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Editorial to the Special Issue: Multi-Scale and Multi-Physics Processes in Geological Systems with Fractured Porous Media

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An in-depth understanding of fluid flow, mass transport, and rock deformation in fractured porous media holds significant implications for engineering subsurface systems, such as waste disposal, oil and natural gas recovery, geothermal energy extraction, and CO2 sequestration. Recent advancements in computational and experimental techniques have brought new insights into the multi-scale and multi-physics processes in geological systems featuring complex discrete fracture networks (DFNs).

The objective of this special issue is to provide a comprehensive overview of the latest developments in multi-scale and multi-physics processes in geological systems involving fractured porous media. This includes examining multi-scale flow, transport, and mechanical processes in fractured reservoirs, exploring analytical, numerical, and experimental methods for fractured reservoirs, and utilizing artificial intelligence (AI) in computations for fractured reservoirs. The special issue comprises 14 contributions that cover various aspects of this topic.

Five papers focus on the fluid transport properties and the interaction mechanisms between fluid and rock. Song et al. (2022) proposed a multiphase pore network transport model that considers capillary pressure, disjoining pressure, and fluid transport mechanisms in irregular pores to comprehend the multiphase distribution and transport properties

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in porous media. Li et al. (2022) presented a pore-scale sandstone model based on the lattice Boltzmann method (LBM) and demonstrated that the existence of pores inhibits heat transfer between rock and liquid nitrogen (LN2). Li (2022) developed a shale gas production prediction model in fractured reservoirs, considering gas rarefaction effects, adsorption, diffusion, and stress sensitivity. Yang et al. (2022) conducted a series of soaking experiments between tight sandstone and dry/water/brine-supercritical CO2 (SC-CO2) for SC-CO2 fracturing applications. Through microstructure analysis, they identified three main mechanisms in the interaction between rocks and brine/SC-CO2: significant dissolution of rock structure, generation of new mineral precipitation, and expansion induced by CO2 adsorption. Tang et al. (2023) performed micro-scale visualization displacement experiments of CO2 and CO2 foam flooding after water flooding. The results indicated that reasonable fracturing and CO2 foam flooding enhance oil recovery after water flooding due to improved connectivity of micromodels and blocking capability of the foam system.

Modeling fluid flow in porous media is a crucial component in geoscience applications as it provides fundamental descriptions, especially for media with complex fracture networks. Five papers in this issue consider analytical, numerical, and semi-analytical methods for modeling fluid flow in fractured porous media. Pei et al. (2022) employed an integrated reservoir–geomechanics–fracture model to optimize the parent–child well spacing in a multilayer deep shale gas reservoir with complex natural fractures. Their model simulated the complex fracture network, in situ stress changes, and multicluster fracture propagation using EDFM, FEM geomechanics model, and DDM hydraulic fracture model, respectively. Wang et al. (2022) introduced a multilevel adaptive implicit scheme with up to four levels of adaption for two-phase flow in heterogeneous fractured reservoirs. The study analyzed the effects of heterogeneity, multiple scale fractures, and fracture distribution on fluid flow. Zhao et al. (2022) developed an efficient model to evaluate hydraulic fracture spacing, considering fluid transport and stress shadow. Qin et al. (2022) presented a semi-analytical well interference model that incorporates non-uniform fracture conductivity and interference from adjacent wells. The pressure and pressure derivative curves were divided into eight regimes, clearly demonstrating well interference among multi-fractured horizontal wells (MFHWs) in fractured reservoirs. Wang et al. (2023) proposed a numerical model of proppant migration within different rough fractures based on the Euler–Euler two-phase flow model. They compared and analyzed the effects of different roughness, injection speed, proppant particle size, proppant density, and sand-carrying solution viscosity on the transport pattern and deposition characteristics of proppant.

The modeling of fractured porous media often involves complex physical, thermodynamic, and geochemical effects. Although direct numerical simulation is commonly used to study fluid transport dynamics in porous media, it can be computationally costly and inefficient for large geological models. Today, AI is being applied to the simulation process due to its fast response speeds and powerful generalization capabilities. Four papers in this issue demonstrate the application of AI in porous media simulation. Demirer et al. (2022) presented a reactive transport model with a machine learning-based geochemistry surrogate model to simulate the three-dimensional hydrothermal dolomitization of a fractured carbonate reservoir. The proposed framework significantly reduces the computational burden, achieving a speedup of one order of magnitude. Zhang et al. (2022) proposed a method based on a multistage concurrent generative adversarial network (GAN) to learn the structural features of porous media from a low-resolution 3D image. This method can stochastically reconstruct larger-sized porous media images. Chen et al. (2022) utilized bi-directional LSTM to build a surrogate model for the pressure transient behavior of shale reservoirs with heterogeneous fractures, achieving a computation speed improvement of three orders of magnitude compared to the original model. The findings of their study provide an efficient tool for evaluating fracture parameters. Li et al. (2023) employed multiple linear regression (MLR), support vector machine (SVM), random forest (RF), and artificial neural network (ANN) to predict the productivity of shale gas with hydraulic fracturing. Among these four methods, ANN was found to have the smallest error, and particle swarm optimization (PSO) was adopted to optimize the model parameters.

We anticipate that the published papers will be heuristic and valuable for scientists and researchers in this field of research. We extend our gratitude to the dedicated authors, reviewers, and the Editorial Office of Transport in Porous Media for their time, effort, and insightful comments.

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