Multi-pulse Hybrid Perforating Technology
— for Low Permeability and Tight Reservoirs in China

Rock Wang
General Manager - NSOTC
Introduction to Multi-pulse Hybrid Perforating

- **Multi-pulse Hybrid Perforating**
  - combine perforating and propellant near wellbore fracturing in single run
  - improve cleanout of formation damage

- **Multi-pulse propellant**
  - enable higher pressure pulses
  - extended pressure pulses enable more effective fracturing

- **Long interval**
  - >100m per run via TCP
  - 4m per run via Wireline
API RP 19B Style Surface Test

- API 19B Concrete Target #5
- Debris of the Gun, the Casing and the Concrete after perforating
- 6 blocks of the fractured Concrete Target
- The 7.00" Casing and 4.50" Gun after Test
Case Study I: Well Cheng-XXX in Changqing Oilfield

**Oilfield:** Changqing Oilfield

**Reservoir:** oil

**Formation:** Yan X, sandstone

**Average Porosity:** 0.9~13.8%

**Average permeability:** 1.7~44.2mD

**Completion:** 5-1/2”

**History:** perforated by regular 4” gun, 5spf, 90deg, but with very low productivity.

**Solution:** Use hybrid perforating to reperforate and frack the zone.
# Cheng-XXX: Basic Information

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Cheng-XXX</th>
<th>Geological location</th>
<th>Qingyang, Gansu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellhead altitude</td>
<td>1459.88</td>
<td>Start Date of Drilling</td>
<td>/</td>
</tr>
<tr>
<td>Date of Completion</td>
<td>/</td>
<td>Formations</td>
<td>Yan X</td>
</tr>
<tr>
<td>Distance of Drilling Platform to Wellhead (m)</td>
<td>4.70</td>
<td>Depth of Top Cement Surface (m)</td>
<td>1396.00</td>
</tr>
<tr>
<td>Depth of Dogleg Point (m)</td>
<td>/</td>
<td>Max well deviation (°)</td>
<td>25.70</td>
</tr>
<tr>
<td>Testing Pressure (MPa)</td>
<td>/</td>
<td>Forecasted formation pressure (MPa)</td>
<td>8.0</td>
</tr>
<tr>
<td>Casing Spec.</td>
<td>OD (mm)</td>
<td>Wall Thickness (mm)</td>
<td>Type of Steel</td>
</tr>
<tr>
<td>Top casing</td>
<td>9”5/8</td>
<td>244.50</td>
<td>8.94</td>
</tr>
<tr>
<td>Production casing</td>
<td>5”1/2</td>
<td>139.7</td>
<td>7.72</td>
</tr>
<tr>
<td>Quality of Cementing</td>
<td></td>
<td></td>
<td>Okay quality</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Formation</th>
<th>Zone (m)</th>
<th>Thickness (m)</th>
<th>Logging Information</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yan 9</td>
<td>1359.8-1370.0</td>
<td>10.2</td>
<td>Electrical resistance (Ωm)</td>
<td>Time delay (us/m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18.89</td>
<td>238.18</td>
</tr>
</tbody>
</table>
## Multi-pulse Hybrid Perforating

<table>
<thead>
<tr>
<th>Conveyance</th>
<th>Perforator model</th>
<th>Perforating zone (m)</th>
<th>Perforating gun length (m)</th>
<th>Gun size</th>
<th>Shot density (spf)</th>
<th>Phase</th>
<th>Propellant Pellet Load (g)</th>
<th>Modular Propellant (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireline</td>
<td>Hybrid Perforating</td>
<td>1361.0-1363.5</td>
<td>2.5</td>
<td>4”</td>
<td>5</td>
<td>90°</td>
<td>780</td>
<td>2000</td>
</tr>
</tbody>
</table>

![Propellant Pellet](image1.png)  
![Modular Propellant](image2.png)  
![Loading Tube](image3.png)  
![Fully loaded gun](image4.png)
Cheng-XXX: Simulation by Simulator

**Perforating Simulator (V1.3)**

- **Peak pressure:** 53.2 MPa
  - **Burn Time:** 133.0 ms

- **Fracture Length:** 1.37 m
  - **Fracture Width:** 0.13 mm

- **Propellant case:** 39 pcs
  - **Modularized propellant sleeve:** 2 m
  - **Total propellant:** 2.78 kg

- **Total gas:** 0.0107 m^3
  - **Total liquid:** 0.0022 m^3

APP-13-020
Cheng-XXX: Fast Gauge Measurements

Simulation:
Peak pressure: 53.2 MPa
Burn time: 133.0 ms

Fast Gauge:
Peak pressure: 56.8 MPa
Burn time: 157.0 ms

First: Maximum Pressure peak = 56.8 MPa (8,238 psi) @ 5 msec
Second: Maximum Pressure peak = 51.2 MPa (7,426 psi) @ 32 msec
Cheng-XXX: Effectiveness Analysis

<table>
<thead>
<tr>
<th>Block</th>
<th>Well#</th>
<th>Formation</th>
<th>Perforating zone (m)</th>
<th>Perforator</th>
<th>Productivity (m³/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>C148-32</td>
<td>Yan 9</td>
<td>1361.0-1363.5(2.5m)</td>
<td>hybrid Perforating</td>
<td>Liquid: 7.43</td>
</tr>
<tr>
<td></td>
<td>C148-30</td>
<td></td>
<td>1360.0-1362.5(2.5m)</td>
<td>Conventional Perforating</td>
<td>Oil: 6.87</td>
</tr>
</tbody>
</table>

- **C 148-32**: Hybrid perforating
- **C 148-30**: Conventional perforating
Case Study II: Henan Oilfield

- Jianghe Block V, Henan Oilfield with low permeability (2-30mD), 8-12% porosity
- Low productivity after conventional perforating due to the tight formation
- Multi-pulse hybrid perforating makes different

<table>
<thead>
<tr>
<th>Perforator</th>
<th>Well</th>
<th>Date of perforating</th>
<th>Production layer</th>
<th>Perforating zone (m)</th>
<th>Permeability mD</th>
<th>Production m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid Perforating</td>
<td>ZA4016</td>
<td>2011.12.26</td>
<td>H1Ⅲ2 1.23 1-2</td>
<td>949.0-951.6</td>
<td>3.0</td>
<td>43.4</td>
</tr>
<tr>
<td>Conventional Perforator 1</td>
<td>A4019</td>
<td>2011.12.20</td>
<td>H1Ⅲ1.2 1-23 1</td>
<td>920.8-951.6</td>
<td>12.0</td>
<td>27.4</td>
</tr>
<tr>
<td>Conventional Perforator 2</td>
<td>A4016</td>
<td>2011.12.12</td>
<td>H1Ⅲ2 1.3 1</td>
<td>934.4-943.6</td>
<td>7.0</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Comparison between hybrid perforating and conventional perforators
Summary

- **Technical features**
  - Perforating and fracturing at the same run with high operation efficiency
  - Matured technique, safe and reliable
  - Simulation before the operation to ensure no damage to wellbore and casing

- **Applications**
  - Can be applied for tight formation with low permeability
  - Re-perforation for old wells to enhance productivity
  - Pre-treatment for hydraulic fracturing to lower breakdown pressure

- **Limitations**
  - No longer than 4m loaded gun per run via wireline to avoid cable damage
  - Cannot replace hydraulic fracturing for very low permeability formation (<1mD)