Optimization in U.S. Shale Plays: Emerging New Techniques and Technologies

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AAPG
Innovation starts with thinking...

- Reconfiguring Perception
- Importing New Techniques
Focus on Reservoir Optimization

- **Part I: Next Phases of Shale Play Development**
- Stranded Pays: Between the Laterals
- Sweet Spot Optimization: Whipstocked Laterals
- Cost Reductions
- Cost Intensifications
- Managing Drilling Fluids to Minimize Formation Damage and Optimize Completions
- Refracturing
- Pre-Stack Seismic Inversion & Reservoir Characterization in Unconventionals
- New Reservoir Stimulation Approaches
  - Identifying understimulated zones
  - Refracturing
Stranded Pays: Between the Laterals

- Not just for mature fields or uneconomic isolates
- Stranded pay within the laterals: going back to the early laterals (the mainly depleted ones in order not to disturb ongoing production)

Note: Halliburton already has a whipstock tool to re-enter laterals ... just a matter of putting all the puzzle pieces together
Integrated Approach

- Sweet spot identification
- Well location optimization
- Completions optimization
- Geochemistry (reservoir characterization – what do you have?)
- Basin analysis (big picture)
- XRD / XRF (while drilling)
- Drilling fluid optimization
New Technologies

• Better integration with sequence stratigraphy, geochemistry, imaging, XRF, etc.
• Under development: Whipstocking the Sweet Spots – Broussard / Arkansas experience
• Whipstock directional drilling for better penetration of sweet spots
• Whipstock off the lateral where microseismic indicates a fracture pod
• Packers or sliding sleeves to perf within the whipstocked part of the lateral?
Process Improvements

• Fracturing efficiency improvements (better pressure management, frac height control)
• Proppant, fluid, water management, pad drilling, logistics improvements
• Proppant behavior
• Water management / water re-use
• Stacked pays (Bakken, Permian, Oklahoma)
Information Yields Understanding of Failure to Stimulate

- Microseismic sensor arrays (10-well installation)
- 3D visualization
- Goal: improve hydraulic fracturing, determine frac heights
  - Find where the sweet spots are (lenticular units with communication)
  - Return to drill additional laterals, or whipstock into the heart of the pods
Part I: Next Phases of Shale Play Development

• **Stranded Pays: Between the Laterals**
• “Stranded pay” denotes pay that might be technically recoverable, but it is not economically recoverable. Here are a few key points:
• The concept of “stranded pay” is not reserved for mature fields or uneconomic isolates: under-stimulated zones in horizontals
• Stranded pay between and alongside laterals.
• To recover stranded pay within the laterals, return to pad
• Identify best laterals for restimulating or re-entering
• “Offsets” or “whipstocks” into sweet spots identified by microseismic or geochemical methods (Broussard et al., 2009)
New Reservoir Stimulation Approaches

• Cation exchange capacity (stabilizing fluids introduced into the reservoir in order to avoid behaviors of clay minerals)
• Simulating charged particles (nano-stimulation)
• Production issues (focusing decline curves)
  – Pressure controls / gas drive maintenance
  – Punctuated refracturing at certain intervals
  – Cluster spacing analysis to optimize induced fractures
  – Fracture interference by design to optimize fracture networks
Clay Swelling

- Understand the clays in order to design fluids that do not result in formation damage

Shale plug before (left) and after (right) swelling test
Pad Drilling Process Enhancements

• Extend the limits of pad drilling & laterals by altering the horizontal landing targets and increasing wellbore lateral lengths
• Optimizing completion techniques: control and refine pump-down procedures and flush procedures
• Optimizing completion design:
  – Proppant optimization (higher strength, ideal size)
  – Frac fluid optimization
  – Frac height determination
  – Frac interference determination
Process Improvements

• **XRD / XRF**: Geosteering in the laterals for sweet spots, as well as in pilot holes: The XRD data is particularly helpful in the determination of total clay, while the XRF measures 10-12 major elements, as well as trace elements (trace metals may indicate areas of high TOC (Tonner et al., 2012).

