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Walid Okaybi, Sophie Roman, Cyprien Soullaine. Microfluidic investigation of the impact of colloidal transport on two-phase flow in geological porous media. 16e Journées d'Etudes des Milieux Poreux (JEMP2023), Oct 2023, Paris, France. <insu-05064185>

HAL Id: insu-05064185

<https://insu.hal.science/insu-05064185v1>

Submitted on 12 May 2025

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Microfluidic investigation of the impact of colloidal transport on two-phase flow in geological porous media.

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Résumé

Microfluidic investigation of the impact of colloidal transport on two-phase flow in geological porous media.

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Colloidal particles show potential in facilitating the movement and extraction of trapped contaminants from porous media, which has implications for various energy and water-related applications. To achieve this target, most studies focus on optimizing surface activity of colloidal particles to freely move along the solid matrix with less depositions as possible until they arrive, and bind at the immiscible fluid interface (1). However, few studies focus on how particle depositions (2) and pore-clogging leading to the redirection of local streamlines aid in mobilizing immiscible fluids. In order to assess their impact on the enhanced recovery of trapped contaminants, it is necessary to downscale to the pore scale (order of micrometers). Therefore, an experimental approach using microfluidics combined with CFD simulations has been deployed. These phenomena are directly visualized and tracked using microfluidic devices that mimic the porous structure of rocks. In this study, we will investigate particle depositions, pore-clogging and transport of colloidal particles in both saturated and un-saturated porous medium in microfluidic chips.

We find that during the injection of the suspension in a simplified systems made of a single-grain collector, most particles are deposited mainly in the front part of the grain facing the flow at higher hydrodynamic forces and salt concentrations. However, at lower salt concentrations and Péclet numbers we find more depositions downstream the grain. In complex saturated porous media, we integrate the observed patterns of deposition, the distribution of clogged pores, and the measured variations in flow rate with a digital twin relying on the Darcy-Brinkman-Stokes model. This approach accounts for the actual pore-clogging distribution observed in experiments. It allows us to investigate the variation in the local velocity

*Intervenant

profiles at different stage of the medium clogging, and establish the relationship between $K()$ (permeability) and the experimental conditions. Similar workflow and tools are used in unsaturated condition to find the optimal physical, electrical and hydrodynamic parameters leading to the maximum recovery of trapped contaminants.

References:

Hendraningrat et al. (2013), Schneider et al. (2021).

1. Introduction

The ability to anticipate the potential impact of nano- and micro-scale particles on the movement of immiscible fluids trapped in the subsurface by capillary forces is an essential aspect in groundwater remediation and enhanced oil recovery.

