MENAPS 13-18

More than just Penetration: Perforation Design for Naturally Completed and Stimulated Wells

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Outline

- Introduction
- Perforation Performance Evaluation
  - Implications of Extrapolating from a Single Data Point
- Perforation Geometry
  - DP Perforation Geometry and Implications
  - BH Perforation Geometry and Implications
- Design and Field Applications
  - Natural Completions: Berea Sandstone
  - Overbalanced Sand Control: Castlegate Sandstone
  - Acidizing: Austin Chalk
  - Pre Frac: Mancos Shale
- Conclusion
API Section I: Unstressed Concrete

- The API Section I Test is conducted by firing a representative gun section from the center of a poured cement target.
- This test can be registered with the API.
- The targets and charges are aged 28 days prior to performing the test for registered data.

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API Section I Test

- The target must meet minimum specifications of construction, composition, and compressive strength.
- After the shot, the targets are split, and data collected on:
  - Hole Size
  - Penetration Depth
  - Debris
  - Burr Height of Casing
API Section I Test Considerations

- The test was originally designed to examine:
  - Interference
  - Charge Quality
  - Hole Size
- It has evolved to be the prime measurement of charge penetration performance as well.
- It is difficult to predict the down hole performance of a charge from its performance in an API Section I test.
- Performance increases in this test may not translate to performance increase in certain rock.
Reversed Charge Performance

- Figure from SPE 27424, Ott, R.E. et al., “Simple Method Predicts Downhole Shaped-Charge Gun Performance.” Nov 1994

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Other Implications - Examples

- Increased penetration in cement does not mean increased penetration in most other targets
  - 2X performance in cement translates to 90% performance in rock in comparative study...
- Single point data cannot predict design dependent extrapolation
  - Dual String, or Triple String, or even Heavy Wall Casing
- Secondary characteristics not captured
  - Big Hole debris interaction with tapered cement tunnel
- Cement QC Performance vs Rock Performance
  - Periodic test during manufacturing is primary control of product produced
Perforation Performance Evaluation

Clear Tunnel vs Cement Penetration
6 month Variation

- Acceptable Performance
- Unacceptable Performance

Cement Target Penetration

Stressed Rock Clear Tunnel

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Perforation Performance Evaluation

- Single Shot Flow Cell
  - Not Perfect Simulation
  - Does not represent near wellbore damage
  - Does not represent near wellbore stress state
  - Does not show perforation interaction
  - Improvement or reduction in performance does not necessarily mean same in field

- Still a very useful tool.

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The Industry is Making Progress!

- API RP 19B Section 4 Revised and Approved
  - Highlights sources of Experimental Error
  - Adds new ways to analyze results
  - Enables more uniform testing between companies

- API RP 19B Section 2: Under Revision
  - Wide Involvement
  - Draft Standard: New Performance Metric
  - New Registered and Witnessed Test
  - Still Concentrating on Penetration Only – No Analysis
  - Currently Evaluating necessary Equipment Specifications
Perforation Geometry – DP Charges
Permeability Map, Conventional Tunnel
Permeability Map, Reactive Tunnel
Perforation Geometry – DP Charges

- 15g HMX Conventional
- API RP 19B 35.1”
- Berea Sandstone
  - 100-150 mD
  - 19% porosity
  - 7000 psi UCS
- Typical Penetration:
  - 8-9 inches
Perforation Performance Evaluation

- 22.7 g Charge
- API Cement 39.02"
- 8” Borehole
- 10” Damage Radius
- Perforations Far Field
- Assumed Open
Perforation and Well Geometry

- Perforations Near WB
- Interaction of perforation geometry with near wellbore geometry
- Improved perforation may not improve some wells
  - (too much or too little damage)
- Critical for others
Perforation Geometry – DP Charges

**Other Considerations**

- Dual String – Plugging in second string
- Gun plugging which alters dynamic surge
- Heterogeneous Formation: Plugging in the hard layers
- Where does the fluid enter (acid) or exit the formation?

