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Quantifying the Influence of Groundwater Flow on Bacterial Chemotaxis near a NAPL Contaminant Source at the Pore Scale

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Bioremediation of nonaqueous phase liquid (or NAPL) contaminants may be accelerated with the presence of chemotactic bacteria that can preferentially migrate toward NAPL upon detecting its chemical gradient. In a heterogeneous porous media [1], chemotactic bacteria accumulated in dead-end pores near NAPL ganglia trapped in low-permeable regions; however, no retention was seen in bacteria near NAPL surfaces distributed in the high-permeability area or along preferential flow pathways. Groundwater flow is a critical feature of contaminated sites in the subsurface and its influence on bacterial transport and chemotaxis remains a challenging aspect to predict.

In this work, we investigated the impact of fluid velocity on chemotactic response at the pore scale using a combination of microfluidic experimentation and continuum modeling. A bacterial suspension flowed parallel to a flat NAPL-water interface over a range of typical groundwater flow rates (0.5-10 m/d) in a T-shaped microfluidic device. In chemotaxis experiments, the side capillary in the T-shaped channel (50 μm in opening) was filled by a NAPL mixture containing chemoattractant naphthalene. Soil bacteria *Pseudomonas putida* G7 (PpG7), chemotactic to naphthalene, were introduced in the main microchannel. At a fluid velocity of 0.5 m/d, greater densities of PpG7 were seen in the vicinity of the NAPL-water interface. As flow velocity increased to 10 m/d, we observed near the interface reductions in bacterial density and residential area (*i.e.*, where normalized bacteria density >1).

In continuum modeling, bacterial transport was described by a modified diffusion-convection equation. The diffusion coefficient (Db) represented uniform spreading in a bacterial population due to motility. For chemotactic bacteria, a chemotactic velocity as a function of chemical concentrations and bacterial intrinsic properties (*e.g.*, chemotactic sensitivity coefficient χo), was added to convection to account for biased migration toward the NAPL source. Simulations indicated that chemotaxis was suppressed in flow as diffusion and sensitivity coefficients (Db, χo) were both reduced to different extents as fluid velocity increased. Bacteria near the NAPL surface experienced shear stress, which might interfere with reorientations in bacterial trajectories so that their swimming became more aligned with flow direction in higher flow velocities [2]. Therefore, reductions in bacterial retention near the NAPL-water interface might stem from the modifications in cell motility due to shear. Bacteria in contaminated subsurface environments are often subject to groundwater flow whose influence on bacterial transport is vital for the implementation of bioremediation. This work revealed that bacterial chemotaxis in shear flow was hampered to a greater extent than predicted by convection. Findings from this study can aid in assessing the significance of chemotaxis in cell navigation of contaminated subsurface aquifers.

Participation

In-Person

References

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