Properly run and interpreted, cement-bond logs (CBL) provide highly reliable estimates of well integrity and zone isolation.

by
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Casedhole Solutions

Presented to the
GEOLOGY & WELL TECHNOLOGY SECTION FALL 2015 WELL LOGGING WORKSHOP
September 2, 2015
Examples in this presentation are courtesy of Halliburton, Schlumberger, Baker Atlas, NCPS, FMC and many other witty forruners of this methodology.
Purpose of Cement

- **structural support** to the casing to reduce the risk of a casing failure
- providing **hydraulic & gas isolation**
- preventing production of **unwanted formation fluids**
- isolating intervals to **ground water (ERCB)**
- providing structural strength and isolation during **fracturing**
Reasons for Bond Log

- Bond logs are run to determine:
  - Cement to casing relationship
  - Cement to formation relationship
  - Evaluate cement conditions:
    - Channeling
    - Compromised cement (i.e. gas cut, dehydrated, etc.)
    - Cement stages
    - Cement top
    - Microannulus
Scenarios to keep in mind for bond log evaluation:

- Channeled cement
- Poor bond to pipe but good bond to formation?
- Good bond to pipe and poor bond to formation
- Poor bond to both pipe and formation
- Compromised cement (i.e. gas cut cement)
What is Measured on Bond Logs

- Recorded on **ALL** sensors:
  - **Amplitude** (strength of the first arrival)
  - **Travel Time** (time it takes for the signal to go from transmitter to receiver)
  - **VDL – Variable Density Log** (entire waveform from 1st arrival and reverberations up to 1200 μs...from one pulse)
Theory of Measurement

- Measures Sound Wave Amplitude (m-volts)
- Measures Sound Wave Transit times (usec)
VDL
Variable Density Log

- After the transmitter fires, the waveform arrives at the sensors via different paths:
  - Casing
  - Formation
  - Mud
- Arrival times are a function of:
  - Distance traveled
  - Slowness of medium (~density)
- The waveform recorded at each sensor is a combination of all arrivals present
VDL – Variable Density

A

Original Wave Form

B

Negative peaks have been biased out of picture.

C

Positive Wave Form has been rotated 90°

D

Expanded view of Seismic Spectrum as recorded on log.
Cement to Pipe Bond & Formation VDL
Variable Density (μs)

Depth

Pipe Arrivals
Straight Bands
(Occur at a relatively constant time)

Mud Arrivals
Straight Bands
(Occur at a relatively constant time)

Formation Arrivals
Wavy or Inconsistent vs. Depth
(A function of porosity/lithology changes)
VDL
Variable Density Log

- VDL displays multiple “slices of data” side by side
  - 200 – 1200 µs for 3’ VDL
- Arrival patterns start to become apparent
- To make a 2D picture of the 3D image:
  - Positive peaks are shaded black
  - Negative peaks are shaded white
- Casing arrivals should be consistent but formation arrivals “should” change with lithology
Cement Quality 1

- **a** Cement
- **b** Formation
- **c** Casing

**a-a) Channel Along the Pipe**

**b-b) Channel Behind the Cement**

**c-c) Communication path Through the Formation**

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Amplitude (mV)</th>
<th>VDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FREE PIPE</td>
<td><img src="image1" alt="Waveform 1" /></td>
</tr>
<tr>
<td>2</td>
<td>GOOD BOND CASING-CEMENT and CEMENT-FORMATION</td>
<td><img src="image2" alt="Waveform 2" /></td>
</tr>
<tr>
<td>3</td>
<td>MICROANNULUS or CHANNELLING</td>
<td><img src="image3" alt="Waveform 3" /></td>
</tr>
<tr>
<td>4</td>
<td>GOOD BOND CASING-CEMENT and POOR BOND CEMENT-FORMATION or HIGH ATTENUATION FORMATION</td>
<td><img src="image4" alt="Waveform 4" /></td>
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<tr>
<td>5</td>
<td>FAST FORMATION ARRIVAL</td>
<td><img src="image5" alt="Waveform 5" /></td>
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</table>
Cement Quality 2
Amplitude Signals vs. Pipe Size of “free” pipe

