Perf/Wash/Cement
Best Practice: PWC Qualification Matrix

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Agenda

- Valhall DP P&A Scope
- Technologies for remedial work
  - Section Milling
  - Perf, Wash & Cement (PWC)
- Norsok D-010 Requirements
- Introduction of PWC on Valhall
- PWC Track Record
- Qualification Plan
- BP Track record before/after qualification
- PWC Performance
- CFD Modelling
- EAC Table for PWC
Valhall DP P&A Scope

- 31 Wells, Maersk Reacher / Maersk XLE4
- Cemented 13 3/8"
- Uncertainty on 9 5/8" cement top
  - Plan for remedial work at two barrier locations:
    - Seal 8 & Seal 7 (DPZ 7 Weak Zone)
  - Options for remedial work:
    1. Section Milling
    2. Perf., Wash & Cement (PWC)
Section Milling (Alt. 1)
High level steps

1. Install bridge plug and cut window for mill
2. Section mill 50m (One barrier)
3. Underream OH section
4. Place OH to Casing cement (min 50m inside csg)
5. WOC/Pressure test

Estimated time (one barrier): 10 days

Main Challenges: Swarf Handling, Losses, Durability of Section Mills
Perf, Wash & Cement (Alt. 2)
High level steps

1. Perforate casing
2. Set internal base for cement
3. Wash behind the perfs, using either a *swab cup tool* or a *jetting tool*
4. Displace the mud and place spacer behind the perfs
5. Place cement inside casing and behind the perfs, resulting in a combined internal and external cement plug
6. WOC / Drill out internal cement plug, log annular cement
7. Re-set internal cement plug
8. Verify cement plug (WOC/Tag/P-test)

Estimated time (one barrier): 6 days

Main Challenges: Losses, lack of experience
**INTERNAL CEMENT PLUGS**  
**NORSOK D010 v4**

- Section 9.6.3.2, EAC Table 24
- Key points:
  - An internal cement plug shall be minimum **50 mMD**, if set on a mechanical plug/cement as a foundation, otherwise **100 mMD**
  - A combined cement plug shall be drilled out until hard cement is found
  - Verification: tag and P test @ 1,000 psi above LO (P test not required if plug set on a P tested foundation), or 500 psi for surface casing plugs

**ANNULAR CEMENT BARRIERS**  
**NORSOK D010 v4**

- Section 9.6.3.1, EAC Table 22
- Key points:
  - Cement length for an annular WBE is **50 mMD** with formation integrity at the base of the interval.
  - If the casing cement is verified by logging, a minimum of **30 mMD** interval with acceptable bonding is required to act as a permanent external WBE.
  - **2 x 30 mMD** verified by bonding logs when the same cement is part of both primary and secondary well barrier.

**Conclusion:** For techniques such as PWC that establish annular and internal barriers in one single operation, requirements can be confusing and possibly contradictory and inefficient depending on how the requirements are being interpreted.
Introduction to PWC as the chosen technology on Valhall DP P&A

- Valhall DP PWC history
  - PWC introduced on well A-25 in October 2014, the first well in the P&A campaign
    - DPZ 7 Barrier, 9 5/8in Csg
    - Swab cup type & Jetting type
  - Later performed on well A-4, A-10, A-5, A-9 and A-6 (Seal 7 & 8)
  - 6 PWC jobs drilled out and logged (one performed with swab cups)

- Qualification process for omitting logging as verification
  - Use Track record, establish a parameter set
  - DNV-RP-A203 Technology Qualification
# BP Track record with PWC

**Basis for Qualification Matrix (9 5/8" Csg)**

<table>
<thead>
<tr>
<th>Well</th>
<th>A25BT3 (1&lt;sup&gt;st&lt;/sup&gt;)</th>
<th>A25BT3 (2&lt;sup&gt;nd&lt;/sup&gt;)</th>
<th>A4B (1&lt;sup&gt;st&lt;/sup&gt;)</th>
<th>A4B (2&lt;sup&gt;nd&lt;/sup&gt;)</th>
<th>A10BT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Perforated interval</td>
<td>77.6 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Internal Base</td>
<td>K-1 Packer</td>
<td>Cement</td>
<td>ICF</td>
<td>Cement</td>
<td>ICF</td>
</tr>
<tr>
<td>Annular base</td>
<td>Creeping Shale</td>
<td>Cement</td>
<td>Kratos</td>
<td>Cement</td>
<td>Kratos</td>
</tr>
<tr>
<td>Inclination</td>
<td>62-63°</td>
<td>62-63°</td>
<td>50°</td>
<td>50°</td>
<td>40-43°</td>
</tr>
<tr>
<td>PWC Tool</td>
<td>Swab Cups</td>
<td>Jetting tool</td>
<td>Jetting tool</td>
<td>Jetting tool</td>
<td>Jetting tool</td>
</tr>
</tbody>
</table>
## Time effect on cement bond

