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A Locally Conservative Multiscale Finite Element Method for Multiphase Flow Simulation through Heterogeneous and Fractured Porous Media

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Abstract

A Multiscale Locally Conservative Galerkin (MsLCG) method is proposed to accurately simulate multiphase flow in heterogeneous and fractured porous media. MsLCG employs a coarse partition of the fine grids and multiscale basis function for mapping the fine-scale information to the coarse-scale unknowns. Different from standard Multiscale Finite Element Method (MsFEM), the main improvement of our MsLCG is to use the property of local conservation at steady state conditions to define a numerical flux at element boundaries. MsLCG provides a way to extend standard MsFEM to handle challenging multiphase flow problems in heterogeneous and fractured porous media. MsLCG preserves all the advantages of the standard MsFEM while it improves to explicitly conservative fluxes through each element. We present a number of representative numerical examples to demonstrate that our method is efficient and accurate for simulating multiphase flow through heterogeneous and fractured porous media.

Keywords: multiscale finite element method; multiphase flow through porous media; locally conservative Galerkin method; reservoir simulation

1. Introduction

Multiphase flow simulation through reservoir formation remains as a challenge in reservoir simulation. Detailed reservoir characterization and petrophysical analysis have revealed that reservoir rock is naturally heterogeneous covering multiple length scales, such as those in shale reservoirs (Akkutlu and Fathi 2012; Wei et al. 2013; Yan et al. 2015; Chai et al. 2018) and carbonate formations (Popov et al. 2009; Sok et al. 2010; Sun et al. 2015; Fadlelmula et al. 2016; Sun et al. 2017). The multiphase flow process in such porous media is apparently affected by the heterogeneities in a wide range of spatial scales. Therefore, this raises challenges for numerical simulation, motivating the development of modeling approaches and numerical methods.

Among the proposed modeling approaches, a traditional way of modeling of fractured systems relies on the dual-porosity model. In dual-porosity model and the generalized multi-porosity model, matrix and fracture are considered as different porosity types (Barenblatt et al. 1960; Warrant and Root 1963; Yan et al. 2016a, 2016b). The matrix and fracture domain are linked to each other through a transfer term. Because of its simplicity, the dual-porosity