Microseismic Monitoring: Engineering Value and Validation

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Microseismic Monitoring – An Engineering Tool

- Microseismic monitoring is a valuable tool for optimizing
  - Well layout (trajectory)
  - Well spacing
  - Stage lengths
  - Perf clusters and/or valves & packers
  - Stimulation design
  - Fracture height and length
  - Complexity
  - SRV
  - Diverter behavior
  - Fault interactions & geohazards
  - Calibrated fracture model

- Environmental issues
  - Fracture height growth (aquifers)
  - Seismicity

SPE 145463, Mayerhofer et al.
Downhole microseismic monitoring

- Array of receivers
  - Positioned in nearby well
  - Approximately at the depth of the treatment
- 3-component geophone systems
- \(\frac{1}{4}\) to \(\frac{1}{2}\) msec sampling

State-of-the-art microseismic receiver arrays

Array apertures of 500 – 1,500 ft

Fiber-optic wirelines

Wall-lock clamped tools
Fracture Behavior: Wide Variations

- **Sandstones**
  - Relatively planar
  - Piceance basin
    - Mesaverde example

- **Barnett Shale**
  - Intrinsic complexity
    - Low stress bias
    - Weak natural fractures
  - Enhanced by slick water stimulations

- **Other shales and most carbonates?**
  - Full spectrum of behavior
Microseismicity Distribution

- Microseisms are distributed approximately proportionately:
  - Near tips (length and height)
  - Around fracture face

SPE 148780 Canadian sedimentary basin example
Fracture Stability

Plan View

σ_{\text{min}}

σ_{\text{max}}

Shear zones

Tensile zone

All stresses tensile:
Reduced frictional forces
Increased shear
DESTABILIZED

Compressive zone

All stresses compressive
Increased frictional forces
Decreased shear
STABILIZED

Leakoff effects into natural fractures

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Hydraulic Fracturing and Microseismicity

- **Microseisms**
  - Fracture tip
    - Tensile events?
    - Shear events ahead of fracture
  - Leakoff into natural fractures
    - Shear events
      - Increased pressure
      - Slippage on natural fractures
    - Tensile events
      - Fissure opening
  - Network
    - Combination of both of above
Where Would These Microseisms Likely Occur?

- Intersections of natural fractures, faults, and bedding planes provide suitable sites for shear processes

Coal

SPE 15258
&
SPE 16422

Fracture offset at discontinuity

Hydraulic Fracture

DOE mineback tests
Fracture Behavior in Multi-Stage, Multi Cluster Completions
Microseismic Interpretation

- Understanding biases and artifacts
  - Distance limitations
  - Radial appearance
  - Noise hindrance
  - Fracture effects

Why is viewing through the fracture difficult?

SPE 131783
Curry et al, 2010
Marcellus example
M-Site Length & Azimuth Validation

- Intersecting Well Drilled Prior To Fracturing
- Microseismic Events Recorded During Fracturing & Compared At Time When Pressure Began To Increase In The Intersecting Well

Primary validation experiments:

- M-Site – microseismic, tiltmeters, intersection wells, tracers, pressure interference
- Mounds Drill Cuttings – microseismic, tiltmeters, intersection wells, tracers
- Mitchell Barnett – microseismic, surface & downhole tiltmeters, offset wells
Fracture Height Versus Downhole Tiltmeter Data

- M-Site
  - Monitoring with 6 tiltmeters cemented in place across from treatment interval
  - Fracture height deduced from inversion of tilt data using 3D Finite Element model
  - Very good agreement between bulk of microseismic data and tilt results
  - Several microseismic outliers
- Linear gel minifracs
  - 2 identical injections
  - 400 bbl
  - 22 bpm
**Microseismic Mapping Results**

Well 2H (completed first)
Well 1H (completed next)

N45°E to N55°E, Xf = 600 to 1,000 ft
(most events <500 ft)

h_f = 250 – 480 ft; w_{nf} = 370 - 920 ft

Pressure interference for all fractures

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**Well 1H Fracture Stimulation**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Surf Press [Csg] (psi)</th>
<th>Bottomhole Press (psi)</th>
</tr>
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<tbody>
<tr>
<td>60293</td>
<td>60812</td>
<td>61330</td>
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<tr>
<td>62367</td>
<td>62885</td>
<td>62530</td>
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**Pressure rise**

- Slurry Flow Rate (bpm)
- Slurry Density (lbm/gal)
Production Interference

Shut-ins cause corresponding rate increase in other well
Shallow Microseismicity: What is it?

Bakken example
Dohmen et al.
SPE 166274

Side view of zones of microseismicity in two wells in the Bakken

Large amount of activity 800 to 1,000 ft above the Bakken
Downhole Tiltmeter Assessment of Height Growth

- Hybrid tools with both microseismic and tiltmeter monitoring provide additional information
  - Where actual deformation is occurring
  - Likelihood of hydraulic connectivity

- Cases:
  - Heights: 50, 100, 200 ft
  - Net pressure: 1000 psi
  - Modulus: 5e+6 psi
  - Length > monitoring distance
Integrating Microseismic and Fiber Optics

- Microseismicity
  - Uncertainty of fracture initiation, entrance conditions & number of fractures

- Fiber optics provides near-wellbore information
  - Diversion
  - Control

- DTS
- DAS
Source Mechanisms

- Analysis of waveforms to determine “fault” characteristics

- Requires:
  - 2 wells
  - High quality data
    - Low noise
    - Good coupling
  - Accurate locations
  - Accurate velocity models

- Provides:
  - “Fault-plane” orientations
  - Slippage direction
  - Strength of the microseism
  - Volumetric behavior

- Major issue:
  - Uncertainty
    - Everything looks volumetric

Some claim it can show fractures closing!
Impossible to create a closure microseism in a fluid filled fracture (try clapping underwater)
It should tell us something about the reservoir
Hydraulic Fracture Energy Budget

- **Total energy of fracturing operation**
  - ~ 50 gJ

- **Strain energy of hydraulic fractures**
  - Single fracture ~ 6 gJ (12%)
  - Three fractures ~ 18 gJ (36%)

- **Microseismic energy**
  - Typically ~ 10 – 100 kJ
  - One part in $10^6$ to $10^9$

- **Quasi-static process**

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**Typical Marcellus treatment**
- \( H = 250 \text{ ft} \)
- \( L = 700 \text{ ft} \)
- \( \Delta P = 800 \text{ psi} \)
- \( w_{avg} = 0.015 \text{ in} \)
- \( \sigma_{min} = 6,000 \text{ psi} \)
- \( Q = 90 \text{ bpm for 90 min} \)

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A DFN built on microseismic data alone is missing >99.9999% of the deformation
Mapped Microseismic Height: North American Shales

- Top: shallowest microseism; Bottom: deepest microseism

Typical aquifer depths

Fracture tops

Fracture bottoms

Average perforation depth

Fracture stages

Depth, ft

Barnett
Marcellus
Eagle Ford
Haynesville
Woodford
Muskwa

SPE 145949
Summary of Observed Seismicity – Shales

- Microseismic monitoring provides detailed data on potential for seismic events
  - Number of monitored fractures approaching 50,000

Largest microseism observed

Typical size of seismic event that can just be felt

Similar to Richter magnitude
Summary

- Microseismicity provides valuable information about fracture behavior and completion effectiveness.
- Microseismic monitoring does have issues that need to be considered when interpreting results.
- The interpretation of microseismicity benefits when integrated with other diagnostics.
- Care needs to be taken when attempting to use source mechanism information.
Shiprock dike,
Louis Maher photograph

Questions?