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Upscaling poromechanical models of coalbed methane reservoir incorporating the interplay between non-linear cleat deformation and solvation forces

Quoc D. Ha [a], Tien D. Le [a], Irina Panfilov [a], Christian Moyne [a], Marcio A. Murad [b,*]

[a] LEMTA, University of Lorraine, CNRS, Nancy, France
[b] LNCC, Laboratório Nacional de Computacao Cientifica, Petrópolis, RJ, Brazil

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ABSTRACT

We construct herein a three-scale coupled mechanical model for naturally fractured coalbed methane reservoir with the ability of describing the stress balance between the solvation force, arising from the gas adsorption in nanopores, and the restoration stress stemming from the elastic response of the cleats. To determine the cleat porosity, the non-linear hyperbolic Barton–Bandis (BB) law, which captures increase in joint stiffness induced by the cleat closure due to matrix swelling, is postulated for the fracture mechanical response. At the microscale, the theory incorporates the coupling between the effects of the solvation force and the elastic response of the matrix. Such system of governing equations is coupled with the fluid pressure in the discrete cleat system with dependency of aperture with the normal stress dictated by the aforementioned BB-model. A reiterated homogenized procedure is pursued and capable of providing the constitutive response of the homogenized poromechanical parameters on gas pressure. Numerical simulations illustrate the performance of the proposed model.

1. Introduction

It has been well documented that gradual increase of carbon dioxide concentration in the atmosphere induces global warming. Several procedures, commonly adopted to mitigate such an undesirable phenomenon, consist in the long-term storage of supercritical CO_2 in underground geological sites, such as active or depleted oil and gas fields, deep saline aquifers, methane hydrate formations, coal seams and salt caverns (Pijaudier-Cabot and Pereira, 2012; Surdam, 2013; Hoteit et al., 2019). Among the aforementioned sequestration scenarios, we are particularly interested in the enhanced coalbed methane recovery (ECBMR) in unmineable coal seams combined with CO_2 sequestration (Seidle, 2011; Moore, 2012; Ross et al., 2009; Kumar et al., 2014; Wang et al., 2018; Fan et al., 2018). Such an attractive combination is motivated by the large quantities of sorbed methane in coal, combined with the high capacity of the coal matrix for storing large amounts of carbon dioxide and consequently generating revenue that mitigates the expenses of sequestration (Seidle, 2011; Moore, 2012). In coalbed methane reservoirs, the primary production stage is dictated by traditional pressure drawdown which induces methane desorption from the nanopores, with subsequent diffusion in the matrix and flow through the higher permeability layers (cleats) towards the production wells (Seidle, 2011; Ayoub et al., 1991). Owing to the higher affinity with the solid phase, particularly higher adsorption capacity, injected CO_2 maintains the reservoir pressure but decreases the partial pressure of methane causing desorption from the surfaces of the coal matrix. In addition, subsequently CO_2 displaces methane towards the production wells enhancing gas production (Seidle, 2011; Moore, 2012).

Fractured coalbed matrix consists of a canonical example of a system characterized by a bimodal structure with two distinct porous systems commonly referred to as cleat (natural fracture) and matrix. The former is associated with the gas (and water) percolation whereas the latter dominates the storativity along with slow diffusion within the matrix (Seidle, 2011). Owing to the molecular nature of adsorption, the description requires the use of discrete models or intermediate statistical mechanics tools. Moreover, multiscale flow and diffusion patterns are ruled by phenomena described in terms of continuum physics at two coarser natural scales associated with the expansive matrix intertwined by the cleat system (micro), and the entire macroscopic picture of the homogenized system (macro) characterized by juxtaposed different continua (see Fig. 1).

* Corresponding author.
E-mail addresses: quoc-dat.ha@univ-lorraine.fr (Q.D. Ha), tien-dung.le@univ-lorraine.fr (T.D. Le), irina.panfilova@univ-lorraine.fr (I. Panfilov), christian.moyne@univ-lorraine.fr (C. Moyne), murad@lncc.br (M.A. Murad).

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