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Multiscale poromechanical model for naturally fractured coal seam reservoir considering non-linear fracture deformation and adsorption effects

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In this work, a three-scale poromechanical model for naturally fractured coalbed methane reservoir is developed. The coal seam reservoir is composed of a coal matrix mainly containing nanopores saturated by adsorbed gases and natural fracture network (called cleats). Beyond the empirical Langmuir law, the adsorption isotherm of the fluid mixture (CH4 and CO2) is rigorously constructed by using the Density Functional Theory (DFT) applied to a Lennard-Jones fluid [1, 2, 3], allowing to compute the fluid distribution in the pores and the adsorption-induced force (solvation force) exerting on the solid phase by the adsorbed fluid. It is highlighted that the solvation force magnitude is much higher than the bulk pressure leading to an important impact on the mechanical properties at higher scale. A first homogenization procedure of the nanopore scale model is performed to derive the mechanical response of the continuum matrix, characterized by a modified Biot-Willis parameter depending on the solvation force magnitude. Such system of governing equations in the matrix is coupled with the fluid pressure in the discrete cleat system with dependency of aperture with the normal stress dictated by the hyperbolic Barton-Bandis model [4]. The problem is strongly non-linear and coupled with the hydrodynamics due to the rapid increase of the joint stiffness and the dependence of the fluid pressure. Moreover, the cleat stiffness is directly related to the cleat closure, which controls the permeability of the reservoir. A second homogenized procedure is pursued and capable of providing the constitutive response of the homogenized poromechanical parameters on gas pressure at the reservoir scale. In this context, increase in the normal BB-stiffness of the cleats tends to reduce the jumps of characteristic functions at the matrix/cleat interfaces which are propagated to the macroscale in terms of perturbations in the macroscopic poromechanical parameters. In addition to the overall three-scale decomposition of the total macroscopic stress, we constructed a new constitutive law for the Lagrangian cleat porosity. The dependence of the two- and three-scale homogenized poromechanical coefficients on the gas pressure is reconstructed numerically quantifying precisely the influence of the solvation force and the non-linear elastic behavior of the natural fractures.

Finally, the poromechanics is coupled with the multiscale hydrodynamic model in order to simulate the enhanced coalbed methane reservoir by CO2 injection. The interplay between the solvation force due to the adsorption effect and the non-linear elastic response of the fractures is numerically analyzed during the CH4 production and the CO2 injection procedure, underlying the increase in fracture stiffness at the injection well due to the matrix swelling stemming from the preferential CO2 adsorption in coal. Moreover, the fracture permeability tends to decrease in the vicinity of the injection well due to the same effect.

Participation

In-Person

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