Microfluidic Advantages for CCS

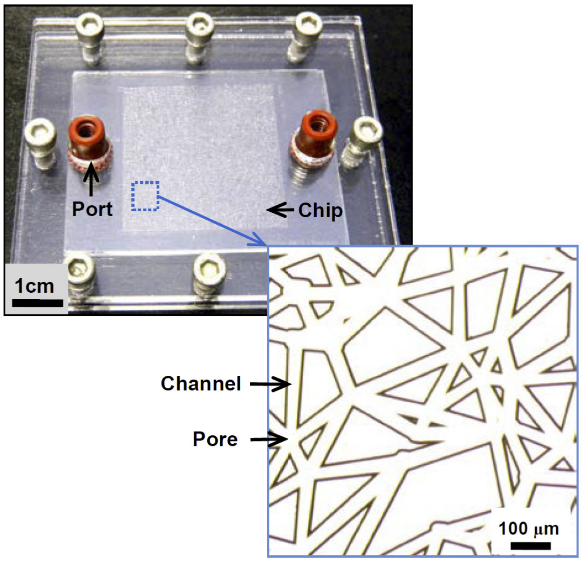
Microfluidic analogues transform how operators approach carbon capture and storage (CCS) by mimicking storage reservoir geology at the pore-scale, for everything from CO_2-foam surfactant screening to pressure-volume-temperature analysis.

While CCS shows great promise, there are potential obstacles to its widespread adoption. The current inability to measure relevant conditions is magnified by:

· CCS not using pure CO_2 but industrial streams with impurities
· CCS operations employing additives to improve injectivity
· Injectivity reduction due to salt and mineral precipitation or hydrate formation

These impurities and additives affect injectivity and storage capacity due to changes in phase behaviour relative to pure CO_2. CCS then becomes a complex process involving complex mixtures under extreme temperatures and pressures. Dealing with these challenges is exactly where Interface contributes value.

For example, the microfluidic technology used to analyze CO_2 sequestration in saline aquifers has already been developed by Interface Fluidics co-founder Prof. Dave Sinton's team at the University of Toronto. Some notable results of this work are shared here.



The lab-on-a-chip based approach to the study of CO_2 injection and salt precipitation in saline aquifers. Labelled images of the microfluidic network chip based setup to study the salt precipitation process with a magnified view of the channel network shown inset.

Out of varying storage formations, saline aquifers are at the forefront with an estimated global sequestration potential exceeding one thousand years of anthropogenic emissions. However, as CO_2 is injected, salt formations lead to pore blockage and a reduction in carbon storage injectivity.

Traditional oilfield monitoring software that predicts this is limited and requires experimental data for validation, while core scale experiments cannot resolve salt precipitation at the pore scale. As a result, microfluidic systems emerge as the ideal choice for this analysis.

The microfluidic analogue is a model of the reservoir that replicates the native media's physical characteristics and displacement efficiency. It allows for the visualization of various phenomena such as water evaporation and salt precipitation dynamics within the chip.

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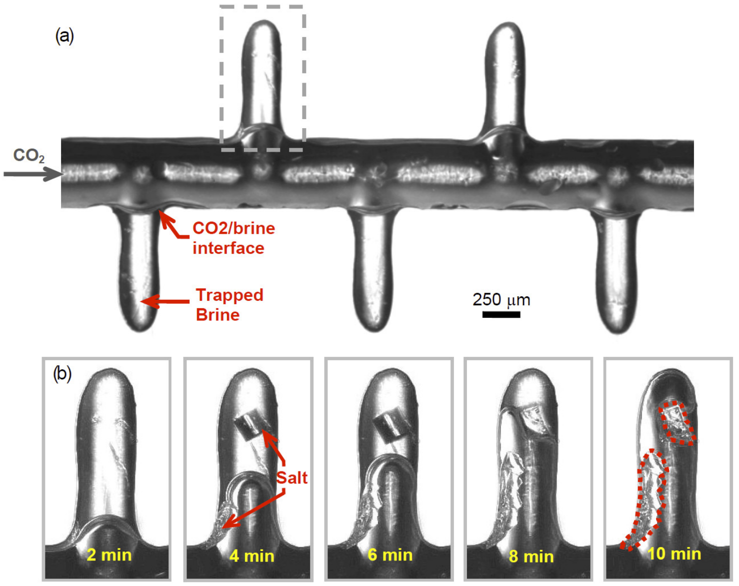
As shown in the work published by Dr. Sinton, during injection the location of the CO_2 phase, solution pH, and precipitation dynamics were tracked and quantified through advanced microscopy. SEM imaging was then used to analyze the resulting salt formations.

