API RP 19B Section 2 Perforation Tests
Conducted at Multiple Facilities to
Guide Latest Section 2 Revision
IPS 16-44
AGENDA/INTRODUCTION

- Test Objectives
- Test Variables
- Test Configuration
- Target Core Analysis
- Performance Testing Results
- Statistical Analysis
- Data Analysis
- Preliminary Test Results
- Additional Testing
- Testing Outcome
- Conclusions
- Acknowledgments
Test Objectives
OBJECTIVE

API RP19B Section 2 Revision

- To evaluate the proposed API RP19B Section II revision to ensure the drafted requirements for equipment and methodology provide the ability to use a broad range of equipment while ensuring consistent results between test facilities.
- Share the results of tests conducted at eight shape charge manufacturer’s facilities. The tests were conducted to determine if differences in test configurations resulted in different depth of penetration results.
- Following the test, the draft revision was updated to reflect the learnings of the test program in the final revision.
Target Distribution and Control

- All Targets cored from the same block of “homogenous” Berea Sandstone.
- Cores were evenly distributed between participants.
Charge Selection

- One Manufacturer specifically made all 400 charges. Rigorously tested during manufacturing run, a total of 12 shots over 400 charges for consistency.

  - Standard QC style setup:
    - Penetration Average: 31.94”
    - Penetration Standard Deviation: 1.37” => 4.29%
    - Hole Size Average: 0.54”
    - Hole Size Standard Deviation: 0.01” => 2.76%
Initial Test Conditions

- UCS determined by either plug or scratch method
- Conduct 2 shots at 1500, 3500, 6500, and 9500 psi overburden
- If 2 shots were not within 15% of one another a 3rd test could be shot to replace the outlier
- Cores saturated with OMS (Odorless Mineral Spirits)
- 0 psi Pore pressure
- Minimal well bore pressure for companies using a Section IV style vessel
Test Configuration

Charge Setup

- Charge Standoff - 0.290”
- Gun Scallop - 0.125”
- Fluid Clearance - 0.75”
- Casing Plate - 0.50” AISI 4140 Steel w/ 18-22HRc and 80 ksi Yield
- Cement Sheath - 0.75” API Class A, Type I/II Cement
Target UCS Analysis- Conducted by Two Methods

Plug Method

- Plug UCS was normally distributed
- Average UCS 7147 psi with Standard Deviation 487 psi
Target UCS Analysis Conducted by Two Methods

Scratch Method

- Scratch UCS was initially bi-modal: Explained by difference in the scratch cutter width
- Average UCS 7170 psi with Standard Deviation 700 psi
Target Porosity Analysis

- The porosity of the cores fell within a normal distribution
- Minimal outliers and no visible correlation to core size and porosity
Performance Results

- Standard deviation of performance began to narrow at elevated pressures
- Overall grouping of data showed consistency in results regardless of vessel configuration and core size

![Complete Data Set, Individual Shots](chart.png)
Averaged Performance Results

- From the averaged data:
  - Consistent variation upwards at 6500psi overburden
  - All data curves follow similar trendline
Test Results

Performance Variation

All Data - Original TTP

- Average
- (+) 1 Sigma
- (-) 1 Sigma
- (+) 2 Sigma
- (-) 2 Sigma
- (+) 3 Sigma
- (-) 3 Sigma
Statistical Analysis

- Independent professional statistical analysis was conducted
- Looked at all the key variables of the testing:
  - Target UCS
  - Target Porosity
  - Target Diameter
  - Target Dry Weight
  - Vessel ID
  - Target Sleeve Thickness
  - Charge Setup Dimensions
- Analyzed individual testing company data for correlations among the same variables
Statistical Analysis