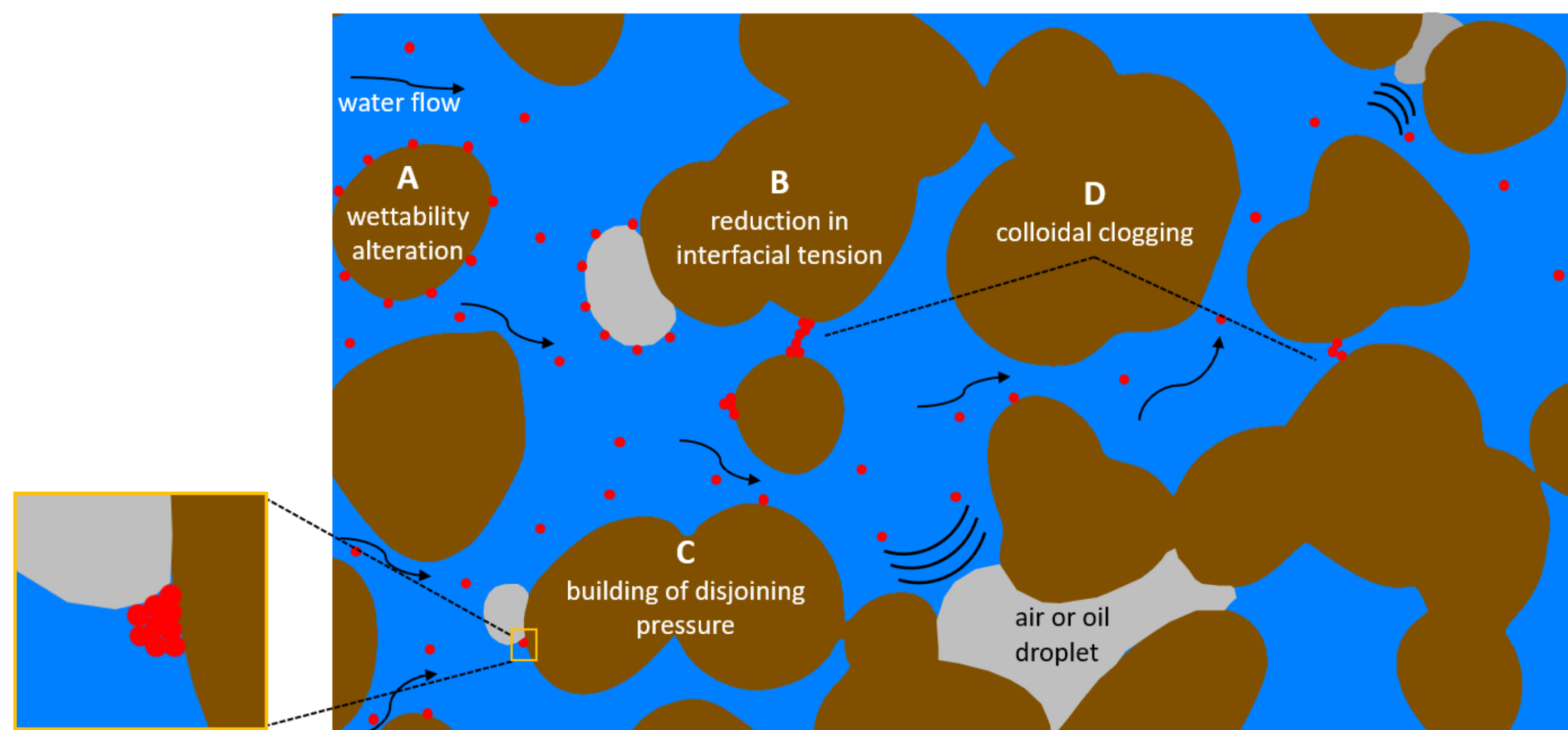


Fig.1: Different mechanisms responsible for mobilizing trapped contaminants in the presence of colloids. **A)** Surface or non-surface active particles tend to modify the wettability of grain rocks. **B)** Surface active NPs reduce the interfacial forces between wetting and non-wetting phase. **C)** NPs self aggregate the confined three-phase oil-nanofluid-rock pushing the interface into the bulk of trapped droplet. **D)** Colloidal clogging redirect local streamlines resulting in pressure drop increase promoting mobilization of trapped contaminants.

1.2 Research Objectives

- 1) Identify the morphology and the effect of depositions and pore-clogging on the build-up in pressure drop leading to redirection of local streamlines at different physical, chemical and hydrodynamic conditions in saturated porous media.
- 2) Enhance our understanding on how higher pressure drop resulted from colloidal clogging leads to mobilization of trapped contaminants in unsaturated porous media.

1.3 Strategy

This study relies on a multiscale strategy to gather quantitative data on mechanisms at the pore-scale using microfluidic experiments combined with CFD simulations, high-resolution imaging and advanced image-processing techniques.

2. Materials and Methods

Microfluidic devices are powerful tools that offer direct visualizations to study fluid flow and particle transport at the pore-scale.

