Performance standard for plug and abandonment of offshore wells

Examples and applications

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Content

- DNV GL RP-E103 Risk based abandonment of offshore wells

  - Risk assessment method for P&A wells
  
  - Performance standards for P&A

- Case examples of alternative P&A designs
Background of Knowledge

- 2\textsuperscript{nd} revision of Recommended Practice DNV GL RP-E103 to be released early 2018.

"Risk based Abandonment of offshore wells"

- The recommended practice DNV GL RP-E103 provides a framework for application of risk based methods in the well abandonment design, when performing risk assessment and in developing performance requirements for the well barriers.
**Fit-for-purpose Method**

**Current P&A Regulations Internationally**
- There are prescriptive requirements as to the number and size of plugs required.
- The requirements are the same for all types of wells.

**Alternative ways / Risk-Based Approach**
- The industry is looking to differentiate between P&A requirements on a well-by-well basis.

**Fit-for-purpose**
- DNV GL RP-E103 is a fit-for-purpose method, where both the risk acceptance criteria is site-specific and the abandonment well design can be well-specific.
- Well barrier specific performance requirement can be established
- New technology, methods, standards and development of best practices can be applied.
What does “performance-based” mean?

- Specific solutions can be applied to wells individually, based on the well’s P&A needs.

- Adjustments to the well abandonment design could be considered and evaluated:
  - Changing the number of permanent barriers required
  - Changing the type of permanent barriers
  - Changing the properties of the permanent barriers (size, length, shape, composition, permeability)
  - Changing the position of the barriers
Well P&A design
Are all P&A wells the same?

Moderate flow potential, hydrocarbon-bearing

Limited flow potential, not hydrocarbon-bearing

HPHT reservoir, moderate flow potential

Depleted reservoir, limited flow potential

Primary barrier
Secondary barrier
Surface barrier
Elements in well abandonment risk assessment

- Well abandonment design
  - Pressure and flow sources
  - Well barrier failure modes
  - Leak potential
  - Impact analysis
  - Performance requirement (PR)

- Design meets PR
  - No
  - Yes
  - Qualified well abandonment design

Input:
- Well specific input
- Geology input
  - Reservoir, Overburden
- Natural resources
- Metocean data
Examples of numerical analysis done
Assessment of plug length and setting depth

Cement barrier length and depth

Leak rate
- Hydrocarbon pressure gradient across plug?
  - Permeable plug?
  - Permeable formation outside plug?

Mechanical forces
- Pressure differential across plug?
  - Plug shear strength?
  - Formation strength at plug depth?
Annulus - Leak rate analysis

Analysis of fluid properties

Flow potential through permeable cement

Shut-in pressure and Pressure differential across annulus plug
Comparative analysis
Minimum annular cement length (1/3)

Step in curve due larger cross section at surface casing cement plug. Larger hole and casing diameter.

9 7/8” casing shoe

13 3/8” casing shoe
Comparative analysis
Minimum annular cement length (2/3)

The shear bond capacity comparison graph shows the minimum cement length where the actual shear stress, interface between cement and formation, is equal to the shear strength in the reference well.
Comparative analysis
Minimum annular cement length (3/3)

The shear bond capacity graph shows the minimum cement length where the actual shear stress, between cement and formation, is equal to the shear strength.
Barrier failure modes

- Shrinking cement
- Micro annulus
- Formation strength and sealing capability
- Cap rock integrity
- Etc.

<table>
<thead>
<tr>
<th>Barrier element</th>
<th>Failure mode</th>
<th>Failure cause</th>
<th>Effect</th>
<th>Risk assessment</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open hole cement (rock-to-rock cement in milled window), primary barrier</td>
<td>Insufficient barrier length, less than milled window.</td>
<td>Reduced structural capacity of cement.</td>
<td>Likelihood with 20 m</td>
<td>Likelihood of structural collapse is reduced with increasing length. Ref. structural capacity calculation of cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Low top of barrier</td>
<td></td>
<td>Likelihood with 30 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- barrier slippage (note: calculation table xx SF)</td>
<td></td>
<td>Likelihood with 50 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Density miscalculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Poor volume calculations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Possible leak of sea water into well</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Risk Evaluation Tool – Risk Matrix

