Upscaling gas permeability in tight-gas sandstones

Behzad Ghanbarian[1], Carlos Torres-Verdín[2], Larry W. Lake[2], and Michael Marder[3]

[1] Department of Geology, Kansas State University, Manhattan 66506 KS, USA (Email address: ghanbarian@ksu.edu)

[2] Department of Petroleum and Geosystems Engineering, University of Texas at Austin, Austin 78712 TX, USA

[3] Department of Physics, University of Texas at Austin, Austin 78712 TX, USA

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BACKGROUND

Factors affecting gas permeability in tight media

- Connectivity
- Pore-throat size distribution
- Slip flow and Knudsen diffusion
- Tortuosity
- Porosity
- Pore shape geometry
- Gas characteristics

Theoretical upscaling techniques

- Bundle of capillary tubes approach
- Effective-medium theory (EMA)
- Critical path analysis (CPA)
- Perturbation theory
- Volume averaging method
- Mean-field theory
- Renormalization group theory
- …

PURPOSES AND ASSUMPTIONS

Objectives

- ✓ To evaluate the EMA's reliability to estimate the Klinkenberg-corrected gas permeability *k* from pore-throat size distribution, tortuosity, and porosity.
- ✓ To estimate *k* from pore-throat size distribution and electrical conductivity measurements.
- ✓ To compare EMA results to those obtained from critical path analysis in tight-gas sandstones.

Assumptions

- ❑ Pores are cylindrical or slit-shaped.
- ❑ The influence of pore pressure on *k* in our samples is small because all permeability measurements were Klinkenberg-corrected.
- ❑ Contact angle is about 140° for mercury.
- ❑ The air-mercury interfacial tension is 485 mN/m.

MATERIALS AND METHODS

Hydraulic and electrical conductances

	Hydraulic flow	Electrical flow
Cylindrical	$g_h = \frac{\pi r^4}{8\mu l}$	$g_e = \sigma_f \frac{\pi r^2}{l}$
Slit-shaped	$g_h = \frac{b w^3}{12\mu l}$	$g_e = \sigma_f \frac{b w}{l}$

The effective-medium approximation (EMA)

An upscaling technique from statistical physics appropriate in homogeneous and relatively heterogeneous porous rocks.

Cylindrical pores: $k = \frac{\phi}{8\tau_h}\frac{r_{he}^4}{\langle r_b^2\rangle}$ and $\frac{\sigma_b}{\sigma_f} = \frac{\phi}{\tau_e}\frac{r_{ee}^2}{\langle r_b^2\rangle}$ ➡ $k = \frac{1}{8}\frac{\sigma_b}{\sigma_f}\frac{r_{he}^4}{r_{ee}^2}$

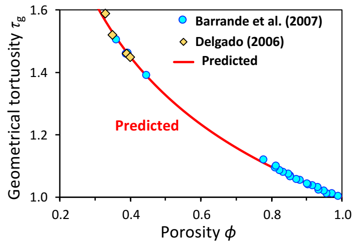
Slit-shaped pores: $k = \frac{\phi}{12\tau_h}\frac{w_{he}^3}{\langle w_b\rangle}$ and $\frac{\sigma_b}{\sigma_f} = \frac{\phi}{\tau_e}\frac{w_{ee}}{\langle w_b\rangle}$ ➡ $k = \frac{1}{12}\frac{\sigma_b}{\sigma_f}\frac{w_{he}^3}{w_{ee}}$

Effective hydraulic and electrical pore sizes are determined from the following EMA governing equation:

$$\int_{g_{min}}^{g_{max}} \frac{(g_e - g)}{g + (Z/2 - 1) g_e} f(g)\, dg = 0$$

As a first-order approximation, the following geometrical tortuosity model may be used to approximate τ_e and τ_h with the geometrical tortuosity τ_g (Ghanbarian et al., 2013):

$$\tau_g = \left(\frac{L_e}{L_s}\right)^2 = \left[\frac{\phi - \phi S_c + (C/L_s)^{\frac{1}{\nu}}}{1 - \phi S_c}\right]^{2(\nu - \nu D_{opt})}$$



