GeoConvention 2014 FOCUS
adapt
refine
sustain

A comparison of plug-derived, probe-derived and crushed-rock permeability in low-permeable shales: Examples from the Duvernay Shale, Alberta (Canada)

Amin Ghanizadeh, Department of Geoscience, University of Calgary, Calgary, Alberta
Santanu Bhowmik, Department of Geoscience, University of Calgary, Calgary, Alberta
Christopher R. Clarkson, Department of Geoscience, University of Calgary, Calgary, Alberta

Summary

We compare different methods for determination of gas permeability in low-permeability Canadian shales. Furthermore, we analyze and discuss the effects of different controlling factors including porosity, TOC content, mineralogy, pore-fluid content and effective stress on permeability.

For the samples analyzed under similar pore-fluid content, probe-derived permeabilities ($3.8 \cdot 10^{-4}$ - $2.7 \cdot 10^{-2}$ mD) were consistently higher than pulse-decay-derived ($8.4 \cdot 10^{-5}$ - $7.6 \cdot 10^{-4}$ mD) and crushed-rock ($3.7 \cdot 10^{-7}$ - $5.9 \cdot 10^{-6}$ mD) permeabilities. Corrected probe-derived permeabilities for Overburden (NOB) pressure ($1.5 \cdot 10^{-5}$ - $5.6 \cdot 10^{-4}$ mD) were, however, comparable with the pulse-decay-derived and crushed-rock permeabilities. Crushed-rock permeabilities measured on cleaned samples ($3.8 \cdot 10^{-5}$ - $1.1 \cdot 10^{-3}$ mD) were up to more than two orders of magnitude higher than those measured on uncleaned samples ($4.3 \cdot 10^{-7}$ - $5.9 \cdot 10^{-6}$ mD). The gas permeability values measured for plugs and crushed-rock increased significantly with increasing porosity (2.5-6.6 %), ranging between $3.7 \cdot 10^{-7}$ and $1.1 \cdot 10^{-3}$ mD. For the samples analyzed, the dominant pore throat diameters for gas (He, N_2) transport could be well estimated from porosity and permeability data using Winland-style correlations.

Introduction

In this work, we present results from an ongoing laboratory study investigating fluid storage and transport properties (porosity, pore size distribution and permeability) in the matrix system of low-permeability Canadian shales. The samples were collected from the Duvernay Shale, an emerging shale oil/gas play in Alberta, Canada (Dunn et al., 2012). The primary objectives were 1) to compare different methodologies for determination of gas permeability in low-permeable shales, and, 2) to analyze the effects of different controlling factors on porosity and permeability.

Methods

Gas permeability measurements were performed using a suite of instruments on Duvernay Shale samples differing in pore network characteristics (porosity, pore size distribution), mineralogy (calcite, clay, quartz), TOC content and pore-fluid content (uncleaned and cleaned samples). Pressure-decay profile (probe) permeability measurements were performed using N_2 gas on core-plug ends. Helium porosity and pulse-decay permeability analyses were conducted under controlled Net Overburden (NOB) pressure on a limited number of plugs to analyze the effect of effective stress on porosity and permeability. Core-plugs were subsequently crushed to obtain rock (matrix) permeabilities using the pressure-decay technique with helium gas.

Selected results (Example)

