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The Impact of Fluid Deformation on Mixing and Fast Chemical Reaction Along Reaction Fronts in Porous Media

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Fast chemical reactions in heterogeneous flows are controlled by fluid mixing, which perturbs local chemical equilibria and thus triggers chemical reactions. The deformation of material fluid elements in inhomogeneous flow fields leads to solute spreading and increased mixing due to the steepening of concentration gradients on one hand, and the increase of interfacial surface area between chemicals on the other. We present an approach based on a lamellar representation of fluid mixing that links fluid deformation, the distribution of concentration gradiens, and the upscaled reaction rates for fast reversible reactions. The evolution of effective reaction rates are governed by the flow topology, which determines the distribution of local velocity gradients, and the elongation rate of the reaction front. This leads to a significant increase of reaction efficiency, which turns out to be orders of magnitude larger than in homogeneous flow. This lamella based approach allows for the systematic evaluation of the temporal evolution of equilibrium reaction rates in inhomogeneous flows, and establishes a direct link between the reaction efficiency and the spatial characteristics of the underlying flow field as quantified by the deformation of material fluid elements.