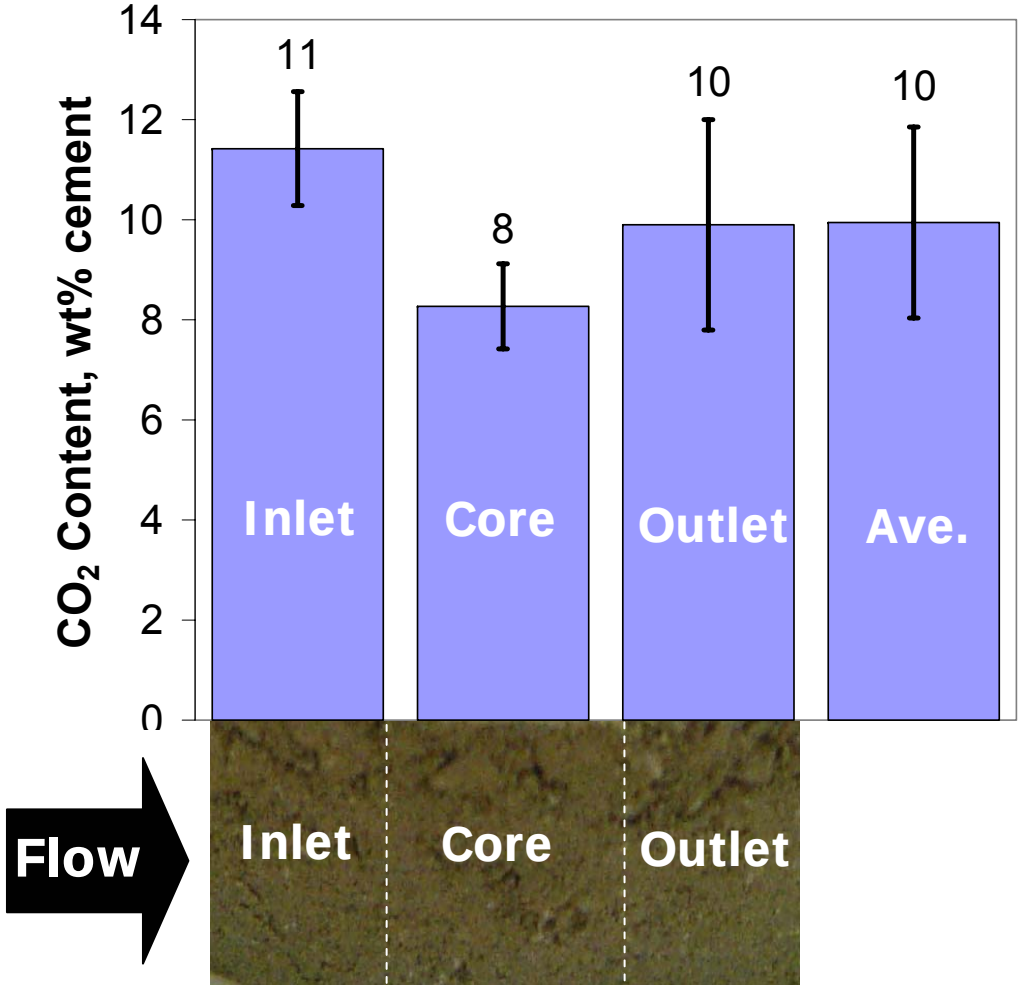
Depth of Carbonation

- Previous limit of penetration
  - 2 - 10 mm (approx)
  - High pressure
  - 100% CO_2
- 1D flow through reactor results
  - Near homogeneous carbonation of sample
  - 2.5 cm thickness
  - Ambient conditions



Carbonation Process Guidelines in 1D Flow Through System

- Largest sequestration gains:
  - Two-step carbonation: 19% higher uptake
  - Sample age: <5hrs
- Optimum carbonation time: 1 hr (std conditions)
- Up to 50% faster curing time (20mins) with higher Pco_2, flow and pressure
- Carbonation efficiency unchanged by: flow, pressure, P_{CO2}, RH

Conclusions

- Governing factor- Permeability

Cement slurry: 40 wt%
Aged Compacted grout: 7 wt%

- Favourable features:
  - Value-added products
  - No steam or heat requirement
  - Rapid curing time (20 – 40 min)
  - Homogeneous carbonate distribution
  - Ambient conditions (25ºC, atm P, low flow) with simulated as-captured flue gases
- CO_2 transport and reaction modelling with constant flow, temperature, pressure and relative humidity
- Part of a broad portfolio of GHG mitigation tools