Enhancing Hydraulic Fracturing and Well Performance via Effective Diversion

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Which of these wells is P&P completed?
Outline

• Product Overview
• Technology Benefit
• Applications
• Case Studies
• Modeling and Verifications
• Experimental Collaboration with TOTAL
• Conclusions

Product Overview

Green technology allowing more efficient fracturing completions and the ability to re-fracture/re-stimulate existing wells and improve upon overall production via in-stage diversion.
Borrowing Green Technology

- Made From Renewable Materials
- Certified Compostable
- Used in Medical Industry for Implantable Degradable Devices
- Used for Degradable Packaging Materials
- Byproduct is Naturally Occurring in Human Body
- Allows to Restore Production or Increase Well Efficiency

An Alternative to Current Diversion Methods: Mechanical Diverter System

- Mechanical Bridging Agent
- Degradable to Liquid Form
- Temperature Range
  - (83°F – 300+°F)
- Aqueous Fluid System Compatibility
- Two Particle System: 100 & 7 US Mesh (1.23-1.25 SG)
Product Overview
Long-Term Degradable Diverters

• When operations are suspended, ball sealers will fall away from the perforations, rock salt and flake diverters rapidly dissolve.
• This creates a need for a material that will remain in the perforations for multiple stages and dissolve over time.
• Degradable mechanical diverters are an environmentally friendly, mechanical diverter that addresses these criteria.

Technology Benefits

• Effectively Blocks Existing Perforations
  • 300 – 1,200 psi increases typical
• Stable Under Large Pressure Increases
  • 6,000 psi pressure increase achieved
• Diverts Fluid to New Perforations
• Divert Fluid to Under-stimulated Clusters
• Remains in Perforations/Near Wellbore
  • Superior to traditional diverting agents
• System Dissolves Over Time
• No Plug Mill-outs / No Squeezed Perforations
Applications

Replace Bridge Plugs
- Replace all bridge plugs or reduce total needed
- Reduce or eliminate mill-out time and equipment
- Provide zonal isolation

Multiple Open Clusters
- Perf-squeeze Alternative
- Recompletes & Re-Fracs
- Understimulated zones
- Sliding sleeve port seal

Casing & ID Restrictions
- Size limitations/restrictive ID’s
- Weak casing limiting entry
- Open Holes/Stuck Casing
- LCM

The Importance of Zonal Coverage Distribution

![Chart showing zonal coverage distribution]

Fig. 1 — Percentage of all perforation clusters that are not producing. Gray bars include all fracture stages. Green is for stages producing from 110% to 105% above the average rate. The red bars are for stages producing greater than 15% the average rate (Miller et al., 2011).
In-Treatment Diversion Case Study

Five Horizontal Eagle Ford Shale Wells
Depth: 9,000’ TVD
BHST: 250°F
54 perforations per interval
One & two diverter pills based on well

Case Study Criteria

- Effectively Diverter a Portion of Perforations During Treatment
- After Each Stage a Plug Will be Set for Isolation
- Determine if In-Treatment Diversion Will Increase Zonal Coverage & Production
In Treatment Diversion

Key Statistic

<table>
<thead>
<tr>
<th></th>
<th>Untreated Wells</th>
<th>Wells Treated with the TBlokSure Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Well #1</td>
<td>Well #2</td>
</tr>
<tr>
<td>True vertical depth</td>
<td>9,352 ft (2,805 m)</td>
<td>9,042 ft (2,760 m)</td>
</tr>
<tr>
<td>Lateral length</td>
<td>4,701 ft (1,439 m)</td>
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<tr>
<td>Proppant</td>
<td>4,100 tons (3,724 tonnes)</td>
<td>4,760 tons (4,344 tonnes)</td>
</tr>
<tr>
<td>Initial oil production</td>
<td>454 bbl (72 m³)</td>
<td>399 bbl (63 m³)</td>
</tr>
<tr>
<td>Initial gas production</td>
<td>274 mcf (8 m³)</td>
<td>216 mcf (6 m³)</td>
</tr>
</tbody>
</table>

217%
In-Treatment Diversion Case Study #2

Tow Horizontal Eagle Ford Shale Wells
Depth: 8,370’ TVD
BHST: 244°F
One diverter pill per stage

### Key Statistic

<table>
<thead>
<tr>
<th></th>
<th>Untreated Offset Wells #1</th>
<th>Untreated Offset Well #2</th>
<th>Diversion Well #1</th>
<th>Diversion Well #2</th>
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</thead>
<tbody>
<tr>
<td>TVD (ft)</td>
<td>7930</td>
<td>8282</td>
<td>8387</td>
<td>8369</td>
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<tr>
<td>Lateral Length (ft)</td>
<td>10223</td>
<td>7101</td>
<td>7530</td>
<td>7972</td>
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<tr>
<td>Proppant per lateral foot</td>
<td>1614</td>
<td>Data is N/A</td>
<td>1370</td>
<td>1340</td>
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<td>30 Day Oil Production (BBL/Day)</td>
<td>222</td>
<td>212</td>
<td>390</td>
<td>413</td>
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<tr>
<td>30 Day Oil Production (BBL/Day/1000’ of Lateral)</td>
<td>21.7</td>
<td>29.9</td>
<td>51.8</td>
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<tr>
<td>30 Day Gas Production (MCF/Day)</td>
<td>113</td>
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<td>209</td>
<td>208</td>
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<tr>
<td>30 Day Gas Production (MCF/Day/1000’ of Lateral)</td>
<td>11.1</td>
<td>21.0</td>
<td>27.8</td>
<td>26.1</td>
</tr>
<tr>
<td>Total Production (BOE/Day/1000’ of Lateral)</td>
<td>23.6</td>
<td>33.4</td>
<td>56.4</td>
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## Results
Percent Increase

