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Brinkman double-layer model for flow at a free-porous interface

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The phenomenon of the Stokes–Darcy flow in coupled systems comprising a clear channel and a complex 3D porous medium is investigated through numerical and theoretical approaches. A quartet structure generation set (QSGS) method is used to generate random complex 3D porous structures imitating real structures in nature. Pore-scale flow simulations are performed using the Lattice Boltzmann method, enabling detailed analysis and characterization of the interfacial flow phenomena. Four key parameters with clear physical meanings are introduced to capture essential aspects of the flow dynamics quantitatively, revealing intriguing linear relationships with the square root of permeability –a fundamental characteristic length scale dominating the phenomenon. Several existing models are examined by these parameters. A Brinkman double-layer(BDL) model is proposed to address the limitations of existing models. Compared with several classic models, the present BDL model stands out due to its simplicity, accuracy, and robustness, providing a comprehensive understanding of the complex flow behavior in the coupled system.

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