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CEMENTING
Planning for success to ensure isolation for the life of the well

Daryl Kellingray, BP Exploration
Wherever we construct a well, we use cement
Why is cementing important?

Prevention of flow to surface

Sustained Casing Pressure
- 25-30% of wells are estimated to have annular pressure problems, cementing is one of the primary route causes.
Why is cement important?

**Mechanical well integrity during drilling**
- Isolation of weak formation & structural support

**Reservoir Isolation and Protection**
- Isolating production from other fluids

**Production Optimisation**
- Optimising stimulation treatments
Cementing Planning For Success

- Drilling Related Problems and Learning
  - Gas migration
  - Deep water
- Long Term Isolation
  - Isolation breakdown
  - Cement bonding
  - Mechanical Issues
- Integrated Mud and Cement Design
  - Balancing drilling fluids and cementing requirements
  - Spacers
  - Cement placement
Annular flow after cementing falls under three general classifications:

- Percolation through unset cement
- Influx via mud channels (poor mud displacement)
- Flow and/or pressure transmission through set cement (microannuli, stress cracks, etc.)

In the MMS reporting system nearly all post cementing flows occurred 3 - 8 hours after the job.
Gel strength terminology

• **Static Gel Strength** - rigidity in the matrix which resists forces placed on it

• **Critical Gel Strength** - the gel strength which the hydrostatic column (when accompanied by volume reduction)

• **Zero Gel Time or Delayed Gel Time** - time to start of critical gel strength (approx. 100 lb/100 ft²)

• **Transition Time** *(nothing to do with thickening time)* - time from zero gel time (usually 100 lb/100 sqft) to 500 lb/100 ft²
Pressure decay

**Fully Liquid**
- Full hydrostatic transmission < 100 lb/100sqft.
- Migration risk from insufficient slurry density.

**Early Gelation**
- Cement static with gels between 100–500 lb/100sqft.
- Volume reduction by fluid loss reduces hydrostatic.
- High risk of migration, mitigated by <30 min transition times and compressible cements.

**Hydration**
- Cement is no longer deformable with rapid development of strength, pore pressure in cement dropping.
- Migration risk if high permeability.

**Set Cement**
- Cement now has high compressive strength and low permeability.
Effect of gel strength on pressure transmission

Gel Strength to support overbalance = \( \frac{(OBP) \times (300)}{\left(\frac{L}{D_{\text{eff}}}\right)} \),

where
- \( OBP \) = overbalance pressure (psi)
- 300 = conversion factor (lb/in.)
- \( L \) = length of the cement column (ft)
- \( D_{\text{eff}} \) = effective diameter (in.) = \( D_c - D_{OH} \)
- \( D_c \) = diameter of the casing (in.)
- \( D_{OH} \) = diameter of the open hole (in.)

E.g.
For 26” OH and 20” casing with a 50 psi overbalance 1000 ft beneath seabed

\[
\text{Gel Strength} = \frac{300 \times 50}{1000/6} = 9 \text{ lb/100sqft} \text{ !!!!}
\]
Prevention of annular flow

- Quantify the risk (overbalance and cement column height dependent)
- Design mud displacement and cement placement
- Determine rate of static gel strength development
- Determine fluid loss requirements
### Common cementing questions?

<table>
<thead>
<tr>
<th>Question</th>
<th>Deepwater Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Should cement be tested at seabed temperatures?</td>
<td>Ignores impact of cement heat of hydration.</td>
</tr>
<tr>
<td>Will WOC always be extended in deepwater surface strengths?</td>
<td>Actual strength requirements are low (&lt;100psi for pipe support)</td>
</tr>
<tr>
<td>Is foam cement the only option?</td>
<td>API RP 65 favours foam but not the only solution.</td>
</tr>
<tr>
<td>Low fracture gradients require low density cements?</td>
<td>In deep water the seawater column reduces cementing ECD’s and can permit use of 1.92 SG slurries</td>
</tr>
</tbody>
</table>
Cementing temperatures in deepwater wells

Computer simulated cement circulating temperatures v API circulating temperatures for a deepwater 13 3/8” casing string 9000 ft below seabed.

<table>
<thead>
<tr>
<th>Water depth</th>
<th>3000 ft</th>
<th>3000 ft</th>
<th>6000 ft</th>
<th>6000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHST (°F)</td>
<td>Simulated cementing temperature (°F)</td>
<td>API Spec 10 cementing temperature (°F)</td>
<td>Simulated cementing temperature (°F)</td>
<td>API Spec 10 cementing temperature (°F)</td>
</tr>
<tr>
<td>106</td>
<td>84</td>
<td>87</td>
<td>80</td>
<td>87</td>
</tr>
<tr>
<td>146</td>
<td>100</td>
<td>128</td>
<td>100</td>
<td>128</td>
</tr>
</tbody>
</table>
Cement setting at low temperature

Are industry compressive strength tests representative when cementing surface strings in deep water?

