[PS]Comparative Study of Relative Permeability and Residual Saturation Estimates of Kerogen and Shale Samples*

Shiv Prakash Ojha[1] and Siddharth Misra[1]

Search and Discovery Article #70308 (2017)**
Posted December 11, 2017

*Adapted from poster presentation given at 2017 AAPG Mid-Continent Section Meeting, Oklahoma City, Oklahoma, September 30 – October 3, 2017

[1]University of Oklahoma, Norman, OK, United States (misra@ou.edu)

Abstract

Understanding of relative permeability and residual saturations is helpful in improving the interpretation of production performance of shale reservoirs. In absence of accurate direct measurements of these two properties, we estimated the relative permeability and residual saturations from the adsorption-desorption isotherm measurements on 80 organic-rich shale samples and seven kerogen samples extracted from Bakken, Wolfcamp, and Woodford formations. These included native and cleaned samples, treated with methanol-toluene mixture to remove bitumen and soluble dead hydrocarbons. These measurements were interpreted to obtain pore size distribution (PSD) using modified Barrett-Joyner-Halenda (BJH) method. Bimodal fractal PSD model was used to estimate percolation parameters (coordination number, percolation cluster length and percolation threshold) and fractal dimension. Thereafter, relative permeability and residual saturations were estimated for the samples using percolation theory, effective medium theory and critical path analysis.

Kerogen samples exhibit larger pore volume fractions for pore widths > 50 nm, whereas the native shale samples exhibit nearly equal pore volume fractions above and below the pore width of 50 nm. Fractal dimension, which indicates the pore network complexity, for both shale and kerogen samples increased from 2.3 to 2.9 with the increase in kerogen maturity. Kerogen and native shale samples show an increase in residual water saturation estimates with maturity. For the kerogen samples, the irreducible water saturation estimates increase from 17% to 30% with an increase in kerogen maturity. Both wetting and non-wetting phase relative permeability decreased by nearly 60% in the water saturation range of 30% to 40% with an increase in kerogen maturity in kerogen samples. Cleaning of native shale samples with toluene-methanol mixture to remove soluble hydrocarbons and bitumen showed an increase in hydrocarbon relative permeability and decrease in aqueous phase relative permeability, which are analogous to the relative permeability curves estimated for kerogen samples.

References Cited

Barrett, E.P., L.G. Joyner, and P.P. Halenda, 1951, The determination of pore volume and area distributions in porous substances. I. Computations from nitrogen isotherms: Journal of the American Chemical society, v. 73/1, p. 373-380.

Daigle, H., S. Ezidiegwu, and R. Turner, 2015, Determining relative permeability in shales by including the effects of pore structure on unsaturated diffusion and advection: Presented at SPE Annual Technical Conference and Exhibition, Houston, Texas, USA, 28-30 September, 2015. SPE-175019-MS. doi:10.2118/175019-MS

Hunt, A.G., B. Ghanbarian, and K.C. Saville, 2013, Unsaturated hydraulic conductivity modeling for porous media with two fractal regimes: Geoderma, v. 207, p. 268-278.

Kuila, U., and M. Prasad, 2013, Application of nitrogen gas-adsorption technique for characterization of pore structure of mudrocks: Lead Edge, v. 32/12 p. 1478–1485.doi: 10.1190/tle32121478.1.

Ojha, S.P., S. Misra, A. Sinha, S. Dang, C. Sondergeld, and C. Rai, 2017, Estimation of Pore Network Characteristics and Saturation-Dependent Relative Permeability in Organic-Rich Shale Samples Obtained From Bakken, Wolfcamp, and Woodford Shale Formations: In SPWLA 58th Annual Logging Symposium.

Ojha, S.P., S. Misra, A. Sinha, S. Dang, A. Tinni, C. Sondergeld, and C. Rai, 2017, Relative Permeability and Residual Saturation Estimates for Organic-Rich Shale Samples From Bakken, Wolfcamp, Eagle Ford and Woodford Formations: In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.

Ojha, S.P., S. Misra, A. Tinni, A. Sinha, S. Dang, C. Sondergeld, and C. Rai, 2017, Alterations in Pore Topology of Organic-Rich Shale Samples Due to the Removal of Dead Oil, Bitumen, and Kerogen: In SPWLA 58th Annual Logging Symposium. Society of Petrophysicists and Well-Log Analysts.

Ojha, S.P., S. Misra, A. Tinni, C. Sondergeld, and C. Rai, 2017, Relative permeability estimates for Wolfcamp and Eagle Ford shale samples from oil, gas and condensate windows using adsorption-desorption measurements: Fuel, v. 208, p. 52-64.

