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Improving the understanding, application & reliability of the Perforate, Wash and Cement technique through the use of cement bond logs, tool enhancements and barrier verification via annular pressure monitoring

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Perforate, Wash & Cement value proposition

Value is eroded if limits not understood and method not correctly applied

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Comparison of two methods

Closed-system Cup Type
1. Has double swab cups above and below nozzles.
2. Washing fluid is 'forced' out of 6 x 0.906in nozzles between swab cups and into annulus via perforations.
3. Fluid has only 1 way to go and has to be forced into the annulus, i.e. is a 'closed system'.
5. Cement is forced between cups and into annulus behind perforations.

Open-system Jetting Type
1. Does not require swab cups.
2. Washing fluid is jetted out of e.g. 30 x 1/8in nozzles in a ca. 2.5 ft long sub at high velocity & impact force.
3. Fluid can flow both through perforations to annulus behind and also OP/casing annulus, i.e. is an 'open system'.
4. Can rotate entire body at 6 rpm (when outside perfs) & 120 rpm (when outside perfs).
5. Cement is sprayed out of nozzles from a ca. 3 ft long cementing valve with 4 x 1/8in nozzles.
6. Cement is pushed in to perforations after spraying using an 'Archimedes' tool.
7. 18 spf with 1.1in EHG or greater preferred

“Cup Type” tool provides standpipe pressure and flow rate signals which can be correlated to annular conditions

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Initial field observations I (workover lower zone)

- **Initial field observations I (workover lower zone)**

  - **Circulation rate**
    - 400 – 500 gal/min

  - **Difficulties circulating**
    - 230 gal/min max with high pressures (1400 psi).
    - Loss of returns, annulus packed-off

  - **Circulating (standpipe) pressure**
    - 1,100 – 1,400 psi

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  - **CBL never above 12mV**
    - (free pipe 57mV)

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  - **Dark patches on AI from 5,705 – 5,746 ft**
    - suggesting formation contact with casing

  - Corresponded with circulation difficulties

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Initial Field Observations II (workover upper zone)

Consistent circulation at 400 – 500 gal/min

Lower circulating pressures 800 – 1100 psi

CBL never lower than 12.5mV and generally above 15mV

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Verification by bond log and SCP monitoring

CBL dropped, bond index, impedance, attenuation min & max all increased indicating improved bond

B-annulus bled off every ~24 hrs following curing of cement: static at 2.9 psi and monitored for ~4 weeks prior to drill-out, tieback casing and upper completion installation

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Tool enhancements

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CFD analysis & yard tests for method verification

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Yard test concept verification
Application to campaigns I (abandonment lower & upper zone)

Establishing circulation difficult initially (red), pressure high (750 - 1750 psi) & erratic (blue)

Circulation stable (orange), pressures lower (650 - 1250 psi) and less erratic (purple)

CBL low (10 – 15 mV)

CBL high (>60 mV)

Circulation consistent at >450 gal/min (red) and pressures lower (650 - 1250 psi) and more stable (blue)

B-annulus static (>6 months of data shown)
Application to campaigns II (workover)

Circulation at 400 gal/min (red), pressure 1000 – 1400 psi (blue)

Circulation harder to establish, reduced to 50 – 350 gal/min (red), persistent high pressure spikes (blue)

CBL low (10 – 15 mV)

CBL high (20 – 38 mV)

CBL dropped, bond index increased.

Note gas build-up below remediated annulus (red)

Well on production, B-annulus static
### Summary table

<table>
<thead>
<tr>
<th>Casing size</th>
<th>Bond quality</th>
<th>Degree of hydraulic isolation</th>
<th>Circulation potential</th>
<th>CBL mV ('average bond') free pipe level</th>
<th>CBL mV</th>
<th>AMAV mV</th>
<th>VDL ('near casing' and 'cement to formation' bond)</th>
<th>Attenuation dB/ft</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-5/8&quot;</td>
<td>Good bond</td>
<td>Hydraulically isolated</td>
<td>Circulation not possible</td>
<td>57.415(^1)</td>
<td>≤5</td>
<td>≤CBL(^1)</td>
<td>No casing arrivals, presence of clear formation arrivals</td>
<td>Above free pipe level(^1)</td>
<td>Clear and consistent circumferential bond. Absence of channeling or discontinuous channeling.</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>Not hydraulically isolated, some communication possible</td>
<td>Circulation difficult</td>
<td>57.415(^1)</td>
<td>6-14</td>
<td>≥10 and ≥ CBL(^1)</td>
<td>No/faint casing arrivals. No/faint evidence of formation arrivals</td>
<td>At or 'just above' free pipe level(^1)</td>
<td>Presence of channeling. May be discontinuous. Ability to circulate may be improved by re-perforating.</td>
</tr>
<tr>
<td></td>
<td>Poor bond</td>
<td>Not hydraulically isolated, full communication</td>
<td>Circulation possible</td>
<td>57.415(^1)</td>
<td>≥15</td>
<td>≥15(^2)</td>
<td>Clear and solid casing arrivals visible.</td>
<td>Below free pipe level: 9 5/8&quot; #40 1.6 dB/ft 9 5/8&quot; #47 2.6 dB/ft 9 5/8&quot; #53.5 3.8 dB/ft</td>
<td>Presence of clear and continuous channeling for circulation.</td>
</tr>
</tbody>
</table>

\(^1\): Free pipe levels provided by logging tool vendor.  
\(^2\): AMAV levels are highly provisional and further investigation is required to better determine the cut-off levels shown.  
\(^3\): Attenuation free pipe levels are casing weight dependent. Further investigation is required to better determine attenuation level cut-offs for intermediate and good bonds.
Conclusions

1. Closed-system "Cup-type” tool ensures direct communication with the annulus & standpipe pressure gives a clear indication of degree of bond and washing effectiveness.
2. Washing parameters can be used to correlate against logging responses and is of great utility in planning & selecting the best zones for remediation.
3. CFD & Yard Testing and 120 field runs confirms "Cup-type” tool as effective.
4. Field observations show that when the method is correctly applied according to the operational limits defined here, job can be de-risked allowing:
   a. Correct identification of the ability to circulate in 94% of cases
   b. Effective remediation of annuli: SCP remediated in every case at point of well handover
5. Track-record of successful remediation vs. logging & washing parameters across >10 fields across in the North Sea qualifies the method as robust.
Acknowledgements / Thank You / Questions
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