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Bridging the Gap Between Drilling and Completions

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Engineering Advisor
My Background

BS Chemical Engineering, University of Oklahoma

11 years Halliburton Research Center

12 years international
  – Leiden, The Netherlands
  – Cairo, Egypt
  – Copenhagen, Denmark

7 years with operating companies
  – Maersk Oil, Danish Operations
  – Chesapeake Energy, Fracturing Services
  – Continental Resources, Bakken
Presentation Format

• Define the challenge
• Evolution of technologies
• Establish today’s baseline
• What does the future hold
• Conclusions
The Challenge

Economic development of unconventional reservoirs necessitated the development of leading edge horizontal drilling and well completion techniques.
The question for today

Can we drill longer wells than we can effectively complete?

Photo courtesy of Continental Resources

Photo courtesy of MT ACTION Photography
Scope: Stimulated horizontal wells

Horizontal wells...

• Are getting longer and longer
• Require more stimulation stages
• Must be optimized; not just efficient and economical
• Environmental concerns cannot be ignored

2 miles = 3.2 km
3 miles = 4.8 km
When, and where, was the first horizontal well with multi-stage fracturing treatments?
Multi-Stage PSI Completions (1988)
Perforate-Stimulate-Isolate

Key drivers:

1) Production more important than efficiency
   • Ensure each frac as productive as possible
   • Allow selective testing of individual zones

2) 48 to 60 hours between stages

Image reference SPE 170981
The Dan Field Today

Reference: Danish Energy Agency “Oil and Gas Production in Denmark” (2013)
When, and where, was the first HZ well to use a ball shifted sleeves completion?
Ball shifted sleeves

*Open Hole Multi-Stage (OHMS)*
The Challenges

• Marginal development
• Variable permeability and fractures
• Supply of stimulation materials

The Solutions

• 1st ball drop sleeves completion
• 4 wells, 10 stages each
• Stimulation completed in 8 to 24 hours per well
• Two stimulation vessels, simultaneous operations
Stimulating a “3-mile lateral”

Introduction of Controlled Acid Jetting Technique

3 miles = 4.8 km
Halfdan Field (2000)

The Challenges

• Thin, flat reservoir requiring stimulation in order to produce at economical rates

• Lateral sections up to 6,000 m

• > 50% of laterals outside of coiled tubing reach

Grey areas are outside of coiled tubing (CT) reach

Reference SPE 71322, 78220, 78318 and SPE 108531
Halfdan “Hybrid Completion”

• Inner 2,500 m: Coiled Tubing (CT) shifted sleeves
  – Stages are fracture stimulated
  – 1 week to complete 14-16 stages

• Outer 3,500 m: Controlled Acid Jetting (CAJ)
  – Single, long interval is matrix acidized
  – 1,500 m³ 15% HCl acid
  – Typically completed in 12 hours
The Halfdan Field Today

4-D seismic confirms effective drainage along the full length of the laterals

Reference SPE 71322, 78220, 78318, and SPE 108531
Unlocking reserves through horizontal drilling and completion technologies

US Energy Information Administration: “Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States” (June 13, 2013)
By 2010, 90% of the wells in the Bakken were horizontal with multi-stage fracs and the operators were preparing to ramp up in the Eagle Ford.
Bridging the gap between drilling and completions

What are today’s challenges?

- Time and money
- Laterals are getting longer
- Availability of materials, especially water
- Public perception and environmental regulations
- Selecting the optimum completion for a given area
Brent Oil Spot Price ($/bbl)

Source: Spears Drilling and Completion Services Cost Index, Q3 2015
Drilling and Completion Costs
CAPEX per EUR

Source: Oil & Gas Financial Journal, November 2015 (Rystad Energy NAS Well Data and Analysis)
Brief Introduction to the Bakken

![Diagram showing gamma and resistivity for different layers of the Bakken Formation. The layers are labeled as Lodgepole, Upper, Middle, Lower, Birdbear. The map on the right highlights drilling targets MB & TF1, MB, TF1, TF2, MB or TF1, MB, TF1, TF2 & TF3.]
Tight Oil Breakeven Prices
2014 “High Grading” Example

Selected Bakken Plays
A. Parshall Sanish
B. Fort Berthold
C. West Nesson
D. Northern Mountrail, Williams Core
E. Williams Perimeter, N. Williston

Source: WoodMackenzie, Barclays Research (November 2014)
What will happen in 2016?