Ojha, S.P., S. Misra, A. Tinni, C. Sondergeld, C. Rai, 2017, Pore connectivity and pore size distribution estimates for Wolfcamp and Eagle Ford shale samples from oil, gas and condensate windows using adsorption-desorption measurements: Journal of Petroleum Science and Engineering, v. 158, p. 454-468.

Seaton, N.A., 1991, Determination of the connectivity of porous solids from nitrogen sorption measurements: Chemical Engineering Science, v. 46/8, p. 1895-1909.

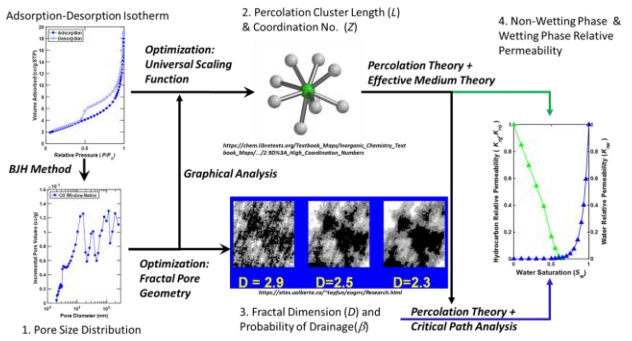
Comparative Study of Relative Permeability and Residual Saturation Estimates of Kerogen and Shale Samples

Shiv Prakash Ojha and Dr. Siddharth Misra
Mewbourne College of Earth and Energy, University of Oklahoma

Motivation

- Limited direct/indirect laboratory-based techniques to estimate relative permeability of shales.
- Estimation of residual saturations and relative permeability using adsorption-desorption isotherms.
- Impact of kerogen maturity on transport properties.

Interpretation Method



Properties of Samples

	Formation	No. of samples	Formation ID.	Maturity
Shale	Lower Bakken	7	L. Bakken	Early Oil
	Wolfcamp (WF)	10	WF-1	Oil window
		9	WF-2	Condensate
		6	WF-3	Condensate
		5	WF-4	Late Condensate
	Woodford	5	WD	Late Condensate
Kerogen	Green River, Kimmeridge & Woodford	3	IM-1,2,3	Immature
	L. Bakken & Wolfcamp	2	L. Bakken & WF	Oil window
	Eagle Ford (EF)	1	EF	Gas window