• **Chemostratigraphy**: using major, minor, and trace element geochemistry to classify strata and to characterize them by means of correlations to sweet spots. It can be used to detect and evaluate subtle yet rapid change in superficially homogeneous rocks (Tinnin, et al., 2014)
Eagle Ford

• Geomechanical data derived through pre-stack seismic inversion (Tinnin et al., 2014)
• Redox-sensitive metals are an excellent proxy for organic richness (Dix et al., 2010)
• Microseismic for determining fracture heights
• Pyrolysis includes determining free hydrocarbon, remaining hydrocarbon generation potential, organic richness (TOC), and Thermal Maturity (Tmax)
• Sequence Stratigraphic correlations: 3D seismic & depositional modeling
Eagle Ford

- XRD / XRF: Geosteering for sweet spots
- Microseismic for determining fracture heights
- Sequence Stratigraphic correlations: 3D seismic & depositional modeling

Geosteering while-drilling data. Image: UOGC
Pore Architecture

- Effective recoverable petroleum
Mississippian Lime

• In order to characterize the reservoirs, the following are needed:
• Image Logs for Fracture networks
• Basin-Level Analyses
  – Petroleum Generation
  – Expulsion / Flow
  – Structure (Faults / Fracture Networks)
  – Convergence with Mississippi Valley-Type Mineralization
Woodford Shale

• Geomechanics
  – Pore pressure regimes
  – Nano-geomechanics
    • (cation exchange capacity)
  – Fracture typing / characterization
  – Fracture networks
• Brittleness & Fracability determination
Woodford Shale

• Geochemistry
  – Total Organic Content (TOC) evaluations
  – Kerogen typing
  – Maturity / Vitrinite reflectance
  – Gas fingerprinting
  – Migration patterns
  – Indicator minerals / deformations
  – Adsorption factors
  – Pyritization
Part II: Case Study: Refracturing Woodford Shale

- S. French, C. Feik, BP America
- Cana Woodford Area
- 500 ft stages vs 300 ft stages
- Significant potential for unstimulated rock volume
- Failure to place significant amounts of proppant
  - Screen-outs
  - High treating pressures
  - Other problems
Initial Stimulation: Stranded Pay

- First four stages:
  - 46,000 lbs/stage of 30/50 Ottawa sand (far short of best practices)
- Average fluid volume: 12,000 bbls/stage of slickwater
- Drilled in 2012
- Average IP30 3.4 mmmscf/d – cum 1.7 BCF – less than expected 5.4 mmmscf/d & 2.4 BCF

Simulation of Heel Diversion and Additional Perforations
Inadequate Drainage = Stranded Pay

- Woodford D-1 well, using 3-D finite difference approach for simulation
- Actual cluster efficiency (70% from production logs)
- Many clusters unaffected by the fracture treatment
- Average 260 ft between fracture clusters
Reservoir Modeling

- Three-dimensional finite difference approach
- Cluster efficiency (70% from production logs)
- A number of clusters unaffected by fracture treatments
- 260 ft between productive clusters
- Lack of adequate proppant volumes resulted in decreasing fracture conductivity with time
Existing Cluster Efficiency

- Micro-seismic information for single stage of a well completion
- Overlay with geometric information from a hydraulic fracture simulator
- Include vertical cross section of simulator input
- Look at calculated fracture width
Finding: Stranded Pay

- Matching 5 years of production
- 50 nano-darcy shale
- Simulation indicated that the reservoir pressure between productive clusters close to the initial reservoir pressure of 3,900 psia
- Model demonstrated that if two or more adjacent perforation clusters not efficiently stimulated, large swaths of unstimulated rock existed between the productive perforations
Additional Consideration: Questionable Pick

- Original completion plans used a deeper top Woodford pick than the presently accepted definition
- Consequence: additional unperforated pay opportunities at the heel of some wells
- Wellbore was still building angle through the curve at the heel of the well
- Woodford D-1 well – a good example
New Pay at the Heel

