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Microfluidics-based experimental study of the use of yield stress fluids to improve organic pollutant removal from contaminated soils

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Urban and agricultural environments are increasingly contaminated by chlorinated solvents, pesticides, nitrates, heavy metals, etc. Such pollutants, which initially impact surface soils, eventually seep into groundwater. It is therefore essential to remediate degraded soils to ensure water and food sovereignty. This study presents a method for remediating soils contaminated by organic pollutants through the selective blocking of local heterogeneities. This technique is based on the use of yield stress fluids, specifically concentrated biopolymer solutions, which, due to their distinctive rheological properties, preferentially flow through larger pores. Once the yield stress fluid is injected, water predominantly moves through smaller pores, thereby redirecting flow to areas that are less accessible during standard remediation operations.
This study presents laboratory experiments performed at the pore scale who were conducted to validate this method and confirm previous findings from core-flooding experiments [1]. To address and confirm these inquiries, we used transparent microfluidic devices that allow flow visualization. Two borosilicate glass micromodels with microchannels representing the topology of a sandstone were used as model porous media. The pore structure of both microchips was identical; however, one was water-wet while the other was oil-wet. Their absolute permeability was 2.5 Darcy, their porosity was 0.58 and their pore volume was 2.4 µl. The pore size distribution of the microchannels was measured on a 2D image of the micromodel mask. The yield stress fluids were aqueous solutions of xanthan gum biopolymer with three different polymer concentrations Cp: 3000, 5000 and 7000 ppm. To enhance differentiation between liquids during multiphase flow in the micromodel, distinct dyes were applied: violet ink in the water at 10 wt.%, green ink in the polymer solution at 10 wt.%, and oil-red-o powder at 3 wt.% in the mineral oil. Aqueous xanthan gum solutions were used to obstruct the larger pores in the micromodels. Image post-processing of the raw images obtained with the microscope camera after each experimental step was performed using ImageJ open-source software. The effects of polymer concentration and flow conditions underscored the benefits of the proposed method. A significant improvement in pollutant removal was achieved with water flow diversion produced by polymer blocking compared to conventional waterflooding in all cases studied in this work. The proposed method enabled significant improvements in pollutant removal with minimal injected pore volumes of polymer and water. The distribution of phases within the pores, the area of pollutant clusters, and the sizes of the pores occupied by each phase were effectively characterized in the current microfluidic experiments.
[1] Rodriguez de Castro A., Ben Abdelwahed A., Bertin H., Enhancing pollutant removal from contaminated soils using yield stress fluids as selective blocking agents. J. Contaminant hydrology. 255, 104142, February 2023

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References

Primary authors: AITKHOZHA, Zhansaya (I2M Bordeaux); RODRÍGUEZ DE CASTRO, Antonio (Arts et Métiers ParisTech); BEN ABDELWAHED, Amine (I2M); BERTIN, Henri (I2M)

Presenter: AITKHOZHA, Zhansaya (I2M Bordeaux)

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