<table>
<thead>
<tr>
<th>Top MD</th>
<th>Base MD</th>
<th>Thickness MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1783.1</td>
<td>1786.2</td>
<td>3.1</td>
</tr>
<tr>
<td>1789.6</td>
<td>1793.2</td>
<td>3.6</td>
</tr>
<tr>
<td>1794.5</td>
<td>1798.1</td>
<td>3.6</td>
</tr>
<tr>
<td>1800</td>
<td>1804.1</td>
<td>4.1</td>
</tr>
<tr>
<td>1804.8</td>
<td>1807.4</td>
<td>2.3</td>
</tr>
<tr>
<td>1807.1</td>
<td>1808.3</td>
<td>1.2</td>
</tr>
<tr>
<td>1810.5</td>
<td>1813.8</td>
<td>3.3</td>
</tr>
<tr>
<td>1815.1</td>
<td>1818.4</td>
<td>3.3</td>
</tr>
<tr>
<td>1820.6</td>
<td>1824.1</td>
<td>3.5</td>
</tr>
<tr>
<td>1825.3</td>
<td>1827.6</td>
<td>2.3</td>
</tr>
<tr>
<td>1827.5</td>
<td>1828.4</td>
<td>0.8</td>
</tr>
<tr>
<td>1830.4</td>
<td>1832.8</td>
<td>2.4</td>
</tr>
<tr>
<td>1835.2</td>
<td>1838.3</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>36.6</strong></td>
<td></td>
</tr>
</tbody>
</table>

An increase of bonding of >20% was seen on the second log performed 6-7 days after the first log.

Additional Bonding Assigned
Qualification Plan
DNV-RP-A203 Technology Qualification Process

- Recognised method to provide qualification evidence
- Not qualifying a new technology, but used a similar approach for qualifying alternative verification method specific to PWC operations
- Internal Process:
  - Make offset database with all relevant parameters
  - Agree on critical parameters with other operators and suppliers
  - Review proposed parameter set with BP Engineering Authority and BP Zonal Isolation Technical Specialist
  - Review proposed Qualification Matrix with BP Zonal Isolation SETA (Segment Engineering Technical Authority)
  - Initiate generic deviation to internal practice
  - Monitoring and periodic review of job outcome
  - Offset Data Base shall be continuously updated for all PWC jobs performed

Source: DNV-RP-A203 Technology Qualification Process
BP’s philosophy with respect to requirements and verification

- Length of single annular barrier restored with PWC: 30 mMD
- Length of combined primary/secondary annular barrier restored by PWC: 60 mMD
- Length of internal PWC wellbore plug: Extend at least 50m above top perf
- Recommended perforated interval length in order to achieve dual barrier requirements: 80 mMD
- Verification of the PWC job as per specific EAC table, initially created by BP using the NORSOK format/philosophy and completed in cooperation with ConocoPhillips and Statoil
  - Logging: optional if design/execution of critical parameters as per Qualification Matrix
  - Qualification Matrix based on:
    - Track record
    - Periodic verification/re-assessment
  - Verification of conformance to Qualification Matrix done by Technical Specialist
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing Size [in]</td>
<td>9 5/8”</td>
<td>9 5/8”</td>
<td>9 5/8”</td>
<td>9 5/8”</td>
<td>9 5/8”</td>
<td>9 5/8”</td>
<td>7 5/8”</td>
<td>9 5/8”</td>
</tr>
<tr>
<td>Length of Perforated interval</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>80 m</td>
<td>80 m</td>
<td>80 m</td>
<td>80 m</td>
</tr>
<tr>
<td>Internal Verification</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
<td>Tag / Pr.test</td>
</tr>
<tr>
<td>Internal base</td>
<td>Cement</td>
<td>ICF</td>
<td>Cement</td>
<td>ICF</td>
<td>ICF</td>
<td>ICF</td>
<td>ICF</td>
<td>ICF</td>
</tr>
<tr>
<td>Annular base</td>
<td>Cement</td>
<td>Kratos</td>
<td>Cement</td>
<td>Kratos</td>
<td>Kratos</td>
<td>Cement</td>
<td>Formation</td>
<td>Formation</td>
</tr>
<tr>
<td>Inclination</td>
<td>62-63°</td>
<td>50°</td>
<td>50°</td>
<td>40-43°</td>
<td>25-30°</td>
<td>42-43°</td>
<td>14°</td>
<td>26°</td>
</tr>
</tbody>
</table>
CFD Modelling for Fluids Flow During a PWC Process for P&A Operation

