Vertical and Horizontal Cement Evaluation

Overview of Basic & Advanced Cement Evaluation

Stray Gas Workshop
Pittsburgh, PA
11/6/2009
Overview

- Cementing Variables
- Cement Evaluation Today
  - Vertical and Horizontal Considerations
  - Traditional Tool Summary
    - CBL-VDL (Cement Bond Variable Density Log)
    - SCMT (Slim Cement Mapping Tool)
    - USIT* Ultrasonic Imager Tool
- Isolation Scanner*
  - Principle of measurement
  - Light-density cement evaluation
  - Third Interface imaging
Poor Slurry Installation
Poorly Adapted Slurry System
Pressure Drop in Cement Setting

Loss of Compressive Strength & Possible Channeling if Slurry Pore $P <$ Formation $P$
Natural Fracture Considerations

3 4000' laterals 1500' apart same zone
FMI Fractures projected on wellbore

N54°E

Sigma_H

N = 72
NE-SW Strike = ~45°

N = 42
NE-SW Strike = ~42°

N = 128
NE-SW Strike = ~39°

Natural or Drilling Induced Fractures can cause lost cement circulation &/or premature fluid loss, promoting channeling, lower compressive strength, deeper cement top
Sonic Measurement – Traditional CBL

Low Attenuation
- Uncemented Casing

High Attenuation
- Cemented Casing

Variable density log
- 5 ft Receiver for VDL Analysis
- Allows differentiation between casing and formation arrivals

Basic interpretation
- Free pipe
  - No cement to casing bond
  - No attenuation of the signal

Free Pipe Signal

Good cement to casing bond
- If casing is well bonded, sound wave will be attenuated.
- The received CBL amplitude will be low.

CBL: Free Pipe
CBL: Good Bond

Fairly low Frequency Measurement - ~20kHz

7 SLB 11/16/2009
Slim Cement Mapping Tool (SCMT)

1 Sonic Receiver 360°

8 Sonic Receivers at 45°

1 Sonic Transmitter 360°

5' VDL

3' CBL

2' MAPs

Xmitter
CBL Quantitative Interpretation

ATTENUATION

- Logarithm of E1 amplitude [first peak of CBL waveform]

BOND INDEX

BI = \frac{\text{Attenuation in zone of interest [dB/ft]}}{\text{Attenuation in best Cemented Section [dB/ft]}}

Bond Index does not tell us if partially bonded intervals provide isolation or if channels exist – 360 Degree Average!

Amplitude and BI do not have a linear relationship
Assumption is that un-bonded interval is not vertically connected - i.e. Channel
Amplitude Measurements

Strengths

- Respond to cmt. density (shear coupling)
- Work well in most well fluids, tolerates corrosion
- Qualitative cement-formation bond from VDL
- Mapping tools indicate broad channels

Weaknesses

- High CBL amplitude can be ambiguous
  - Liquid microannulus (shear coupling lost)
  - Channels of contaminated cement and/or light cement
  - Not always related to poor hydraulic
UltraSonic Imager (USIT)

Objective: Map Channels, evaluate Casing

✔ Operates between 200 and 700 kHz

✔ Rotating Transducer provides full casing coverage – programmable resolution

✔ Each firing measures radius, thickness and Acoustic Impedance of annular material for cement evaluation

✔ Measurements Provide
  - Cement evaluation
  - Casing corrosion and wear

The transducer rotates at approximately 7.5 revs per second sampling 18-36 times per revolution every 5 or 10 degrees as needed/programmed.
Principle: The resonance technique
USIT Measurements

- Each Firing provides an Internal Amplitude, Radius, Thickness, and Annular Impedance Measurement at that point.
- Sub rotates firing 18-36 times per rotation and spins at ~7.5 RPS.
- Results Mapped providing much more complete information than CBL.
Now you have Bond Index and can visualize Channels
### Drilling Wear Example – USI Radius and Thickness Mapping

![Graphical representation of drilling wear example with USI Radius and Thickness Mapping](image)

### Table: Radius and Thickness

<table>
<thead>
<tr>
<th>Metric</th>
<th>Min.</th>
<th>Max.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td></td>
<td></td>
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</tbody>
</table>

### Additional Data

- **Cable Speed (PSI)**
- **Azimuth of eccentric (AZMIC)**
- **Average of Amplitude (AVMA)**
- **Maximum of Amplitude (AVMC)**
- **Internal radius Average (IRAV)**
- **Internal radius Minimum (IRMN)**
- **Internal radius Maximum (IRMX)**
- **External radius Average (ERAV)**
- **External radius Minimum (ERMN)**
- **External radius Maximum (ERMX)**
- **Min of Thickness (THMIN)**
- **Max of Thickness (THMAX)**

**Note:** The table above includes various measurements related to drilling wear example, specifically focusing on radius and thickness metrics. The graphical representation complements the data, providing a visual analysis of wear patterns and variations.
UltraSonic Corrosion Imager (UCI)

- Same USI tool with UCI Sub
  - Provides smaller “spot” size
  - Higher Resolution
  - Corrosion Mode Only
  - Needs clean fluid for logging
  - 3D products available

