Completion and Artificial Lift Strategies for the Life of the Well

William Lane
Overview

- Unconventional production challenges
- Current best practices
- A better way forward
Challenges

UNCONVENTIONAL PRODUCTION
# Rapid Decline Rates

<table>
<thead>
<tr>
<th>Metric</th>
<th>Barnett</th>
<th>Eagle Ford</th>
<th>Woodford</th>
<th>Haynesville</th>
<th>Marcellus</th>
<th>Bakken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (ft)</td>
<td>100-600’</td>
<td>23-183’</td>
<td>70-290’</td>
<td>200-350’</td>
<td>45-225’</td>
<td>10-40’</td>
</tr>
<tr>
<td>Typical TVD (ft)</td>
<td>6,000-8,500</td>
<td>6,000-13,000</td>
<td>10,000-16,000</td>
<td>10,000-13,500</td>
<td>4,000-8,000</td>
<td>7,450-11,100</td>
</tr>
<tr>
<td>Typical MD (ft)</td>
<td>11,500</td>
<td>16,800</td>
<td>14,400</td>
<td>16,500</td>
<td>11,500</td>
<td>20,000</td>
</tr>
<tr>
<td>Typical Lateral (ft)</td>
<td>3,500-5,000</td>
<td>3,500-5,000</td>
<td>4,000-5,000</td>
<td>4,000-7,600</td>
<td>4,000-5,500</td>
<td>4,000-10,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Permeability</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40µd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Average Decline Year 1 | 65%  | 75%  | 59%  | 81%  | 64%  | 80%  |
| Average Decline Year 2 | 34%  | 43%  | 41%  | 35%  |      |      |
| Average Decline Year 3 | 19%  | 32%  | 26%  | 21%  |      |      |
| Decline Out Years     | 6%   | 6%   | 5%   | 5%   |      |      |

| Water usage¹          | 4 MMGal | 5 MMGal | 4.5 MMGal | 6 MMGal | 5 MMGal | 4 MMGal |
| Water flow-back¹      | 5% to 30% |        |           |         | 1 MMGal |        |

Long, slender well geometries

\[
\frac{4'' \text{ ID}^1}{5,000' \text{ lateral}} = \frac{\frac{1}{4}'' \text{ straw}}{104 \text{ yards}}
\]

^1Assumes 4'' ID for 4½'' casing.
“Horizontal” wells
Complex Well Geometries

Turbulent Slug Flow

Liquid/gas separation?

Video Source: Tulsa University Horizontal Well Artificial Lift Project (TUHWALP).
Turbulent Slug Flow

Source: TUHWALP simulations.
Uncertain Inflow
Current Best Practices

UNCONVENTIONAL PRODUCTION
Well Preparation

- Fracturing fluid recovery
  Jet pump @ 2000 bpd
- Gas well unloading
- Initial production
Early Production Practices

- Back-pressure management (chokes)
  - Avoid formation damage from excessive drawdown
  - Stabilize production (less slugging, flatter decline curve)

Early Production Practices

- Back-pressure management (chokes)
  - Avoid formation damage from excessive drawdown
  - Stabilize production (less slugging, flatter decline curve)

- Artificial Lift systems
  - Gas lift where possible
  - Jet pumps for initial high rates
  - Rod pumping for GVF < 1000 to 2500 SCF/bbl
    - Pumps landed in vertical or near vertical
Later Production Practices

- Lift systems
  - Rod pumping
  - Plunger lift
  - Hydraulic piston pumps
  - Capillary foam
  - Velocity enhancement

• Gas injection: $FBHP < P_{(injected\ gas)} < SBHP$

Sweep liquids through laterals

FBHP - flowing bottom-hole pressure
SBHP - static bottom-hole pressure
Deliquification of shale gas wells

Challenge
• Deliquify 4000 foot laterals.
• Varying water inflow.

Solution
• Capillary tubing to crossover at 70° deviation.
• 2-3/8” tubing to toe, annular foam return.

Results
• Sustained foam & dewatering along laterals.
• Increased gas production.

Crossover @ 70°
Later Production Practices

- Recommended Practices
  - Build sections and tubing sizes to accommodate lift pumps.
  - Pumps landed $<70^\circ$ deviation in straight tangent sections.
  - Construct straight laterals where possible, minimize undulations.
  - Deviation $\geq 91^\circ$.
A Better Way Forward

UNCONVENTIONAL PRODUCTION
Planned phasing of lift systems

Jet Pump
Gas Lift
ESP
Rod Pump
Hydraulic Piston Pump
Plunger Lift
Foam

Well Prep
Early Production
Later Production

© 2015 Weatherford. All rights reserved.
Hybrid lift systems

Jet Pumps
Initial unloading & frac flow-back

Gas Lift
Production

Change between lift systems without rig intervention
Optical permanent monitoring

- Temperature, pressure, acoustic
- Seismic stress monitoring
- Zonal inflow contribution
- Multiphase flow measurement
- Slug flow advanced warning
Production Optimization

Starts with integrated planning

- Well-construction geometry
  - Lateral drainage
  - Pumps landed in straight tangents

- Completions
  - Plan for lift systems
  - Subsurface sensors

- Production optimization systems
  - Reservoir monitoring
  - Analyses and controls
  - Data management
Questions?