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A wave-mediated effective diffusion model for gas production from a semi-sealed system

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Massive hydraulic fracturing has made economical production from well-compacted deep geological formations such as shale possible. Despite the commercial success, the physical mechanisms for the significantly enhanced production rate versus the conventional models remains unresolved. The mass flow from the matrix blocks to their adjacent fractures are the sources fed to the fracture network as well as the bottleneck of this semi-sealed production system. Earlier studies attribute the enhanced flow rate from the matrix blocks to the fractures to slip flow and Knudsen diffusion within the matrix blocks. Patzek [1], on the other hand, has argued that Knudsen-like scaling model is inappropriate for describing gas flow in tight formations such as shale. He demonstrated that the effect of slip on gas flow in tight formations is very weak. Both slip flow and Knudsen diffusion are only suitable for describing rarefied gas flows, but not for shale gas, which is under very high pressure in deep formations. Similar arguments on the unsuitability of the slip model for shale gas were also provided by Chen & Shen [2]. Gas flow from the matrix block to the adjacent fractures is a problem of production from a semi-sealed system. For such a system, our previous works based on the pore-scale compressible Navier-Stokes equations have shown that the motion of a viscous compressible gas is governed by a damped wave equation, and it exhibits a slip-like mass flow rate with a no-slip velocity profile [2-6]. Here we numerically and experimentally investigate how the rarefaction wave initiated at the start-up of gas flow affect the gas production from a semi-sealed dense porous plug. When a wave tries to penetrate a dense random porous medium, it loses its coherence and degenerates to a diffusion front beyond the so-called penetration length, resulting from repeated random reflections of the wave from the solid surfaces in a dense porous medium. Effective diffusion models have been long used by the physics community to describe such gas transport [7-14]. In our work, rarefaction wave induced gas transport at the pore-scale is first numerically simulated in randomly distributed porous media. By matching the computed macroscale mass flow rate with the one computed using a macroscale diffusion equation, the effective diffusion coefficient and its structure can be identified. With a large number of such computations, a machine learning model is established to extract the dependence of the effective diffusion coefficient on the mean radius and the variance of the solid grain, the porosity of the porous medium and the ratio of the outlet to the mean radius of the solid grain. A laboratory scale gas production experiment is then carried out to validate the effective diffusion model. Comparison between the model and the experiments shows that the wave-mediated effective diffusion model provides significantly better predictions for the gas production rate than that based on the Darcy's law. The newly proposed wave-mediated effective diffusion model is therefore promising for applications to gas production from semi-sealed systems with fractured networks.

Participation

In-Person

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