Designing Shaped Charges to Perform In Reservoir Rock

IPS 16-45

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Agenda

• Introduction
• Objectives
• Design Process
  - Flow Laboratory
  - Computational Modeling
• Results
• Conclusions
Introduction

• Most industry models (used for predicting penetration) are based on API-Section I concrete based tests.
• A standard model may predict 23.43” in Berea sandstone for a Deep Penetrator (35.8” TTP Section I).
• In reality, penetration for this charges was measured to be 11.13” in an API Section-IV test under downhole conditions.
• This example clearly highlights how penetration models can be misleading when making critical job design decisions.
• We have also conducted laboratory experiments and compared measured data with advanced penetration models and comparisons have shown a discrepancy of up to 50%.
Introduction

• Several factors influence penetration characteristics
  ➢ Pressures (wellbore to pore to confining)
  ➢ Internal Stand-Off and Water Gap
  ➢ Rock properties (bedding plane orientations, porosity, permeability, UCS etc.)
  ➢ Cement and casing material strength and thicknesses.

• None of the models that exist in the industry are capable of accounting all of the above factors (in particular, the natural variances and anomalies that exist in a rock) while modeling penetration.

• A scientific and engineered approach is the best way to design a shaped charge for reservoir conditions.
Objective: Optimize Charge Design

Scenario:

- Shaped charges for oilfield perforating have long been evaluated on the basis of their performance in concrete targets shot at ambient conditions, failing to clearly evaluate performance at downhole conditions.

Solution:

- By designing a shaped charge around performance at true downhole conditions has enabled significant performance and therefore productivity improvements.

- The Rock Optimized Deep Penetrating Shaped Charge has been designed and optimized in this way. Utilizing high-end numerical modeling and extensive testing on reservoir rocks at downhole conditions, can achieve up to 47% of additional penetration in some of the most challenging reservoir conditions.
Design Process

- Technical and Engineering Expertise
  - Charge Design
  - Charge Optimization

- Flow Laboratory
  - Standard Section-II
  - Modified Section-II
  - Section-IV

- Computational Modeling
  - Hydrocode
  - Computational Fluid Dynamics
Perforation Flow Laboratory

The flow laboratory provides the capabilities to:

- Study and qualify the performance of different perforating systems in formation rock at reservoir conditions.
- Study the influence of various factors on well productivity.
- Integrate this knowledge to select the optimal perforating system and clean up strategy for improved productivity.

<table>
<thead>
<tr>
<th></th>
<th>Section-I</th>
<th>Section-II</th>
<th>Section-II Modified</th>
<th>Section-IV</th>
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<tbody>
<tr>
<td>Target</td>
<td>Concrete</td>
<td>Analog Rock</td>
<td>Analog Rock</td>
<td>Analog Rock</td>
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<tr>
<td>Confining Pressure</td>
<td>Atmospheric</td>
<td>10000</td>
<td>25000</td>
<td>15000</td>
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<td>Fluid</td>
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<td>Saturation fluid (OMS)</td>
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<td>Wellbore Pressure</td>
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<td>Not Applicable</td>
<td>25000</td>
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<td>Pore Pressure</td>
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<td>25000</td>
<td>10000</td>
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<td>Temperature</td>
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<td>Pre-shot Flow</td>
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<tr>
<td>Post-shot Flow</td>
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<td>Not Applicable</td>
<td>Applicable</td>
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</table>
Perforation Flow Laboratory - Measurements

- Pre-shot porosity
- Pre/post perforation permeability
- Perforation tunnel diameter
- Perforation tunnel depth
- Detailed tunnel characterization using advanced CT scanning methods
- Dynamic pressure data
- Core flow efficiency and productivity ratio
- Evaluate perforation cleanup mechanisms
- Optimization of underbalance methods

Designing Shaped Charges to Perform In Reservoir Rock
Hydrocode modeling for shaped charge design to change various parameters which will enhance charge performance in reservoir rock.