2.1 Experimental setup

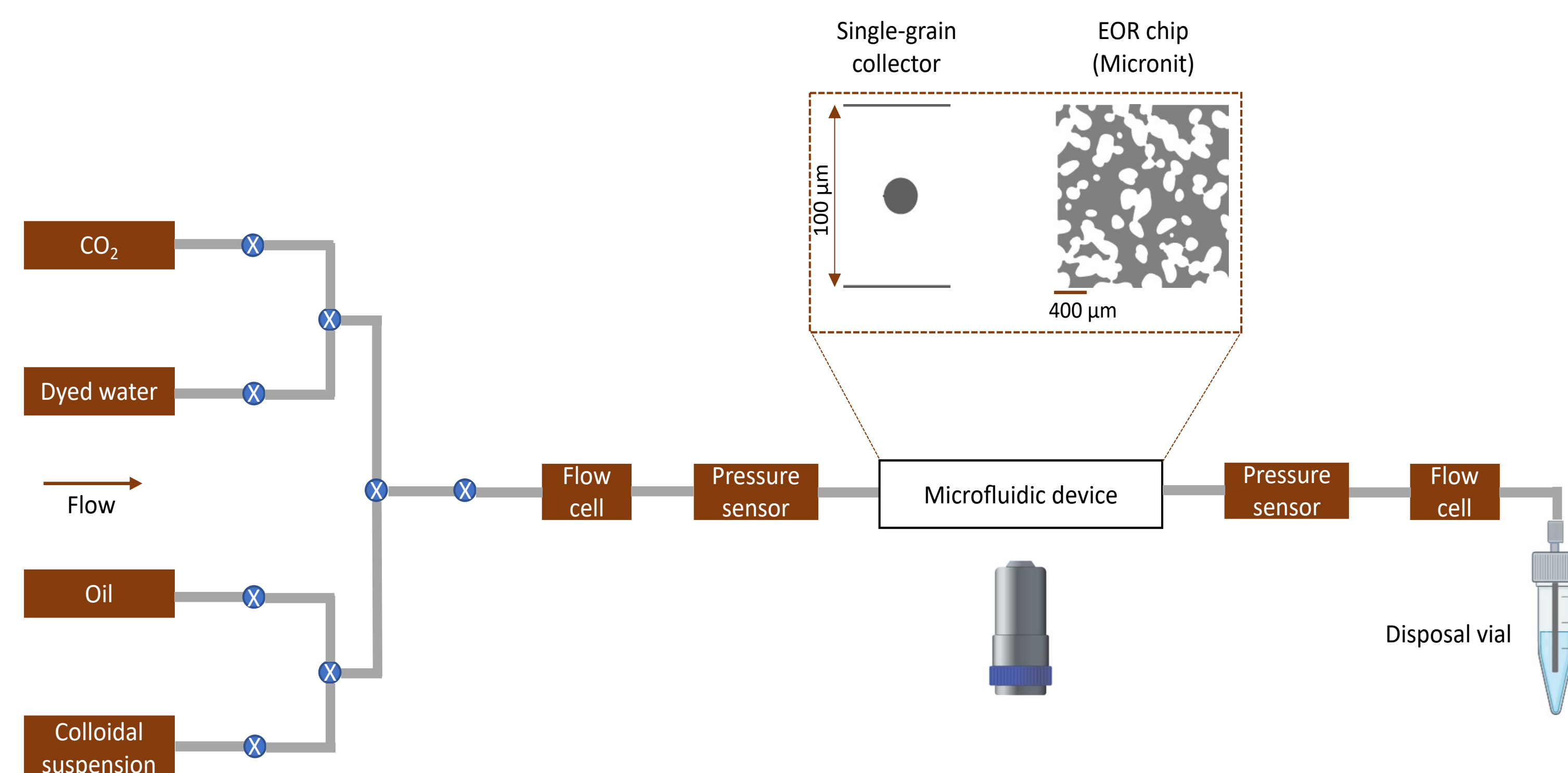


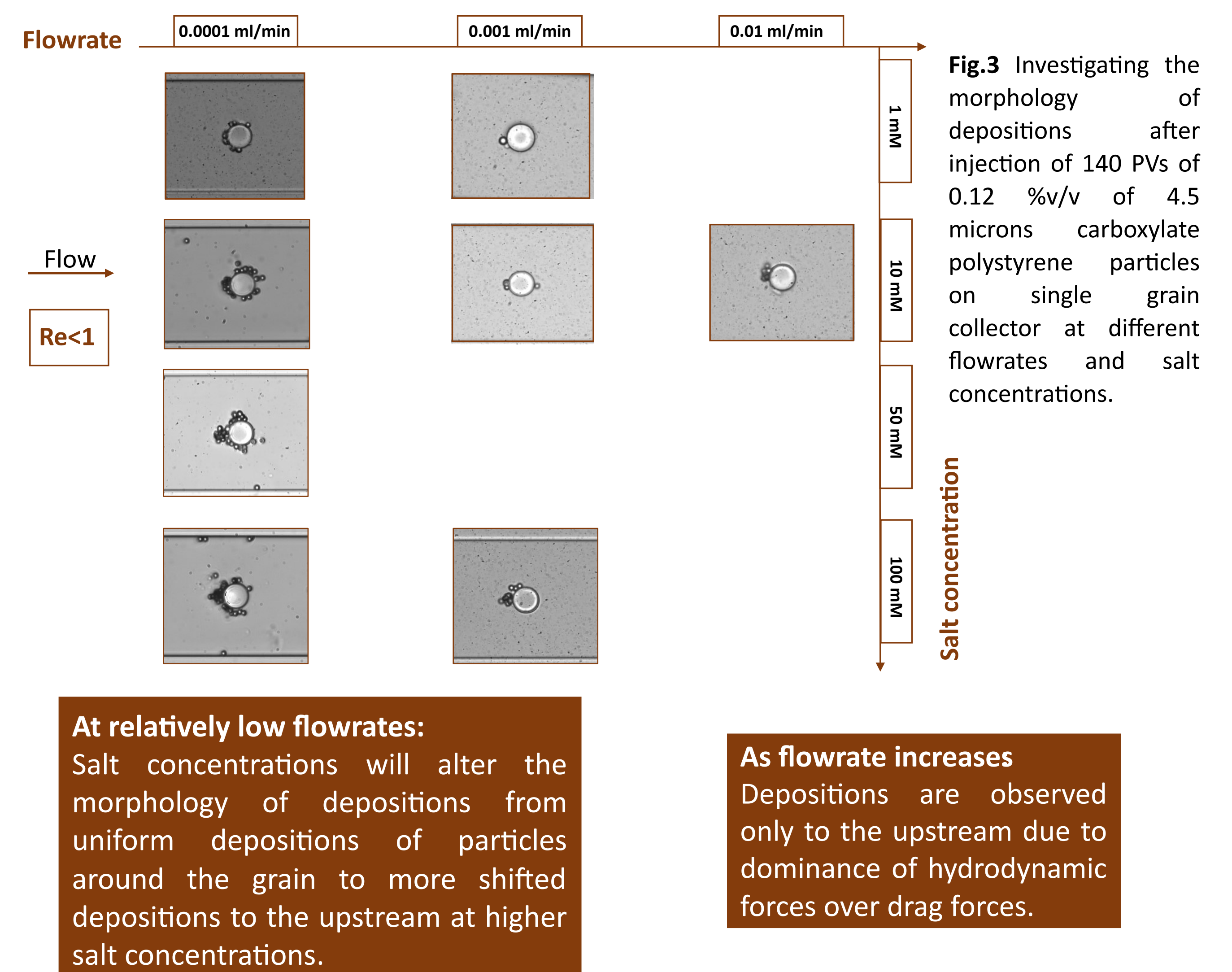
Fig.2 It shows the experimental setup of a two-phase flow experiment, where different fluids are injected using the syringe pump. The valves are used to direct flow, flow cells will be connected to a spectrometry to measure concentrations gradients at the inlet and outlet. Pressure sensors will be located at the extremity from both sides of the microchip to acquire pressure drop. The chip is placed under a microscope to capture image sequences for various experimental conditions. This setup is simplified when we are working on saturated single grain collectors and heterogenous porous media.

Acknowledgements

We acknowledge funding from the ERC on the COCONUT project. (Grant agreement 101043288) <https://erc-coconut.cnrs.fr>

