Identification and Qualification of Shale Annular Barriers Using Wireline Logs During Plug and Abandonment Operations - SPE/IADC 119321


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Sidetrack activity on mature offshore fields

- Many offshore mature fields have a shortage of well slots
- Sidetrack activity needed to extend field life - increasing activity
- Typical sidetracks planned below 20” - 13 3/8” casing
- P&A of old well track requires suitable barriers to be put in place
- Barrier requirements on NCS controlled by Petroleum Safety Authority (PSA).
- Similar requirements on other offshore areas
PSA Barrier philosophy

• Norwegian PSA and StatoilHydro require tested double barrier approach
  – Follows NORSOK standard D-010

• Annular barriers are typically cement and wellhead
• During P&A an additional barrier is often needed
Secondary barrier problem during P&A

- Primary annular barrier usually good
- Secondary annular barrier often missing
- 50 m barrier often needs to be proven / added
- Solutions:
  - Perforate & pressure test suspected barrier
  - Perforate / squeeze / run bond log
  - Section mill casing
- All methods
  - Destructive
  - Time consuming
  - Failure prone

- Shale observed swelling / colloming into hole
- Can formation be used as a barrier instead?

Diagram showing the annular barriers and well completion details.
Using collapsed formation as a barrier – PSA requirements

**NORSOK Standard D-010**

9 Sidetracks, suspension and abandonment

9.3 Well barrier acceptance criteria

9.3.8 Permanent abandonment

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……

A permanent well barrier should have the following properties:

a) Impermeable.

b) Long term integrity.

c) Non shrinking.

d) Ductile – (non brittle) – can withstand mechanical loads/impact.

e) Resistance to different chemicals/ substances.

f) Wetting, to ensure bonding to steel.

**Shale satisfies all these criteria**
Using collapsed formation as a barrier – Practical requirements

- We need to prove the collapsed formation is shale (impermeable, long term, non-shrinking, ductile, chemical resistance, wetting)

- We need to prove the formation has collapsed all around the casing over a sufficient interval (50m).

- We need a high enough formation strength to avoid propagating upward fracture propagation
Using collapsed formation as a barrier – Practical Solutions

• We need to prove the collapsed formation is shale (impermeable, long term, non-shrinking, ductile, chemical resistance, wetting)

• We need to prove the formation has collapsed all around the casing over a sufficient interval (50m).

• We need a high enough formation strength to avoid propagating upward fracture propagation

• Ensure geological data indicates good shale presence

• Run ultrasonic & CBL bond log

• Need to know formation fracture pressure (leak-off).

• Must ensure this exceeds max theoretical reservoir pressure with a gas column to barrier

Also need to qualify that an identified barrier really is good
Ensuring sufficient fracture strength

- Use pressure prognosis
- Ensure proven by leak-off test
- Exceeds fracture pressure at top green clay
- Sufficient thickness of clay below fracture pressure for barrier

Hordaland Green Clay
Bond logging - Basics of measurement

Measurement corresponds with the stiffness of the annular material

- CBL free pipe $> 50 \text{ mv}$
- CBL good cement $< 10 \text{ mv}$
- CBL shale barrier $< 20 \text{ mv}$

Measures Acoustic impedance of annular material

- $Z$ fluid $< 2.5 \text{ Mrayl}$
- $Z$ cement $4 - 7 \text{ Mrayl}$
- $Z$ shale $> 3 \text{ Mrayl}$
Formation collapse – mechanism

• Theory and drilling observations tells us:
  • Shale can deform and move into the borehole
  • Such deformation can be rapid or slow

• The processes involved are:
  • Shear or tensile failure
  • Compaction failure
  • Thermal expansion
  • Chemical effects
  • Creep

• Important to understand collapse mechanism to ensure barrier is good
• Tests & Evidence shows collapse observed on bond logs is creep
Collapse mechanism - test jig evidence