Results

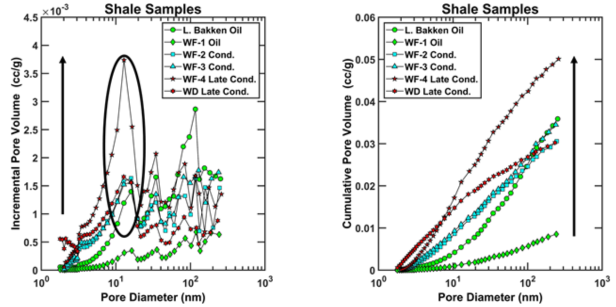


Fig. 1 – Change in PSD with maturity for shale samples

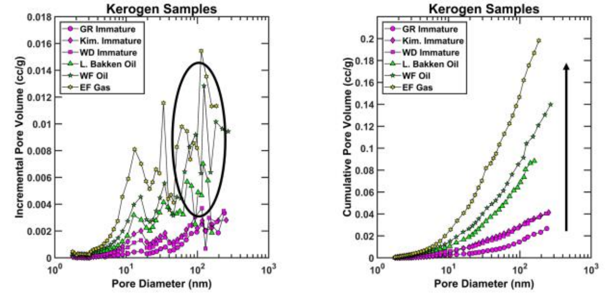


Fig. 2 – Change in PSD with maturity for kerogen samples

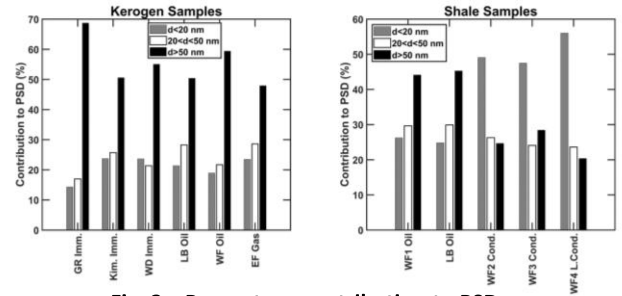


Fig. 3 – Percentage contribution to PSD

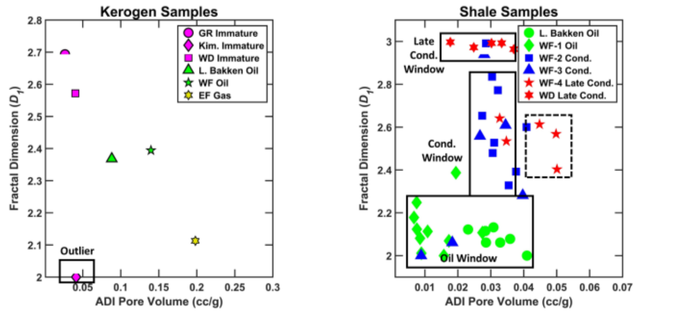


Fig. 4 – Trends in fractal dimension

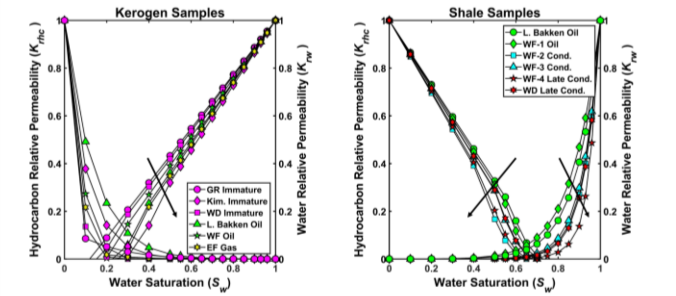


Fig. 5 –Relative permeability results

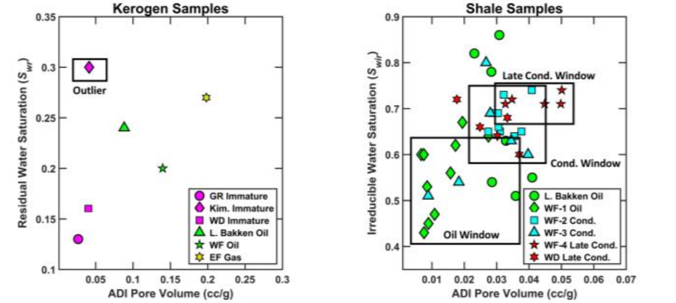


Fig. 6 – Trends in residual water saturation

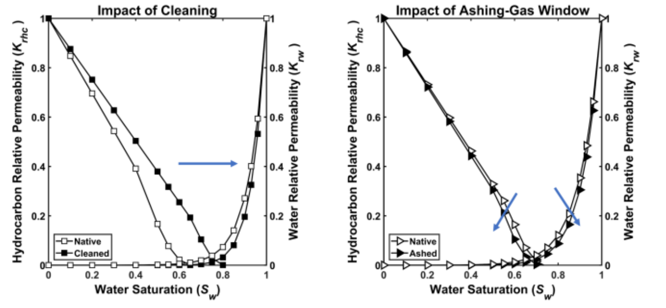
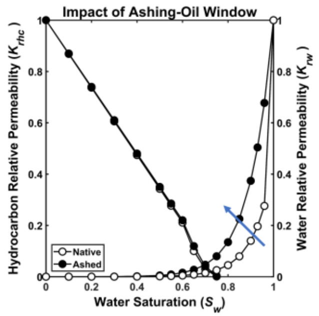


Fig. 7 – Impact of cleaning and ashing.



- Cleaning: Increase in hydrocarbon relative permeability and decrease in aqueous relative permeability.
- Ashing: Slight change for gas window. Increase in water relative permeability for oil window.

Conclusions

- Relative permeability for aqueous phase decreases with increase in thermal maturity for kerogen samples.
- PSD for kerogen samples shows higher contribution from pores with d>50 nm.
- Increasing thermal maturity leads to lower pore complexity in kerogen pore network and higher residual water saturations.

Contact: Dr. Siddharth Misra (misra@ou.edu)
Mewbourne College of Earth and Energy, University of Oklahoma

References: Ojha, S. P., Misra, S., Tinni, A., Sondergeld, C., & Rai, C. (2017). Relative permeability estimates for Wolfcamp and Eagle Ford shale samples from oil, gas and condensate windows using adsorption-desorption measurements. Fuel, 208, 52-64.
Ojha, S. P., Misra, S., Sinha, A., Dang, S., Sondergeld, C., & Rai, C. (2017, June). Estimation of Pore Network Characteristics and Saturation-Dependent Relative Permeability in Organic-Rich Shale Samples Obtained From Bakken, Wolfcamp, and Woodford Shale Formations. In SPWLA 58th Annual Logging Symposium.