The Marcellus Shale Energy and Environment Laboratory (MSEEL)*

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Search and Discovery Article #42024 (2017)**
Posted March 20, 2017

*Adapted from oral presentation given at AAPG Eastern Section Meeting, Lexington, Kentucky, September 25-27, 2016
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Abstract

The Marcellus Shale Energy and Environment Laboratory (MSEEL) consists of a multidisciplinary and multi-institutional team undertaking integrated geoscience, engineering and social science research in cooperation with the operator, Northeast Natural Energy, numerous industrial partners and the National Energy Technology Laboratory of the US Department of Energy. MSEEL consists of two legacy horizontal production wells, two new instrumented horizontal production wells, a vertical pilot bore-hole, a microseismic observation well and surface geophysical and environmental monitoring stations. Production from the new horizontal wells began in December 2015. The MSEEL approach is data driven with a platform to store, manage, publish and share very large and diverse (multiple terabyte) datasets among researchers. MSEEL integrates drilling and fracture stimulation operations, geophysical observations, fiber-optic monitoring of high-resolution temporal and spatial flow of injected and produced fluids during completion and production, mechanical properties logs, microseismic and core data to better characterize subsurface rock properties, stimulated reservoir volumes, faults and fracture systems. Surface monitoring of operating machinery emissions was undertaken at the exhaust pipe, pad and regional scales. Produced fluids and gases are being
monitored during completion and production. The MSEEL goal is to develop and validate new knowledge and technology and identify best practices for field implementation that can optimize hydraulic fracture stimulation, and minimize environmental impacts of unconventional resource development.

We provide several examples that illustrate technologies and approaches that are being developed to store, query, display, and analyze large and diverse data sources and new data types derived from surface and subsurface to evaluate stimulation effectiveness, cluster-by-cluster and design innovative stage spacing and cluster density practices that can be used to optimize recovery efficiency.
Carr, Timothy¹, Shikha Sharma¹, Thomas Wilson¹, Paul Ziemkiewicz¹, B.J. Carney², Jay Hewitt², Ian Costello², Emily Jordon², Zachary Arnold², Ryan Warner², Andy Travis², David Cole³, Jeffery Daniels³, Paula Mouser⁴, Kelly Wrighton⁵, Ray Boswell⁶, Dustin Crandall⁶, Robert Vagnetti⁶

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The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term collaborative field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development.
The Shale Revolution affects everything. Technology has made quadrillions of BTUs of new energy resources available to humanity.

- Costs and Benefits
  - Largest Increase in Oil and Gas Production in the World
  - Decreased Energy Prices
  - Electrical Grid is changing at an unprecedented rate
  - Reduced CO2 Emissions

- Potential Environmental Challenges and Opportunities
  - Greenhouse Gas Emissions
  - Local Air, Noise and Water Pollution
  - Major Infrastructure Changes

Goal: Minimize Environment Costs While Maximizing Benefits

While energy markets are complex, energy predictions are simplified representations of energy production and consumption, regulations, and producer and consumer behavior, and are subject to much uncertainty.
West Virginia Gas Production

Billions of Cubic Feet

Year

West Virginia Gas Production

Unconventional Production

Conventional Production
West Virginia Gas Wells

- Unconventional Wells
- Conventional Wells

Year: 2005 to 2015

Producing Gas Wells

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West Virginia Oil & Liquids Production

- Unconventional Production
- Conventional Production

Thousands of Barrels

Year

West Virginia Oil & NGL Wells

Producing Oil & NGL Wells

Year

West Virginia Oil & NGL Wells
Unconventional Wells
Conventional Wells

Unconventional Wells
Conventional Wells

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MSEEL Site

West Virginia

Morgantown, WV
MSEEL Site

MSEEL

2.5 miles

WVU
## MSEEL Field Schedule

### 2015

<table>
<thead>
<tr>
<th>Event</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP-5H Lateral Drilling</td>
<td>7/6/2015 - 7/15/2015</td>
</tr>
<tr>
<td>MIP-5H Stimulation</td>
<td>9/10/2015 - 9/13/2015</td>
</tr>
<tr>
<td>MIP-3H Vertical Drilling</td>
<td>10/28/2015 - 11/6/2015</td>
</tr>
<tr>
<td>MIP-3H Lateral Drilling</td>
<td>8/25/2015 - 9/1/2015</td>
</tr>
<tr>
<td>MIP-3H Core Recovery</td>
<td>9/19/2015 - 9/21/2015</td>
</tr>
<tr>
<td>MIP_3H Core Recovery</td>
<td>9/25/2015 - 9/1/2015</td>
</tr>
<tr>
<td>MIP-3H Stimulation</td>
<td>8/25/2015 - 9/1/2015</td>
</tr>
<tr>
<td>MIP-3H Stimulation</td>
<td>11/5/2015 - 11/16/2015</td>
</tr>
<tr>
<td>MIP-SW Drilling</td>
<td>5/13/2015 - 9/24/2015</td>
</tr>
<tr>
<td>Micoseismic Monitoring</td>
<td>10/27/2015 - 11/16/2015</td>
</tr>
</tbody>
</table>

