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The Pore-Scale Darcy-Brinkman-Stokes Model for the Description of Advection-Diffusion-Precipitation Using Level Set Method

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Abstract : Hydraulic fracturing fluid (HFF) is widely used in shale reservoir productions. HFF contains diverse chemical additives, which result in the dissolution and precipitation of minerals through multiple chemical reactions. In this study, a new pore-scale Darcy–Brinkman–Stokes (DBS) model coupled with Level Set Method (LSM) is developed to address the microscopic phenomena occurring during the iron–HFF interaction, by numerically describing mass transport, chemical reactions, and pore structure evolution. The new model is developed based on OpenFOAM, which is an open-source platform for computational fluid dynamics. Here, the DBS momentum equation is used to solve for velocity by accounting for the fluid-solid mass transfer; an advection-diffusion equation is used to compute the distribution of injected HFF and iron. The reaction–induced pore evolution is captured by applying the LSM, where the solid-liquid interface is updated by solving the level set distance function and reinitialized to a signed distance function. Then, a smoothened Heaviside function gives a smoothed solid-liquid interface over a narrow band with a fixed thickness. The stated equations are discretized by the finite volume method, while the re-initialized equation is discretized by the central difference method. Gauss linear upwind scheme is used to solve the level set distance function, and the Pressure–Implicit with Splitting of Operators (PISO) method is used to solve the momentum equation. The numerical result is compared with 1–D analytical solution of fluid-solid interface for reaction-diffusion problems. Sensitivity analysis is conducted with various Damkohler number (DaII) and Peclet number (Pe). We categorize the Fe (III) precipitation into three patterns as a function of DaII and Pe: symmetrical smoothed growth, unsymmetrical growth, and dendritic growth. Pe and DaII significantly affect the location of precipitation, which is critical in determining the injection parameters of hydraulic fracturing. When DaII<1, the precipitation uniformly occurs on the solid surface both in upstream and downstream directions. When DaII>1, the precipitation mainly occurs on the solid surface in an upstream direction. When Pe>1, Fe (II) transported deeply into and precipitated inside the pores. When Pe<1, the precipitation of Fe (III) occurs mainly on the solid surface in an upstream direction, and they are easily precipitated inside the small pore structures. The porosity–permeability relationship is subsequently presented. This pore-scale model allows high confidence in the description of Fe (II) dissolution, transport, and Fe (III) precipitation. The model shows fast convergence and requires a low computational load. The results can provide reliable guidance for injecting HFF in shale reservoirs to avoid clogging and wellbore pollution. Understanding Fe (III) precipitation, and Fe (II) release and transport behaviors give rise to a highly efficient hydraulic fracture project.

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