Advances in Water Resources 193 (2024) 104838

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

An extended two-parameter mixed-dimensional model of fractured porous media incorporating entrance flow and boundary-layer transition effects

Marcio A. Murad [a,*], Luciane A. Schuh [b], Igor Mozolevski [b], Josue Barroso [a]

[a] Laboratório Nacional de Computação Científica, Av. Getúlio Vargas, 333, 25651–075, Petrópolis, RJ, Brazil
[b] Departamento de Matemática, Universidade Federal de Santa Catarina, 88040900 Florianópolis, Santa Catarina, Brazil

ARTICLE INFO

Keywords:
Entrance boundary-layer flow
Discrete fracture model
Navier–Stokes
Pressure jump conditions
Discontinuous Galerkin method
Interior penalty formulation

ABSTRACT

We develop an enhanced reduced model for single-phase flow in fractured porous media capable of incorporating more realistic interface conditions at the fracture terminations. In addition to the traditional dimensional model reduction, where the elements of the discrete fracture network are treated as lower dimensional manifolds embedded in the porous matrix, we explore the microscale behavior of the boundary layer flow at the entrances of a fracture bounded by two parallel plates to construct a new set of interface conditions of Robin-type, giving rise to localized pressure jumps at the fracture edges. Within this enriched description, sharper reduced flow and tracer transport mixed-dimensional models are constructed in the asymptotic limit ruled by two small parameters related to the ratio between fracture aperture and entrance developing length and a macroscopic length scale. The discrete flow/transport mixed-dimensional model is discretized by a new discontinuous Galerkin(dG)-based formulation. An adequate version of the Galerkin-Newton method is developed for the numerical treatment of the non-linear Robin interface condition. Considering several fracture arrangements, numerical results illustrate the sharper description of the model proposed herein in predicting flow and tracer transport patterns in fractured media.

1. Introduction

The development of robust and accurate computational models for flow in fractured porous media is of utmost importance in a widespread variety of applications including geofluid extraction and storage, solute transport, geothermal energy, movement of pollutants in the subsurface, among others (Adler et al., 2012; Dietrich et al., 2005; Sahimi, 2011). In particular, a large portion of conventional oil and gas reserves are located in highly fractured carbonate rocks (Lucia, 2007), where the essential role of discrete fracture networks (DFN) topological and petrophysical properties upon flow and transport patterns is widely recognized (Berre et al., 2019).

Owing to the high contrast in petrophysical properties between the network and surrounding rock matrix, fractures may provide high permeability pathways, wherein solutes are preferentially advected by the streaming velocities, which may be of several orders of magnitude larger than in the intact rock. Such a disparity can be even magnified in the presence of clusters, swarms and fracture corridors (Gabrielsen and Braathen, 2014). In the regime of primary withdrawal of geofluids, permeability enhancement implies in great advantage, as it allows for a direct access to the resources. Conversely, fracture networks induce severe drawbacks during water alternate gas injection processes, where high-permeability pathways may anticipate the arrival of breakthrough curves, consequently jeopardizing the hydrocarbon production (Kim and Deo, 2000). Furthermore, they may give rise to serious environmental risks by promoting leakage of hydrocarbons to water resources and migration of pollutants in the subsurface which are spread by the groundwater dynamics, Berkowitz et al. (1988).

A vast amount of research has been carried out in order to incorporate most effectively DFN in flow models (Adler et al., 2012). Here, we particularly draw attention to the class of homogenized single or dual porosity/dual permeability models, wherein fractures and matrix are treated as juxtaposed continua (Barenblatt et al., 1960; Warren and Root, 1963) and mainly to the school of thought based on finer scale flow models constructed trustworthy to the fracture network topology (e.g. Berre et al. (2019) for a review). In this latter context, high-fidelity fine-scale models entail excessive mesh refinement in the vicinity and within the discontinuity, since the elements of the network are treated as localized heterogeneities of high aspect ratio and assigned with high contrast values to the corresponding petrophysical properties, turning the computational costs involved unfeasible. Such shortcomings can be overcome within the framework of reduced flow

* Corresponding author.
E-mail addresses: murad@lncc.br (M.A. Murad), luciane.schuh@ufsc.br (L.A. Schuh), igor.mozolevski@ufsc.br (I. Mozolevski), jsantos@lncc.br (J. Barroso).

https://doi.org/10.1016/j.advwatres.2024.104838
Received 21 October 2023; Received in revised form 29 July 2024; Accepted 11 October 2024
Available online 22 October 2024