• Additional 738 of pay at the heel of the D-1 well was enough for two entire Plug and Perf stages to be performed
• Potential ball drop re-fracture treatment of the deeper section of the lateral
Criteria for Re-Fracturing Candidate Selection

- Single well in the section (avoid “frac hits” on other wells)
- Frac stage spacing (original completion) > 500 ft per stage
- 30% or more of original stages placed minimal proppant
- Unperforated interval at the heel (accessible by Plug & Perf)
- Low cumulative production
- Thick reservoir
- Best rock quality
More Criteria

• High current reservoir pressure
• No perceived faults
• Low water production
• Adequate surface location size for the operations
• Adequate water source for frac fluid supply
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- Low water production
- Adequate surface location size for the operations
- Adequate water source for frac fluid supply
Goals of the Re-Fracture Pilot Project

• Add rate and reserves

• Determine
  – Additional gas present?
  – Is refracturing economic?
  – What is the best way to refracture?
  – Can refracturing minimize the impact of the frac interference with older wells?
Coiled Tubing Deployment

- Ability to pinpoint bypassed pay
- Downsides:
  - Mechanical risk
  - Cost concerns
  - Requires a straddle packer assembly
  - Too restrictive in isolating the clusters
Sliding Sleeve

Sliding-Sleeve Inner-String Fracturing System.

- A possibility ...
Sliding Sleeve Inner String

- Another possible treatment option
- Potential system costs
- Requires the cleaning of existing wellbore
- Subsequent deployment of external casing packers along entire lateral length
- Reduced internal diameter of inner string
- Injection rates significantly reduced
- Additional stages
Cemented Insert Liner

• Can isolate and re-stimulate entire lateral section
• Risk of losing the cement was high
• Would lose cement to existing stimulated and depleted perforations
• Likelihood of creating additional damage within existing fracture network
• Risks outweighed advantages of stimulating new pay
• Would require new casing, extensive workover to run casing, plus cementing operation
• Would need new stages
Ball Sealer Diversion

- Add a number of perforation clusters (where appropriate)
- Design a schedule of stages, rates, and ball-drops
- Achieve a gross diversion between stages from one cluster to another
- Requires efficient ball action
- Does not provide very high level of accuracy (as in mechanical isolation)
- But – very cost-effective
- Could be (with surveillance and learning)
- A valid technique for horizontal well refracturing
Ball Sealer Considerations

• Ball diversion: not new, but potentially problematic in horizontal wells
• Ball sealer buoyancy and injection rate considerations
• Need to achieve efficient seating action (balls can settle to the bottom of the casing during the pumping of the treatment)
• Must maintain steady flow / pump rate
• Fluid viscosity important, as is density contrast between fluid and the ball
Ball Diversion & Additional Clusters

- Woodford H-1 well
- 944 ft of unperforated interval
- Located in middle of lateral section
- Fracture simulation modeling: most fracture growth would be vertical and out of the Woodford shale target unless some pressure depletion had occurred
Refracturing Operational Procedures

• Move in workover rig 1 month early
  – Pull tubing
  – Set bridge plug
  – Perform mechanical integrity test (MIT)
  – Drill out composite bridge plug

Coiled Tubing Mobilized
Refracturing stimulation (continuously pump 10 stages using ball dropper and diverter balls)
Flow-back up the casing
Move in workover
Run production tubing string
General Approach to Refracturing for the Pilot Wells

- Establish slickwater injection rate of 90 bpm
- Drop 30 – 50 balls
- Record volume, watch for pressure increase
- Increase pump rate to 90 ppm
- Drop more balls while sand slurry still in wellbore
- Repeat the process
- After 4 – 5 hours, bring job down to grease equipment
## Typical Pump Schedule for an Individual Stage of a Woodford Re-Frac (from Well F-1 Procedure)

