Dynamics of reactive microbial hotspots in concentration and velocity gradients

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Abstract

In subsurface environments, bacteria play a major role in controlling the kinetics of a broad range of biogeochemical reactions. In such environments, nutrients fluxes and solute concentrations needed for bacteria metabolism may be highly variable in space and intermittent in time. This can lead to the formation of reactive hotspots where and when conditions are favorable to particular microorganisms, hence inducing biogeochemical reaction kinetics that differ significantly from those measured in homogeneous model environments. To investigate the impact of chemical gradients on the spatial structure and growth dynamics of subsurface microorganism populations, we develop microfluidic cells allowing for a precise control of flow and chemical gradient conditions, as well as quantitative monitoring of the bacteria's spatial distribution and early-stage biofilm development.

Using the non-motile Escherichia coli JW1908-1 strain and Gallionella capsiferriformans ES-2 as model organisms, we investigate the behavior and development of bacteria over a range of single and double concentration gradients in the concentrations of nutrients, electron donors and electron acceptors. We measure bacterial activity and population growth locally in precisely known hydrodynamic and chemical environments. This approach allows time-resolved monitoring of the location and intensity of reactive hotspots in micromodels as a function of the flow and chemical gradient conditions. We compare reactive microbial hotspot dynamics in our micromodels to classic growth laws and well-known growth parameters for the laboratory model bacteria Escherichia coli, namely Michaelis-Menten-Monod nutrients uptake and Doop's growth law.

The validated growth laws are then integrated into a mixing model quantifying the dynamics of nutrient gradients in shear flows. The main objective is to investigate the influence of combined chemical and velocity gradients on biogeochemical reactions kinetics and biomass production. We discuss the consequences of these results in the context of biomass production in heterogeneous velocity and chemical gradients.