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Is it safe to continue relying on traditional porosity-permeability relationships?

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The precipitation of secondary phases in porous media carries profound implications for the functionality and efficiency of diverse natural and engineered systems. This encompasses applications ranging from subsurface CO2 storage sites, geothermal systems, deep geological disposal repositories, tunnels, oil and gas reservoirs, to the treatment of contaminated groundwater. These precipitation processes alter the structure of porous media, reduce pore space, influence hydrodynamics, and even modify reaction rates by reshaping reactive surfaces. As a result, it becomes crucial to thoroughly investigate the hydrodynamic consequences of mineral precipitation in porous geometries. However, the prevailing practice of assessing the impact of precipitation reactions on flow and transport relies on simplistic permeability-porosity relationships. Commonly employed empirical, experimental, or theoretical models such as Kozeny-Carman, Verma-Pruess, and power law are favored for their convenience and simplicity. These models find widespread application in commercial or open-access simulators for diverse geo-energy and geo-environmental purposes. Nevertheless, our previous research has revealed that relying solely on such porosity-permeability relations introduces significant uncertainty. To address this knowledge gap and mitigate the associated uncertainty, we propose a hierarchical statistical approach to upscale the porosity-permeability relationship from the microscale to the macroscale. Our approach acknowledges the complexity of permeability-porosity evolution while still leveraging practical and readily available formulations. Simulations of the mineral precipitation process in diverse homogeneous and heterogeneous settings were conducted, and a power-law formulation for the porosity-permeability relation was fitted, resulting in a distribution of power-law parameters for each setting. This resulted in a lognormal probability distribution function (PDF) for all the cases. By incorporating this PDF into continuum scale simulations, a fit-for-purpose porosity-permeability relation is established, linking the microscopic dynamics of probabilistic nucleation and growth in porous media with the macroscopic application domain. For most objectives in reactive transport modeling, a three-step scheme adequately captures the pore-scale physics and dynamics, ensuring the representation of these properties at the application scale.

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