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# Clogging with Colleagues

## Enzyme Induced Calcium Carbonate Precipitation in Porous Media

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## Introduction

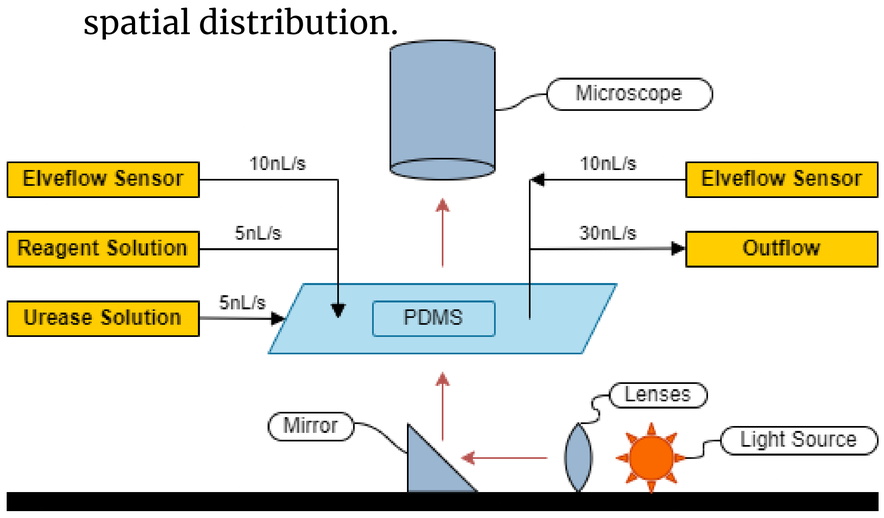
- The hydraulic changes upon enzyme induced precipitation of calcium carbonate in a two-dimensional porous medium model have previously been investigated in e.g. Kim et al. 2020, Weinhardt et al. 2022, Zhao et al. 2023.
- Innovations proposed here are a 2D sand model (Fig. 1), and unequal reagent ratios, parallel to Ottenheim et al. 2024 who investigates for the FeS system.

## Objective

- Monitoring the permeability changes over time and over porosity.
- Observing the shifting of flow paths due to precipitation and clogging.
- Characterizing the chemistry of $CaCO_3$ polymorphs and their location in the porous medium.

## Methodology

The experiments are conducted with reagent solutions of $CaCl_2$ and Urea dissociated by the enzyme Urease, mixing in situ. Transmission microscopy (Fig. 2) and pressure monitoring (Fig. 2) provide information about the permeability and porosity. Cross polarized light microscopy and Raman spectroscopy give information about the chemical characteristics and their spatial distribution.



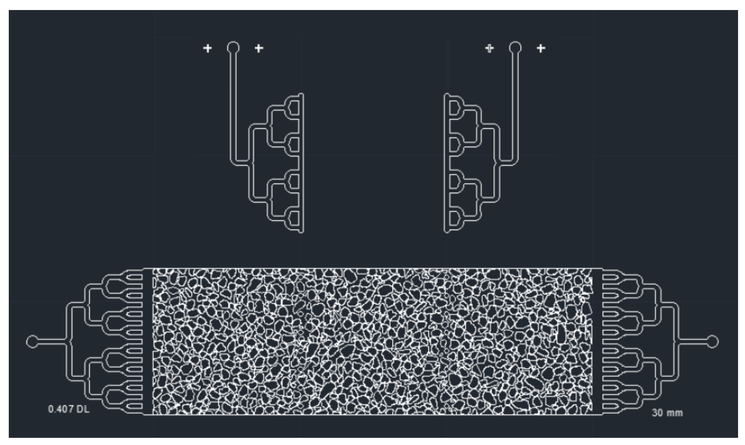
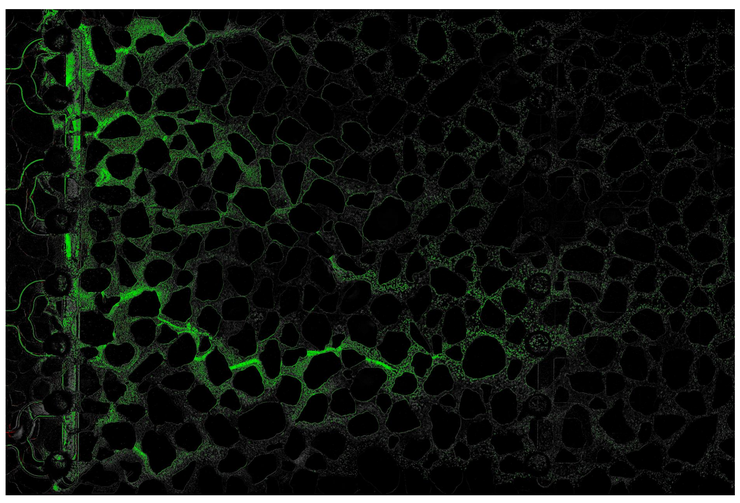




**Figure 1**
Schematic of the 2D PDMS model. The spacing of 8/16 branches in the ports intends to get a homogeneous flow profile throughout the model. The space between the two arrays of ports is 1cm, as is the width of the chip parallel to these arrays. The top ports stack on top of the bottom model.

