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Critical Application Cementing – Redefining The Issues

James Heathman
Halliburton
Houston, Texas
What are some of the “Critical” Hot Buttons That Come to Mind?

- Formation water/gas migration
- Sustained annular casing pressure
- High temperature
- High pressure
- Corrosion (acid gas, CO₂, etc.)
- Narrow Equivalent Circulating Density (ECD) windows
- Displacement mechanics
- Mechanical failure - point loading, Annular Pressure Buildup (APB)
- Any combination of the above
Issues Ranked as #1 in Priority by Various Respondents on SPE TIG Discussions

- Density control/delivery of homogenous slurry
- Bulk blending quality control
- Appropriate use of cement and additive chemistry
- Centralization – both extremes observed
- Hole quality
- Mud filter cake quality (presumably thin and impermeable)
- Mixing water quality
- Gas migration
- Must always run an External Casing Packer (ECP) to prevent annular gas flow
- Must always have a very high compressive strength
- Shoe track length
- Always pump as fast as you can
- Always achieve turbulent flow
Healthy Organizations
(Full engagement, fair and equitable, higher competency, lower cost)

Engagement Curve

Corporate Character & Competency

Higher efficiency, higher innovation, lower cost

Employee Character & Competency

Low

High

Low

High

Slide Courtesy of Abdul Jaleel Khalifa, 2007 SPE President
Job Design Behavior

Effort

High
Low

Complexity / Uncertainty

Low
High

Engagement Curve

higher efficiency, higher innovation, lower cost
Critical Application Cementing – What is it REALLY all about?

- **Zonal isolation**
- **Casing protection**
- **A necessary step to effectively produce reserves**
- **Enhancement (cement) to a conduit (casing) connecting a subterranean formation to the surface**
Today’s Challenge - Revise the Frame of Reference for What are “Critical” Issues

Understand that in today’s environment, cementing requires a true multi-disciplinary approach

- **Chemical engineering** to understand the thermodynamic variables that affect cement design and longevity
- **Mechanical engineering** to understand the material behavior of cement, rocks, and metals and how they interrelate to each other
- **Chemistry** to understand the effects of long term corrosion on both metals and cements
- **Petroleum engineering** to understand the reservoir changes that contribute to stresses on a cemented wellbore
Example Proxy of Well Complexity Trends - Non-Vertical New Wells

- Year-over-year nominal quarterly effects
  - Increase of 200 non-vertical rigs
  - Vertical drilling grew by 49%
  - Non-vertical then grew by 119%

- This month (Feb 5, 2007)*
  - US Horizontal Rig count – 324
  - One Year ago Today – 230
  - One year ago September – 171

Source: Mason, World Oil, August 2006, page 44
* Smith International
Key Cementing Issues That Don’t Always Get the Attention They Deserve

- Wellbore thermal modeling
- Formation-cement interaction
- Mechanical modeling of the cement sheath interactions with the casing and formation
Real-World Comparison: Static Estimation Schedules Versus Dynamic Computer Simulation – Expandable Liner Job

Bottom-hole Static Temperature = 145°F

Liner Expansion Period

Start Lead Slurry

End of Cement Job Placement

Start Tail Slurry

(deg F) First Sack

(deg F) Conventional BHCT Method

(deg F) Last Sack
Job Design Behavior

Effort

High

Low

Complexity / Uncertainty

Engagement Curve

higher efficiency, higher innovation, lower cost
Part 2 - Formation Issues Related to Cement Design

- Interactions between cementing fluids and formations
  - may affect formation integrity (shales) in much the same way as drilling fluids
  - water-soluble formations – evaporites such as halite - can be a problem in ways other than simple wellbore washout

REF: SPE 79913
Traditional Arguments – Salted vs Fresh-Water Cement Slurries

• **Pros**
  – Usually offsets hydration bulk shrinkage
  – Easier to retard slurry at medium to high temperatures
  – Thought to be easier to design around compatibility issues at times

• **Cons**
  – Adversely affects admixture performance
  – Lowers ultimate compressive strength
  – Hard to accelerate hydration at low temperatures

• **The big “debatable” areas**
  – Formation/slurry interactions – what are they and are they meaningful?
  – Compressive strength development – what is really important and what is simply arrived at via supposition?
  – What is the cumulative effects on fluid mechanics?
  – Is the final result really as intended?
Water-Sensitive Formations -

Exposure to Fresh Water -

Exposure to Fresh Water-Based Cement Filtrate

Our version of “Myth Busters!”
Water-Sensitive Formations - Exposure to 7% KCl Filtrate
## Effects of Formation Salt on Cements

**Halite samples from +18,000 ft TVD**

<table>
<thead>
<tr>
<th>Formation Sample Source</th>
<th>Salt Description*</th>
<th>12 hr Comp. Strength</th>
<th>24 hr Comp. Strength</th>
<th>36 hr Comp. Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW Reference</td>
<td>0</td>
<td>2230</td>
<td>2640</td>
<td>NT</td>
</tr>
<tr>
<td><strong>Sat. Reference</strong></td>
<td><strong>37% NaCl</strong></td>
<td><strong>1380</strong></td>
<td><strong>1840</strong></td>
<td>NT</td>
</tr>
</tbody>
</table>

