Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

FWP FE-772-16-FY17: Tributary zone fractures (small-scale) contributions to hydrocarbon production in the Marcellus shale

Bill Carey and Luke Frash
Earth & Environmental Sciences
Los Alamos National Laboratory

U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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Overview of Project: Quantify Production Curve Processes

Haynesville Dataset
LANL Simulation

Tributary zone processes
Task 3: Carey (PI): First talk

Develop/apply multiscale modeling tools
Task 2: Karra (PI): Third talk

Fluid behavior in matrix
Task 4: Xu (PI): Second Talk
Technical Status:
Fracture-permeability evolution of Marcellus shale

- Natural, pre-existing fractures are critical to hydrocarbon production.
- Permeability of natural fractures controls hydrocarbon production at mid- to long-term.
- Measurement of permeability of newly created fractures as a function of effective stress.
- Measurement of permeability of restimulated fractures.
- Max Pressure: 34.5 MPa (5,000 psi)
- Max Axial Load: 500 MPa (70,000 psi)
- Max Temperature: 100 °C

Carey et al., J. Unconv. O&G Res., 2015; Frash et al. (2016) JGR; Frash et al. (2017) IJGGC
Methodology

- Samples of Marcellus shale (outcrop) and Utica shale (core) and 2.5x2.5 cm cylinders
- Confining pressure from 3.5 to 30 MPa (500 to 4300 psi)
- Room temperature
- Permeability from continuously injected water
- Fracture geometry continuously monitored with x-ray radiography
Low Confining Pressure: 3.5 MPa
Low Confining Pressure: 3.5 MPa

MS01-01:
3.0 MPa Effective Confining

90.00 min

False-Color X-ray Radiography
High Confining Pressure: 30 MPa
Marcellus: Q+F=20%, Carbonate=67%, Clay=13%
High Confining Pressure: 30 MPa

MS01-03: 0.0 MPa Effective Confining

False-Color X-ray Radiography

Direct Shear Stress (MPa)

Aperture (mm)

Permeability (mD)

Test Time (min)
Marcellus Shale Radiography
Carbonate Facies

<table>
<thead>
<tr>
<th>$\sigma'$ (MPa)</th>
<th>Intact Specimen</th>
<th>Initial Fracture</th>
<th>At 1.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<td>14.5</td>
<td><img src="image4.png" alt="Image" /></td>
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<tr>
<td>29.3</td>
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<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
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</table>
Marcellus Shear Strength

Direct Shear Strength:
\[ \phi_f = 58 \pm 7^\circ \]
\[ \sigma_{cf} = 26 \pm 2 \text{ MPa} \]

Reactivation:
\[ \phi_r = 55 \pm 7^\circ \]
\[ \sigma_{cr} = 6 \pm 2 \text{ MPa} \]
Permeability and Restimulation

Marcellus

Stress (MPa) vs. Time (minutes) for Direct-shear stress and Permeability.
Accomplishments to Date

• Developed an experimental system capable of simultaneously measuring and visualizing fracture-permeability relations

• Measured permeability of shear fractured Utica and Marcellus shale
  – Transition from high permeability at shallow depths (brittle) to low permeability at greater depth

• Measured hydrocarbon production with high-P/T microfluidics system
  – Significantly enhanced production with the use of soluble fracturing fluid (supercritical CO₂)
Lessons Learned

• Fracture permeability a strong function of effective stress
  – Changes in effective stress are less impactful
  – Restimulation of fractures can be short-lived
• Previous tectonic and burial history may control fracture productivity
• Impact of lithology (clay vs. carbonate vs. quartz) has not yet been determined
• Impact of heterogeneity (bedding, pre-existing fractures) has not been determined
• Big challenge: net behavior of heterogeneous shale
Synergy Opportunities

• Marcellus Shale Energy and Environment Laboratory: Work with MSEEL core
  – USEEL and Permian Basin projects also represent good collaboration opportunities

• National Risk Assessment Project: Analysis of leakage risk from caprock

• SubTER: Permeability manipulation

• Other projects in Oil and Gas Fundamental Science Portfolio
  – Emphasizing geochemistry (SLAC), nanopore interactions (Sandia), hydraulic fracturing propagation (LBNL)

• Caprock studies for CO$_2$ sequestration: Colorado School of Mines, NETL, UT-Austin

• Fracture behavior and stress/strain: Penn State, Clemson, UT-Austin
• Developed fracture permeability data for tributary fracture zone
• Input data for hydrocarbon production from Hongwu’s matrix project
• Output results to Satish’s discrete fracture network model of reservoir behavior
Appendix
Benefit to the Program

- Measurement of the permeability and multiphase flow behavior in small-scale fractures comprising the tributary fracture zone
- Improving the efficiency of hydraulic fracturing through production curve analysis
- Determination of key mechanisms controlling unconventional oil and gas migration
- Development of tools to analyze production curves and thereby enhance hydrocarbon production
Project Overview
Goals and Objectives

• Quantification of fracture-network permeabilities
  – Use state-of-the-art facilities to measure and characterize permeability at reservoir conditions

• Determine influence of reservoir stress conditions on fracture permeability
  – Fracture-permeability as a function of the conditions of fracture formation (i.e., depth) and as a function of changing stress conditions (potential effect of fracture closure)

• Multiphase fluid flow processes
  – Use high P/T microfluidics system to directly observe and characterize multiphase flow in fractures
### Gantt Chart

#### Phase 1

<table>
<thead>
<tr>
<th>Task</th>
<th>FY15</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
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<tr>
<td>3.1 Project Management</td>
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<td>3.2 Sample Acquisition</td>
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<td>3.3 Fracture Generation</td>
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<td>3.4 Fracture Characterization</td>
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<td>3.5 Fracture Permeability</td>
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<td>3.6 Fracture Penetration</td>
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<td>3.7 Fracture Surface Area</td>
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<td>3.8 Integration</td>
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#### Phase 2

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<td>Cost</td>
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**Total Cost:**
- Phase 1: $234k
- Phase 2: $468k
Publications
2016/2017
Supported in total or in part by this project