* immersed in water

Challenge is as casing sizes get larger, the range of measurement from no cement to fully cemented gets smaller.
Fig. 6—Semilog plot.
<table>
<thead>
<tr>
<th>CASING SIZE</th>
<th>TRAVEL TIME</th>
<th>FREE PIPE SIGNAL</th>
<th>CLASS H CEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1/2</td>
<td>~9.5</td>
<td>0.2 mv</td>
<td>3000 PSI 60% BOND</td>
</tr>
<tr>
<td></td>
<td>11.6</td>
<td>4.6 mv 5 Feet</td>
<td>100% CEMENT CUT OFF</td>
</tr>
<tr>
<td></td>
<td>13.5</td>
<td>0.8 mv 7.0 mv</td>
<td></td>
</tr>
<tr>
<td>5&quot;</td>
<td>15.0</td>
<td>0.9 mv 5.5 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>2.2 mv 10.0 mv 5 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21.0</td>
<td>3.6 mv 15.0 mv</td>
<td></td>
</tr>
<tr>
<td>5-1/2&quot;</td>
<td>15.5</td>
<td>0.7 mv 4.8 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.0</td>
<td>1.0 mv 6.0 mv 6 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>2.1 mv 9.0 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.0</td>
<td>3.5 mv 13.0 mv</td>
<td></td>
</tr>
<tr>
<td>7&quot;</td>
<td>23.0</td>
<td>1.0 mv 5.5 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.0</td>
<td>1.7 mv 7.5 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29.0</td>
<td>2.4 mv 9.3 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32.0</td>
<td>3.3 mv 13.0 mv 11 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35.0</td>
<td>4.0 mv 14.0 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>38.0</td>
<td>5.0 mv 15.0 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>6.0 mv 17.0 mv</td>
<td></td>
</tr>
<tr>
<td>7-5/8</td>
<td>~26.4</td>
<td>1.1 mv 5.5 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29.7</td>
<td>1.8 mv 7.5 mv 12 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33.7</td>
<td>2.6 mv 10.0 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>39.0</td>
<td>3.5 mv 13.0 mv</td>
<td></td>
</tr>
<tr>
<td>9-5/8&quot;</td>
<td>40.0</td>
<td>1.8 mv 6.8 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>43.5</td>
<td>2.2 mv 8.5 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>47.0</td>
<td>2.7 mv 9.0 mv 15 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>53.5</td>
<td>4.0 mv 12.0 mv</td>
<td></td>
</tr>
<tr>
<td>10-3/4&quot;</td>
<td>40.5</td>
<td>1.2 mv 5.1 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45.6</td>
<td>1.6 mv 6.6 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48.0</td>
<td>2.1 mv 7.6 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51.0</td>
<td>2.5 mv 8.0 mv 18 Feet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>54.0</td>
<td>2.7 mv 8.4 mv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.5</td>
<td>2.8 mv 8.8 mv</td>
<td></td>
</tr>
</tbody>
</table>
VDL Example Summary

Good bond to both pipe and formation

Free Pipe
VDL Example Summary

Transmitter
Isolator
Radial Receivers

3 ft Receiver
5 ft Receiver

Good bond to pipe but poor bond to formation

FMC Technologies
Quality Control CBL – Cementing & Drilling

- Poor Centralization
- Cement Shrinkage or Micro-annulus
- Drilling fluids
- Cement density
- Deviated Wells
- Cement setting time.
- Inefficient Pre-flush
Amplitude changes caused by Compressive Strength vs. Time

- Green cement
  - Low compressive strength hence higher than normal amplitudes
  - Rule of thumb is to not run bond logs up to 48 hours after cementing (cement types such as thermal cements may vary)

- Chart shows the reduction in amplitude with time after cementing
  - 4 hours
  - 18 hours
  - 28 hours
  - 33 hours
Micro-annulus

- Micro-separation (yellow) between pipe and cement (< 1 mm) caused by a drop in temperature or pressure.
- Identified by doing a “pressure pass” to a “non-pressure pass” comparison.
Micro Annulus – Pressure Logging
Do I need a Pressure Pass?

