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Research paper

Reduced flow model and transmissibility upscaling in multi-layered faulted reservoirs

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ABSTRACT

We construct a new three-scale model for single phase incompressible flow in faulted rocks containing multiple damage zones. At the finer scale ($\mathcal{O}$(1m)), flow is influenced by the high-contrast layered heterogeneities inherent to the core and adjacent damage zones, which are populated by geological anomalies, such as compaction bands, debris, and fine sediments and joints. In the first stage of the reiterated homogenization procedure, we construct a lower-dimensional reduced model, where the discontinuity is envisioned as $(n-1)$-dimensional manifold ($n = 2, 3$), topologically attached to multiple layered structures, with flow patterns characterized by various jumps in pressure and velocity fields. Subsequently, by aligning the fault with the interface between adjacent simulation cells of a coarse grid, the upscaling of the reduced flow model gives rise to transmissibility multipliers, whose constitutive response stems naturally from the local flow patterns, exhibiting improved accuracy compared to the traditional harmonic mean, inherent to the two-point flux approximation. Computational simulations obtained with the finite element method with localized discontinuous spaces illustrate the ability of the three-scale model to provide further insight into the behavior of the transmissibility multipliers, which capture the effects of fault zone texture upon the flow discretization. The methodology proposed herein shows enormous potential for the development of more accurate transmissibility preprocessors at relatively low computational costs, consequently overcoming the shortcomings of a direct application of the local high-fidelity approach.

1. Introduction

The presence of shear-induced fault zones in geological formations leads to the appearance of strong discontinuity surfaces embedded in the 3D reservoir matrix, which may significantly modify flow regimes and have a major impact on the signature of flow streamlines (Fossen, 2010). The role of these heterogeneities of high aspect ratio on the hydrodynamics may vary from high-permeable conduits to effective barriers, which may obstruct or divert fluid movement precluding hydraulic communication between distinct reservoir compartments (Bense and Person, 2006). Recently, it has become increasingly important in reservoir simulation to account for the several features underlying fault zones. These include insights into the shear stresses and fault evolution over geological time-scales to the detailed assessment of mechanical and petrophysical properties, architecture, texture, and microstructure (see e.g., Caine et al. (1996) and Odling et al. (2004)). Improved knowledge of the fault zone texture, including localized hydro-mechanical behavior, has an enormous impact on the prediction of geofluid withdrawal, evaluation of economic viability, and reservoir management (Sternlof et al., 2006).

Among other effects, multiple petrophysical heterogeneities distributed across fault core and damage zones within the fault zone are engendered from the succession of shear deformation caused by tectonic events (Uehara and Takahashi, 2013). Unlike traction-induced fractures (joints), faults are commonly envisioned as highly complex zones with intricate internal structures giving rise to discontinuities within the previously deformed rock. Petrophysical properties in the fault zone are modified considerably with proximity to the core and may give rise to complex non-symmetric damage zones (Joussineau and Aydin, 2007; Faulkner et al., 2011). Moreover, it has been observed that permeability maps associated with multiple damage regions are directly correlated with the local stress state and the nature of the microstructure (Bense and Person, 2006).

In the context of finite volume discretizations, commonly adopted in reservoir flow simulators, the computational meshes are usually constructed using corner-point or pillar grids with the adjacent cell interfaces aligned with the fault plane (Pettersen, 2006). In this setting, faults are represented as 2D planar surfaces with the capability to

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