### 2016

<table>
<thead>
<tr>
<th>Event</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Start of Drilling</td>
<td>9/13/2015</td>
</tr>
<tr>
<td>5H End of Lateral Drilling</td>
<td>9/13/2015</td>
</tr>
<tr>
<td>3H End of Lateral Drilling</td>
<td>9/21/2015</td>
</tr>
<tr>
<td>SW End of Drilling</td>
<td>11/6/2015</td>
</tr>
<tr>
<td>3H End of Stimulation</td>
<td>11/16/2015</td>
</tr>
<tr>
<td>SW SideWall Coring</td>
<td>9/24/2015</td>
</tr>
<tr>
<td>5H End of Stimulation</td>
<td>12/11/2015</td>
</tr>
<tr>
<td>3H &amp; 5H Start of Production</td>
<td>3H &amp; 5H Producing</td>
</tr>
</tbody>
</table>

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Drilling Waste Monitoring

Mud

Cuttings
Subsurface Sampling

Retrieved 111’ of a targeted 120’ whole core

Collected 197 sidewall cores from the SW and 3H well
Geosteering MIP-3H
PRECISION PETROPHYSICAL ANALYSIS LABORATORY (PPAL) AT WVU

MEASUREMENT CAPABILITIES

• PERMEABILITY (NANO-DARCY RANGE).
• PORE VOLUME (0.1% ACCURACY).
• ABSOLUTE PERMEABILITY (GAS PRESSURE CORRECTION).
• IMPACT OF STRESS (RESERVOIR CONDITIONS).
• IMPACT OF ADSORPTION
• PORE STRUCTURE CHARACTERIZATION

ACCURATE, CONSISTENT, AND REPEATABLE RESULTS

Kashy Aminian - WVU
Impact of Stress

SAMPLE 7547.03

Fracture Closure Stress = 4770 psi

Kashy Aminian - WVU
Brunauer–Emmett–Teller (BET) theory - The Type H4 loop, which does not exhibit any limiting adsorption at high p/p₀, is observed as aggregates of plate-like particles and slit-shaped pores, often associated with microporosity (IUPAC Recommendation 1984).

Pores of diameters less than 5 nm make the greatest contribution to SSA, whereas pore volumes are affected by larger pores. Samples with higher thermal maturity have less smaller pores (pore diameter less than 5 nm).
SEM Core Analysis

Porosity

Organic Matter

Liaosha Song - WVU
SEM Core Analysis

Organic porosity

Inorganic porosity
MSEEL
Completion MIPU 3H and 5H
MSEEL - LOGGING LATERAL

High Definition open hole logs in lateral with synthetic mud

7,753' - 9,271'   9,271' - 9,731'   9,731' - 11,092'   11,092' - 12,451'   12,451' - 13,809'

E   D   C   B   A
SURFACE MONITORING OF SLOW SLIP (LPLD)
Synopsis of slow-slip deformation

Not critically oriented in stress field, results in “slow” slip with low frequency (1-30 Hz) seismic expression typically missed during microseismic monitoring.

Optimally, critically oriented in stress field, results in “fast” slip with high frequency microseismic expression.

Adapted from Kumar et al. 2016 and Zoback et al., 2012
MSEEL - LOGGING LATERAL

High Definition open hole logs in lateral with synthetic mud
Fiber Optic Installation

- Fiber Optic Cable
- Casing
- Blast Shield
- Cement
MIP3H - Stage 10: Uneven Distribution
MIP 3H - Stage 18 Even Distribution

![Graph showing temperature and pressure distribution over time and depth.](image-url)
Anisotropic Closure Pressure
Anisotropic Closure Pressure
Thin Data Prediction
Potential Future Work

- Continued Monitoring
  - Produced Fluids and Gas
  - Production

- Modeling
  - Reservoir Facies Quality
  - Completion Facies Quality
    - Fracture Development and Persistence
  - Multi-Scale Flow Modeling (Nano ➔ Reservoir Scales)

- Production Logging
  - Spinner Survey
  - DAS and DTS

- Big Data ➔ Thin Data Modeling
  - Lateral Facies Modeling
  - Regional Modeling

- Re-Stimulation – New Wells
Building Partnerships for Research, Education, and Outreach

Industry

MSEEL

Community

Academia

Government

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