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Wave-mediated diffusion model for semi-sealed systems: effective diffusion coefficient and experimental validation

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It is widely known that the motion of a gas at a low Mach number can be approximated as an incompressible flow at the leading order in a small Mach number expansion of the full solution (Anderson 1995; Panton 2013). However, it has been shown recently that such an incompressible approximation becomes invalid for a semi-sealed system with no inlets and no boundary movements. Studies based on linearized compressible Navier-Stokes equations for such a system made of small capillary tubes have revealed some counter intuitive flow characteristics such as no-slip flow with a slip-like mass flow rate (Chen and Shen 2018a, b; Shen and Chen 2019a, b; Shen and Chen 2020). In this work, we extend these works to a semi-sealed porous system which has applications to microfluidics and primary production from a tight gas reservoir.

Based on the compressible N-S equations and the theory of Klainerman and Majda (1982) for low Mach number flow, Jin and Chen (2019) has shown that at the pore-scale, the flow of the gas obeys a damped wave equation. Applying multi-scale analysis and volume averaging upscaling to the pore scale equation, Jin and Chen (2019) obtained a self-diffusion equation at the macroscopic scale in the limit of infinitesimal pore size. To account for small but not infinitesimally small pores, the effective macroscopic diffusion coefficient must be modified to consider the effect of wave-mediated diffusion. We first perform pore-scale numerical simulations of drainage flow from a porous plug using the damped wave equation. The mass flow rate from this simulation is then matched to the one computed from the macroscopic diffusion equation with an adjustable diffusion coefficient. The diffusion coefficient that provides such a match in the mass flow rate is then the effective diffusion coefficient.

A large number of pore scale simulations are performed for various pore structures. We study slow viscous drainage flow of a viscous compressible gas from a semi-sealed porous plug to a large vessel. The semi-sealed porous plug has a length of , height of ; and the vessel has a height of and extends to infinity downstream. We then use the homogenized medium shown in Figure 1 and the macroscopic diffusion equation with various effective diffusion coefficients to compute mass production rate from the plug. From the simulation results, it is found that the larger the porous plug length and its porosity, the larger the effective diffusion coefficient. The larger the expansion ratio, the smaller the effective diffusion coefficient. An empirical correlation of the effective diffusion coefficient is then established for applications to larger physical size. The proposed wave-mediated effective diffusion model as well as Darcy's law are both used to perform historic match with the data from laboratory experiments. The comparison shows that the wave-mediated effective diffusion model provides good agreement with experiments whilst Darcy's law severely underestimates the flow rate.

The proposed wave-mediated diffusion model is promising for applications for primary production from tight gas reservoirs. Testing of this model with field data is currently underway.

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References

Anderson, J. D., Computational Fluid Dynamics (McGraw-Hill, New York, 1995). Chen, K. P., Shen, D., "Drainage flow of a viscous compressible fluid from a small capillary with a sealed end,"J. Fluid Mech. 839, 621-643 (2018a). Chen, K. P., Shen, D., "Mechanism of fluid production from the nanopores of shale,"Mechanics Research Communications. 88, 34-39 (2018b). Jin, Y., Chen, K. P., "Fundamental equations for primary fluid recovery from porous media", J. Fluid Mech. 860, 300-317 (2019). Klainerman, S. & Majda, A. 1982 Compressible and incompressible fluids. Comm. Pure Appl. Math. 35(5), 629–651. Panton, R. L., Incompressible Flow 4th Ed (Wiley, New York, 2013). Shen, D. and Chen, K.P., "Self-diffusion in compressible gas flow through a micro-conduit,"Physical Review Fluids. 4(2), 024202 (2019a). Shen, D., Chen, K. P., "Symmetric drainage flow of a compressible fluid from a fracture: analytical solution and slip-like flow rate,"Mechanics Research Communications, 99, 15-21 (2019b). Shen, D., Chen, K. P., "Wave dominant transport in gas drainage flow from a narrow conduit,"Physics of Fluids, 32(10), 106105 (2020).

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