Cement Technology for Permanent P&A

Gunnar Lende,
Technology Manager,
Cementing Scandinavia
Topics in this presentation

Advances in cementing technology for permanent P&A

1. Sealant shrinkage during curing – Deal with it
2. Volume control on depleted well bullhead squeezes
3. Avoid section milling in overburden
4. Attacking conventional P&A critical path WOC time
5. Logging & evaluation
NORSOK D010 requirements for permanent P&A

**Table 22 – Casing cement**

<table>
<thead>
<tr>
<th>Features</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Description</td>
<td>This element consists of cement in solid state located in the annulus between concentric casing strings, or the casing/liner and the formation.</td>
</tr>
<tr>
<td>B. Function</td>
<td>The purpose of the element is to provide a continuous, permanent and impermeable hydraulic seal along hole in the casing annulus or between casing strings, to prevent flow of formation fluids, resist pressures from above or below, and support casing or liner strings structurally.</td>
</tr>
<tr>
<td>C. Design, construction and selection</td>
<td>1. A design and installation specification (cementing programme) shall be issued for each primary casing cementing job. 2. The properties of the set cement shall be capable to provide lasting zonal isolation and structural support. 3. Cement slurries used for isolating permeable and abnormally pressured hydrocarbon bearing zones should be designed to prevent gas migration. 4. The cement placement technique applied should ensure a job that meets requirements whilst at the same time imposing minimum overbalance on weak formations. ECD and the risk of lost returns during cementing shall be assessed and mitigated. 5. Cement height in casing annulus along hole (TOC): 5.1 General: Shall be 100 m above a casing shoe, where the cement column in consecutive operations is pressure tested the casing shoe is drilled out. 5.2 Conductor: No requirement as the target is not defined as a WBB. 5.3 Surface casing: Shall be defined based on load conditions from wellhead equipment and operations. TOC should be inside the conductor shoe, or to surface/seabed if no conductor is installed. 5.4 Casing through hydrocarbon bearing formations: Shall be defined based on requirements for zonal isolation. Cement shall cover potential cross-flow interval between different reservoir zones. For cemented casing strings which are not drilled out, the height above a point of potential inflow/leakage point/ permeable formation with hydrocarbons, shall be 200 m, or to previous casing shoe, whichever is less. 6. Temperature exposure, cyclic or development over time, shall not lead to reduction in strength or isolation capability. 7. Requirements to achieve the long hole pressure integrity in slant wells to be identified.</td>
</tr>
</tbody>
</table>

**ISO 10426-1 Class ‘G’**

**Table 24 – Cement plug**

<table>
<thead>
<tr>
<th>Features</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Description</td>
<td>The element consists of cement in solid state that forms a plug in the wellbore.</td>
</tr>
<tr>
<td>B. Function</td>
<td>The purpose of the plug is to prevent flow of formation fluids inside a wellbore between formation zones and/or to surface/seabed.</td>
</tr>
<tr>
<td>C. Design, construction and selection</td>
<td>1. A design and installation specification (cementing program) shall be issued for each cement plug installation. 2. The properties of the set cement plug shall be capable to provide lasting zonal isolation. 3. Cement slurries used in plugs to isolate permeable and abnormally pressured hydrocarbon bearing zones should be designed to prevent gas migration. Permanent cement plugs should be designed to provide a lasting seal with the expected static and dynamic conditions and loads downhole. 4. It shall be designed for the highest differential pressure and highest downhole temperature expected, inclusive installation and test loads. 5. A minimum cement batch volume shall be defined for the plug in order that homogenous slurry can be made, to account for contamination on surface, downhole and whilst spotting downhole. 6. The plug length shall be 100 m MD. If a plug is set inside casing and with a mechanical plug as a foundation, the minimum length shall be 50 m MD. 7. It shall extend minimum 50 m MD above any source of inflow/leakage point. A plug in transition from open hole to casing should extend at least 50 m MD below casing shoe. 8. A casing/liner with shoe installed in permeable formations should have a 25 m MD shoe track plug.</td>
</tr>
</tbody>
</table>

- Capable of providing lasting zonal isolation and structural support
- Provide lasting seal with expected static & dynamic conditions/loads
- No detrimental reduction in strength or isolation capability from temperature exposure
- Possible to place properly
- Length minimum 100 mMD (OH) or 50 (CH) mMD
9.3.8.2 Permanent well barriers

Permanent well barriers shall extend across the full cross section of the well, include all annuli and seal both vertically and horizontally (see illustration). Hence, a WBE set inside a casing, as part of a permanent well barrier, shall be located in a depth interval where there is a WBE with verified quality in all annuli.

