Improving Entry Hole Consistency for Shaped Charges in Sequentially-Phased Perforating Carriers

AUTHOR: Alphie Wright and Chris Sokolove, Hunting Titan
AGENDA

- Past Methods
- Consistent Hole (CH) Technology
- Opportunities for Advancement
- Comparison of Charges in Common Well Configuration
- Guidelines for Selection, Evaluation, Comparison and Feedback
- Recommendations for Improvement to API RP19B
- Conclusions
Conventional DP, SDP and BH Shaped Charges

- Maximum and Minimum Clearances
- Non-uniform distribution of entry hole diameters
- Erosion and slotting of small perforations
- Under-utilization of all perforations
- Less efficient well stimulation
- Slow ramp-up to higher treating pressures
Past Example for Consistent Hole Technology

- Perforating Gun Centralized using:
  - Centralized fins welded to tandem subs, top subs, bull plugs
  - Centralized rings place over perforating guns

- Disadvantages:
  - Additional OD on downhole equipment
  - Additional costs for associated hardware
Shaped Charge Jet Profiles

Common P-110

Wide Jet Profile

Narrow Jet Profile

Common P-110

API Standard L-80

Uniform Jet Profile
Importance of CH Technology

- Planned Hole Size & Flow Area
- Correction Factors
- Well Stimulation Plan
- Variable Hole Size & Flow Area
- Unused Perforations

+ [ ]

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Importance of Consistent Hole Technology

Consistent Hole Technology enables opportunity for optimal well stimulation.
Advancing Consistent Hole Technology

CH Technology

Unlikely that the same stimulation design is optimal for both perforation profiles

Phasing in Casing Clearance

Conventional Charge
Consistent Hole Shaped Charges

- New category of shaped charges
- Sequentially Perforating Design
  - 45° / 60° / 90° / 120° phasing
- Designed for decentralized or eccentric perforating guns
- Improves efficiency of well stimulation
- Achieves consistent hole size regardless of fluid clearance
- Advertised with Average Hole Size AND Variation in Hole Size

<table>
<thead>
<tr>
<th>Angle</th>
<th>CH Technology</th>
<th>Conventional Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.0 in</td>
<td>0.0 in</td>
</tr>
<tr>
<td>60°</td>
<td>0.5 in</td>
<td>0.5 in</td>
</tr>
<tr>
<td>120°</td>
<td>1.1 in</td>
<td>1.1 in</td>
</tr>
<tr>
<td>180°</td>
<td>1.5 in</td>
<td>1.1 in</td>
</tr>
<tr>
<td>240°</td>
<td>1.1 in</td>
<td>1.5 in</td>
</tr>
<tr>
<td>300°</td>
<td>0.5 in</td>
<td>0.5 in</td>
</tr>
</tbody>
</table>
Consistent Hole Market Trend

CH Technology has seen significant growth in the past couple of years

Estimated Industry Market

CH Market
Charge Market
Oil

CH Usage Growth Factor

Charge and Oil Market Reduction Factor

2014
2015
2016
Consistent Hole System Growth

- Exponential growth in availability of CH perforating systems
- Growth driven by market demand for efficient technology
Why Growth in Consistent Hole Technology?

- ...Operator *Increased Injectivity* by 20%
- ...Evaluated 15 frac stages to show *Lower Treating Pressures* at the same pump rate or 8-10% higher pump rate
- ...Two well studies show 10% *Reduction in Breakdown Pressure*, 2% *Reduction in Treating Pressure*, and 3% *Increase in Proppant Placement*
- ...*Reduced Injection Pressure* by 15%
- ...Achieved and maintained *Faster Pump Rate* with *Reduced Stimulation Pump Pressure*
- ...*More Consistent Treating Rate* with *Increased Sand Concentration* at *Lower Pressure*
- ...*Decentralized* CH charge resulted in 10% *Higher Treating Rate* than a *Centralized* DP charge

*Case study information compiled from multiple CH technology providers*
Advancing Consistent Hole Technology

Existing case studies highlight benefits of CH Technology utilizing the same well simulation method

**Good News!!**

These studies have established a foundation for CH Technology

Are current well simulation methods and designs best?
Advancing Consistent Hole Technology

**Conventional Shaped Charges**
- Variation in hole size (a key design input) yields unpredictable stimulation result
- Accept that actual results differ from design – often without explanation

**Consistent Hole Technology**
- Consistent hole size increases control and predictability of stimulation ⇒ More strategic placement of perforations
- Removing hole size variability provides opportunity to investigate difference between design and actual results ⇒ Increased understand of effective stimulation
Improving Entry Hole Consistency for Shaped Charges in Sequentially-Phased Perforating Carriers

3-3/8” 6 SPF 60 deg. Gun
5-1/2” Casing

**API Test: 5-1/2” 23# P-110**
- Average: 0.425 in.
- Min: 0.40 in.
- Max: 0.46 in.
- Variation: 5.3%

**API Test: 5-1/2” 17# L-80**
- Average: 0.40 in.
- Min: 0.26 in.
- Max: 0.51 in.
- Variation: 12.6%

**Conventional GH**
- Average: 0.36 in.
- Min: 0.24 in.
- Max: 0.52 in.
- Variation: 35.7%
## Calculation of Variation

Range: \( \frac{\text{Max} - \text{Min}}{\text{Avg}} \times 100 \)

Coefficient of Variation: \( \left( \frac{\text{St.Dev}}{\text{Avg}} \right) \times 100 \)

<table>
<thead>
<tr>
<th>System</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
<th>% Range</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-3/8” (5-1/2” P-110)</td>
<td>0.40</td>
<td>0.46</td>
<td>0.06</td>
<td>14.1%</td>
<td>5.8%</td>
</tr>
<tr>
<td>3-3/8” (5-1/2” L-80)</td>
<td>0.26</td>
<td>0.51</td>
<td>0.25</td>
<td>62.5%</td>
<td>28.0%</td>
</tr>
<tr>
<td>3-3/8” GH</td>
<td>0.24</td>
<td>0.52</td>
<td>0.28</td>
<td>77.1%</td>
<td>35.8%</td>
</tr>
</tbody>
</table>

**Important Statistically Important**

**Important**
Selection Principles

- Only compare performance data for charges tested:
  - Casing of equivalent or higher strength/weight
  - Fluid clearance of equivalent or greater distance
- Ensure the same calculation method is used when comparing variation
- Verify suitable Quality Control for CH Technology
Recommendations for API Standardized Testing

- Decentralized or Eccentered perforating gun
- Align perforating gun with one bank of shots at the minimum and maximum fluid clearances
- Common casing strength (i.e. P-110 casing)
- Common casing size (i.e. 5-1/2” casing for 3-3/8” gun)
- Minimum of two shots at each fluid clearance
## Recommendation for Data Publishing

<table>
<thead>
<tr>
<th>Gun Size</th>
<th>Casing</th>
<th>Min</th>
<th>Max</th>
<th>Avg.</th>
<th>Range</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-3/8&quot;</td>
<td>5-1/2&quot; 23# P-110</td>
<td>0.39</td>
<td>0.47</td>
<td>0.44</td>
<td>0.08</td>
<td>5.9%</td>
</tr>
</tbody>
</table>

OD, Weight, Grade  Specific Hole Size Range  Comparison Values
Conclusion

- Consistent Hole Technology will continue to improve for the industry

- Consistent Hole Technology has proven to benefit the stimulation of the well

- There is need for standardized testing and data publication
  - Testing in heavier weight casings
  - Minimum and Maximum Clearances with at least 2 shots per clearance
QUESTIONS?
THANK YOU!

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