Drilled Uncompleted Wells

- 3,600 in U.S. (~ 1 mil BOPD)*
- 998 in Bakken at year end 2015

Important questions:

- Where is the opportunity in this challenge?
- How do we prepare for the recovery when it happens?

* PIRA Energy Group, Midland Reporter Telecom, January 10, 2016
Drilling vs. Completion Efficiencies

Source: US Energy Information Administration Bakken Rig Efficiencies Report August 2015
Enhanced Completions

90-DAY PRODUCTION COMPARISON FOR 30-STAGE COMpletIONS IN BAKKEN\(^{(1)}\)

30\% - 45\% INCREASE IN EUR

PRODUCTION UPLIFT

\~50\% Slickwater (46 Wells)

\~35\% Hybrid (52 Wells)

AVERAGE STANDARD COMPLETION OFFSETTING LEGACY WELLS

Source: Continental Resources November 2015 Investor Presentation
Bakken and Three Forks Study (5,327 wells)

Reference SPE 169531 and SPE 171629
Life Cycle of Unconventional Plays

Source: HIS Bakken Playbook (May 2015)
Water Requirements – Horizontal Wells

Drilling vs. Completions

- Significantly more water is used during completion compared to drilling; however,
- The amount is a small percentage of all industrial water usage

Source: US Geological Survey Fact Sheet 2014-3010 (March 2014)
Water Recycling: Why or why not?

Considerations:

- Availability of fresh water
- Legislation
- Quality of produced water
- Water transfer options
- Central storage

Source: USGS Article 10.1002/2015, June 2015

Remediating for entrained oil and for solids
Produced Water Recycling Facility
Reference SPEPOS Panel Session on Water Management for Hydraulic Fracturing, March 2015

Components
• Produced water storage
• Flocculation to remove solids
• Treatment to remove organics
• Underground water transfer pipelines

Economic Benefits
• Low OPEX ~ $0.30-$0.50/bbl
• Facilities generate revenue
• Minimizes salt water disposal
• 30% reduction in fresh water consumption

Note: Temporary recycling facilities are available which do not require CAPEX. OPEX is $2.50-$3.60/bbl, depending upon produced water quality and throughput.
Pushing the limits of lateral length

- 1st horizontal Bakken well with multiple frac stages: 1.6 km
- 1st 2-mile lateral: 3.2 km
- 1st 3-mile lateral: 4.8 km
Challenge:

• Economic full field development
• Conventional development
  – Full township (6 miles x 6 miles)
  – 18 units (1 mile x 2 miles)
  – Each unit HBP (held by production)

Example data modified from American Association of Drilling Engineers (AADE) Technical Symposium held in Tulsa, OK, February 19, 2014
Drilling Efficiency Gains with Longer Laterals

Solution:
Extended lateral development:
• Infill using 14 4-, 6- and 8-well pads
• 18 fewer pads and 32 less wells
• 36% reduction in footprint

<table>
<thead>
<tr>
<th></th>
<th>2-mile development</th>
<th>3-mile development</th>
<th>Potential Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>10,000 ft</td>
<td>15,000 ft</td>
<td>~ Neutral</td>
</tr>
<tr>
<td>Wells required</td>
<td>141</td>
<td>109</td>
<td>- 32 wells</td>
</tr>
<tr>
<td>Number of pads</td>
<td>64</td>
<td>46</td>
<td>- 18 pads</td>
</tr>
<tr>
<td>Total footprint</td>
<td>280 acres</td>
<td>179 acres</td>
<td>- 101 acres</td>
</tr>
</tbody>
</table>

Red wells are 3-mile laterals

Example data modified from American Association of Drilling Engineers (AADE) Technical Symposium held in Tulsa, OK, February 19, 2014
Drilling Efficiency Gains with Longer Laterals

Challenge:

• Accessing “offshore reserves”
• Surface constraints
Drilling Efficiency Gains with Longer Laterals

Solution:
- Directional drilling
- Extended lateral developments
Chasing the drilling rig

- Steering the lateral
- Where to perforate
- Toe stimulation
- Stage isolation
- Post frac cleanout
Challenge: Steering the Lateral

- Geo-steering
- Mud logging
- Cuttings analysis
- Gas analysis
- Biostratigraphy
- Logging while drilling
- Thru-bit logging
- Paleo-environmental analysis

Is this what your lateral looks like?
Challenge: Steering the Lateral
Challenge: Quantifying rock properties

Is your rock brittle or ductile?

