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An Enhanced Reduced Flow Model for Paleokarst Reservoirs Incorporating Multi-stage Collapse Breccia Pipes

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Abstract
We develop an innovative mixed-dimensional 3D/1D flow model in carbonate rocks containing multiple karst cave conduits with underlying heterogeneity in the petrophysical properties stemming from different geological stages of cave-pipe collapse systems. Such geological structures manifest in distinct heterogeneity patterns inherent to the successive stages of burial, mechanical failure, and collapse, resulting in discrete collapsed passages in the conduit network. In addition, breakdown products appear within the cave system associated with chaotic breccia, suprastrata deformation, and vertical tube-like geo-bodies, herein referred to as breccia pipes, containing faults and fractures around the vertical pipe. The input parameters of the mixed-dimensional flow model show the ability to incorporate the complex multiple heterogeneities associated with the geological objects at different stages of collapse. After populating the geo-bodies with proper petrophysical properties, the mixed-dimensional flow equations are discretized by a locally conservative extended version of the mixed-hybrid finite element method, which incorporates the new nonlinear discrete transmission jump conditions between elements adjacent to the breccias within the conduits. Computational simulations are performed for particular configurations of heterogeneous karst conduit systems with distinct geological time scales, illustrating the influence of the karst and solution breccia-pipe deposits upon the flow regimes, streamline patterns, and well productivity in real-case scenarios of hypogenic cave networks.

Keywords Carbonates · Karst cave conduits · Mixed-dimensional flow model · Nonlinear Robin transmission condition · Solution breccia pipes · Hybridized mixed methods

1 Introduction

Deeply buried carbonate paleokarst reservoirs may contain large oil and gas reserves and consist of potential sites for prospective hydrocarbon targets in many basins worldwide (Burchette 2012; Fernandez-Ibanez et al. 2019). On the other hand, paleokarst may pose a factor of complex prediction during the exploration and production phases—operation safety and reservoir flow (Jensen et al. 2021; Maksimov et al. 2021; Nworie et al. 2023). The terminology paleokarst is generally associated with an ancient karst, which is

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