Internal Radius Specs
- Accuracy = 0.04”
- Resolution = 0.004”
- Beam Width = 0.11”

<table>
<thead>
<tr>
<th>Thickness</th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>0.18 to 0.6 in.</td>
</tr>
<tr>
<td></td>
<td>[4.5 to 15.2 mm]</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>±4%</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>0.015 in.</td>
</tr>
<tr>
<td></td>
<td>[0.4 mm]</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td></td>
</tr>
<tr>
<td>Azimuthal</td>
<td>2°</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.2 or 1.5 in.</td>
</tr>
<tr>
<td></td>
<td>[5.1 to 38.1 mm]</td>
</tr>
<tr>
<td><strong>Logging speed</strong></td>
<td>425 or 3000 ft/hr (dependent on sample rate)</td>
</tr>
</tbody>
</table>
USI Tool Thresholds Setting

The USI discriminates between solid, liquid and gas/dry microannulus using acoustic impedance thresholds. Works very well in uncontaminated cements above 11 ppg.

Works very well in uncontaminated cements above 11 ppg

When new “Light” Cement Acoustic Impedance approaches liquid impedance by design or by contamination – customize parameter selection.
UltraSonic Imager

USI Log illustrates cement evaluation before and after squeeze. Gas was creating problems in the annulus prior to squeeze and is indicated by red shading.
Sonic and Traditional Ultrasonic Limitations

- Heavy mud, thick casing limitations
- Shallow depth of investigation
- Dependant on logging fluid properties
- Low-density cement evaluation
- Contaminated Cement Interpretation

Difficult to diagnose with acoustic impedance or CBL-VDL measurements alone
Isolation Scanner* Introduction

- Service built on USI* UltraSonic Imager hardware
  - New Sub design and cartridge modifications

- Combines USI* measurement with a second measurement of *flexural attenuation*
  - Improved evaluation of lightweight and contaminated cements
  - Cement evaluation up to 20-mm [0.79-in] casing thickness

- Enhancement
  - Circumferential imaging, up to formation or second casing
Isolation Scanner Principle

Combine USI (ultra sonic imager) measurement:

- Excitation of thickness mode of the casing
- Single transducer (Tx/Rx) configuration measuring resonance and decay of thickness mode
- Inversion for the acoustic impedance immediately behind the casing

with FWI (flexural wave imager) measurement:

- Excitation of flexural mode of the casing
- Pitch-catch configuration (one Tx, two Rx) measuring flexural attenuation to evaluate cement

\[ \alpha = \frac{20}{\Delta x (cm)} \log_{10} \left( \frac{\text{Amplitude Near}}{\text{Amplitude Far}} \right) \text{ dB/cm} \]

Imaging also possible (conditionally) up to third interface (formation/double string) due to flexural energy leakage
Acoustic Impedance and Flexural Attenuation

The behavior of $Z$ and of the flexural attenuation are independent. This allows for identification of the material in the annulus with greater confidence.

To determine fluid properties in real time, the two independent measurements are combined, which eliminates the need for a separate logging pass or calculation.

Flexural Attenuation provides increased sensitivity to low impedance cements and is less affected by borehole fluid affects.
Material Identification in the Annulus

Traditional ultrasonic methods
- Determine acoustic impedance and set thresholds to discriminate between solid, liquid, and gas (SLG)

Isolation Scanner* service
- Map independent measurements to define annulus material in 1 of 3 SLG states, limiting reliance on thresholds
- Determining key fluid properties through combination of 2 independent measurements
Cement Evaluation: Existing Measurements

- 9 ppg LiteCRETE Cement
- Acoustic Impedance & CBL Only
Cement Evaluation: SLG & Hydraulic Communication

Flexural Attenuation Added
- Simplified picture via SLG Map
- Identifies significant channels in Hydraulic Communication Map
- Displays measured channel width
CBL vs SLG with Light Cement

Lead / Tail contact! – Not Cement Top!
CBL vs SLG with Light Cement
Third Interface Echo Response

3rd Interface Echo Signals

Amplitude R1
Amplitude R2
FAR
NEAR

Time in µs

Far
Near
Emitter

Δx
Log Example: LiteCRETE 9 ppg (1050 kg/m3)
Third Interface Echo (TIE) Evaluation

- Views reflections in impedance contrasts away from casing
- Can Image Surface casing location
- Eccentering Evaluation for improving next well design
- Channel Elimination – Hydraulic Isolation for frac containment
- Excellent tool for systematic cement improvement

Casing touching BH wall

Seen on the map as rings
Best tool to run?

Depends on Objective of evaluation

- **Simple TOC only** - Amplitude type measurement
  - CBL
  - SCMT – 8 Segment Cement Map for Channel ID
- **Channel & Gas ID for Zonal Isolation in Neat >13 #/gal Cements**
  - USI
- **Contaminated (Gas) Neat Cements or Lighter Slurries**
  - USI or Isolation Scanner
- **Lightweight cement evaluation (<11 ppg) or eccentric evaluations**
  - Isolation Scanner

*Conveyance by Tractor, eCoil (heptacable) or with TLC on Tubing/DP*