Bakken Horizontal Best Practices Review

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Improved Horizontal Well Stimulations in the Bakken Formation, Williston Basin Montana

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SPE Presentation
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Outline

• Area Overview and Geology
• Reservoir Modeling & Well Performance
• Evolution of Well Construction
• Evolution of Completion & Frac Design
Early Challenges:

- Can horizontal wells provide economic uplift for development?
- Is stimulation required for success?
- Can laterals be effectively stimulated?
- What is effective drainage area for low K reservoir?
Short Answers:

- Yes
- Yes
- Yes
- More than you would think
Sleeping Giant Bakken Play
Area Overview & Geology
Middle Bakken Geologic Summary

• Reservoir rock is a dolomite, slightly shaly, minor calcite and quartz grains

• Consistent lateral extent and uniform vertical stratigraphy

• Lateral gradation to siltstones and sandstones

• Sourced by organic-rich shales above and below

• Stratigraphically trapped by porosity pinchout, primarily to NE and SW

• Dominantly matrix porosity system with minor fracturing
Bakken Reservoir Properties

- Net Thickness: 6 – 15 ft
- Porosity: 8 – 12%
- Permeability: 0.05 - 0.5 md
- $K_v/K_h = 0.1$
- Water Sat.: 15 – 25%
- Oil Gravity: 42 API
- GOR: 500 scf/stb
Type Log - Bakken

UPPER BAKKEN SHALE

BAKKEN DOLOMITE

LOWER BAKKEN SHALE

NISKU
Modeling Results
Initial Reservoir Modeling

- **Objective**: Define potential benefit of horizontal completion

- History match performance of vertical Bakken producers – using reservoir parameters from logs, cores and well tests

- Use history matched reservoir model for mechanistic study to determine:
  - Productivity uplift from horizontal completions
  - Optimal orientation of laterals
  - Benefit of stimulation in lateral section
  - Estimated effective drainage area
Vertical Well
Estimated Ultimate Recovery

Cumulative Producing Time, days

Cumulative Oil Production, MSTB

EUR, MSTB
Np, MSTB
Horizontal Well Simulation
Input Parameters

- 3-4 independent fractures totaling 2,000 ft.
- 3,000 ft horizontal lateral.
- Drainage area
  - 160, 240, & 320 acres
- Permeability
  - 0.165 md
  - 0.330 md
  - 0.660 md
- Lateral Orientation – Longitudinal vs Transverse fracture
Horizontal Well Simulation
Estimated Ultimate Recovery
(240 & 320 Acres)

- $K = 0.33$ md, $h = 17$ ft, $A = 240$ ac
- $K = 0.66$ md, $h = 17$ ft, $A = 240$ ac
- $K = 0.33$ md, $h = 17$ ft, $A = 320$ ac
- $K = 0.66$ md, $h = 17$ ft, $A = 320$ ac
Frac Design Simulation

• **Study fracture growth character** —
  – estimate proppant placement in zone
  – height growth
  – perforating effects

• **Study frac job design** —
  – determine effect of proppant type & concentration
  – determine effect of job parameters
Key Modeling Conclusions

- Hydraulic fracturing - needed due to low perm, low $K_v/K_h$, limited natural fracturing
- Fracture Orientation – longitudinal vs transverse fracture growth
  - Simulation shows negligible reserve differences
  - Cost effective fracture placement more likely with single stage longitudinal frac
Key Modeling Conclusions

• Maximize stimulated length – needed to improve productivity and drainage effectiveness

• Establish Uniform Spacing – create well design that allows for consistent downspacing if justified
Well Construction & Completion
Current Best Practices Basic Well Design

- Drill Vertical & Curve, Land In-Zone w/ No Pilot Hole.
- Drill Lateral Along Maximum Principal Stress Azimuth to Facilitate Longitudinal Hydraulic Fracture.
- Drill Lateral to Maximum Length Allowable Per Spacing.
- Run Uncemented Pre-Perforated Liner to Toe to Permit Clean-out & Other Re-Entry.
- Fracture Stimulate w/ Low Loading Polymer and Large Volume of Sand Proppant. Use Diversion Techniques.
Short Lateral

Short laterals are 4,000’ in length

Single 640 acre Section Spacing
Lyco Energy Corp.

