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ORIGINAL PAPER

Bridging between macroscopic behavior of shale gas reservoirs and confined fluids in nanopores

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Abstract The macroscopic behavior of gas flow in multi-porosity shale gas reservoirs is rigorously derived within the framework of the reiterated homogenization procedure in conjunction with the Thermodynamics of Inhomogeneous Gases in nanopores. At the nanoscale, the Density Functional Theory is applied to reconstruct general adsorption isotherms and local density profiles of pure methane in the intraparticle porosity of the gas-wet organic matter. The description of adsorption incorporates both repulsive hard sphere effects and Lennard–Jones attractive intermolecular interactions between fluid-fluid supplemented by a fluid-solid exterior potential. Such local description reproduces the monolayer surface adsorption ruled by the Langmuir isotherm in the asymptotic regime of large pore size distributions. The nanoscopic model is upscaled to the microscale where kerogen particles and nanopores are viewed as overlaying continua forming the organic aggregates with adsorbed gas at local thermodynamic equilibrium with the free gas in the water partially saturated interparticle pores. The reaction/diffusion equation for pure gas movement in the kerogen aggregates is coupled with the Fickian diffusion of dissolved gas in the water phase and free gas Darcy flow in the adjacent interparticle pores which also lye in the vicinity of the inorganic solid phase (clay, quartz, calcite) assumed impermeable. By postulating continuity of fugacity between free and dissolved gas in the interparticle pores and neglecting the water movement, we upscale the microscopic problem to the mesoscale, where organic and inorganic matters along with interparticle pores are viewed as overlaying continua. The upscaling gives rise to a new nonlinear pressure equation for gas hydrodynamics in the interparticle pores including a new storativity coefficient dependent on water saturation, total organic carbon content (TOC), and intra- and interparticle porosities. When coupled with the nonlinear single phase gas flow in the hydraulic fractures, the homogenization of the mesoscopic model leads to a new microstructural model of triple porosity type with distributed mass transfer function between the different levels of porosity. Computational simulations illustrate the potential of the multiscale approach proposed herein in providing accurate numerical simulations of methane flow in shale gas reservoirs.

Keywords Shale Gas · Pressure Equation · Reiterated Homogenization · Adsorption in Nanopores · Thermodynamics of Inhomogeneous Gases · Density Functional Theory

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1 Introduction

Unlike conventional sources of energy, unconventional reservoirs are characterized as geological formations which