<table>
<thead>
<tr>
<th>Fracture Geometry</th>
<th>Stress Anisotropy</th>
<th>Britteness</th>
<th>Completion Focus</th>
<th>Reservoirs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex Systems</td>
<td>LOW</td>
<td>0.18</td>
<td>STRESS INDUCED COMPLEXITY</td>
<td>Barnett Woodford</td>
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<tr>
<td>Complex Planar w/ Fissures</td>
<td></td>
<td></td>
<td>RESERVOIR DIVERSION</td>
<td>Marcellus Eagle Ford Gas</td>
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<tr>
<td>Complex Planar</td>
<td>HIGH</td>
<td>2</td>
<td>RESERVOIR DIVERSION</td>
<td>Eagle Ford Oil Bakken</td>
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<tr>
<td>Planar w/ Fissures</td>
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<tr>
<td>Planar</td>
<td></td>
<td>0.35</td>
<td>FRACTURE INTENSITY</td>
<td>Montney</td>
</tr>
</tbody>
</table>

Reference SPE 115258, 152704, 164271, 167726, 168763
Challenge: Where to perforate

Need to balance
• Reservoir quality with
• Completion quality

Various approaches
• Thru-bit quad-combo logs
• Projecting pilot hole data via resistivity or density logs
• Specific mechanical energy (SME) from drilling parameters

Image courtesy of Halliburton Energy Services
Challenge: Stage Isolation

Mechanical systems
• Plug-and-perf
• Ball and sleeves
• Coiled tubing activated

Dynamic systems
• Jet assisted
• Proppant plugs

Images courtesy of Halliburton Energy Services
Plug-and-Perf Completions

- The plug, guns, casing collar locator, and setting tools make up the bottom hole assembly (BHA)

- BHA is run most often on wireline, but can be run on coiled tubing

- BHA will fall in the vertical section; fluid is pumped to push the BHA along the lateral
Plug-and-Perf Completions

Plug-and-perf technologies, along with “zipper fracturing” reduced completion times significantly.
Zipper Fracturing
Challenge: Frac plug mill-out

Solutions:
• Larger coiled tubing
• Large ID frac plugs
• Dissolvable frac plugs

Images courtesy of Halliburton Energy Services, Baker Hughes, Magnum Tools, and Schlumberger
Ball and Sleeves Systems

Historically: open hole with single ports

Today: fully cemented with multiple ports

Images courtesy of Halliburton Energy Services
Ball and Sleeves Systems

<table>
<thead>
<tr>
<th>Maximum number of stages</th>
<th>Open Hole</th>
<th>Cemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single entry sleeve systems</td>
<td>50-55</td>
<td>35-40</td>
</tr>
<tr>
<td>Multi-port systems, 3-5 ports/stage</td>
<td>48-54</td>
<td>20-25</td>
</tr>
</tbody>
</table>

• Exact number of stages possible is dependent upon
  – Formation characteristics
  – Wellbore construction
  – Stimulation treatment parameters

• Balls are made of various materials
  – Generally in 1/8” size increments
  – Degradable balls are available

Images courtesy of Schlumberger
Coiled Tubing Fracturing

Sleeves are run in the liner, then shifted with coiled tubing during stimulation operations.
Coiled Tubing Fracturing

Coiled tubing inside the work string provides a circulation path for the frac fluid and proppants.

Frac is pumped down the annulus between the coiled tubing and the liner then exits out the frac port.

Resettable plug grips and shifts the sliding sleeve.

Ports at the bottom allow circulation to cleanout wellbore.

Images courtesy of NCS Energy Services
Full circle in horizontal well completion technologies

Today and Future: Completion technologies developed onshore being applied offshore

North Sea:
• Directional drilling
• Extended reach wells
• Horizontal wells with multi-stage stimulations

1980 - 2000

Unconventionals:
• Fracturing technologies
• Completion techniques
• Completion hardware

2000 - 2020

Onshore conventional reservoirs:
• Tight gas
• Mature fields
• Horizontal wells
  – Austin Chalk, Texas
  – North Slope, Alaska

Inspiration credit: Martin Rylance, JPT, April 2015
Technology sharing

• Collaborate
  – All disciplines: geosciences, drilling, completions, production
  – With service providers and other operators

• Accelerate learning curve
  – Learn from both successes and failures
  – Think outside the box when looking for analogs

• Be prepared
  – There will be a shortage of skilled people
  – Keep focus on being effective not just efficient
In conclusion:

Does completion technology lag behind drilling technology?

- Drilling envelope is pushed first
- Completion technology is a fast follower
Your Feedback is Important

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