Results of this work provided insights into injection mechanisms, including:

- A porosity decrease of 15-25%, which was verified with previous core experiments
- A transition period occurring with phase redistribution and initial evaporation
- Salt precipitation occurring with a steady progression rate of 14 μm/s
- Large bulk crystals and polycrystalline aggregate structures identified as the dominant types of salt formations, and their dynamics analyzed

This laid the groundwork for the capability of microfluidics to study a range of CO_2 injection and sequestration mechanisms. Interface then developed further vital measurements. Work is now also being done at reservoir conditions, not just standard.

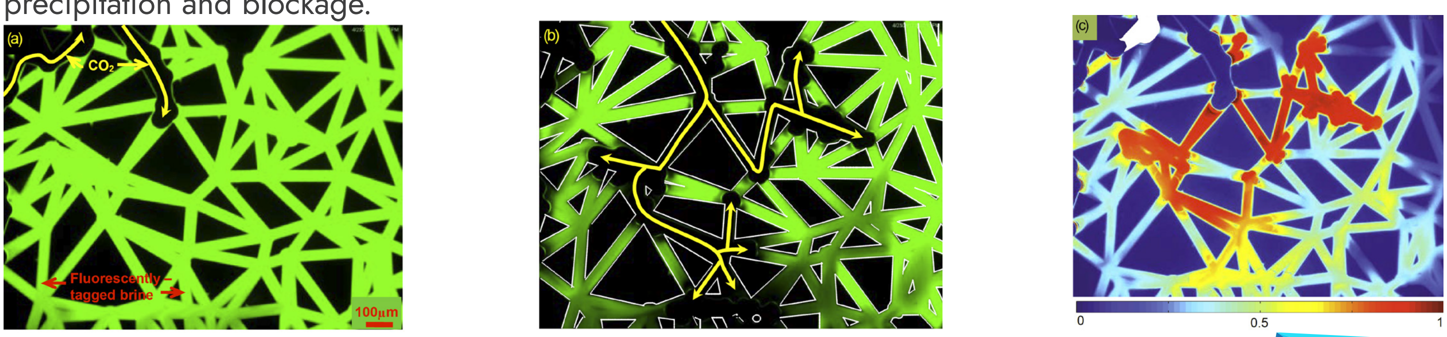


Salt precipitation during dry CO_2 injection in the straight channel chip with isolated pores. (a) An image of the chip immediately following CO_2 injection. Dry CO_2 flows through the main channel, trapping brine at each isolated pore. (b) Time sequence images of water evaporation oserved at one isolated pore (i.e., grey rectangle shown in Fig. 2a). A red dotted line at 10 min delineates the final precipitated salt formation in the pore.

Another notable application is adding surfactants to CO_2 pre-injection to increase its viscosity. This creates a foam that helps trap the CO_2 by reducing its mobility. This, in turn, increases the residence time with porous media.

However, storage reservoir and water compositions vary globally, leading to companies making hefty cost and time investments in foam stability optimization. Interface solves this problem via microfluidic analogues that can screen various supercritical CO_2 surfactant foams at differing conditions simultaneously.

Recent work by Interface Fluidics and Saudi Aramco on this involved screening six commercially available surfactants where sensitivity analysis resulted in a top contender and an optimal concentration for foam stability. Results aligned with conventional rheology measurements but added time, cost, and sample size benefits. Pore-scale analysis allowed for calculating the foam's half-life while observing damage due to precipitation and blockage.



Fluorescence images and image analysis of CO_2 injection into brine solution in the microfluidic network. (a) Image at the onset of CO_2 injection and (b) at 5 min after the injection. The change in fluorescence intensity between (a) and (b) is due to both CO_2 phase invasion and pH drop within the brine. The yellow line shows the path of the CO_2 phase. Both images are similarly contrast enhanced here for illustration. (c) Contour plot of normalized intensity difference between Fig. A and B. The portion indicated in white corresponds to negative values, showing where brine re-wet a CO_2 invaded region as the flow field evolved (top left).

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