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Coupled charge migration and fluid mixing in reactive fronts

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Quantifying fluid mixing in subsurface environments and its consequence on biogeochemical reactions is of paramount importance owing to its role in processes such as contaminant migration, aquifer remediation, CO_2 sequestration or clogging processes, to name a few (Dentz et al. 2011). The presence of strong velocity gradients in porous media is expected to lead to enhanced diffusive mixing and augmented reaction rates (Le Borgne et al. 2014). Accurate in situ imaging of subsurface reactive solute transport and mixing remains to date a challenging proposition: the opacity of the medium prevents optical imaging and field methods based on tracer tests do not provide spatial information. Recently developed geophysical methods based on the temporal monitoring of electrical conductivity and polarization have shown promises for mapping and monitoring biogeochemical reactions in the subsurface although it remains challenging to decipher the multiple sources of electrical signals (e.g. Knight et al. 2010).

In this work, we explore the coupling between fluid mixing, reaction and charge migration in porous media to evaluate the potential of mapping reaction rates from electrical measurements. To this end, we develop a new theoretical framework based on a lamellar mixing model (Le Borgne et al. 2013) to quantify changes in electrical mobility induced by chemical reactions across mixing fronts. Electrical conductivity and induced polarization are strongly dependent on the concentration of ionic species, which in turn depend on the local reaction rates. Hence, our results suggest that variation in real and complex electrical conductivity may be quantitatively related to the mixing and reaction dynamics. Thus, the presented theory provides a novel upscaling framework for quantifying the coupling between mixing, reaction and charge migration in heterogeneous porous media flows.

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