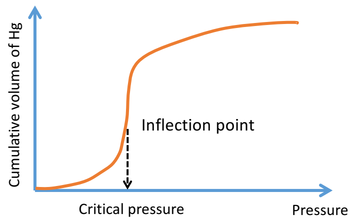
Critical path analysis (CPA)

Another upscaling technique from statistical physics appropriate in heterogeneous porous media with broad pore-throat size distribution.

Cylindrical pores: $k = \frac{2^{-y}}{8}\frac{\sigma_b}{\sigma_f} r_c^2$

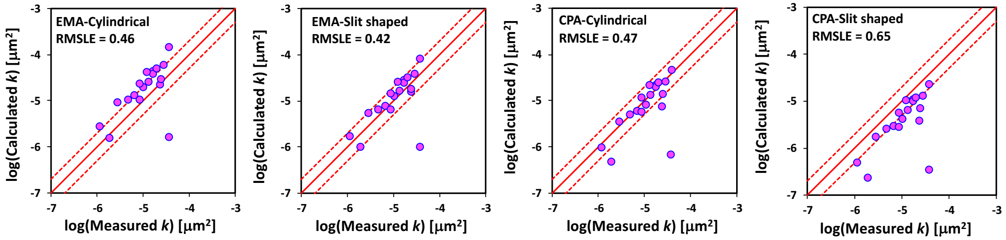
y = 0.74 (Skaggs, 2011)

Slit-shaped pores: $k = \frac{3^{-y}}{12}\frac{\sigma_b}{\sigma_f} w_c^2$

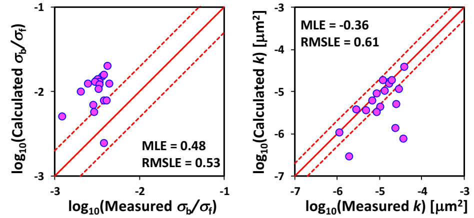


RESULTS

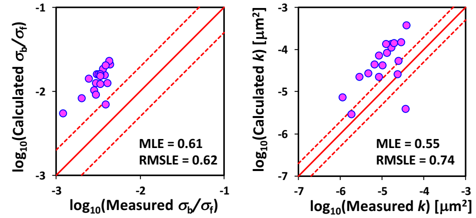
The eighteen tight-gas sandstones used in this study were cut from whole cores retrieved from a tight-gas sandstone formation located in East Texas. In all samples, gas permeability was measured using the transient pulse technique at a net confining stress of 2500 psi and corrected by extrapolating to infinite pressure using the *Klinkenberg* method.



Estimating σ_b/σ_f and *k* via EMA from MICP, porosity and tortuosity assuming that pores are cylindrical



Estimating σ_b/σ_f and *k* via EMA from MICP, porosity and tortuosity assuming that pores are Slit-shaped



CONCLUSION

- ❑ EMA with slit-shaped pores estimated *k* slightly more precisely than CPA with cylindrical pores, although both method estimations were mainly within a factor of two of the measurements.
- ❑ Depending on input parameters and upscaling methods, the assumption of cylindrical pores could yield more accurate σ_b/σ_f and *k* estimates than the assumption of slit-shaped pores and vice versa.

REFERENCES

Ghanbarian, B., Hunt, A. G., Sahimi, M., Ewing, R. P., & Skinner, T. E. (2013). Percolation theory generates a physically based description of tortuosity in saturated and unsaturated porous media. Soil Science Society of America Journal, 77(6), 1920-1929.

Skaggs, T. H. (2011). Assessment of critical path analyses of the relationship between permeability and electrical conductivity of pore networks. Advances in Water Resources, 34(10), 1335-1342.