- Tools (incl. nozzle size and placement), wellbore configuration (incl. perforation parameters), and fluids properly modelled in CFD
- Ability to simulate tool rotation and tool movement (up/down)
- Results in line, so far, with visual observations from yard test
- Only washing has been simulated to date, and with 100% casing standoff, but results are very promising
  - Clear indications that washing sequence could be reduced to single trip (from top to bottom), instead of current round trip
  - time savings
  - In some cases (very high inclination, poor casing stand off), up and down wash trips may be required (further simulations required to assess this)

- Next steps
  - Include casing eccentricity in washing simulations
  - Cement placement simulations
Norsok section 4.2.4: “A new EAC table shall be developed in cases where an EAC table does not exist for a specific WBE. The level of detail shall be defined by the user.”

<table>
<thead>
<tr>
<th>Features</th>
<th>Acceptance criteria</th>
<th>See</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Description</td>
<td>This element consists of cement placed in the annulus between the casing/liner and the bore hole wall while also forming a cement plug inside the wellbore by using the Perf, Wash &amp; Cement technique (PWC).</td>
<td></td>
</tr>
<tr>
<td>B. Function</td>
<td>The purpose of the element is to provide a continuous, permanent and impermeable hydraulic seal across a perforated interval in the casing annulus and inside a wellbore, to prevent flow of formation fluids between formation zones and/or to surface/seabed</td>
<td></td>
</tr>
<tr>
<td>C. Design, construction and selection</td>
<td>1. A program shall be issued for each PWC operation, covering the following as a minimum: a) Foundation requirements in casing and annulus b) Perforation hole size and density, relative to casing size and hole size c) Parameters for washing perforations, and placement of spacer and cement. d) Properties of mud and spacer, relative to formation and cement slurry design 2. The cement plug shall a) Be designed as per EAC Table 24 paragraph C, section 1-7 b) Cover the perforations and the logged/verified interval in the annulus c) For the primary barrier, extend into the casing above the top perforation. For the secondary barrier, extend at least 50m MD above the top perforation 3. Planned perforation interval length: d) Shall be sufficient to obtain minimum 30m MD of cement bonding verified by logging for the element to act as a single barrier e) Shall be sufficient to obtain minimum 2 x 30m MD of cement bonding verified by logging for the element to act as a combined primary and secondary barrier</td>
<td></td>
</tr>
</tbody>
</table>
| D. Initial verification | 1. The annulus cement length shall be verified by one of the following:  
   a) Bonding logs: Logging methods/tools shall be selected based on ability to provide data for verification of bonding. The measurements shall provide azimuthal/segmented data. The logs shall be verified by qualified personnel and documented.  
      a. Actual cement length verified by bond logs shall be minimum 30m MD for one barrier and minimum 2 x 30m MD for a combined barrier.  
   b) If the element has previously been qualified for the same casing/borehole geometry, lithology and fluid system, by drilling out cement and running cement bond logs, and a successful track record has been established, using a qualification matrix with a documented parameter set is considered sufficient for subsequent wells.  
      a. In the event of losses, or the inability to perform the PWC operation according to the parameter set defined in the qualification matrix, the cement plug shall be drilled out and bond logging shall be performed.  
 2. The internal cement plug shall be verified as per EAC Table 24, paragraph D  
   a) If the element has previously been qualified for the same casing/borehole geometry, lithology and fluid system, by tagging the internal cement plug, and a successful track record has been established, tagging may be omitted for subsequent wells.  
      a. The cement plug shall be verified by pressure testing |
| E. Use | None |
| F. Monitoring | 1. The annulus pressure above the casing cement shall be monitored at a defined frequency when access to this annulus exists. |
| G. Common well barrier | If one continuous cement plug (same cement operation) is defined as part of the primary and secondary well barriers, it shall be verified according to EAC Table 24, paragraph G |
Questions?

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One Team
Whenever the strength of the individual, we will accomplish more together. We put the team ahead of our personal success and commit to building its capability. We trust each other to deliver on our respective obligations.