Optimizing Perforating Charge Design for Stimulation
Fracturing Unconventional Reservoirs

- Deep Penetrating (DP) Charges
  - Natural Completions
  - Focused on depth of Penetration
  - Hole size is usually an after thought

- New Design FRAC Charge
  - Stimulated Completions
  - Focused on Hole Size and Consistency
Optimal FRAC Gun

- 6 spf 60
- 3 1/8” gun in 4 1/2” casing with a 0.48” avg. casing hole
- 3 3/8” gun in 5 1/2” casing with a 0.42” avg. casing hole
- Depth of penetration is not important
- Hole size consistency without centralization
What is more important

- Hole size
- Hole size consistency

<table>
<thead>
<tr>
<th>Shot Phase Angle</th>
<th>Clearance</th>
<th>Average A (21g)</th>
<th>Average B (19g)</th>
<th>Frac Charge Design (21g)</th>
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<tr>
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<td>0.50</td>
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<td>(A Max - A Min)/Ave</td>
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<td>26.8%</td>
<td>31.8%</td>
<td>13.0%</td>
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<tr>
<td>(A Max - A Min)/Ave</td>
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<td>52.4%</td>
<td>75.0%</td>
<td>27.9%</td>
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</table>
Consistent Hole Size Without Centralization

3 3/8” gun in 5 ½” casing

Industry Charge B

- 75% difference from high to low with a 0.40 avg.

Frac Charge Design

- 28% difference from high to low with a 0.43 avg.
21 gram Frac Charge Design Gun System

- 21 grams RDX
  - 3 1/8” 6 spf 60
    • 0.46” hole in 4 ½” casing
    • 13% variance*
  - 3 3/8” 6 spf 60
    • 0.43” hole in 5 ½” casing
    • 28% variance*

*(Ave. Max Hole - Ave. Min Hole) / Ave Hole
FEA Modeling

- Abaqus™ is a software application for finite element analysis (FEA) and computer-aided engineering
  - Calculate stress distribution along the perforation tunnels and the wellbore
  - Established a correlation between the breakdown pressure and the entrance hole diameter of perforation tunnel

Abaqus is a trademarked by SIMULIA
### 3 3/8” Gun in 5 ½” Casing Scenario

<table>
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<tr>
<th>Shot Phase Angle</th>
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<th>Ideal Case</th>
<th>Industry Charge (19g)</th>
<th>Frac Charge Design (21g)</th>
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<td>Total Average</td>
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<td>0.40</td>
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<tr>
<td>(AMax-AMin)/Ave</td>
<td>0%</td>
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<td></td>
</tr>
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</table>

Full-scale model, six perforating tunnels, 12” height of reservoir, 5.5” wellbore diameter, 0.304” casing wall thickness.
FE Mesh Configuration

Uniform pressure (=100MPa) is applied to the surface of the casing and the perforation tunnels.
Numerical Results

Distribution of the Local Max Principal Stress on the surface of perforation tunnels

Distribution of the Local Max Principal Strain in the reservoir
Numerical Results

**Ideal Case:** six tunnels have the same hole size

**Frac Charge Design**

- MPS = 152.1 MPa, D = 0.40"
- MPS = 157.2 MPa, D = 0.48"
- MPS = 155.9 MPa, D = 0.46"
- MPS = 149.9 MPa, D = 0.36"

**Industry Charge**

- MPS = 160.7 MPa, D = 0.53"
- MPS = 147.1 MPa, D = 0.30"
- MPS = 144.8 MPa, D = 0.25"
- MPS = 147.1 MPa, D = 0.30"
- MPS = 160.7 MPa, D = 0.53"
- MPS = 162.5 MPa, D = 0.55"
FEA Conclusions

- Breakdown pressure will increase as the perforation tunnel diameter decreases
- The Frac Charge Design provides less variation in the breakdown pressures thus improves pressure distribution to ensure even treatment of perforations
  - Increase stimulation efficiency

### 3 3/8” Gun Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Rotation</th>
<th>Clearance (in)</th>
<th>Hole Diameter (in)</th>
<th>Max Principal Stress (MPa)</th>
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<td>0.43</td>
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<tr>
<td>Frac Charge Design</td>
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<td>0.40</td>
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<td>Industry Charge</td>
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Case History
Field Trial 1 – Permian Basin
21 gram Frac Charge Design Field Trial #1

- Subject test well in Martin County, Texas
  - Stage #1 Perforated August 2011
    - Atoka Formation – 6 Clusters with 49 holes total
    - Formation characteristics:
      - Medium hard Limestone inter-bedded with soft to medium hard siltstone and shale.
    - History in this formation:
      - Difficult to breakdown and obtain injection rate
      - Difficulty is attributed to the wide variation in formation hardness
  - Stage #2 Perforated August 2011
    - Strawn Formation – 5 Clusters with 44 holes total
    - Formation characteristics:
      - Medium hard Limestone inter-bedded with medium hard shale.
    - History in this formation:
      - Difficult to breakdown, injection rates obtainable
21 gram Frac Charge Design Field Trial #1

- Benchmark well was also in Martin County, Texas
  - Located 9 miles to the Southwest of test well
  - By log correlation is correlative to test well
  - Perforated with Commercial ‘Good Hole’
  - Stage #1 Perforations
    - Atoka Formation – 6 Clusters with 49 holes total
  - Stage #2 Perforations
    - Strawn Formation – 6 Clusters with 50 holes total
Stage #1 Results and Observations

- Comparison of Rate and Pressure Response
  - Test Well reached designed rate (70 bpm) and pressure in 33 minutes
    - Charges were loaded in a low pressure carrier therefore the bottom cluster was not pumped into prior to the treatment as recommended
  - Benchmark well reached a stabilized rate and pressure in 29 minutes. The final rate was 55 bpm, 15 bpm less than designed.

- The 21 gram Frac Charge perforations resulted in an increase of 15 bpm at the same treating pressures
Stage #1 Rate and Pressure Overlay
21 gram Frac Charge Design Field Trial #1
August 2011 Martin County, Texas

Stage 1 Atoka Formation
Industry Charge - 6 Clusters - 49 Holes
Frac Charge Design - 6 Clusters - 49 Holes

- Industry Charge Rate and Pressure Stabilized - 29 minutes
  55 bpm at max pressure not 70 bpm as designed
- Frac Charge Design Holes Rate and Pressure Stabilized - 33 minutes
  70 bpm at max pressure as designed
Stage #2 Results and Observations

- Comparison of Rate and Pressure Response
  - Test Well reached designed rate and pressure in 25 minutes
    • Third party water transfer could not keep up causing this time to be longer than it should have been and also resulted in erratic rate during the job
  - Benchmark well reached the designed rate and pressure in 18 minutes.

- The 21 gram Frac Charge perforations resulted in a lower treating pressure from 500 to 1000 psig.
Stage #2 Rate and Pressure Overlay
21 gram Frac Charge Design Field Trial #1
August 8 & 9, 2011 Martin County, Texas
Field Trial #1 Conclusions

- **Stage #1**
  - The observed injection rate was 15 bpm higher for the same injection pressure for the same number of clusters and number of perforations.

- **Stage #2**
  - The observed treating pressure was 500 – 1000 psig lower for 1 less cluster and 6 fewer holes.

- **Overall**
  - The Frac charges have exhibited better performance in terms of rates and pressures than the industry Good Hole charges shot in the baseline comparisons.
THANK YOU

Questions and Answers