3. Preliminary results

3.1 Single-grain collector



3.2 Rock on a chip (saturated porous media)

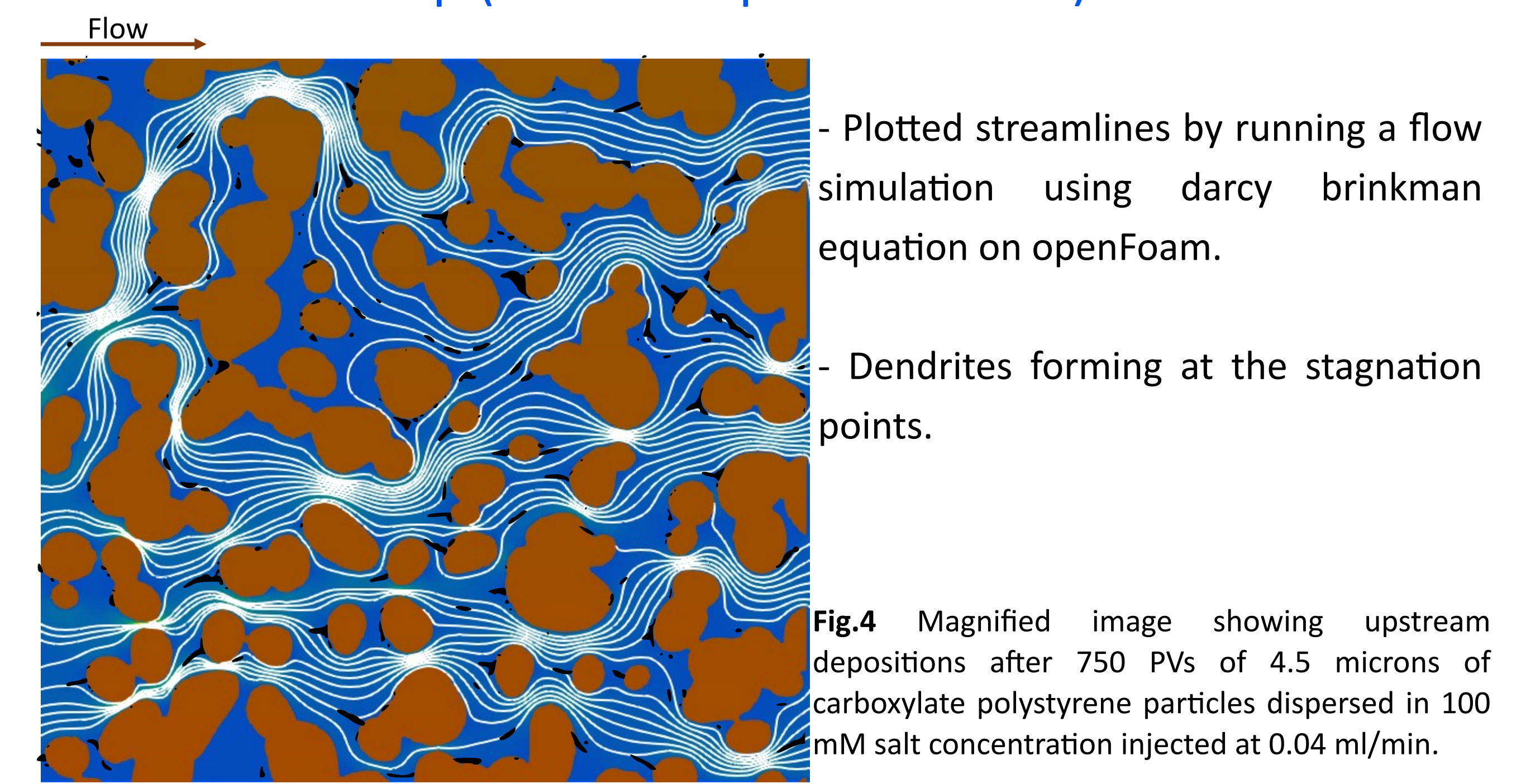


Fig.4 Magnified image showing upstream depositions after 750 PVs of 4.5 microns of carboxylate polystyrene particles dispersed in 100 mM salt concentration injected at 0.04 ml/min.

3.3 Rock on a chip (unsaturated porous media)

After the injection of 200 PVs at 0.005 ml/min as waterflooding, 500 PVs of colloidal suspension was injected directly, and there was no change in oil residual. Particles clogging was not observed, but there were some pore filling. To observe the effect of colloidal clogging on enhanced recovery of trapped contaminant:

- 1) Experimental duration should be higher as $W/D = 26$ (relatively big).
- 2) Perform experiments on lower W/D ratios and for that, we designed two heterogenous micromodels with W/D 7 & 4.