Diversion
Wells showed 30 day productions improvement of 83%
Results Well 1

Results Well 2
ReFrac Case Study
Permian Basin Vertical Well Study

Depth: 8,900’ – 9,800’ TVD
BHST: 135°F – 140°F
480 Perforations
Combine multiple stages into one utilizing diverter

Permian Basin Vertical ReFrac Well
Permian Vertical Multiple Stage Completion Case Study

- Achieved Zonal Isolation without Bridge Plugs
- Long-term Perf Sealing and Diversion Compared to Traditional Diverters
- No Plug Millouts Post-Treatment
- Waiting for Production Results
- Tracer Logs Showed True Zonal Sand Distribution
ReFrac Case Study
Permian Basin Vertical Well Study

Depth: 8,900’ – 9,800’ TVD
BHST: 135°F – 140°F
480 Perforations
Combine multiple stages into one utilizing diverter

Case Study Criteria

• **Effectively Replace Bridge Plug Use By Sealing Existing Perforations**
• **Achieve 1,000 psi Increase or 7,000 psi TP Per Run**
  • Run diverter slugs until achieved
• **No Well Intervention Needed**
  • Eliminate Plug Mill-out
  • Eliminate Coiled Tubing
  • Increase Customer Efficiency
Well 1 • (March 2013), P&P • 3727' IL, 13 stages (100' spacing) w/300x300

Well 2 • (Oct. 2013), Tblocktuff® • 5925' IL, 18 stages (50' spacing) w/300x300

Well 3 • (Oct. 2013), P&P • 4205' IL, 24 stages (50' spacing) w/200x200

Well 4 • Completed (Oct. 2013), P&P • 6353' IL, 32 stages (50' spacing) w/200x200

Pad Layout

Job Execution

Perforate and fracture first stage of job as normal
Pump degradable diverter to temporarily plug existing fractures
Without setting a plug, perforate and fracture second stage of job
Degradable diverter turns into mild acid, cleans up, and flows back

Wait 10 days for degradation & flowback
Pressure Increase, Some Perf Diversion

Diverter pill with multiple perforation diversions and breakage observed.

Pressure Increase, Perf Diversion

Diverter pill with multiple perforation diversions and breakage observed.
Pressure Increase, Perf Diversion

Diverter pill with multiple perforation diversions and breakage observed.

1,233 psi increase

Pressure Increase, Perf Diversion

Diverter pill with multiple perforation diversions and breakage observed.

1,282 psi increase
Pressure Increase, Perf Diversion

3,624 psi pressure increase.

Intentional Screen-Out Using Diverter

Final batch of diverter used to seal remaining perforations. 3,855 psi pressure increase.
Well 1 & 2 Total Wellbore Cloud

Near-Wellbore TFIs for Both Wells
Modelling and Verification
Collaboration with TOTAL

Collaborative Research : Total

- Slots were placed in pressure vessel and diverting slurry pumped under pressure to determine if diversion would occur
  - Monitored by differential pressure across slot
  - Monitored mass of effluent flowing thru with time
Collaborative Research : Total

- Metallic Slots with various size opening were evaluated for diversion
  - 1 mm to 5 mm
- Uniform in shape throughout entire length
- No adherence points

Collaborative Research : Total

- Carbonate Slots with various size opening were evaluated for diversion
  - 1 mm to 6 mm
- Irregular shaped opening
- Opening size tapered from inlet to outlet
  - Simulates perforations / natural fractures
- Naturally rough surface
Collaborative Research: Total

What Have We Learned?
1 mm Slot Opening Metallic
What Have We Learned?
5 mm Slot Opening Carbonate

Physics & Modeling

1 mm

2 mm

3 mm

4 mm

5 mm

Particle Size / Slot Opening

Pressure drop (mbar)

Volume (mL)
Modeling – Other Parameters

- Base Simulation
  - Small Particles
  - Particle Shape
  - Geometry

Plug existing perforations

Field Data
Analytical
Numerical
Experimental

Diverting Agent

Optimum Concentration
Optimum Size
Optimum Combination
Pressure Build-up

52
### Particle Ratio

**Field Data**

<table>
<thead>
<tr>
<th>Particle Ratio</th>
<th>15:85</th>
<th>50:50</th>
<th>30:70</th>
<th>40:60</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>15:85</td>
<td>50:50</td>
<td>30:70</td>
<td>40:60</td>
</tr>
<tr>
<td>1.0</td>
<td>15:85</td>
<td>50:50</td>
<td>30:70</td>
<td>40:60</td>
</tr>
<tr>
<td>1.5</td>
<td>15:85</td>
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<tr>
<td>3.0</td>
<td>15:85</td>
<td>50:50</td>
<td>30:70</td>
<td>40:60</td>
</tr>
</tbody>
</table>

**Experimental Data**

**Next Experiments**

- **Pressure Build-up**
- **Rate (mL/min)**
- **Slot Size (mm)**
- **Particle Shape**
- **Concentration (ppg)**
- **Particle Ratio**

**slot**

- Metallic Slot Test (1 mm, 3 mm, 4 mm and 5 mm)
- Carbonate Test (4 mm – 2 mm)
- Carbonate Test (6 mm – 2 mm)
- Cylindrical Particles
Conclusions

• Degradable Diverter Advantages
  • Extensive BHT Range for Products
  • More efficient perforation sealing & diversion
  • Remains in perforations long term & degrades

• Potential Candidates
  • Re-Completes / Re-Fracture Treatments
  • Temporary Perf Squeeze Alternative
  • In-Treatment Diverter

Thank You For Your Attention

Questions?