### Contamination of Fresh-Water Reference Slurry

<table>
<thead>
<tr>
<th>S-1</th>
<th>10%</th>
<th>1000 psi</th>
<th>NT</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-2</td>
<td>10%</td>
<td>1020 psi</td>
<td>NT</td>
<td>NT</td>
</tr>
<tr>
<td>S-3</td>
<td>10%</td>
<td>1060 psi</td>
<td>NT</td>
<td>NT</td>
</tr>
<tr>
<td><strong>S-1</strong></td>
<td>Saturation</td>
<td>0</td>
<td>0</td>
<td>NT</td>
</tr>
<tr>
<td>S-2</td>
<td>Saturation</td>
<td>0</td>
<td>0</td>
<td>1440 psi</td>
</tr>
<tr>
<td>S-3</td>
<td>Saturation</td>
<td>0</td>
<td>0</td>
<td>600 psi</td>
</tr>
</tbody>
</table>

* Salt concentrations based on weight of water

### Elemental Scan by XRF

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>S-1 NaCl</th>
<th>S-2 S₂O</th>
<th>S-3 CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1 NaCl</td>
<td>~ 93%</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>S-2 S₂O</td>
<td>~ 89%</td>
<td>2.3</td>
<td>6.0</td>
</tr>
<tr>
<td>S-3 CaO</td>
<td>~ 88%</td>
<td>2.7</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**Misc. trace elements**

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1 NaCl</td>
<td>3.1</td>
<td>2.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

REF: AADE 06-DF-HO-36
Effect of Formation Salt Dissolution on Slurry Density
# Mechanical Properties Comparison

Class H cement mixed at 16 lb/gal, cured at 100°F & 1000 psi for 28 days

<table>
<thead>
<tr>
<th>Parameter under confining load</th>
<th>Fresh-water cement, cured in fresh water</th>
<th>NaCl-Saturated cement, cured in saturated brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young Modulus, psi</td>
<td>1.68 x 10E06</td>
<td>1.16 x 10E06</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>0.12</td>
<td>0.146</td>
</tr>
<tr>
<td>Tensile Strength, psi</td>
<td>450</td>
<td>280</td>
</tr>
<tr>
<td>Friction Angle, degrees</td>
<td>7.25</td>
<td>8.52</td>
</tr>
<tr>
<td>Cohesion, psi</td>
<td>2479</td>
<td>1267</td>
</tr>
<tr>
<td>Bulk volume Change, %</td>
<td>-1.8</td>
<td>0.55</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>6238</td>
<td>3291</td>
</tr>
</tbody>
</table>
Salt vs No Salt – An Improved Mindset

• **Pros to running salt systems**
  – Newer synthetic additives not as affected (by salts)
  – More desirable mechanical properties
  – Less detrimental to slurry/formation interactions
  – Design around formation contamination issues
  – Ultimate compressive strength is generally not a deciding factor

• **Cons**
  – Still difficult to accelerate some high-salt slurries at very low temperatures
Part 3 - More or Less Elastic?

Extreme examples are used to make a point, but this practice in itself can be misleading.
Portland cement by nature is brittle and low in tensile strength. The higher the cement Young’s Modulus, generally the higher the likelihood of sheath failure, which can lead to sustained casing pressure, casing collapse, and loss of wellbore integrity.

The mechanical behavior of the entire system – the cement, casing, formation, and associated interfaces - with Finite Element Analysis should be studied under realistic wellbore conditions.
Conventional Cement Design

- Subjected to over 100 pressure cycles
- Failed integrity test
- Stress cracking evident

REF: SPE 99869
FEA Model Verified Failure Modes of Cemented Annulus
“Elastic” Cement Design

- Modified cement blend, plus elastomer beads
- Subjected to over 100 pressure cycles
- Passed annular integrity test
- Casing, coupling, and completion design still had to be changed drastically to prevent collapse
This may be our expectation

But this may be what we get!
So how do we make sure we have all of the necessary design parameters properly framed?

- Stop & Remove all assumptions
- Re-establish the chain of substantiation so as to differentiate between
  - Facts
  - Intuition
  - Guessing
- Reassemble the proof or facts so that observations make sense and fit the underlying logic
Design Behavior Should Not Be Sequential

Without Excellent Execution, Planning is Meaningless

The same underlying principles apply to all levels of complexity for all well types.

Completion & Stimulation

Reservoir & Geomechanical Knowledge

Casing & Cement Plan

Execution
Summary Remarks

• Technology – old and new - is our greatest asset

• Poor execution, or even misuse, of technology is our greatest liability

• Behavior is at the root of all execution
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