Micro-annulus Example

- Non-pressure pass looks like mostly free pipe
- Pressure pass indicates strong micro-annulus due to decreased amplitudes as seen on radial map as well as reduced casing arrivals in VDL.
Open Hole Data –vs.- Travel Time Log

- Red – TT3
- Blue – Rhob
- Coal Seams
- Coal Seams
- Coal Seams
Amplitude, Travel Time & VDL – Example Extremes

Good Bond to Pipe and Formation
- Very low 3ft amplitude “No Pipe Ring”
- Late (left) and inconsistent travel time
- VDL shows strong formation arrivals – little to no pipe arrivals

Free Pipe with no cement
- High amplitude at “Free Pipe” values
- Travel time is straight at expected pipe arrival time
- VDL shows strong pipe arrivals (train tracks) and no formation arrivals

Note: L to R: standard Amplitude scaled 0-100 mV; standard Travel Time scaled 650-150 μsec, VDL scaled 200 – 1200 μsec
Bond log considerations of SCVF/GM

- Poor Primary Cementing/Hole conditioning
  - Mud Contaminated cement
  - Gas Cut Cement
  - Channeled cement
- Decentralized casing string
  - Vertical
  - Slant
  - Horizontal
Well Conditions That Affect Bond Logs –

Light Weight Cement

- Pipe is allowed to carry some pipe arrivals even under perfect bonded conditions.
- 3ft amplitudes may range between 5-10 mV (depending on density).
- Formation arrivals, if present, may have a faded appearance.
- Collars DO NOT chevron but may exhibit a straight line response.
- Cementing information from the well is critical for interpretation:
  - Stages, Cement Density, Volumes

1550 kg/m³ cement
Parted Casing Example
What is Measured & Presented on Radial Bond Logs

- Presented on the log:
  - Natural Gamma Ray
  - Casing Collar Locator
  - Amplitude from the 3ft
  - Amplitude x 5
  - Travel Time from the 3ft
  - VDL from the 5ft
  - Amplitudes from the eight / six radials (if RBL)
  - Min, Max and Average of the Radials (if RBL)
Channeling

- CBL outputs show overall good cement
- Radial outputs show inconsistency of several of the radial receivers
- Image mapping of 8 x 2' amplitudes shows channel of lower compressive cement
- Single CBL 3' amplitude can not identify channeling
- VDL is also inconclusive
Log presentation for the Baker Atlas SBT tool containing individual log curves, cement map, and VDL display (courtesy of Baker Atlas)
EPA - Injection Well Mechanical Integrity

Logging Equipment

None of the logging tools presently available located any of the 6 degree channels in Logging Well No. 1. The second generation tools located all of the 30, 60 and 90 degree channels that were designed into and could be identified in the well. A calibrated single transmitter/dual receiver cement bond tool with 3-foot/5-foot spacing located the 60 and 90 degree channels and all but one of the 30 degree channels. The other cement bond tools with single transmitter/single receiver 3-foot, 4-foot, or 5-foot spacing presented very inconsistent results.

The 3-foot spacing is the best currently available for measuring and evaluating the amplitude of the first compressional arrival and the attenuation of this signal is a measure of the bonding of the cement to the casing. However, this spacing is not satisfactory for determining data on or evaluating the relationship of the cement to the formation. Five-foot spacing between the transmitter and receiver is the best currently available for evaluating the relationship of the cement to the formation, but it is not accurate for determining bonding to the casing. Four-foot spacing is being used; however, it does not have satisfactory resolution for evaluating the relationship of the cement to either the casing or formation.

