The Dark Art of Cement Bond Log

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Overview

- Purposes of Cement Bond Logging
- Typical Cementing Problems
- Petrophysical Methods for Cement Bond Evaluation
- Acoustic Methods in Detail
- Log Quality Control
- Basic Cement Bond Log Interpretation
- Examples
Purposes Of Cement Bond Logging
Good cementing is needed for:

- Hydraulic isolation of the casing annulus and permeable intervals
- Casing mechanical support
- Perforation holes’ stability
Little test

Do you have hydraulic isolation at the proposed perforation interval:

- ICV\(^1\) = 15m\(^3\), pumped 20m\(^3\) plus displacement volume, no returns at surface

- ICV = 15m\(^3\), pumped 20m\(^3\), 3m\(^3\) of returns, but the level has dropped as soon as the pump stopped

- ICV = 15m\(^3\), pumped 20m\(^3\), 3m\(^3\) of returns, 3 days later – still solid cement cake at surface

\(^1\) ICV – Integrated Cement Volume
Little test – answers…

Hydraulic isolation:

- ICV = 15m³, pumped 20m³ plus displacement volume, no returns at surface
  Inconclusive (most likely, no)
- ICV = 15m³, pumped 20m³, 3m³ of returns, but the level has dropped as soon as the pump stopped
  Inconclusive (most likely, no)
- ICV = 15m³, pumped 20m³, 3m³ of returns, 3 days later –still solid cement cake at surface
  Inconclusive (most likely, yes… but would you bet your life on it?)
Cement Bond Logging

- Continuous downhole measurement over the entire cementing intervals
- Good quantitative measurement of cement quality and placement
- Allows to plan remediation work
- May provide clues for cementing programs’ improvements

- Solid conclusive answers if done properly
- Inconclusive or just wrong if any shortcuts are taken
Typical Cementing Problems
1. Incorrect volumes

• Too little / too much pre-wash, slurry, displacement
• Unexpected fluid losses (including the losses increase after the casing run)
What is wrong here?

Integrated Hole/Cement Volume Summary

Hole Volume = 5.29 M3
Cement Volume = 5.29 M3 (assuming 0.00 IN casing O.D.)
Computed from 410.3 M to 265.9 M using data channel(s) BS

- Integrated Hole Volume Minor Pip Every 10 F3
- Integrated Hole Volume Major Pip Every 100 F3
- Integrated Cement Volume Minor Pip Every 10 F3
- Integrated Cement Volume Major Pip Every 100 F3

Time Mark Every 60 S
2. Cement composition

- Too little / too much retardants
- Density
- Viscosity
- pH
- Water salinity
- Reactions with formation minerals (esp. clay minerals, limestone, dolomite)
- Reactions with mud components (esp. water-polymer mud systems)
3. Pumping procedure

- Flow rate is too slow / too fast
- Stop-overs or pump break-downs
- Stages and valves…
Effects (in order of significance):

- No cement behind casing
- Channeling
- Poor quality cement behind casing
- Poor formation bond
- Micro-annulus
- Cement mechanical degradation
- Cement chemical degradation
Volume effect:

- No cement behind casing:
  - Not enough slurry
  - Too much displacement fluid pumped
  - Not enough displacement fluid pumped (so you probably have some bigger problem here!)

- Cement / fluid return at surface is not a guarantee of proper cement placement
Placement effects:

- Channeling
  - Physical effects (e.g. flow rate)
  - Chemical effects (e.g. clay minerals)
  - Insufficient pre-wash
- Poor formation bond
  - Mostly chemical effects (e.g. clay minerals)
  - Insufficient pre-wash
- Micro-annulus
  - “Aggressive” cementing programmes
  - Low casing grades
Material effects:

- Poor quality cement behind casing
  - Chemical effects (e.g. clay minerals, water-based polymers)
  - Insufficient pre-wash
- Cement mechanical degradation
  - Vibration
  - Perforation
- Cement chemical degradation
  - Very unusual for modern slurries
Petrophysical Methods for Cement Bond Evaluation
Non-petrophysical methods

- Surface cement samples
- Pressure / rate / density record
- Returns observation
- Pressure tests
- LOT / FIT

- “Nullius in verba!” (Horace)
Petrophysical methods

- Temperature Log
- Neutron Log
- Acoustic Logs
  - Sonic Log (CBL / VD or Sector CBL)
  - Ultrasonic Log
  - Combination Log
Acoustic Logs

- Tool response is related to Acoustic Impedance:
  \[ Z = \frac{\rho}{S} \times 304.6 \quad \text{in MRay, } 1\text{Ray}=\text{kg/s/m}^2 \]
  \[ S - \text{slowness, } \mu\text{s/ft} \quad \rho - \text{density, SG} \]

