Pore Structure and Gas Recovery in Barnett Shale

(Max) Qinhong Hu\textsuperscript{a}, Sheng Peng\textsuperscript{a}, Zheyi Gao\textsuperscript{a}, and Robert P. Ewing\textsuperscript{b}

(maxhu@uta.edu)

\textsuperscript{a} Department of Earth and Environmental Sciences, University of Texas at Arlington, Arlington, TX 76019

\textsuperscript{b} Department of Agronomy, Iowa State University, Ames, IA 50011
Low gas recovery factor 15-30% for Barnett Shale (King, 2012)
MARCELLUS PRODUCTION COMPARISON OF VERTICAL AND HORIZONTAL WELLS

AVERAGE DAILY PRODUCTION (in Mcf)

YEAR IN PRODUCTION

Vertical wells

Horizontal wells

Barnett Shale

Nanopores in Organics

Orange dots are 20 nm in diameter

$\text{CH}_4$ size: 0.375 nm

T.P. Sims #2; 7625'

After Reed, BEG
Shale Gas Storage: “Sorbed” vs. “Free” gas


CH₄ - Methane molecule 0.375 nm

Three Data Points

• Gas molecule movement in shale on the order of 10 feet in the lifetime of a well - Dr. Mohan Kelcar, University of Tulsa.

• Gas molecule movement of about a meter/year modeled by Nexen’s Unconventional Team, presented at Global Gas Shales Summit, Warsaw, Poland.

• Gas molecule movement of a few feet/year modeled by Dr. Chunlou Li, Shale Gas Technology Group.

\[ \sim 1 \text{ m/yr movement (advection vs. diffusion ?)} \]

Multiple Approaches to Studying Pore Structure

- Imbibition with samples of different shapes
- Edge-accessible porosity
- Liquid and gas diffusion
- Mercury injection porosimetry
- N\(_2\) adsorption/desorption isotherms
- Vapor absorption
- Nuclear Magnetic Resonance Cryoporometry
- SEM imaging after Wood’s metal impregnation
- Focused Ion Beam/SEM imaging
- Pore-scale network modeling
Imbibition: Low Pore-Connectivity of Shale Samples

Cumulative imbibition (mm) in log scale

Time (min) in log scale

Barnett Shale
2,166.8 m (7,109 ft)
Rectangular prism (1.33 cm long × 1.76 cm wide × 1.43 cm tall)

Imbibition slope = 0.262
3D Elemental Mapping: Edge-Accessible Porosity

ReO$_4^-$ (non-sorbing)

Rb (intrinsic)

Co$^{2+}$ (sorbing)
Saturated Diffusion

\[
\frac{C}{C_0} = \frac{1}{2} \text{erfc} \left( \frac{x}{2\sqrt{D_e t}} \right)
\]

\[
\tau = \frac{D_0}{D_e}
\]

- Re exterior data
- Re interior line 1
- Re interior line 2
- Re background (avg ± stnd dev)
- fitted De: 1.46E-11 m²/s
- fitted De: 1.46E-13 m²/s

Barnett shale: 7,136 ft (2,175 m)
saturated diffusion time: 24 hr

Fitted tortuosity: 100 (exterior) and 10,000 (interior)
CH₄ sorption isotherm (ongoing at BEG)
CH$_4$ sorption onto shale: moisture, particle size effect
Barnett drilling location at 2008 University of Texas at Arlington

1 mile (1,609 m; 5,280 ft)

24 horizontal wells from a well pad
All 22 Producing UTA Horizontal Wells

Barnett Shale
UTA wells
Carrizo Oil and Gas, Inc

Average daily production (mcf)


Production date
Decline Slope for 11 Wells (50% of All)

Average daily production (mcf)

Barnett Shale
UTA wells
Carrizo Oil and Gas, Inc

slope of -0.5
Gas Production Rate in a Fractured Shale System

Dmitriy Silin (RPSEA presentation in 2011)
Silin and Kneafsey (2011; SPE 149489)

“Early” \((t < t_*)\) recovery rate

\[
|Q(t)| = 2AD \frac{1}{\varrho_* Z_R RT} \sqrt{\left(\phi + \frac{Z_R RT}{M} \varrho_0 \varrho_K S_K c_f \right) \frac{k}{\mu p_R} \frac{p_R - p_W}{\alpha \sqrt{t}}}
\]

\(t_* \approx \left(\phi + \frac{Z_R RT}{M} \varrho_0 \varrho_K S_K c_f \right) \frac{\mu D^2}{kp_R \alpha^2}

“Late” \((t > t_*)\) recovery rate

\[
|Q(t)| = 2A \frac{1}{\varrho_* \mu Z_R RT} (p_R - p_W) \exp \left(-3 \sqrt{\frac{p_W}{p_R}} \left( \frac{1}{\phi + \frac{Z_R RT}{M} \varrho_0 \varrho_K S_K c_f} \frac{kp_R}{\mu_R D^2} \frac{t}{\alpha^2} \right) \right)
\]

\(c_f: \) gas desorption rate \([m^3/(kg \ Pa)]\)
Summary

- Steep 1\textsuperscript{st} year decline and low gas recovery observed in shales
- Pore structure information is essential in understanding hydrocarbon storage and transport
- Nano-pore shales show low pore connectivity, which reduces gas diffusion from matrix to stimulated fractured network
- Gas sorption, affected by moisture and sample size, further contribute to steep decline and low recovery
- How to link pore structure and gas sorption mechanism to field-scale gas recovery?
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