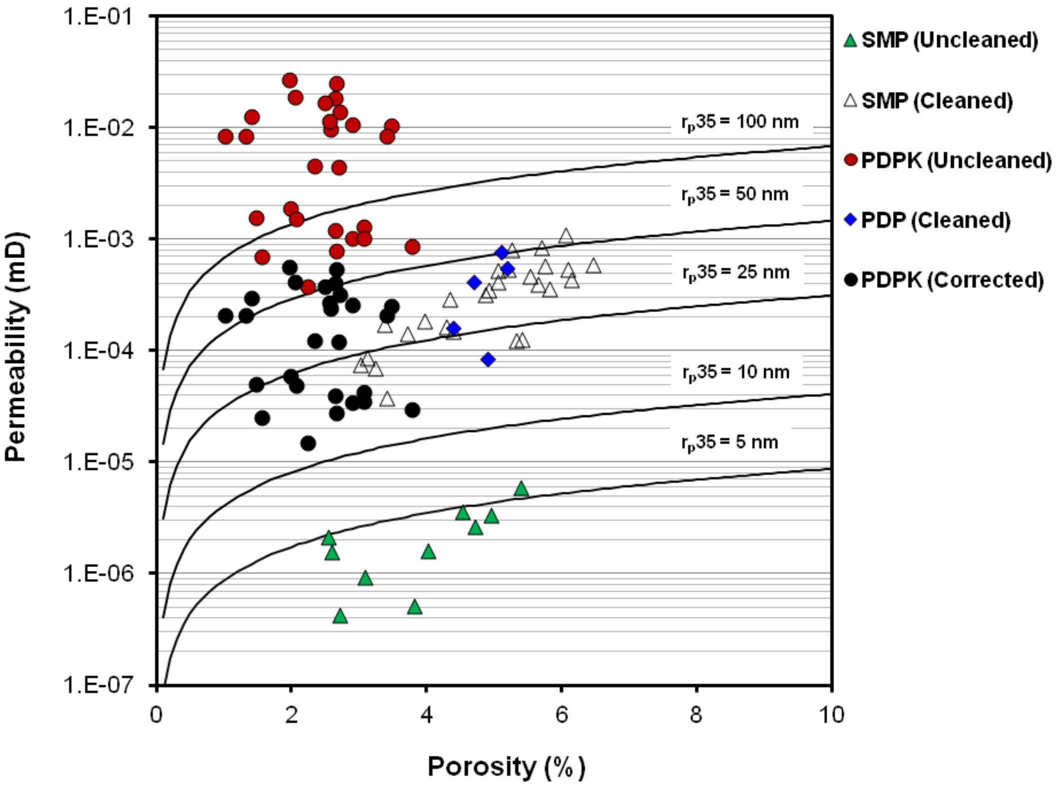

Figure 1: Comparison of different methods for determination of gas permeability in low-permeability shales (SMP: crushed-rock permeability, PDPK: pulse-decay profile (probe) permeability, PDP: pulse-decay permeability). The samples were tested in uncleaned ("as-received") and cleaned conditions. For the samples analyzed, the dominant pore throat diameters for gas (He, N_2) transport could be well estimated from porosity and permeability data using Winland-style correlations.

Selected conclusions

- Effect of permeability measurement method: For the samples analyzed under uncleaned ("as-received") condition, probe-derived permeabilities ($3.8 \cdot 10^{-4}$ - $2.7 \cdot 10^{-2}$ mD) were consistently higher than pulse-decay-derived ($8.4 \cdot 10^{-5}$ - $7.6 \cdot 10^{-4}$ mD) and crushed-rock ($3.7 \cdot 10^{-7}$ - $5.9 \cdot 10^{-6}$ mD) permeabilities. Corrected probe-derived permeabilities for Overburden (NOB) pressure ($1.5 \cdot 10^{-5}$ - $5.6 \cdot 10^{-4}$ mD) were, however, comparable with the pulse-decay-derived and crushed-rock permeabilities.

- Effect of pore-fluid content on porosity and permeability: Porosity values measured by helium pycnometry on cleaned plugs were up to 1.7 times higher than those measured on uncleaned plugs. Crushed-rock permeabilities measured on cleaned samples ($3.8 \cdot 10^{-5}$ - $1.1 \cdot 10^{-3}$ mD) were up to more than two orders of magnitude higher than those measured on uncleaned samples ($4.3 \cdot 10^{-7}$ - $5.9 \cdot 10^{-6}$ mD).

- Poro-perm relationship: The gas permeability values measured for plugs and crushed-rock increased significantly with increasing porosity (2.5-6.6 %), ranging between $3.7 \cdot 10^{-7}$ and $1.1 \cdot 10^{-3}$ mD. For the samples analyzed, the dominant pore throat diameters for gas (He, N_2) transport could be well estimated from porosity and permeability data using Winland-style correlations.
- Stress-dependence of porosity and permeability: For the plugs analyzed, porosity values measured with helium under Net Overburden (NOB) pressure of 12.8 MPa were up to 22% lower than those measured under unconfined conditions. Plug-derived permeability decreased up to one order of magnitude with increasing Net Overburden (NOB) pressure (3.5-40 MPa) for a tested plug.
- Effect of sample size (cuttings/plug) on grain density: The grain density values measured by helium pycnometry on plugs were consistently higher than those measured on crushed samples. The differences appeared to decrease with increasing grain density.

Acknowledgements

The core and financial support for this study was provided by Black Swan Energy Ltd. This support is gratefully acknowledged. The authors also thank the management of Black Swan Energy for giving the permission to present and publish this material. Chris Clarkson would like to acknowledge Encana and Alberta Innovates Technologies Futures (AITF) for support of his Chair position in Unconventional Gas and Light Oil at the University of Calgary, Department of Geoscience. Funding for Amin Ghanizadeh's work was provided in part by Eyes High Postdoctoral Fellowship (University of Calgary) as well as by the sponsors of the Tight Oil Consortium, hosted at the University of Calgary.

References

Dunn, L., Schmidt, G., Hammermaster, K., Brown, M., Bernard, R., Wen, E., Befus, R., and Gardiner, S. The Duvernay Formation (Devonian): Sedimentology and Reservoir Characterization of a Shale Gas/Liquids play in Alberta, Canada. Presented at GeoConvention 2012: Vision, Calgary, Alberta.