Steel (bulk): \( S=51.4, \quad \rho=7.80 \quad Z=46.2 \)
Steel (pipe): \( S=57.3, \quad \rho=7.80 \quad Z=41.5 \)
Cement: \( S=58-72, \quad \rho=1.76-2.72 \quad Z=7.46-14.3 \)
Water/Brine: \( S=189, \quad \rho\approx1 \quad Z=1.61 \)
Mud: \( S\approx200, \quad \rho=1.03-1.8 \quad Z=1.45-2.70 \)
Formation: \( S=40-400, \quad \rho=1.5-2.7 \quad Z=1.2-21 \)
Acoustic Logs (2)

- Reflection coefficient from Acoustic Impedance:
  \[ C_R = \frac{(Z_2 - Z_1)}{(Z_1 + Z_2)} \]
- Transmission coefficient from Acoustic Impedance:
  \[ C_T = \frac{2Z_1}{Z_1 + Z_2} \]
- Note:
  \[ C_R + C_T = 1 \]
Acoustic Logs (3)

- Due to the great contrast between fluids, steel and cement, sound reflections provide excellent way of determining the cement presence and quality
- De-facto industry standard
- Regulatory requirement in many countries
Acoustic Methods in Detail
Acoustic Log (CBL-VDL)

- Cement Bond Log (CBL) – 3 ft between the transmitter and the receiver
- Visual Density Log (VDL) – 5 ft between the transmitter and the receiver
- DSLT – Schlumberger Ltd.
Acoustic Log (Sector CBL)

- Cement Bond Log (CBL) – 3 ft between the transmitter and the receiver
- Visual Density Log (VDL) – 5 ft between the transmitter and the receiver
- 8 "sectoral" piezoelectric receivers, providing rough cement image at 45° steps

- SBT – Weatherford International
Sound propagation in casing

Tube Wave Type I
Tube Wave Type II
Head Wave (mud)
Head Wave (Form)
Formation Arrivals

R
S
Waveforms at receiver

This Amplitude is proportional to:
1. $c_R$ (casing - behind casing) AND
2. $c_T$ (casing - mud)

Formation Arrivals

Casing Arrival (Tube Wave Type II)

Mud Arrival (Tube Wave Type I)
Cement dissipates tube wave II

\[
C_R = \frac{0.4 - 8.5}{8.5 + 0.4} = -0.91
\]

\[
C_T = \frac{2 \cdot 8.5}{8.5 + 0.4} = 1.91
\]

\[
C_R = \frac{2.0 - 8.5}{8.5 + 2.0} = -0.62
\]

\[
C_T = \frac{2 \cdot 8.5}{8.5 + 2.0} = 1.62
\]

\[Z_{\text{casing}} = 8.5\]

\[Z_m = 0.4\]

\[Z_c = 2.0\]

Impedance in lbs/uS/ft²

1 lbs/uS/ft² = 4.881 MRay
CBL Log Components

- "Collar Chevrons"
- Formation Arrivals
- CBL Amplitude
CBL Log Components (2)

- VDL “wavetrain” provides means for qualitative interpretation and log quality control
- CBL amplitude provides means for quantitative interpretation of content behind casing – the lower the CBL, the better the cement.
- Transit time is the most important quality indicator
CBL Interpretation Charts (Cem-1, GN 8-7, etc)
CBL Uncertainty

• CBL is an “integrating” tool
• Same response for:
  – 100% cemented pipe with low compressive strength cement OR
  – Partially cemented pipe with high compressive strength cement (e.g. channels) OR
  – Micro-annulus
Sector CBL
Ultrasonic tools

- Resolve CBL uncertainty by metering 360° surrounding

- Schlumberger (USIT) or Weatherford URS – one rotating transducer

- Isolation Behind Casing Tool (IBC) – three rotating transducers
Ultrasonic tool principle
Ultrasonic tool principle (2)

Arrival Time ~ Casing Radius

$t_o$

Arrival Amplitude ~ Mud Properties $A_o$

Signal Frequency ~ 1 / Casing Thickness

$A = A_o \sin(\omega \cdot (t-t_0)) \cdot \exp(-\lambda \cdot (t-t_0)), \ t > t_o$
# Ultrasonic Presentation (Cement)

<table>
<thead>
<tr>
<th>Collar Locator</th>
<th>TIR1 3' TT</th>
<th>3' Amp Amplitude</th>
<th>Max Impedance</th>
<th>Avg Impedance</th>
<th>Impd Map Scale</th>
<th>Impd Map</th>
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<td>600 us 200</td>
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<td>Gamma Ray</td>
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<td>Tension</td>
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<td>3' Amplitude</td>
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FINISH DEPTH: 46.6 Meters
DIRECTION: UP
DATE: 03/18/2012
TIME: 16:17
MODE: ORIGINAL

Courtesy of Schlumberger Ltd.
Ultrasonic limitations

• Have difficulty detecting formation bond
• May give false readings in high-viscosity mud
• Cannot distinguish between Micro-Annulus and absent cement
• Ideally, should always run in combination with CBL/VDL

• IBC can be run without CBL/VDL, but the service does not provide the standard 3’ and 5’ logs
  – Combine with CBL/VDL if possible
Combination logs

“Nolite id cogere, cape malleum majorem”
-If it does not want to go, don’t force it.
Just take bigger hammer.