Variable Correlations

- Pearson’s correlation coefficient is a measure of the linear dependence between two variables.
- The coefficient ranges from 1 (a perfect positive correlation) to -1 (a perfect negative correlation) with zero being no correlation.
- TTP is negatively correlated with overburden.
- TTP may have slight correlation with porosity.
- Nothing else appears correlated.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation</th>
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<tbody>
<tr>
<td>Porosity</td>
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<tr>
<td>Vessel ID</td>
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<td>Hole Size Average</td>
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<tr>
<td>Scallop Plate Thickness</td>
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<td>Fluid Clearance</td>
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<tr>
<td>Target Diameter</td>
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<td>Final Dry Weight</td>
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<td>Charge Standoff</td>
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<td>Cement Thickness</td>
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<td>Sleeve Thickness</td>
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<td>Target UCS</td>
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<tr>
<td>Target Length</td>
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<tr>
<td>Overburden</td>
<td>-0.780</td>
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</table>
Data Analysis

- Inconsistencies in performance around 6500 psi overburden stress
- Was not attributed to any specific core size or vessel configuration
- Due to this additional tests were conducted at 3500 and 5500 psi
- 5500 psi was selected as a midway point between 1500 and 9500, as well as being between 3500 and 6500
Test Results

Preliminary Analysis

- Results showed to be more consistent at 5500 psi than 3500 psi
- Test method was altered to test 4 shots at 1500 psi, 5500 psi and 9500 psi
- This also requires all 4 data points be reported
  - Test can only be considered invalid if the penetration exceeds the boundary conditions of the core
Additional Testing

- The trendline shows the 5500 psi stress state fits the curve better than the 3500 and 6500 psi states.
- Justifies the modification to 5500 psi.

**Averaged Performance**

![Graph showing averaged performance](chart)

- **TTP [inches]**
- **Overburden Stress [PSI]**

- Original 4 Pressures
- Modified 3 Pressures
Simulation and Sample Size Determination

- Largest amount of shots conducted at 6500 psi, 27 total
- A 20 trial Monte Carlo simulation was used to evaluate the effect of sample size assuming the average and standard deviation of the 27 shots reflected the population average and standard deviation
- Selection based on cost-accuracy compromise
- Best value determined to be 4 samples at each stress level
- Stress range reduced from 4 to 3 to reduce costs due to the increase in samples at each stress from 2 to 4 samples

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<th>3</th>
<th>4</th>
<th>5</th>
<th>10</th>
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<td>3.5%</td>
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<td>2.6%</td>
<td>1.1%</td>
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<td>Min.</td>
<td>0.9%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>0.8%</td>
<td>0.4%</td>
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</tr>
<tr>
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<td>8.7%</td>
<td>8.5%</td>
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Difference from Population Mean

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Testing Outcome

- The reciprocal testing showed several process variations between facilities, which did not appear to show substantial differences in test results.
- The testing showed various methodologies and interpretations of the standard, which helped to correct and rewrite the final document.
- Testing ultimately showed that the testing standard was robust and could be followed at any facility as well as demonstrating its capability to produce consistent test results.
Lessons Learned / Changes

- Target Type / UCS – Berea, set from 3 sigma analysis
- Target Porosity set from 3 sigma analysis
- Target Diameter 4”-7”
- Vessel ID no min. or max (1/2” clearance sleeve OD to vessel ID)
- Target Sleeve Thickness (max 3/4”)
- Ends of target constrained
- Sample size
- Overburden stresses
- Improved core plug criteria
- Allow Scratch testers / Specify scratch cutter width
  - Two scratches 90 degrees apart & not on a bedding plane
- Reduce min. vacuum time from 6 to 3 hours
Conclusions

- The vessel design did not appear to have significant effects on performance.
- Experimental error (data scatter) showed to be more than any variation due to test configuration.
- Core size did not appear to have an effect.
- The new standard was proven out through the 8 test sites.
- Penetration accuracy of the test is +/- 7%.
- API RP 19B Section 2 is ready for review and ballot by API.
Acknowledgements

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- Tim Sampson, Baker Hughes
- Chris Sokolove, Hunting Titan
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QUESTIONS? THANK YOU!