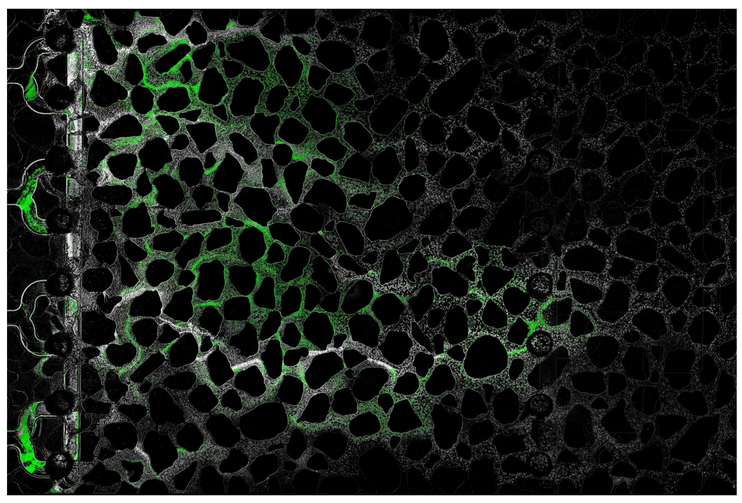
**Figure 2**
Diagram of the experimental setup. Urease is injected in the first port, The second inlet combines through a Y-junction the reagent solutions and the output of the elveflow sensor. The first outlet likewise has an elveflow sensor output add to a Y-junction, leading directly to an outflow. Although the elveflow sensor does not measure pressure directly (it measures volumetric flowrates), the modulation of the flow rate is facilitated through setting a supplying pressure, effectively reporting the pressure values. The light source supplies ~617nm light, with an improvised condenser lens homogeneously distributing the light over the porous medium.

## Results & Discussion

A: 1-3 Hours



B: 3-5 Hours



C: 5-7 Hours

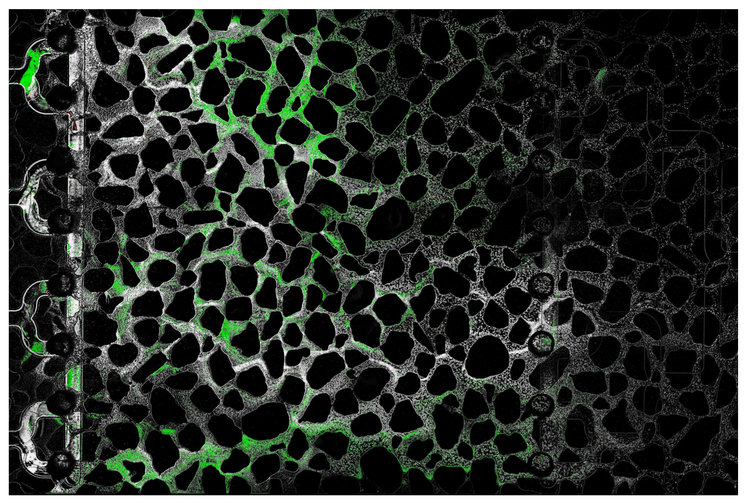


**Figure 3**
Transmitted light microscope images acquired from an injected solution containing 80mM $CaCl_2$ and urea, over a course of 7 hours of injection representing the evolution of precipitate formation and reduction of permeability after: A) 3 hours, B) 5 hours and C) 7 hours of injection.

The permeability reduces as a consequence of precipitate formation blocking the flow paths. The preferential locations for precipitation change noticeably over time. The precipitation starts in the first half of the model. Curious is the splitting into a limited number of bands (Fig. 3A) (presumably the edges of two differentiated flow paths), and later fills up transverse (Fig. 3B), eventually primarily depositing inside presumed preferential flow paths (Fig. 3C).

## Theory

We use Darcy's law to calculate the permeability (Fig. 4) of the porous medium using the pressure measurement data:

$$u = -\frac{k\Delta P}{\mu L}$$

Length $L$,viscosity $\mu$ & flow speed $u$ are experimental settings, and Pressure gradient $\Delta P$ is measured, allowing the permeability $k$ to be determined.

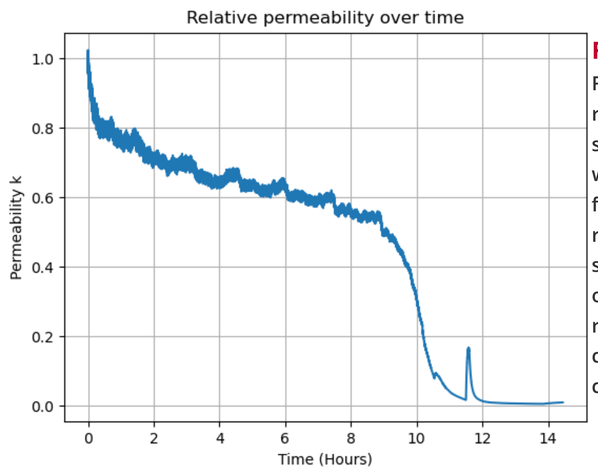



**Figure 4**
Relative permeability results over the course of several hours, beginning with a gradual decline, followed by a staggered regime, and ending with a steep decline with occasional pressure releases. The exact correlation with Fig. 3 is currently unknown.

## Outlook

The preliminary results are promising, showing precipitation in different parts of the model over time alongside a decline in permeability. The proposed setup is capable of producing reliable results in this project. However, it has not yet been used extensively to gather data. It will prove itself in practice in the upcoming months.

References

1. Kim, Daehyun, Nariman Mahabadi, Jaewon Jang, and Leon A van Paassen (2020). "Assessing the kinetics and pore-scale characteristics of biological calcium carbonate precipitation in porous media using a microfluidic chip experiment". In: Water Resources Research 56.2, e2019WR025420.
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3. Zhao, Chang, Yang Xiao, Jian Chu, Ran Hu, Hanlong Liu, Xiang He, Yi Liu, and Xiang Jiang (2023). "Microfluidic experiments of biological CaCO3 precipitation in transverse mixing reactive environments". In: Acta Geotechnica, pp. 1–20.
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