Courtesy Schlumberger Ltd.
Log Quality Control
Tool positioning: centering

• Both Ultrasonic and CBL/VDL have to be perfectly centered (typically anything above 0.2” is unacceptable)

• Off-center effects:
  – CBL shows lower amplitudes (e.g. “better cement”)
  – VDL arrivals “smeared” (e.g. “bad cement”?)
  – Ultrasonic shows “channels” in direction perpendicular to offset and casing thickness increase in the same direction

• For both type of tools, eccentering is easy to see
Tool positioning: tilt

- Both Ultrasonic and CBL/VDL should not run “tilted” (that may happen due to centraliser failure)

- Tilt effects:
  - CBL shows lower amplitudes (e.g. “better cement”)
  - VDL usually unaffected
  - Ultrasonic shows “channels” in direction of tilt and casing thickness increase in the same direction

- For Ultrasonic tool, tilt, especially sporadic tilt due to jerky cable motion, may pass undetected, resulting in wrong interpretation
Transit Time should be right!

\[ \text{Smud } \sin \Theta = \text{Scsg } \cdot \sin 90^\circ \]

\[ \sin \Theta = \frac{\text{Scsg}}{\text{Smud}} \]

\[ \text{TT} = 2 \text{TT}_{\text{mud}} + \text{TT}_{\text{csg}} \]

\[ \text{TT} = 2 \cdot \frac{d}{2} \cdot \frac{1}{\cos \Theta} \cdot \text{Smud} + \]

\[ + \left( L - 2 \frac{d}{2} \cdot \tan \Theta \right) \cdot \text{Scsg} \]

\( d \) - casing inner diameter

\( L \) - source spacing

\[ \cos \Theta = \sqrt{1 - \frac{\text{Scsg}^2}{\text{Smud}^2}} = \frac{\sqrt{\text{Smud}^2 - \text{Scsg}^2}}{\text{Smud}} \]

\[ \text{TT} = \frac{d \cdot \text{Smud}^2}{\sqrt{\text{Smud}^2 - \text{Scsg}^2}} + L \cdot \text{Scsg} - \]

\[ - \frac{d \cdot \text{Scsg} \cdot \text{Smud}^2}{\sqrt{\text{Smud}^2 - \text{Scsg}^2}} \cdot \frac{\text{Scsg}}{\text{Smud}} = \]

\[ = L \cdot \text{Scsg} + d \sqrt{\text{Smud}^2 - \text{Scsg}^2} \]
TT should not change fast
TT should not change fast (2)

- TT should be within $\pm 0.5 \ \mu s$ on each of the casing segments
- Changes at the casing collars are expected
- Minor changes on casing jewellery are possible
- Gradual change from TD to surface is OK ($S_{\text{mud}}$ changes with temperature)
- Fast-changing TT indicates poor tool centering or sporadic tilt
CBL must be calibrated!

- If CBL reads above Free Pipe amplitude or below 100% amplitude – suspect poor tool calibration
- Fluid Compensation Factor (FCF) should be used with caution
Basic Cement Bond Log Interpretation
1. Calculate Min and Max amplitudes

- Casing Thickness
- Free Pipe CS = 0 MPa
- Fully cemented pipe:
  - Normal 10 MPa
  - Foamed 6 MPa
  - OR: use lab data if available
2. Perform “CBL Triage”

- Poor Cement
- Intermediate Case
- Good Cement

Low Compressive Strength?
Channels
Micro-Annulus

Check VDL, then use Ultrasonic
3. Determine Formation Arrivals

- Prominent formation arrivals indicate channeling as opposed to weak cement or micro-annulus
- Decide to follow path 4a or 4b
4a. Calculate C.S. (from Cem-1)

Weak cement or Micro-annulus case
4b. Calculate % of coverage

Cement coverage = \( \frac{A_{\text{cbl}} - A_{100\%}}{A_{\text{free}} - A_{100\%}} \)

Channeling case
5. Micro-annulus or Weak Cement?

- Micro-annulus is caused by two factors:
  - Aggressive cementing program (low retardants, high pumping rates) AND
  - Low-grade casing

- CBL/VDL alone cannot distinguish between micro-annulus or low compressive strength cement

- Micro-annulus can be positively resolved by SCBL-URS combo or by IBC
Cement Bond Interpretation (Recap)

Step 1: Determine CBL amplitude limits
Step 2: Perform CBL Triage
Step 3: Check formation arrivals
Step 4a: Calculate C.S. OR Step 4b: Calculate Coverage
Step 5: Distinguish between micro-annulus or low weak cement (e.g. by sector bond)

Locate zones of interest and decide on hydraulic isolation
References

• P. Theys, Log data acquisition and quality control, 1999
• Schlumberger Log Interpretation charts, 2004
• Weatherford Log Interpretation charts, 2009