Fiber-Optics results From an Intra-Stage Diversion Design Completions Study in the Niobrara Formation of DJ Basin

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Outline

• Objective
• Introduction
• Frac Treatment Information
• Limited Entry vs. Intra-stage Diversion
• Distributed Temperature (DTS) & Acoustic Survey (DAS) with FiberCoil
• Fiber-Optics Diagnostics
• Production Results
• Conclusions
Objective

• Optimize DJ basin completions with low cost diversion technology yielding equal or better production with fewer stages.

• Validate the results with fiber-optics technology
Introduction
Introduction: Niobrara Structure Map

Structure on top of A Chalk showing the 5 well plan

Central Graben Faulting

5-Well Pad
Introduction: Wells K and L with Niobrara Structural Cross Section
Frac Treatment Information

Well K
- Lateral Length: ~4300 ft
- CMHPG Hybrid Fluid System
- Primary Target: Nio “C”
- 28 stages, 153 ft spacing
- 3 perf clusters, 6 spf, 0.35” EHD
- Total perf clusters: 84
- 4,156,371 lbm-30/50 mesh sand
- Total fluid: 85,424 bbls
- Limited Entry

Well L
- Lateral length: ~4300 ft
- CMHPG Hybrid Fluid System
- Primary target: Nio “C”
- 20 Stages, 215 ft spacing
- 4 perf clusters, 6 spf, 0.35” EHD
- Total perf clusters: 80
- 3,752,202 lbm-30/50 mesh sand
- Total fluid: Pumped 101,270 bbls
- Intra-stage Diversion
Limited Entry vs. Intra-stage Diversion

SKYSCRAPER Coverage with Limited Entry

Possible/Potential Coverage with AF Intrastage Diversion
Limited Entry vs. Intra-stage Diversion

Well-K: Stage 26

Well-L (Intra-stage Diversion Design): Stage 3
DTS and DAS Review

- Distributed Temperature Sensor
  - Continuous Temperature data along the length of Fiber (along MD of wellbore when deployed)
  - 0.5m spatial resolution

- Distributed Acoustic Sensor
  - Continuous Acoustic data
  - 1m spatial resolution
  - Noise Intensity or differential phase

Temperature or Acoustic signal as a proxy for flow
Retrievable DTS and DAS (FiberCoil)

- Can be deployed in various non-instrumented wellbores to obtain diagnostic data at lower cost
- Flexible coiled tubing BHA
- Coiled tubing run-in-hole procedures remain the same
- Entire wellbore is imaged with temperature and acoustics post CT reaching TD
Fiber-Optics Diagnostics: Project Timeline

<table>
<thead>
<tr>
<th>Task</th>
<th>Well L</th>
<th>Well K</th>
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<tbody>
<tr>
<td>Stimulation Treatment</td>
<td>12 Days</td>
<td>12 Days</td>
</tr>
<tr>
<td>Flow-back</td>
<td>26 Days</td>
<td>25 Days</td>
</tr>
<tr>
<td>Wells Shut-In</td>
<td>5 Days</td>
<td>8 Days</td>
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• Fibercoil diagnostic run was made in Well L first followed by Well K

• Fibercoil survey provided DTA and DAS data across the entire wellbore with its temporal variations
DTS: Identification of Near Wellbore Frac-Initiation Points

- Near-wellbore temperature
- Remnant cooling effects of “cold” frac fluid creating fractures near-wellbore
- “Local Minima” on temperature traces are used to determine these initiation points using proprietary trace persistence methodology

- 4 Frac Initiation points in Stage 1
- 3 Frac Initiation points in Stage 2
DAS: Shut-in vs. Flowing

- Shut-in Data
- Producing Data

Production DAS Data zoomed in on depth and time
Summary of Cluster Efficiency: Wells L and K

Well L: 64 FIP (80 perforation clusters)

Well K: 51 FIP (84 perforation clusters)
Chalks vs. Marls: Perf Cluster Efficiency in Wells K and L

<table>
<thead>
<tr>
<th>Stage No.</th>
<th>Fracture Efficiency (No. of FIP/No. of Perf Clusters) %</th>
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<tbody>
<tr>
<td>Chalk</td>
<td>Avg efficiency</td>
</tr>
<tr>
<td>Marls</td>
<td>Avg Efficiency</td>
</tr>
<tr>
<td>Well-L</td>
<td>82%</td>
</tr>
<tr>
<td>Well-K</td>
<td>64%</td>
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</tbody>
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Production Results

Cumulative production from all 5 wells in the pad

Normalized production from Wells K and L
Conclusions

• 80% (64/80) fracture-initiation points in Well-L with Intra-stage diverter design vs. 61% (51/84) for Well-K
  • Well-K with shorter stage spacing (153 ft) had 20% less frac-initiation points than Well-L that had longer stage spacing (215 ft)
  • 20% translates to 650 ft of additional reservoir contact in Well-L

• Intra-stage diversion design in Well-L helped save $85,000 in frac costs without compromising production
  • Intra-stage diversion design was not optimized and yet it yielded similar production

• 10/28 stages in Well-K had only 33% cluster initiation efficiency while none of the stages in Well-L had less than 50% cluster efficiency
Conclusions

• Marly layers had lower percentage of initiation points than chalks in both wells, but Well-L Marls had higher efficiency than Well-K Marls

• Intra-stage diversion design in Well-L helped increase the initiation points in both Marls and Chalks than Well-K

• Successful validation of intra-stage diversion design process using Fiber-optics diagnostics
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Thank you!