A permanent well barrier should have the following properties:

a) Impermeable
b) Long term integrity.
c) Non shrinking.
d) Ductile – (non brittle) – able to withstand mechanical loads/impact.
e) Resistance to different chemicals/ substances (H₂S, CO₂ and hydrocarbons).
f) Wetting, to ensure bonding to steel.

Steel tubular is not an acceptable permanent WBE unless it is supported by cement, or a plugging material with similar functional properties as listed above, (inside and outside).

Elastomer seals used as sealing components in WBEs are not acceptable for permanent well barriers.
Perception – Portland cement shrinks, other sealants don’t

Well, here are some facts:

Most materials going liquid → solid will shrink during solidification / chemical reaction

- Metals, glues, paints, plaster, resins, silicones, fly ash, etc. Water
- Do not rely on bench-top demos or irrelevant test conditions
- Examples below tested at relevant conditions, unconfined, no water feed, no mercy!

- Undiluted Portland cement: 4 %, optimized Portland cement: 2 %, maybe less
- Non-Portland alternative A: 7,5%
- Undiluted Polyester based resin: 9,4% (with filler 5,2%)
- Undiluted Epoxy based resin: 4% (with filler 2,5%)
- PlastiSeal: <0,1%
- Unconfined ΔV tests!
Is the shrinkage a problem for abandonment plugs?

We know that Portland cement has hydration shrinkage

- Reaction products are denser than starting components \(\Rightarrow\) shrinkage
- Proportional to degree of hydration and water feed during hydration
- Bulk (effective external) shrinkage is \(\pm 4\%\) (pure) if no external water feed
- Reduced to 1 – 1,5 \% with effective external water feed during hydration
- These are unconfined \(\Delta V\) test results

- In reality the external radial shrinkage is low
- Due to strong bond to pipe? Also seen when container is plastic material

Why do we know this?

1. Cased hole plugs generally are pressure tested successfully with mud if properly placed
2. In some cases water pressure tests leak slightly
3. \(\Rightarrow\) leak path if any must be tight (microns)
4. 4\% of 8,5” is 8,6 mm \(\Delta D\) \(\Rightarrow\) impossible!
5. Lab specimens have to be pressed out with X MT

- In reality the external radial shrinkage is more likely to be 0,1 – 0,5 \%
Is the shrinkage a problem for abandonment plugs?

Improved test methods
- Getting closer to reality

Volumetric
Multi-directional

Advanced shrinkage test - no water access @5000 psi
Is the shrinkage a problem for abandonment plugs?

Does that mean we are OK?

- No – HC in gas or liquid form can migrate through very tight slots
- Good mud pressure test → no gas migration

We know there will be tensile stresses in cement-pipe interface

- Normally bonding is stronger than the tensile stress coming from shrinkage
  - Within reasonable shrinkage vs. Tensile Strength & Young’s Modulus the result will be porosity rather than debonding
- A proper barrier based on such a material is dependent on this disparity

We have seen that pressure tests have damaged the seal

No gas migration → pressure test → gas migration
How do we prevent or mitigate debonding?

So what can we do?

- Focus on displacement efficiency and water wetting → maximize bonding
- If possible cure cement plugs with pressure on casing → inflate pipe
- Eliminate pipe-cement interface tensile stress
  - Post curing cement expansion
    → Interface tension → compression
    → Eliminate potential for debonding
How do we prevent or mitigate debonding?

**Evidence - Plug integrity test**

- Tananger JVS 1000 test cell
- ExpandaCem HT 1,95 SG
- Phase 1: Cure in N2 → worst case shrinkage, no expansion
- Phase 2: Flow test with H₂O → fuel an expansion

JVS-1000 now located at Halliburton fluids lab, Tananger
Pipe: ID =100mm, L = 210 cm
How do we prevent or mitigate debonding?

Plug integrity test phase 1 – cure in dry environment

ExpandaCem plug integrity test
Step 1 - Curing 1200 psi \( N2 / 144^\circ C \) No water access

- **Bottom pressure decrease due to shrinkage of cement**
- **Heat of Hydration**
- **Sudden communication between top & bottom pressure sensor --> debonding**
- **Bleed off top pressure, bottom pressure follows --> communication between top & bottom sensor**
How do we prevent or mitigate debonding?