The significant fact remains that none of the tools located channels smaller than 30 degrees in the well. Such channels represent a significant avenue for movement of fluid and methods must be developed to locate these and even smaller channels. It is recommended that the logging industry continue research efforts toward increasing the sensitivity of the logging tools.

The research conducted on Logging Well No. 1 indicates that with the presently available tools, the ideal approach for evaluating the cement in an injection well is to run both the second generation tool and a calibrated cement bond tool with single transmitter/dual receiver...
None of the logging tools presently commercially available located any of the 6 degree channels in Logging Well No. 1. The "second generation" tools located all of the 30, 60, and 90 degree channels and a calibrated "cement bond" tool with dual receiver 3-foot/5-foot spacing located all but one of the 30 degree and all of the 60 and 90 degree channels.

Results of tests in Logging Well No. 2 indicate that none of the presently available tools are capable of evaluating cement behind fiberglass pipe. Initial indications are that some prototype tools are able to identify 10 degree channels on the steel casing; however, this is based on preliminary data and much more testing must be done before definitive conclusions can be reached.
The “second generation” tools generate a pulse of ultrasonic energy from each of the eight focused transducers that are arranged around the circumference of the tool. The strength and duration of the echoes reflected from the casing and cement are used to form an image of the cement distribution and quality around the casing. This information and the cement compressive strengths are two very useful pieces of data for evaluating the casing/cement bonding in a well.
February 8, 2010

RE: Cement Evaluation Log.

On February 2, 2010 Superior Well Services ran a Cement Evaluation Log using a Dual Receiver Bond Tool. This tool uses Sonic Wave Train to evaluate cement quality. The Bond Index is the percentage of pipe circumference bonded by cement and is classified as; Good Bond = 80%-100%, Fair Bond = 60% - 80%, and Poor Bond = 60% or less bond indicated. In my evaluation of the Bond Tool signal the Bond Index is as follows:
720’ to 714’ Fair Bond, 714’ to 184’ Good Bond, 184’ to 181’ Poor Bond, 181’ to 152’ Good Bond, 152’ to 130’ Fair Bond, 130’ to 99’ Good Bond, 99’ to 91’ Fair Bond, 91’ to 76’ Good Bond, 76’ to 50’ Fair Bond, 50’ to 33’ Poor to No Bond, 33’ to 0’ Fair Bond.

Cement Bond Log does not indicate any Fluid Channeling problems.

Sincerely,

Fred Barber
<table>
<thead>
<tr>
<th></th>
<th>Conventional CBL</th>
<th>Radial Ultrasonic</th>
<th>Radial Pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude/attenuation</td>
<td>Yes</td>
<td>Yes (different)</td>
<td>Yes</td>
</tr>
<tr>
<td>Travel time (transit time)</td>
<td>Yes</td>
<td>Yes (different)</td>
<td>Yes</td>
</tr>
<tr>
<td>Full waveform</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Good bond identification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(if shear arrival)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial bond identification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Channel identification</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Microannulus effect</td>
<td>Strongly affected</td>
<td>Moderately affected</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(repeat log under pressure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeat (calibration) runs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Centralization</td>
<td>Essential</td>
<td>Less critical</td>
<td>Not a factor</td>
</tr>
<tr>
<td></td>
<td>(Use attenuation-ratio log where centralization is difficult)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free-pipe calibration (above top of cement)</td>
<td>Desirable</td>
<td>Not necessary</td>
<td>Not a factor</td>
</tr>
<tr>
<td>Heavy mud</td>
<td>Moderately affected</td>
<td>Strongly affected</td>
<td>Not a factor</td>
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<tr>
<td>Gas in microannulus</td>
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<tr>
<td>Casing geometry</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Casing thickness</td>
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<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Casing corrosion</td>
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<td>Yes</td>
<td>No</td>
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