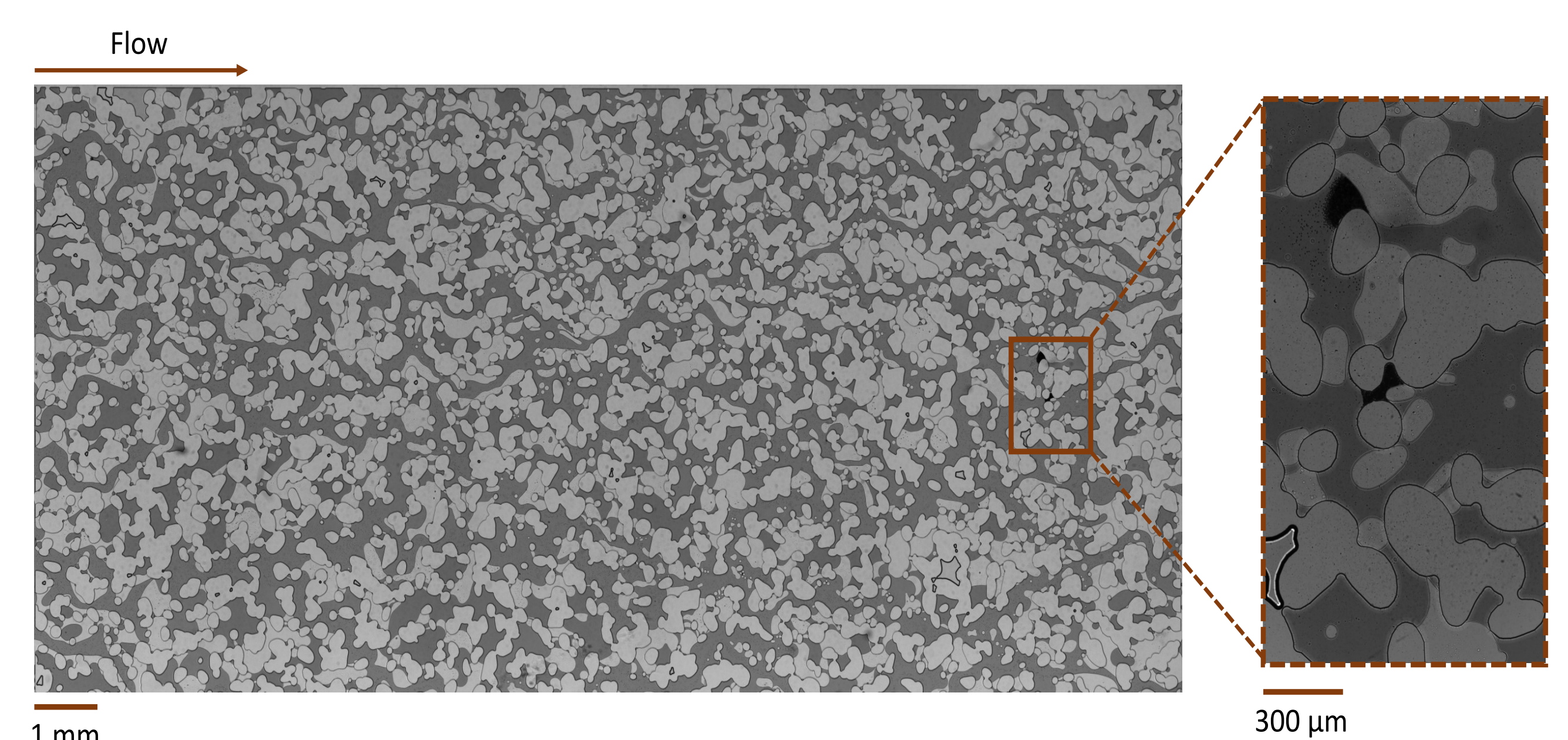


Fig.5 Stitched image of an EOR chip after 500 PVs of 4.5 microns of carboxylate polystyrene particles dispersed in 100 mM salt concentration. To the right is a magnified image of the pore filling with particles. Dark grey is the dyed colloidal suspension, particles in black, oil and grains in light grey.

4. Perspectives

- Complete the series of experiments on saturated single grain, and heterogenous porous media at different experimental conditions.
- Perform two-phase flow experiments on the newly designed micromodels to describe the effect of clogging on mobilizing trapped contaminants.
- Validate existing models with single grain collector experimental results.