Large scale experiment in temperature controlled room at 43°F using simple 16 ppg class G cement.

Drilling Related Problems
Crossflow in a micro annulus

Assumptions
Water viscosity 0.3 cP
Pressure drop only in microannulus
Microannulus all around the liner

Long-Term Isolation
When does cement provide a seal?

Only good primary cement jobs were included in the analysis.

Differential pressure between zones (psi) vs. Cemented standoff between zones (ft).

- High risk zone
- No Breakdown Field A
- No Breakdown field B
- Isolation Breakdown

Long Term Isolation
Design steps for selecting a slurry

Develop an assurance process

- Review analogous developments
- Identify options and risk assess including assessment of flow potential
- Determine mechanical loadings and complete modelling
- Can robust pumpable slurries be designed which can be effectively placed?
- Are the benefits real? Warranting cost and complexity?
Cement expansion

Does expansion occur when you need it?

Long Term Isolation
Internal and external volume changes

<table>
<thead>
<tr>
<th>Slurry</th>
<th>Internal Shrinkage</th>
<th>Bulk Volume Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 ppg neat G</td>
<td>-4.1%</td>
<td>-1.7%</td>
</tr>
<tr>
<td>14 ppg Pozmix</td>
<td>-2.6%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Long Term Isolation
Cement mechanical properties

- To impact the mechanical resistance novel cements must decouple stiffness (Young's modulus) from tensile strength.
- Determination of mechanical properties under triaxial conditions is critical for modelling.

Long Term Isolation
Commonly, cement evaluation indicates superior bonds are obtained against shale's compared to sandstones.
Possible explanations for lithology effect

- The log is wrong!
- Cement shrinkage due to fluid loss or bulk shrinkage
- Formation fluids entering cement impacting acoustic properties
- Shale squeezing onto the pipe
- Mud filter cake
OBM and WBM filter Cakes

WBM @ 280 deg F
24 hour fluid loss = 40.2 ml
Cake height = 5/32”

OBM @ 280 deg F
24 hour fluid loss = 9.9 ml
“Cake” height = 6/32”

Long Term Isolation
Areas of concern

- Contamination of fluids
- Spacer Design
- Cement Bonding
- Cement Placement
- Execution / Logistics
- Annular Pressure Build Up
- Completion / Productivity
Mud Contamination of the cement spacer

- Barite Sag due to surfactants impacting oil based fluids
- Unpumpable mixtures formed in surface lines or downhole

Note: Problem not really evident at 25% mud contamination!
Temperature effect on compatibility

Surfactants are Temperature Dependent, Very Critical in Deep Water

Integrated Mud and Cement Design
Mud contamination of cement

- Acceleration of cement due to brine phase in cement (cemented in liner running tools)
- Retardation by WBM (lignins/HEC/citrates/borates)
- Impact on strength/acoustic impedance and ability to quantify cement bonding
Forces dictating efficient fluid displacement

- **Pressure Force**
  - Due to rheology hierarchy and increases with increasing flow rate.

- **Buoyancy Force**
  - From the density contrast between fluids, the buoyancy force reduces with increasing hole angle.

- **Resistance Force**
  - The resistance to movement of the gelled mud in the annulus, increases as mud rheology increases and casing centralisation decreases.

Simplistically for mud removal

\[
\text{Pressure} + \text{Buoyancy} > \text{Resistance}
\]
Displacement variables

Thin muds with good pipe centralisation and high flow rates

Thicker gelled muds displaced with ineffective spacers and poor centralisation

Thicker gelled muds displaced with lighter fluids with poor centralisation

Variables to Improve Displacement

* Density Difference
* Flow Rate
* Rheology of Pill and Mud
* Volume / Contact Time
* Pipe movement

Integrated Mud and Cement Design
Predicted effect of rotation on annular velocity

7” liner in 8.5” hole
Stand Off = 40%

Axial Velocity (m/s)

No Rotation

10 RPM

25 RPM

Integrated Mud and Cement Design
Does pipe rotation help?

Computer modelling of flow during liner rotation

**PV/YP 50/21, 70% Standoff**

No channelling = 1

Integrated Mud and Cement Design
Extended gel strength development for gel mud

Integrated Mud and Cement Design
Conclusions

- There is a large industry problem related to the integrity of the cement sheath providing Long Term Isolation.
- Cement mechanical properties are important, but are highly dependent on confining forces.
- Temperatures in deepwater have a big impact on cementing temperatures and surfactant efficiency in cement spacer.
- Mud displacement and subsequent cement placement is the main cause of poor zonal isolation.
END