**Other Lithology**

- Shale: In some cases much shorter than expected. Open tunnel a primary function of charge design, and not of perforating balance.
Perforation Geometry BH Charges

- Back to the Section 1 Test
- Maximize Area Open to Flow (Square Inches/Foot) in Standard Casing Only
- Standard Casing is L-80 Grade, and thinner than most modern applications
- Extrapolation is used by software to predict down hole performance.

Figure 1—Example Concrete Target

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Perforation Geometry BH Charges

- Translation to Heavy Wall Casing is Design Dependent
  - In one instance heavy wall performance exceeds that in thin wall casing

- Design For Heavy Wall Casing
  - Publish performance in both standard casing and heavy wall casing
  - Two data point design allows for better prediction
  - Superior charges translate across all applications
Perforation Geometry BH Charges

- Affected area much larger in diameter than hole size
- Crushed sand can form an effective injection plug
- In lab, plug can be broken down, fluidized without fracture
Berea Sandstone Flow Performance

Production Ratio vs. Overbalance for 15g Conventional and 15g Reactive\(^{(TM)}\) Charges in Berea at 4000 psi Effective Stress

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Laboratory Evaluation: Berea Sandstone

- Flow Performance is 55% to 76% superior to the conventional charge at every balance condition.
- Reactive Charge at 1000 psi overbalance performed equivalently to the conventional charge at 500 psi underbalance.
- With slight underbalance, the reactive perforation tunnel flow performance surpasses 1.0 Production Ratio.
Field Applications • Shoot and Produce

- Wells in which no stimulation is required
- Success = increased productivity
- Bonus = reduced cost, complexity, risk
  - Eliminate underbalance, release rig (TCP to W/L)

Examples:
- Thailand • +50% initial productivity based on performance of appraisal wells perforated with premium system
- Pakistan • 3x productivity of previous best-in-field well
- North Sea • Equivalent productivity with 1 run vs. 3 runs
Field Applications • Re-Perforation

- Generally a tough task for perforators
  - Effective stress increases as reservoir pressure drops
  - Hard to apply underbalance with open perforations etc.

- Success = increased productivity

- Examples:
  - UK • 30x productivity after re-perforation (best in field)
  - USA • 10x productivity ... more than 2x the increase seen re-perforating offset wells with conventional systems
  - USA • 10x increase in gas well production after re-perforation ... already shot twice with premium DP system
Castlegate Sandstone Flow Performance

Production Ratio vs. Overbalance for 23g Conventional and 23g Reactive (TM) Charges in Castlegate at 4000 psi Effective Stress

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Laboratory Evaluation: Castlegate

- Flow Performance is 6% to 59% superior to the conventional charge at every balance condition.
- Optimized Reactive Charge provided a PR of 0.92 at overbalance condition.
- Conventional charge produced deeper tunnels, however reactive design produces cleaner perforations, with better side wall condition.
Field Applications • Low Strength Rock

- Success = reduce TSS at same/higher rate due to greater number of open tunnels and reduced flux rate

- Example:
  - Oman • Well produced 2x gross liquids of comparable offsets but only 10% of the field average sand rate
  - North Sea • Excellent Performance on High Perm Injection Wells
Matrix Acidizing
Reactive Charges-23 gm Load
Needs 1/6 of Acid to break through

Conventional

Reactive

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CT Scans, Mancos Shale, 23g XEH Charges
CT Scans, Mancos Shale, 23g XEH Charges
Field Results – Breakdown Pressure Red

Breakdown Pressure as % of Offset Average

- ConA
- ConA1
- Read A
- Con B
- Con B1
- Con B2
- Read B
- Con C
- Read C
- Con D
- Read D

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Field Results – Treating Pressure Reduction

![Treating Pressure as % of Offset Average](chart)

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Field Results – Productivity Improvements

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Field Results – Offset Comparison

- 4 Offset Groups
- 13% to 29% Reduction in Breakdown Pressure
- 6% to 15% Reduction in Treatment Pressure
- Improvement in Early Productivity Decline
Field Results: Eagleford Shale

Design Performance in Eagleford Shale

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Thank you!

For more: SPE144167, SPE 116226, SPE 122174, SPE 125901

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