Drilling Cost-Effective 10K+ Laterals

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Speaker Information

- Stu Keller
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Speaker Bio

- Oxy Worldwide Drilling & Completions Central Drilling Group
- 3 years with Oxy; 30 years with ExxonMobil
- Purdue University B.S. Engineering Science
- Based in Houston
- Specialized in BHA & Tubular Design
Occidental Oil and Gas

Permian Basin Is The Core Domestic Asset

**EOR Business**
- YTD ’16 Production - 144 MBOEPD
- 1 million net acres
- 1.9 Billion BOE remaining in reserves and resources

**Resources (Unconventional)**
- YTD ’16 Production – 125 MBOEPD
- 1.4 million net acres
- 8,500 identified well locations*

**Midstream**
- 12 processing plants
- ~2,900 miles of pipeline
  - CO₂ pipelines
  - Oil infrastructure and pipelines
  - Marketing business

* Based on 4Q15 metrics

Infrastructure difficult to duplicate
Oxy Has Significantly Decreased Permian Horizontal Well Costs and Drilling Days Since 2014

Permian Resources – Manufacturing Mode

- Delaware Wolfcamp A 4,500’ HZ
  - 2014: $10.9M (Drilling $5.6, Completions $5.3)
  - Current: $6.3M (Drilling $3.4, Completions $2.9)
  - Best: $5.4M (Drilling $2.7, Completions $2.7)
  - 42% decrease

- East Midland Wolfcamp A 7,500’ HZ
  - 2014: $9.2M (Drilling $5.5, Completions $3.7)
  - Current: $6.1M (Drilling $3.8, Completions $2.3)
  - Best: $5.3M (Drilling $1.9, Completions $3.4)
  - 34% decrease

- Drilling Days
  - 2014: 43 (1Q14 20, 2Q15 19, 3Q15 17, 4Q15 19, Best 13)
  - 1Q15 37
  - ~63% decrease

  - 2014: 46 (1Q15 20, 2Q15 18, 3Q15 17, 4Q15 16, Best 11)
  - 1Q16 31
  - ~65% decrease
Directional Drilling System Options for 10K+ Laterals

- Directional Motors
- Rotary Steerable Tools
- Motors and Rotary Steerables
Directional Motors for 10K+ Laterals

Key Pros
- Lowest directional tool day rate
- Less complexity than alternatives
- Many options available

Key Cons
- Sliding on-bottom ROP is slow
- Time required to adjust tool face
- Hard to control tool face as measured depth increases

Example Long Motor-drilled Laterals:

<table>
<thead>
<tr>
<th>Lateral Length (ft)</th>
<th>Area</th>
<th>Time Frame</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,413</td>
<td>Bakken</td>
<td>2016</td>
<td>NOV*</td>
</tr>
<tr>
<td>14,358</td>
<td>Bakken</td>
<td>2013</td>
<td>Oxy</td>
</tr>
</tbody>
</table>

Data from 36 Oxy Permian Laterals in One Field

<table>
<thead>
<tr>
<th>Fraction on-Bottom Time Sliding</th>
<th>Average Sliding ROP (fph)</th>
<th>Average Rotating ROP (fph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>32</td>
<td>103</td>
</tr>
</tbody>
</table>

* https://www.google.com/#q=NOV+Products+drill+longest+distance
Rotary Steerables for 10K+ Laterals

Key Pros
- Directional control generally not affected by MD
- Improved hole cleaning
- Continuous directional control

Key Cons
- High day rate
- Tool complexity
- High lost-in-hole cost

Example Long RSS-drilled Unconventional Lateral:

<table>
<thead>
<tr>
<th>Lateral Length (ft)</th>
<th>Area</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,544</td>
<td>Utica</td>
<td>2016</td>
</tr>
</tbody>
</table>

Source: AOGR, May 17, 2016
Improving Directional Motor Performance for 10K+ Laterals

- Engineering Rotational Directional Tendency
- Engineering Design to Mitigate BHA Vibrations
- Increasing Bit Gauge Length
- Identifying Best Operational Parameters
Engineering Lateral Rotational Directional Tendency

<table>
<thead>
<tr>
<th>BHA</th>
<th>Predicted Rotational Build Rate</th>
<th>Actual Avg Rotational Build Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized Motor</td>
<td>0.68</td>
<td>0.5</td>
</tr>
<tr>
<td>Slick Motor</td>
<td>0.15</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Engineering Stabilizers

Oxy-Design Stabilizers

Benefits Include:
- Lower drilling torque
- Less problems tripping
- Improved hole cleaning

Adjustable Gauge Stabilizers

Benefits Include:
- Improve Directional Performance
- Vibration Mitigation
- Mitigate Tripping Issues

Photo courtesy Arrival Oil Tools
Engineering Stabilizers

Adjustable Gauge Stabilizers

Benefits Include:
- Improve Directional Performance
- Vibration Mitigation
- Mitigate Tripping Issues
Mitigating Lateral Vibrations Via Modeling

Original BHA

BHA with Added Stabilizer

Lateral Vibrations

88 Degree Inclination

Added Stabilizer
Increasing Bit Effective Gauge Length to Help Improve Performance

Progression of Oxy Midland Area Lateral Bit Effective Gauge Lengths in Motor BHAs

- 4" gauge length
- 6" gauge length
- 6" gauge length + 2" near-bit stabilizer - record lateral ROP
- 8" gauge length + 2" near-bit stabilizer - new record lateral ROP

7-7/8" Bit with 8" Gauge Length
Selecting Operational Parameters to Mitigate BHA Vibrations

Vibration Bit Speed

Hot Spot

Lateral Vibrations
Oxy Positive Displacement Motor (PDM) vs Rotary Steerable System (RSS) Risked Economics Calculator

Example Only

- Calculates Risked Cost of PDM, RSS, RSS+PDM
- Includes probability of trip, probability of LIH, fishing economics
- Sensitivities to ROPs
Conclusions

- A key challenge for 10K+ unconventional laterals is drilling economics.
- Both rotary steerables and bent motors are viable directional systems for 10K+ wells.
- Engineering can help improve motor drilling performance.
- A risked-based economics calculator can be useful for selecting the most cost-effective directional drilling system.
Thank You