Plug integrity test phase 2 – flow with water

ExpandaCem plug integrity test - water injection & expansion
Step 2 - Water injection test 144°C, ΔP = 1000 psi (1200 psi inlet 10 cm off bottom, 200 psi on top)

Flow out = flow in --> end of expansive reaction
Stable flow at 0,01 ml/min --> permeability

Flow Rate [ml/min] vs. Time [hrs]
Pressure/Temperature [psi/°C]
Flow Rate (Injection) | Flow Rate (Receive) | Delta P | cement Temperature | Oil Temperature

Stable flow at 0,01 ml/min --> permeability
Flow out = flow in --> end of expansive reaction
Portland cement is well known and globally proven as barrier element

- Has some shortcomings, but is in general a reliable, environmentally compliant and cost effective sealant
- However for critical barriers must be used with caution and be modified to mitigate shortcomings
- There are solutions available, making Portland cement a competent barrier material

1. Ensure the cement is placed where it must be located, and does not slump afterwards

2. Reduce hydration shrinkage, post set expansion
   - Ensure external water source in one end of plug
   - Allow expansion time
Dealing with it 1

- **Water fuelled crystal growth** to provide net expansion
  - Ensures tight seal against tubulars or formation
  - Will expand as long as there is an external source of fluids
  - Long track record on permanent well abandonment projects

**Options:**
- Reduced inherent hydration shrinkage
- Modified elasticity and mechanical strength
- HC fuelled expansion & self healing feature

- **AbandaCem™** suitable for plugs
- **LifeCem™** recommended for annulus barriers or for HC response

LifeCem response to HC
Dealing with it 2

Modern materials and blends to mitigate shrinkage

• In the future we may see Portland based blends with minimal shrinkage
Deployment methods – phase 1 completed wells

- Rig-less through-tubing bullhead to squeeze perforations as phase one P&A is cost effective but requires volume control
- Density of fluids creates a challenge on depleted wells
- Free-fall causes loss of volume control

The solution:

- **AbandaCem™ Light**
  - 12 ppg / 1.50 SG
  - High strength
  - Low permeability
  - Low shrinkage
  - Post set expansion

- Lightweight displacement fluid
  - 5 – 7 ppg / 0.6 – 0.84 SG

- Vacuum period reduced
- Can be inflow-tested

Simulated Hydrostatics

- Regain Pressure with 5.0 ppg Disp. Fluid and 13.0 ppg Cmt
- Regain Pressure with SW and 15.9 ppg Cmt
P&A methods – phase 2 insufficient annular barrier fix

- Traditionally handled with section milling or casing pulling
  - Time savings, cost, swarf are main drivers
- **2011 solution:**
  - PWC & Halliburton perforation combo system (one trip)
  - Strong support from CoPNo
  - System engineered approach
  - Significant learning’s
- **Current experience:**
  - Savings: 210 rig days and 148 tons swarf
  - 3 plugs installed in one well in 9.4 days
  - Installed on fixed platforms and semi-submersible rigs
  - Increasing job count and customer base
  - Very successful
- **2012 further enhancements:**
  - Great learning’s, improved procedures
  - Tailored TCP
  - Tailored AbandaCem & AbandaSpacer solutions
  - More features
P&A methods – WOC time during OH P&A operations

Challenge:

• WOC necessary to meet requirement for cement plug verification after OH P&A
  • Physical tag
  • Pressure test / inflow test
• WOC function of cement fluid time
  • Can be quite long due to long operation time
  • WOC = 3 x TT quite common
  • Uncertainty of temperature
• Several plugs often required
  • Multiple plugging operations

Solutions:

• Multiple plug & long fluid time can be addressed with BHKA-D system
  • Long global success history (>300 jobs), SPE 102534
• WOC time uncertainty to some extent addressed with offshore UCA
• Reduced WOC vs fluid time designs to certain extent available
• Physical verification solution being developed
  • Pending IP, substantial WOC time saving expected
Advanced logging solutions for barrier verification

**Challenge:** Verify adequate barrier in annulus with logging methods

- Existing cement job
- After Perforate-Wash-Cement operation
  - Possibly poorly or non-centralized pipe
  - Perforated pipe
  - Spacer and cement possibly mixed together $\rightarrow$ higher AI on homogeneous fluid
  - Possibly spots of fluid embedded in the cemented interval
  - Uncertain about annulus content above cement $\rightarrow$ uncertain reference AI

**Solutions:**

- Determine quality of cement sheath using:
  - Traditional CBL tool (including Radial tool) and Ultrasonic tool
    - Cement to pipe bond
    - Cement to formation bond
  - **Advanced Cement Evaluation (ACE)** analysis method
    - Statistical Variance Processing
    - Differentiate cement from fluid $\rightarrow$ Differentiate spots from homogeneous mixture

Norway support contact: **Peyton Lowrey**
Summary & questions

1. Sealant shrinkage during curing – Deal with it
2. Volume control on depleted well bullhead squeezes
3. Avoid section milling in overburden
4. Attacking conventional P&A critical path WOC time
5. Logging & evaluation

- Several projects ongoing
- Patents pending
- Looking for partners and funding
- Looking for cases to work on

Stay tuned for more great solutions to come!