Microseismic Monitoring Shale Gas Plays: Advances in the Understanding of Hydraulic Fracturing

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Introduction

Early days:
- Microseismic monitoring has been around since the early 1990s
- It’s application to the oil and gas industry came about in the late 1990s
- Analysis was based just on number of events and event locations

Microseismic Evolution:
- New understandings and technologies led to “more than just dots”
- New understandings of hydraulic fracturing challenged microseismic providers to provide more analysis
- Current market environment is pushing operators to get more from less – how can microseismics help?

We review the evolution of microseismic monitoring as it has been applied to hydraulic fracturing and how it has helped shape the current understanding of reservoirs and fracking.
Fracture Variability, Barnett Shale, 2000
Role of Structure in Production

Complex Fracture Network

Symmetric Fracture

Days after treatment

Production per day

Days after treatment

SPE 77440
Moving From Vertical to Horizontal Treatment Wells - Detectability
Monitoring Options

- Array geometry needs to be designed specifically for the project goals
- Adding multiple arrays:
  - Reduces detection bias
  - Provides wider coverage of treatment wells
  - Improves location accuracy
  - Provides opportunity for more advanced analysis
Hybrid Solutions: Combining Surface + Downhole + lower Freq. Geophones

Correct Event Radius based on ISM network (ft) | Event Fault Radius based on saturated downhole data (ft)
---|---
99 | 12
101 | 11
77 | 14
87 | 15
93 | 26
82 | 19
82 | 15

Energy (14304 events) 88.3%
Energy (seven events) 11.7%

(Surface Array Dataset) (Downhole Array Dataset)
Variations in Rupture Behaviour

**Rough**
- many small asperities breaking
- high frequency energy signal

**Smooth**
- few large asperities breaking
- lower frequency energy signal

**Fracture surface roughness**

**Most energetic asperity – resistance to sliding**

**Introduction of fluids and proppant**

**Proppant** -> increase in contact area and change of stiffness

**Fluids** -> decrease in contact area and lubrication
More Than Just Dots...

- **S wave window**
- **Time series**
- **Fourier Transform**

- **Spectral level**, \( \Omega_0 \)
- **Corner Frequency**, \( f_c \)
  \( \propto \frac{1}{\text{rupture duration}} \)
- **Decay slope**, \( \omega^{-2} \)

**Chart:**
- \( \Omega_0 \)
  - Seismic Moment, \( M_0 \)
  - Moment Magnitude, \( M_W \)
  - Stress Drop, \( \Delta \sigma \)
- \( f_c \)
  - Fault Radius, \( r \)
  - Stress Drop, \( \Delta \sigma \)
- \( \Omega(f) \)
  - Radiated Energy, \( E_S \)
  - Apparent Stress, \( \sigma_a \)
Using Source Parameters to Assess Treatment Plan

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stage A</th>
<th>Stage B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Events:</td>
<td>2416</td>
<td>1700</td>
</tr>
<tr>
<td>Fracture Length (ft):</td>
<td>1225</td>
<td>1075</td>
</tr>
<tr>
<td>Type of Sand Used:</td>
<td>70/140, 40/70</td>
<td>70/140, 40/70, 40/80</td>
</tr>
<tr>
<td>Crosslink (bbl)</td>
<td>28,000</td>
<td>11,500</td>
</tr>
</tbody>
</table>

Seismic Moment (N*m)

- Stage A: 40/70 prop begins
- Stage B: 40/70 prop begins
Bridging the Gap Using Microseismicity

Microseismic waveforms include information about the source of the failure and the rock conditions leading to failure.
Seismic Moment Tensor Inversion

Modes of failure have three end-members:
- isotropic
- double-couple (DC) / shear
- compensated linear vector dipole (CLVD)

Common modes of failure:
- Tensile opening of a fracture (normal to tension axis)
- Closure of a fracture (normal to pressure axis)
- Slip on a fracture surface (DC) – resolvable solutions
- Relative dimensions based on modified Brune Model (shear-tensional)
Response to Treatment

Fine Grained Mesh | Coarser Mesh | Coarsest Mesh
Well landing
Moment Tensors

Openings slightly below perforation depth.

Closures above and below
Large opening components at depth.

Mid point of Perfs.
Enhanced Fluid Flow - EFF

Opening aperture is calculated based on the strain from the moment tensor factoring in the source dimensions.

Average individual fracture openings over a neighbourhood (nearest neighbour statistical approach) of fractures with similar orientation
Well Landing
Enhanced Fluid Flow

Wells targeting Layer B show the least tendency to grow out of zone.
Stage Spacing
Moment Tensors

- The overlapping events of stage 19 are recorded within 10 minutes from beginning of treatment and the overlapping events of stage 20 are recorded within 20 minutes at the end of treatment.

- Overlapping events from stage 19 illustrates a crack-opening source type plot though the stage 20 events are more consistent with crack-closure type mechanisms.
Stimulation Response: Fractures

Core natural fractures
Core drilling-induced fractures

Changed Completion
Stimulation Response: Failure Types
Thank You!!

Questions??