### Woodford Pump Schedule - STAGE 1-9

<table>
<thead>
<tr>
<th>Stage</th>
<th>Fluid Volumes</th>
<th>Total Rate</th>
<th>Stage Prop %</th>
<th>Prop Total %</th>
<th>Blender Conc</th>
<th>Cum Time Mins</th>
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<tbody>
<tr>
<td></td>
<td>Clean Gal</td>
<td>Clean Ebbs</td>
<td>Dirty Gal</td>
<td>Dirty Ebbs</td>
<td>2.65 S.G.</td>
<td></td>
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<tr>
<td>Main Pad 1</td>
<td>50,000</td>
<td>1,190</td>
<td>50,000</td>
<td>1,190</td>
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<td>0:13:14</td>
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<tr>
<td>Slick Water 2</td>
<td>70,000</td>
<td>1,667</td>
<td>50,000</td>
<td>1,190</td>
<td>2</td>
<td>0:14:29</td>
</tr>
<tr>
<td>Slug 0.1 ppg 3</td>
<td>100,000</td>
<td>2,381</td>
<td>100,001</td>
<td>2,383</td>
<td>0</td>
<td>0:20:20</td>
</tr>
<tr>
<td>Pad 4</td>
<td>128,000</td>
<td>3,048</td>
<td>28,253</td>
<td>673</td>
<td>40-70 Ottawa</td>
<td>0:26:29</td>
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<tr>
<td>Slick Water 5</td>
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<td>3,762</td>
<td>158,344</td>
<td>3,770</td>
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<tr>
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<td>186,724</td>
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<tr>
<td>Pad 7</td>
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<td>216,724</td>
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<tr>
<td>Pad 10</td>
<td>290,000</td>
<td>6,905</td>
<td>292,410</td>
<td>6,926</td>
<td>40-70 Ottawa</td>
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<td>Pad 13</td>
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<tr>
<td>Slick Water 14</td>
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<td>7,114</td>
<td>317,529</td>
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<td>40-70 Ottawa</td>
<td>0:41:53</td>
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<tr>
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<td>375,000</td>
<td>8,870</td>
<td>360,870</td>
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<td>381,021</td>
<td>9,021</td>
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<td>Slick Water 17</td>
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<td>0:05:40</td>
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<tr>
<td>Ball Drop</td>
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<td>9,241</td>
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<td>388,140</td>
<td>9,241</td>
<td>395,688</td>
<td>9,241</td>
<td>0</td>
<td>0:20:36</td>
</tr>
</tbody>
</table>

### Notes
- Flush volumes DO NOT include 100 bbl overflush

### Chemical Additives
- TFR-21L Friction Reducer 0.5-1.0 gpt
- TGB-343 Bicocide 0.15-0.5 gpt
- TSA-230L Scale 0.15-0.5 gpt
- TNE-156 Ln. Nonemulsifier 1-3 gpt
- TIG-331L Iron Control 1-5 gpt
- TAII-107L Corrosion Control 1-10 gpt
- 15% HCl HCl Acid 15%
Woodford Refrac Results

• Significant improvements
• Best candidates: Those with highest IP30 rates
Conclusions

• Economic gas rate and reserves can be economically added by the refracturing of horizontal shale gas wells
• Refracturing has the potential to increase recovery
• Wells in good rock areas perform better
• Selecting wells with highest original IP30 is a good indicator of inherent rock quality
• Refracturing operations can protect parent well from impact of frac hits if performed sequentially
• Many techniques for achieving mechanical diversion
• High-rate horizontal gas wells can be refractured without significantly damaging baseline production rates
Lessons Learned

• Early refracturing stages treat easily
• Later stages more difficult
• At beginning, high leak-off – affects ability to achieve frac length
• Low levels of sand concentration
• Drop balls right after flush
• Limit use of rubber balls (post-frac cleanout problems)
• Use biodegradable balls
• Use workover rig for cleanout (not coiled tubing)
• Ensure sufficient water for frac operations
Thank you!!