Computational Fluid Dynamics – Export actual tunnel geometry from CT Scans & input flow lab flow data to predict well flow.
Shape charge Penetration: Section-I & 2

- Irrespective of charge size, penetration characteristics are quite different in a true downhole condition test when compared to Section-I.
- Based on existing test data, pore pressure does seem to have an influence on charge performance.
- Modified Section-II testing is the recommended method to evaluate/understand shaped charge performance.

<table>
<thead>
<tr>
<th>Charge</th>
<th>Section I Rank</th>
<th>Section II Rank</th>
<th>Modified Section II Rank</th>
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<td>Charge 1</td>
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<td>1</td>
</tr>
<tr>
<td>Charge 2</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Charge 3</td>
<td>2</td>
<td>n/a</td>
<td>3</td>
</tr>
<tr>
<td>Charge 4</td>
<td>1</td>
<td>n/a</td>
<td>4</td>
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<tr>
<td>Charge 3</td>
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# Rock Specific Modified Section-2 Testing

<table>
<thead>
<tr>
<th></th>
<th>Section-II Berea, no pore or wellbore</th>
<th>Modified Section-II Carbon Tan</th>
<th>Modified Section-II Buff Berea</th>
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<tbody>
<tr>
<td>Pressure Conditions (psi)</td>
<td></td>
<td>9500</td>
<td>10370, 6960, 7250</td>
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<tr>
<td>Rock Optimized Charge, HMX</td>
<td>TTP, avg, 18.2”</td>
<td>19.8”</td>
<td>21.0”</td>
</tr>
<tr>
<td></td>
<td>EHD, avg 0.40”</td>
<td>0.30”</td>
<td>0.33”</td>
</tr>
<tr>
<td>Premium Deep Penetrator, HMX</td>
<td>TTP, avg 20.2”</td>
<td>14.0”</td>
<td>16.9”</td>
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<tr>
<td></td>
<td>EHD, avg 0.33”</td>
<td>0.29”</td>
<td>0.32”</td>
</tr>
<tr>
<td>Standard Deep Penetrator, HMX</td>
<td>TTP, avg 14.8”</td>
<td>11.8”</td>
<td>14.6”</td>
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<tr>
<td></td>
<td>EHD, avg 0.42”</td>
<td>0.37”</td>
<td>0.37”</td>
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</tbody>
</table>

**Rock Optimized Charge**

**Standard Deep Penetrator**
### API Section-4 Testing

- Rock Optimized perforating charge provides improved Surface Area in the perforation tunnel, thereby providing better productivity.

- Testing conducted with Buff Berea Sandstone core under similar conditions

<table>
<thead>
<tr>
<th>Tier</th>
<th>Shaped Charge</th>
<th>Core Penetration</th>
<th>Perforation Diameter (Casing)</th>
<th>Perforation Diameter (Tunnel)</th>
<th>Perforation Surface Area</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>Rock Optimized</td>
<td>18.25 in.</td>
<td>0.29 in.</td>
<td>1.24 in.</td>
<td>36.7 sq.in</td>
<td>1.56</td>
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<tr>
<td>Better</td>
<td>Premium Deep Penetrator</td>
<td>16.00 in.</td>
<td>0.31 in.</td>
<td>1.02 in.</td>
<td>26.5 sq.in</td>
<td>1.14</td>
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<td>Good</td>
<td>Standard Deep Penetrator</td>
<td>13.31 in.</td>
<td>0.36 in.</td>
<td>0.76 in.</td>
<td>16.3 sq.in</td>
<td>1.07</td>
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</table>
Conclusions

- A scientific and engineered approach is the best way to design a shaped charge for reservoir conditions (rather than Section-I/II or predictive models)

- Utilizing sophisticated numerical modeling and extensive testing on reservoir rocks at downhole conditions, a shaped charge for reservoir specific conditions has been developed.

Applications
- Natural or Stimulated completions, producers or injector wells
- Oriented perforating strategies
- Onshore and Offshore environments
- Ultra high pressure/high temperature completions
- Extended reach and highly deviated wells
- Tubing conveyed, wireline or coiled tubing conveyed perforating

Features and Benefits
- Increases production or injection by deeper formation connectivity with the wellbore
- Ensures perforation contribution efficiency
QUESTIONS? THANK YOU!