COMSOL Modeling of Nonlinear Transport Properties

Research Themes

The Gas Research Institute (GRI) technique is commonly used to estimate permeability in unconventional reservoirs. The measurements are made on ground, unstressed samples and require empirical correlations for interpretation. Four different plug scale based measurement protocols are modeled in this paper, including their strengths and weaknesses. The necessity of using the full nonlinear flow equation for the interpretation of the data is also discussed. Our implementation of the nonlinear transport equation includes the assumption of constant viscosity, rock compressibility,and pressure dependent permeability, i.e. the gas slippage effect (Klinkenberg corrections). Four different protocols are modeled: steady state, unsteady state, pulse decay and sinusoidal pressure. These differ by the addition of reference chambers to the steady state apparatus and the pressure boundary conditions applied.

We find that including pressure dependent density increases the average pressure in the sample due to the nonlinear pressure profile induced. This leads to the estimation of permeability that is too small compared to an assumption of a linear profile (i.e. Darcy flow). In contrast, the Klinkenberg effect causes an increased estimate of permeability. It is difficult to separate these two effects, as a result, modeling the full nonlinear behavior of the transport properties is necessary.

The modeling indicates that plug scale measurements are practical, and that use of the GRI measurement technique is not necessary. We recommend using unsteady state measurements, supplemented with sinusoidal pressure and pulse decay to calibrate the magnitude of the nonlinear effects, and the impact of diffusion and sorption.

Recent Accomplishments

Four different plug based measurement were modeled with different boundary conditions. The necessity of using the full nonlinear flow equation for the interpretation was demonstrated. The following models were developed:

Steady State: Historically the most widely used technique for measuring permeability. For low permeability samples there are nonlinearities that must be taken into account. To apply a linearized version of the equation the flow rates are too low to be reliably measured.

Unsteady State: Takes the least time to perform the measurement and involves a wide range of flow rates. The measurement time is comparable to many other petrophysical measurements. This technique should become the standard for low permeability plug measurements. At low permeabilities the full nonlinear equation must be used.

Pulse Decay: The measurement provides mass balance which allows the effects of sorption and diffusion to be included. This makes it the most robust measurement for determining all the physical mechanisms but small leaks negate the advantages.

Sinusoidal: It is most sensitive to nonlinearities. There is a purely nonlinear pressure density effect which raises the average pressure in the outlet chamber. Addition of the Klinkenberg effect reduces this average pressure. This may be the most accurate method of determining the magnitude of the Klinkenberg correction.

The goal of the model is to extract parameters from measured data by comparing to the COMSOL Multiphysics models. This sort of parameter extraction requires at most a few hours of computation time but are well within the capabilities of most desktop computers.

Issues

1. The Gas Research Institute (GRI) measurement protocol is commonly used to estimate permeability in unconventional reservoirs. Unfortunately, the GRI measurement is unstressed and requires grinding of the samples. Both of these effects significantly alter the flow properties.

2. Flow equations for gas are nonlinear, and we are aware of no analytic solutions. For a small change in pressure, the equation may be linearized. This is a source of significant error in low permeability samples

Yuan-Yun Lin

Major/Field of Study: Chemical Engineering

College: Cullen College of Engineering

Professor: Dr. Michael Myers

Email: ylin41@uh.edu

CHBE