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A generalized finite-difference diffusive-advective (FDDA) model for gas flow in micro- and nano-porous media

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Abstract

We develop a new method to model gas flow through porous media with pores in the range of nanometers to micrometers. Numerical random porous media with various grain sizes are constructed from packings of spherical grains. The size of spherical grains is varied through several orders of magnitude to assess the non-linear trend of rate of fluid flow versus applied pressure in the submicron range. A generalized Laplace equation is solved to calculate the fluid velocity distribution in the interstitial space domain. The solution invokes Neumann's boundary condition at the grain-pore surface and finite pressures at the inlet and outlet. Depending on Knudsen's number (no-slip: $K_n<0.001$; slip: $0.001<K_n<0.1$), both diffusive and advective flow are considered in the model together with the enforcement of no-slip or slip boundary conditions on the surface of the solid matrix. The assumed conditions permit us to neglect the effects of inertia and gas compressibility. We validate model predictions with Lattice-Boltzmann calculations within 20% error for similar random packs with pore-throat sizes in the micrometer range. When throat-pore sizes lie in the nanometer range, a maximum difference of two orders of magnitude is observed between the two models. Model predictions for nanoporous media are validated with published experimental data. We found that the slip-flow condition is necessary to describe gas flow in nanoporous systems at low pressures and for porous systems with small pore-throat sizes. Our work indicates that the advective slip flow dominates the flow in nanoporous systems and that the diffusive term contribution to the flow is smaller than 2% in a system wherein the smallest throat size is equal to 200 nm.

***Key words**: Grain pack, Random porous media, Permeability, Shale gas, Knudsen diffusion, Slip and no-slip flow*

1. Introduction

Gas-bearing shale strata are important energy supplies in North America and recently in Europe and Asia. Determining permeability in these natural, fine grained porous systems is necessary for capital investments and field development decisions by governments and major oil companies. Gas production from such reservoirs is technically challenging, even though the production is

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