Improving the Estimation of Shale Permeability with Process-Based Pore Network Modeling Approach*

Shanshan Yao¹, Xiangzeng Wang², and Fanhua Zeng¹

Abstract

In shale, kerogen and clay make the pore network intricate. For example, in kerogen subspherical pores are connected by cylindrical throats while in clay both pores and throats are triangular or sheet like. To our knowledge, few studies considered the influence of kerogen and clay in reconstructing pore networks. This study uses a process-based modeling approach to reconstruct pore networks of shale. Our process-based approach considers the influence of kerogen and clay on pore morphology and distribution. The estimations of shale permeability based on generated pore networks are improved.

First, analysis of FE-SEM images gives grain size distributions of shale. With the grain size distributions and the process-based method (Bakke and Øren, 1997), this study develops a network A that connects interparticle pores, organic matter (OM) particles and clay agglomerates. With random sphere packing algorithm, this study extracts a network B that connects nanopores in OM particles and a network C that connects pores in clay agglomerates. The pore morphology is set to be different in networks B and C. Then networks B and C are inserted into the selected OM particles and clay agglomerates in network A for the final network D. The pore network D connects interparticle pores, subspherical nanopores and triangular/sheet like pores in clay. Finally, this study applies no-slip permeability equations in the network D and predicts no-slip permeability of shale. The permeability equations are modified according to pore morphology.

This study analyzed FE-SEM images of shales from Sichuan Basin in China and Appalachian basin and then built pore networks. The pore size distributions (PSD) of our pore networks matched well with the PSD defined by the mercury intrusion data. In addition, the resulted permeability estimations are in good agreement with the reported lab measurements. Based on our pore networks, this study further investigated the effect of shale diagenesis on shale permeability. It comes to our knowledge that no process-based approach and networks are exclusively developed for shale. Our process-based modeling considers the influence of kerogen and clay distribution on ultimate pore structure in shale.
Reference Cited

Conclusions

- An integrated method utilizing 2D SEM images and process-based modeling was developed to reconstruct 3D pore networks in shale matrix.
- No-slip permeability of shale was estimated based on the 3D pore networks.
- High connectivity of organic matter (OM) particles and clay agglomerates leads to higher shale permeability.
- High aspect ratio of pores in clay reduces shale no-slip permeability.

1. Introduction

- Interparticle pores: large (~1μm) and jagged
- OM pores: small (10–100 nm) and rounded
- Pores in clay: Triangular to sheetlike shape

2. Methodology

Step1: Reconstruction of μm-scale network
(Interparticle pores-OM particles-Clay agglomerates)

Step2: Reconstruction of nm-scale pore network
OM nanopore size distribution based on 2D SEM images analysis
Random sphere packing
Pore networks in OM

Aspect ratio of pores in clay based on 2D SEM images analysis
Random sphere packing
Pore networks in clay

Step3: Integrated network generation
Coordination number shows the connectivity in μm-scale network
Embedding nm-scale pore networks into selected particles/agglomerates in μm-scale network
Nanopores dominate in the integrated pore network.

Step4: Gas flow modeling
Mass flux equation is applied to each throat.
Mass balance equation is applied to each pore.

\[ K = \frac{3\pi d_l^4}{16} \]

\[ q = \frac{\sigma A}{
\left( \frac{\partial \phi}{\partial x} \right)_{L}^2 \Delta P \left( \frac{1+z}{2} \right) \mu L} \]

3. Results

- When nanopore volume fraction reaches 0.4, nm-scale pore networks dominate the flow path.
- Large compaction factor leads to low connectivity between OM particles and clay agglomerates.
- When all nanopores are sheetlike, higher aspect ratio reduces shale no-slip permeability.

Acknowledgements
Authors acknowledge Yanchang Petroleum Group for the permission of publishing the experimental data.

Contact Info
Shanshan Yao
yao223@uregina.ca
(1) 306-5962188
3737 Wascana Pky
Regina, SK Canada
S4S 0A2

Fanhua Zeng
Fanhua.Zeng@uregina.ca
(1) 306-3375256
3737 Wascana Pky
Regina, SK Canada
S4S 0A2