• Concern that loose material could look like a barrier on logs

• Test jig built to test logging tools with different materials in annulus
  – Loose non-consolidated material (sand)
  – Water (control)

• Results in sand showed poor bonding (bubbles in pore spaces)
  – Rules out mechanisms creating loose annular material (shear/tensile failure and compaction)
Collapse mechanism – log evidence

- Bond logs over shale zone with chalk beds
- Non cemented zone
- Sinuousoidal features correlate with chalk
  - Indicates annular material is geological beds
- Barrier occurs only in the shale sections
  - No evidence of rubble filled annulus
  - No evidence of thermal expansion
- Similar effects in OBM and WBM wells
- **Creep is the primary mechanism**
Formation barrier qualification - first test case

• NORSOK regulations allowed use of formation as a barrier.

• Sidetrack planned below 18 5/8” casing shoe

• Second annular barrier needed behind 9 5/8” casing

• Hordaland Green clay could provide required barrier

• Qualification process to be carried out by:
  • Recording bond logs and confirming good “bond”
  • Good pressure test through perforations up to leak-off
  • Monitoring surface annular response

• Annular barrier proven: P&A and sidetrack carried out

• Log used as a “calibration” for the response required for a shale annular barrier.
Test case #1

- Green clay at 2705m – 2100m
- Good barrier response at base green clay
  - Increased USI impedance,
  - Lower CBL
  - Low contrast VDL
- Good ”bond” all the way up through the green clay
- Line at 270 degrees is due to casing wear groove
Test Case #2

• Good bond observed in shale zone required for barrier
• Pressure tested using wireline conveyed cased hole pressure testing tool and pump.

Set tool and seal off small area
Drill hole with flexible bit
Pressure test through hole drill
Plug hole and retract tool

Pressure test made to leak-off at 3275m
Test case #2 – wireline leak off qualification @ 3275m

Repeated extended leak-off tests showing good annular barrier
Governed documents update

• Operator’s governing documents updated to accept bond logs alone as a method to verify shale annular barriers

• Complies with NORSOK standard D-010 (Well integrity in drilling and well operations)

• Key governing document points:

  • Position and extent of collapsed formation shall be identified through appropriate logs.
    – …two independent logging tools…
    – …Properly calibrated & suitable for applicable well conditions…
    – …interpreted by personnel with sufficient competence.
    – Both log measurements/tools show continuous good bonding over minimum 50 meter
    – Log cut offs defined in table below:

<table>
<thead>
<tr>
<th></th>
<th>Cement bond log amplitude</th>
<th>Variable Density log</th>
<th>Ultrasonic acoustic impedance scanner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Barrier</td>
<td>CBL less than 20 mV over 80% of interval</td>
<td>Low contrast casing signal and clear formation arrivals</td>
<td>AI reading greater than 3 MRayl on all azimuthal readings</td>
</tr>
<tr>
<td>No Barrier</td>
<td>CBL reading within 20% of free pipe reading</td>
<td>High contrast casing signal and weak formation arrivals</td>
<td>Reading less than 2 MRayl on some azimuthal readings</td>
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Summary

• Old annular barrier qualification procedures expensive and not practical
• Shale barriers proven by pressure testing & “calibrated” to logs
• New shale barrier verification procedure in line with NORSOK
• Governing docs and best practices updated
• Technique used on P&A operations since 2007 in over 50 wells
  – Annular barrier proven in most wells mainly in Tertiary and Cretaceous shales.
  – Approx 10% of wells have shown unacceptable shale barriers
  – Good barriers seen within 2 weeks after setting casing.
Conclusions

• Benefits
  – Multi-million dollar rig operating time savings
  – Reduced leakage risk due to non-destructive technique
  – Can prolong well life
  – Multiple HSE benefits
    • Improved well integrity, reduced operations and less material waste

• Mother nature’s barrier provides safest and most cost effective solution
  – Self-healing
  – More robust than man made barriers
  – Highly durable - will last for ever
Thank you for listening – any questions?