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Wettability alteration of microfluidic devices using plasma and its influence on trapping mechanisms in geological reservoirs

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To tackle climate change and help smoother energy transition, Carbon Capture, Utilization and Storage (CCUS) technologies are seen as a primary line of defense. Storing carbon dioxide (CO2) in geological formations appears to be a feasible solution, yet there are many unknowns concerning the dynamics and safety of the storage. One of the important CO2 storage mechanisms is solubility trapping, i.e. mass exchange at the interface between the CO2 and the resident fluid (usually brine). Current Representative Elementary Volume (REV) models have difficulty resolving complex interplay between different parameters like wettability, pore size distribution, multiphase flow field, entrapment/remobilization, etc; which imposes a serious limitation for accurate description of mass transfer processes at large scale. To capture and understand the full physics of the problem, it is necessary to look at the scale of one or several pores, typically in micrometer order. Since there is a lack of data on the influence of micro-scale parameters, we have decided to study the influence of hydrodynamic conditions, geometry and wettability, to propose a new formulation for pore-scale mass transfer rates. With the help of microfluidics experiments and atmospheric/cold plasma, this study contributes to the understanding of the processes governing subsurface systems at the pore scale which is the key to improving the accuracy of modeling of transport phenomena at a large scale. Simple rectangular dead-end pore glass micromodels are deployed to imitate geological porous media as the material is inert, sturdy and allows direct visualization of the flow and transport mechanisms at the pore scale. These micromodels allow us to trap one fluid (CO2 or water) while the other is flowing, thus studying the coupling between flow and mass transfer at the fluid-fluid interface. Having micromodels of various wettability is still challenging, therefore we developed a new method based on the injection of a helium plasma jet in the micromodels to modify the surface properties of the microchannels to imitate different rock wettabilities encountered in nature. So far, we have successfully propagated the plasma jet through microchannels with a minimum cross-section of 250x100 μm covering the distance from the inlet to the outlet of 4 cm. As a result of treatment, the wettability of microchannel surfaces varies from moderately water-wet (contact angle $\approx 45°$) to dominantly water-wet (contact angle $\approx 20°$). We show that this wettability alteration can last for days in storage and several hours in experiments depending on experimental parameters. Moreover, we study the influence of wettability on the mass transfer rates following imbibition (dissolution of trapped CO2 bubbles in a stream of flowing water), and drainage (evaporation of water droplet in a stream of dry CO2) experiments by analyzing image sequences of the process for altered and non-altered micromodels. Our first results show that during imbibition the alteration of the wettability towards water-wet characteristics affects the trapping mechanism of CO2, while during drainage it influences the mass transfer rate. To explain and back up these results with statistical relevance, more experiments are being performed.

Participation

In-Person

References

Agaoglu et al., 2015;
Li et al., 2020;
Maes & Geiger, 2018;
Nernst, 1904

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