A non-linear transport model for determining porous shale rock characteristics

Ilkikhar Ali and Nadeem A. Malik
Department of Mathematics & Statistics, King Fahd University of Petroleum & Minerals, Saudi Arabia
namalik@kfupm.edu.sa and nadeem.malik@cantab.net

European Geophysical Union, General Assembly, Vienna, Austria, 17-22 April 2016

The Gas Transport Model: an advection-diffusion equation for the pressure field

\[
\frac{\partial p}{\partial t} + U(p, p_t) \frac{\partial p}{\partial x} = D(p) \frac{\partial^2 p}{\partial x^2}
\]

This is a transport model for the pressure field \(p(x,t)\). It contains many (about 20) parameters, \(t\), and the same number of compressibility coefficients, \(\zeta\).

The porosity, and the permeability are the two most important rock characteristics and they play a central role in the model.

The apparent velocity \(U(p, p_t)\) and the apparent diffusivity \(D(p)\) are complicated functions of \(p\); so they also are functions of the pressure and the pressure gradient, making this a highly nonlinear system.

This is a simplified 1D version of the 3D transport model. See [1–4] for details.

\(p(x,t)\) – pressure field; \(U\) – apparent velocity; \(D\) – apparent diffusivity; \(\zeta\) – turbulence correction, \(\mu\) – viscosity; \(\rho\) – density; \(\zeta\), \(\zeta\), \(\zeta\) – compressibility coefficients.

Results: A. Determining rock properties

Experimental data (symbols) from pressure pulse tests in a shale rock core sample of length 3mm, from Pong [5], was matched from simulations (solid lines) using the new transport model developed here. The data is in the form of pressure measurements at various stations along the core sample, for different inflow pressures \(P_i\) as shown on the figures, left. The steady-state model was used in this case. The model parameters were adjusted until the error between simulations and data was minimized.

**Fig. 1 (Top).** Best fit model using steady-state transport model without turbulence correction, \(\beta = 0\). The porosity is \(\phi = 20\%\), and permeability is \(K = 10^6\) nD. These are very large, but comparable to Civan’s model [6,7] results.

**Fig. 2 (Bottom).** Best fit model using steady-state transport model with turbulence correction, \(\beta = 0\). The porosity is \(\phi = 10\%\), and permeability is \(K = 10^6\) nD. These are much more realistic of shale rocks than from previous models, such as Civan’s model [6,7].

This illustrates the importance of including high velocity correction term in the model.

Results: B. Sensitivity analysis of model parameters

To determine the most critical and most insensitive model parameters, a One-At-a-Time sensitivity analysis was carried out on all model parameters. In OAT, starting from a base set of model parameter values, each model parameter in turn is multiplied first by 2 and then by \(\frac{1}{2}\) and the simulations re-run. The change in error between simulation and data is displayed as a percentage for each parameter.

The simulations for the lowest \(P_i\) = 135 KPa were found to be insensitive to variations in model parameters. The results below are of the highest \(P_i\) = 275 KPa.

**Fig. 3 (Top).** OAT sensitivity analysis using steady-state transport model without turbulence correction, \(\beta = 0\). Only \(C_p\) shows critical sensitivity. \(C_p\) is a parameter that appears as a power in the correlation for the porosity. All other parameters are weak to moderately sensitive.

**Fig. 4 (Bottom).** OAT sensitivity analysis using steady-state transport model with turbulence correction, \(\beta = 0\). Again only \(C_p\) shows critical sensitivity. All other parameters are weak to moderately sensitive. Importantly, except for \(C_p\), there is no clear pattern compared to Fig. 3.

Conclusions

- A new non-linear shale gas transport model has been developed incorporating greater realism than previous studies, yielding more realistic values for rock properties than previous models.
- For optimal generality in application, all model parameters must be kept in the model as pressure dependent quantities. (Previous models of often neglected some parameters or made them constants.)
- To determine rock properties accurately, high values of \(P_i\) should be used in experiments.

References


Acknowledgements: Funding from NSTIP project numbers 11-OL1663-94, and 14-OL208-04 is gratefully acknowledged.

To determine rock properties accurately, high values of \(P_i\) should be used in experiments.