Long Lateral

Richland County, MT

Proposed Wellbore Schematic

As of 26-Jul-04

Elevation GL = 2,350' 60"
Elevation KB = 2,369'

16" Conductor

13½" Hole

2,025' Surface:
9-5/8" 36# J-55 LTC
8¾" Hole

Top of Perforated joints

Est. TOC 1,000' above Dakota Silt

KOP @ 9,906' @ 351.8 deg. Azimuth
planned dogleg 12 deg/100'

4½" liner from 10,650' to 20,100'
11.6# N-80
6½" hole

7" casing at 10,794'
29# L-80 LTC 0 - 6,792'
29# P-110 LTC 6,792 - 8,222'
29# L-80 LTC 8,222 - 9,822'

TD @ 20,100' MD
10,496' TVD

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Multi-lateral Uncemented Liner

Single or Double Section Development
Multi-lateral Open Hole

Single or Double Section Development

Richland County, MT

Wellbore Schematic

13 1/2" Hole

9 5/8" 36# J55 LTC

7" 29# L-80 & P-110 LTC Casing to End of Curve

build rate 12°/100'

Sidetrack with retrievable whipstock

Lodgepole formation exposed

drilled with brine

Liner through curve just set in well with no cement
Well Types

- Long Lateral
- Dual Lateral
- Short Lateral
Early Completion Design

- Wellbore oriented for longitudinal fracture growth
- ASR measurements indicate max stress direction at +/- 340°
- Perforations biased towards toe section
Early Completion – Cemented Liner

Transverse Frac

Perforations

Longitudinal Frac

Heel

3200 feet

Toe
Why didn’t the heel treat?

• Drilling damage in the heel section from fines and extended exposure

  – Or

• Combination of damage in heel and lower pore pressure in toe cause toe to preferentially treat
Why an Uncemented Liner?

• Problems with open hole fracs
  – Frac the heel only in open hole fracs
  – By using perforated casing able to divert the frac and treat the entire wellbore
  – SpectraScan tracer logs indicate improvement with this method

• Ability to easily re-enter wells
  – Cleanouts –
    • Medium lateral production increased from 175 bopd before cleanout to 691 after
  – Re-frac – ability to retreat poorly treated zones
    • Initial refrac treatment increased from 30 bopd before refrac to 190 after
Noncemented Liner Completion

-Preperforated casing/liner w/ 5 holes every 5 joints
-5 ½” casing in short laterals (4000 ft)
-4 ½ “ liners in long laterals (9000 ft)
Evolution of Fracture Treatments

- **Fluids Tried**
  - Borate, Gelled Oil, CMHPG

- **Proppants Tried**
  - AcFrac Black (resin coated sand)
  - VersaProp (ceramic)
  - Sand

- **Multistage jobs with ball sealers and high ppg sand slugs**
Why Sand at 10,000’ TVD?

- Frac is longitudinal
- Only ~20’ high
- Fluid flow path through sand is short
- Increased perf spacing

StimLab Predict-K predicts very little difference in production with different proppants.
Some early diversion

Effective diversion
Tracer Log - Noncemented, Preperforated Liner

Start of noncemented liner

Heel  4000 feet  Toe
## Normalized Production Results

<table>
<thead>
<tr>
<th>Operator</th>
<th>MaxMo/1000’</th>
<th>6MoProd/1000’</th>
<th>Units</th>
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<tbody>
<tr>
<td>Current Comp</td>
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<td>10,985</td>
<td>Bbl</td>
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<tr>
<td>Early Comp</td>
<td>1,818</td>
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<tr>
<td>Operator A</td>
<td>1,721</td>
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<td>Bbl</td>
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<tr>
<td>Operator B</td>
<td>1,590</td>
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<td>Bbl</td>
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<tr>
<td>Operator C</td>
<td>1,396</td>
<td>5,730</td>
<td>Bbl</td>
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<tr>
<td>Operator D</td>
<td>1,157</td>
<td>4,993</td>
<td>Bbl</td>
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</table>
## Normalized Production Results – Updated – April, 2005

<table>
<thead>
<tr>
<th></th>
<th>Average of 6MoCum/1000’</th>
<th>Average of 12MoCum/1000’</th>
<th>Units</th>
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<tbody>
<tr>
<td><strong>Current Comp</strong></td>
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<td><strong>Early Comp</strong></td>
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<td><strong>Operator A</strong></td>
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<td><strong>Operator B</strong></td>
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<td><strong>Operator C</strong></td>
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<tr>
<td><strong>Operator D</strong></td>
<td>5,099</td>
<td>8,997</td>
<td>Bbl</td>
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</tbody>
</table>
Cemented Short Lateral: 3034’
Re-Frac of Original Well w/ Current Approach

![Graph showing production rates of oil, water, gas, and NGL over years.]

- Oil, bbl/mo
- Water, bbl/mo
- Gas, mcf/mo
- NGL, bbl/mo
Further Refinements

• **Stimulation Design**
  – Increase number of stages & diversion
  – Continue efforts to facilitate frac cleanup

• **North Dakota Development**
  – Lodgepole Fm integrity favors isolation of curve section
  – Apparent lower reservoir quality places increased emphasis on completion efficiency
Conclusions

• Maximum stimulated lateral length is primary factor in well productivity
• Positive diversion techniques improve fracture coverage
• Noncemented, perforated liners allow effective diversion and treatment of long lateral sections
• Both longitudinal and transverse fractures are created along the lateral length
• Tendency of the lateral to frac back from toe to heel has been consistently observed
• Refracturing of early wells has improved lateral coverage, well production and total recovery
Questions?