<table>
<thead>
<tr>
<th>Reputation</th>
<th>Platform Safety Risk</th>
<th>Time &amp; Cost</th>
<th>Long-term Environment</th>
<th>Operational Risk</th>
<th>Increasing probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>I5</td>
<td>Visible oil on surface</td>
<td>&gt; 1 kg/s hydrocarbons on platform</td>
<td></td>
<td>Loss of both barriers</td>
<td>P1 1x10^{-4} P2 1x10^{-3} P3 1x10^{-2} P4 5x10^{-2} P5 1x10^{-1}</td>
</tr>
<tr>
<td>I4</td>
<td>Gas bubbles detected at surface, well site</td>
<td>&gt; 0.1 kg/s hydrocarbons on platform</td>
<td></td>
<td>Loss of one barrier</td>
<td></td>
</tr>
<tr>
<td>I3</td>
<td>Gas bubbles detected at seabed, well site</td>
<td>&gt; 0.01 kg/s hydrocarbons on platform</td>
<td>Operator &amp; Location Specific</td>
<td>Uncertain well barrier condition</td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>Gas bubbles detected on license</td>
<td>Undetectable hydrocarbons on platform</td>
<td>Operator &amp; Location Specific</td>
<td>Negligible well integrity situation</td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>No impact</td>
<td>No hydrocarbons on platform</td>
<td></td>
<td>No impact</td>
<td></td>
</tr>
</tbody>
</table>

- The proposed risk matrix is aligned with industry codes and operator best practice.
Examples
Case A

- Subsea Template
- Oil production reservoir
- Two overburden zones (gas, oil)

- No significant annulus leakages were observed and recorded, good annulus cement
- No migration of overburden fluids and no hydrocarbons observed in environment
Case A

- Analyses provided the required minimum permanent well barrier length.

**Results**

- For the deepest reservoir
  - minimum of 30m interval with acceptable bonding and casing cement verified by logging.

- Lower overburden zone
  - minimum of 15m interval with acceptable bonding and casing cement verified by logging.

- For the upper overburden zone
  - minimum of 18m interval with acceptable bonding and casing cement verified by logging.
Case A
The alternative P&A design was selected as the required permanent barrier lengths, which could be used operationally to simplify decision making and to potentially lower operational costs and well P&A time.
Case B

[Diagram showing various barriers]

Legend:
- Primary barrier
- Secondary barrier
- Surface barrier
Case B

Comparison of fit-for-purpose well barriers (RP ch 2.3.2-2.4.2)

Conclusions

- Reservoir pressure is lower than hydrostatic pressure. **There is no gas flow potential across the barrier plugs.**
- Plug length of 20 m considered sufficient to withstand the anticipated combined loads.
- The plugs can withstand the anticipated environment.
- The setting depth is acceptance as long as the barriers are set within the boundaries for mechanical strength and formation strength.
Case B

Regarding the length of the reservoir barrier, compare the leak risk between 20, 30 and 50 m barrier plug in a milled window.

A length of the reservoir barrier of 20 m (cement in a milled window or annulus plug logged good > 20m) provides an acceptable risk level to withstand the expected mechanical forces on the cement plug. Increased length provides reduced vulnerability.

<table>
<thead>
<tr>
<th>Activity 2</th>
<th>Base case</th>
<th>Alternative case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reputational</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Platform Safety</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Time &amp; Cost</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Long Term Environment</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Operational</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

P&A risks categories

Reputational risk
Considering the risk of visible oil at surface, or gas bobbles at surface or subsea.

Platform safety risk
Gas release rate at platform

Long-term environment
Consequence for the environment, sea floor, water column, surface.

Operational risk
Loss of well barriers
Case C

- Major cost savings been implemented in well P&A in Norway on the Huldra field with the help of DNV GL.¹

- Risk assessing the alternative well abandonment designs proved the strength of the alternative solutions.

¹ – Huldra PP&A project – from five to one double barrier - PAF Seminar, Stavanger – 29. October 2015
# Case C

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform Safety</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Time &amp; Cost</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Long Term Environment</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Operational</td>
<td>Low</td>
<td>Low</td>
</tr>
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</table>

- Cost savings claimed to be 100 MNOK per well x 5 wells.
Summary

- DNV GL provides P&A risk assessment method
- Performance requirements can be defined to P&A
- Examples show that considerable savings can be achieved
- “Fit-for-purpose” designs can be used rather than “one size fits all”
Risk-based abandonment of offshore wells, DNV GL

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