Perforation Laboratory Testing:
How Close is Close Enough?

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Outline

- Test program description
- Objectives
- Results
- Conclusions
4 laboratory experiments
Explored 2 parameters
- Cement puck geometry (lateral dimension)
- Test pressures (full downhole, vs. reduced/scaled)
Same starting static effective stress for all
Several key performance indicators investigated:
- Casing hole size
- Formation penetration depth
- Tunnel stability & formation fracture pattern
- Flow performance

Test Program Description & Objectives

<table>
<thead>
<tr>
<th>Test #</th>
<th>Type</th>
<th>Overburden stress (psi)</th>
<th>Reservoir pressure (psi)</th>
<th>Wellbore pressure (psi)</th>
<th>Effective stress (psi)</th>
<th>Static overbalance (psi)</th>
<th>notes</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Section 2+</td>
<td>22,700</td>
<td>14,700</td>
<td>16,100</td>
<td>8,000</td>
<td>1,400</td>
<td>Standard cement puck geometry</td>
<td>Assess influence of cement puck diameter</td>
</tr>
<tr>
<td>2</td>
<td>Section 2+</td>
<td>22,700</td>
<td>14,700</td>
<td>16,100</td>
<td>8,000</td>
<td>1,400</td>
<td>Larger diameter cement puck</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Section 4</td>
<td>22,700</td>
<td>14,700</td>
<td>15,000</td>
<td>8,000</td>
<td>300</td>
<td>Full downhole pressure</td>
<td>Assess influence of absolute pressures</td>
</tr>
<tr>
<td>4</td>
<td>Section 4</td>
<td>10,000</td>
<td>2,000</td>
<td>2,300</td>
<td>8,000</td>
<td>300</td>
<td>Reduced (scaled) pressure</td>
<td></td>
</tr>
</tbody>
</table>

- 25g BH charge
- Castlegate sandstone, OMS saturated
- Simulating Q125 casing
Program Results

Effects of cement puck size – cement hole diameter

Test 1

Cement exit; hole dia~1.2”

Test 2

Cement exit; hole dia~0.7”
Program Results

Effects of cement puck size – sandface fractures

Test 1

Top view

Side view

fractures at core perforated surface: extent limited to region of cement contact

Test 2

Top view

Side view

fractures at core perforated surface: extent expanded to increased cement contact
Program Results

Effects of cement puck size – sandface fractures

Test 1

3D view of expanded zone of fractures at core perforated surface

Test 2
Conclusion:

Cement puck lateral dimensions can influence cement hole diameter and sandface fracture pattern.
Program Results

Full vs scaled pressure - casing hole size

Test 3
Downhole Pressure

Wellbore pressure = 15,000 psi
Casing EH dia ~ 0.56”

Test 4
Scaled Pressure

Wellbore pressure = 2,300 psi
Casing EH dia ~ 0.78”

Conclusion:
Testing pressures can influence hole size in casing
Full vs scaled pressure – formation penetration depth

Tests 1, 2 *

* See next slide for discussion on test 3 core

Full pressures:
Penetration depth ~ 3.5"

Scaled pressures:
Penetration depth = 4.3"

Conclusion:
Testing pressures can influence penetration depth in formation
Test 3 discussion

- During post-perforation flow:
  - Confining sleeve ruptured
  - Resulting in confining fluid (water) rushing into core
  - Partially washing out perforation tunnel
- This was caused by core material behind the confining sleeve eroding, due to one or more of the following:
  - Excessive DUB / DES (see next slide)
  - Excessive flow rates
Program Results

Tests 3 and 4 (shot-time pressure transients)

- **DUB** = Dynamic underbalance (critical parameter for **cleanup**)
- **DES** = Dynamic effective stress (may be critical parameter for **tunnel stability**)

### Test 3

- **Downhole Pressure**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 3 Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore start</td>
<td>14,700</td>
</tr>
<tr>
<td>DUB</td>
<td>8,580</td>
</tr>
<tr>
<td>Overburden start</td>
<td>22,700</td>
</tr>
<tr>
<td>DES</td>
<td>16,580</td>
</tr>
</tbody>
</table>

### Test 4

- **Scaled Pressure**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 4 Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore start</td>
<td>2,000</td>
</tr>
<tr>
<td>DUB</td>
<td>1,490</td>
</tr>
<tr>
<td>Overburden start</td>
<td>10,000</td>
</tr>
<tr>
<td>DES</td>
<td>9,490</td>
</tr>
</tbody>
</table>
Program Results

Tests 3 and 4 (flow)

- **Pre-perforation flow**
  - Core prep involved flowing in 2 configurations (FF, RF...sketch below)
  - Multiple rates in each configuration
  - Establish productivity index ($PI = Q/dP$) for each configuration ($PI_{FF}$, $PI_{RF}$)
  - *Flowed at absolute pressures matching planned post-perf flow*

- **Perforated cores were flowed over a similar range of dP values as pre-perf flow**
  - $PI_{postperf}$ established

- **Analysis**
  - Post-perf $PI$ normalized to pre-perf $PI$...to establish PR
  - $PR(FF) = \frac{PI_{postperf}}{PI_{FF}}$
  - $PR(RF) = \frac{PI_{postperf}}{PI_{RF}}$
Program Results

Tests 3 and 4 (flow results)

Test 3
Downhole Pressure

Test 4
Scaled Pressure

Test 3: Post vs Preflow

Test 3: 2 measures of Post flow efficiency

Test 4: Post vs Preflow

Test 4: 2 measures of Post flow efficiency
Program Results

Test 3 vs Test 4 (flow comparison)

<table>
<thead>
<tr>
<th>Test 3 vs Test 4: PR (Full Face)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhole Pressure (Test #3)</td>
</tr>
<tr>
<td>Scaled Pressure (Test #4)</td>
</tr>
</tbody>
</table>

Conclusion:
Testing pressures can influence flow performance.
Summary and Conclusions

- 4 laboratory tests were conducted, to investigate 2 parameters
  - Cement puck geometry (lateral dimension)
  - Test pressures (full downhole, vs. scaled/reduced)

- Conclusions
  - Cement puck geometry can influence the results
    - Fracture pattern at perforated rock face
    - Exit hole diameter in cement (at cement/rock interface)
  - Test pressures can influence the results
    - Casing hole diameter (wellbore pressure influence)
    - Perforation depth (simply matching effective stress is not adequate)
    - Tunnel stability (dictated by transients, which generally don’t scale with static conditions)
    - Flow performance
  - Core size
    - Large diameter (eg >=9”) important to minimize core boundary effects, especially with larger charges
PS - Repeat testing

- Tests 3 and 4 were repeated (but without flow)
QUESTIONS? THANK YOU

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