A Flow Laboratory Study of an Enhanced Perforating System Designed for Well Stimulation

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During the perforating event, the detonation of the explosive charge inevitably compresses the formation, resulting in “crushed” or “damaged” rock surrounding the tunnel.

Remediation of formation damage due to shaped charge perforating and subsequent improvement in productivity is critical.

Bypassing damage, cleaning up the tunnel and initiating fractures.

Accomplished by propellants and extreme overbalance techniques.
Background: Propellant Types and Benefits

**TYPES**

- Propellant sleeve around a perforating gun
- Molded cylinder with propellant-like oxidizing material surrounding an internal steel support tube.
- **Propellants arranged within the perforating system for specific applications to horizontal wells and improve reliability.**

**BENEFITS**

- Enhance well productivity or injectivity
- Deliver perforation breakdown and cleanup
- Deliver near-wellbore stimulation
- Overcome formation damage created during the perforating event
- Reduce hydraulic fracture initiation pressures and improve proppant placement
Background: Internal Propellant System

- Combines perforating and well stimulation in one operation.
- The system integrates perforating charges with a proprietary energetic material.
- The detonation of the perforating charges initiates a complex, sequentially burning reaction of the energetic material generating high pressure gas pulse.
- This pulse cleans the tunnel and initiates fractures into the surrounding reservoir improving production/injection performance.
Background: Internal Propellant System

- Successfully run in heavy oil SAGD (steam assisted gravity drainage) wells in Canada. Injection wells showed substantial increases in productivity.

- Tight unconventional reservoirs: West Texas field studies and Woodford shale studies have shown higher inflow performance and decrease in hydraulic fracturing breakdown pressures.
Objectives of the Study

- Quantitative and Systematic Evaluation: Development of a customized flow laboratory apparatus to understand the effect of an internal propellant in conjunction with standard shaped charges.

- A thorough assessment of HSE (Health, safety and environment) was conducted prior to the testing.

- Quantify the complex transient dynamics associated with the enhanced perforating system.

- Measure the physical characteristics of the perforated cores to provide insight into specific features as characterized by the use of propellant disks.
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.
Laboratory Test Apparatus

- Customized fixture for accommodating propellant disk and shaped charge, appropriate standoff and free gun volume.

- First-of-its kind experiment, specific aspects of HSE were evaluated first.

- 2-7/8” perforating gun with appropriate propellant system modeled for the laboratory scale testing.

- The propellant is typically a cylindrical puck shape that rests in between the perforating charges in the gun system.
- Berea sandstone with representative in-situ conditions including overburden, pore and wellbore pressures.
- Shaped charge only, zero gram propellant
- Shaped charge + 20 gram propellant (10 gram on each side)
- Shaped charge + 30 gram propellant (20 gram and 10 gram)
- Shaped charge + 40 gram propellant (20 gram on each side)
Results: Transient Pressure Data

- High-speed transient gage data (100,000 samples/sec) measured within the wellbore.

- Peak pressure measured from the baseline “shaped charge” test is around 2750psi.

- Peak pressure increased to 3100psi (20 gram propellant) and ~3750psi (30 and 40 gram propellant).

- Peak pressure signature extends for a larger time with propellants compared to the case with shaped charge only.

- 35% increase in peak pressure combined with a longer duration peak pressure regime.
Results: Post-shot analysis

- Significant amount of debris present inside the tunnel with shaped charge only.
- Minimal debris within the tunnel with propellants + shaped charge. Effective clean-up with propellants.
- Extension of the tunnel at the tip-section. This beak-like extension of the tunnel could serve as ideal regime for creating tip-fractures.
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![Images of shaped charge only and shaped charge + propellant (40 grams)]
Results: Post-shot analysis

- Tests with the propellant showed a 10% increase in core penetration compared to the test with just a shaped charge.

- Core entry hole size is slightly larger for the tests where propellants were utilized.

<table>
<thead>
<tr>
<th>Propellant Weight (g)</th>
<th>Core UCS (psi)</th>
<th>Core Penetration (in)</th>
<th>Casing EHD (in)</th>
<th>Core EHD (in)</th>
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Conclusions

- Flow laboratory study of an enhanced perforating system designed for well stimulation has been conducted in this study.

- A fit-for-purpose flow laboratory apparatus which combines standard shaped charges along with propellants within a gun system was developed to understand the aspects of clean-up and tunnel efficiencies.

- The results from this study show promising trends with respect to decreased debris, better clean-up, and more importantly, increased surface area when propellants are used in conjunction with shaped charges.

- **Plans for future**: Important aspects including tighter rocks, increased mass of propellant material etc. will be incorporated to better understand the influence of these internal-propellants.

- Use of propellants requires an integrated knowledge of perforating strategy, formation properties, well architecture and well-stimulation techniques. Computer modeling methods that simulate the dynamic behavior of this enhanced propellant/perforating system are critical to a successful job design and optimization and will need to be developed in the near future.
QUESTIONS? THANK YOU