Cement Integrity Log Basic Concepts

Cement Quality Evaluation

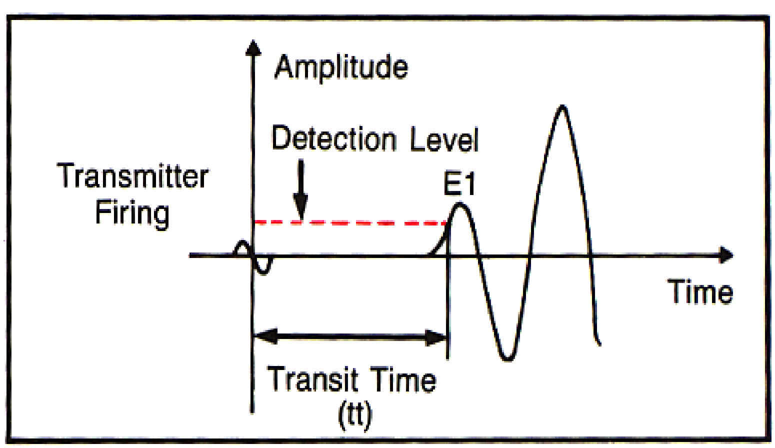
An estimated value of a cement top can be obtained from a calculated annular volume and the amount of cement pumped. The top of the cement can also be determined from a temperature generated during the hydration of the cement. However, neither of these methods can determine if complete mud removal has occurred and cement is in place downhole for zonal isolation. For example the cement may not be completely around the casing and leave a portion of the casing with mud in the annulus. This mud could be displaced by producing fluids forming a channel for fluid to flow in the annular space from one permeable zone to another.

In order to determine the placement of the cement around the casing versus depth two methods have been employed. The first method utilizes sounds waves and is called a cement bond log. The assumption is that the level or amplitude of the sound is dampened when cement is in contact with the casing. This measurement usually represents an average of the response around the casing. However, recent technologies have been developed to indicate from 6 to 8 sections around the casing.

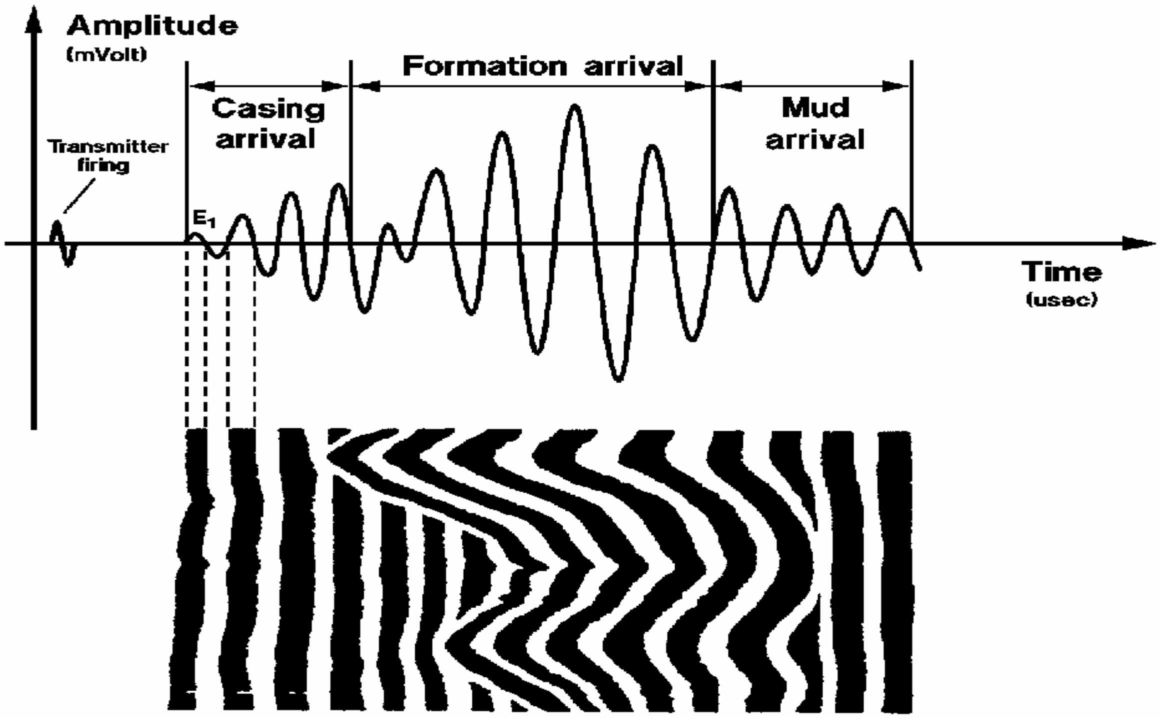
The second method utilizes an ultrasonic pulses that investigates the casing radially and measures from 36 to 100 measurements around the casing. The measurement is a result of the acoustic impedance of the cement and, subsequently, the quality of the cement. This technology can offer both a radial distribution and quality of the cement. However, these measurements are dramatically affected by the presence of gas in the cement. For example foam cement would be difficult to evaluate with this technology only.

Cement Bond Log & Variable Density

The Cement Bond Log or **CBL** is a recording of the amplitude of the first positive or negative peak of the sonic waveform. A detection level is used to determine the time taken by the wave to propagate from the transmitter to the receiver and can be used as a quality control indicator. When a tool is poorly centralized or a sound is coming from a formation with a speed of sound greater than casing, the time may be less than the normal or base line travel time (**TT**). A 3-foot (or shorter distance) receiver to transmitter spacing should be used for these measurements.



A receiver spaced 5 feet from the transmitter should also receive a sonic waveform. This waveform can be presented either in a full waveform presentation or after rectification and color (or grey) coding proportional to the amplitude of each of the waveform positive arrivals. This allows visualizing the **formation (compressional and shear) arrivals** due to sound energy transmitted through the casing and cement sheath. This sound travels through the formation and is received at a later time after the **casing arrival**s. The casing arrivals are usually the fastest, travelling at 57 microseconds per foot.



In free pipe the **casing arrivals** are strong and parallel like railroad tracks. There is no acoustic coupling to the formation and no formation arrivals will be seen. When partial mud removal around the casing or **channelling** has occurred a portion of the sound wave will not be attenuated and the first portion of the VDL will be seen as these straight and parallel lines. Additionally part of wave is allowed to be transmitted to the formation. Wavy lines that will represent the compressional and shear waves from the formation will follow the straight lines. The example above is an illustration of a channel or a micro annulus.

When **good mud removal** has occurred around the casing the sound wave will have maximum attenuation. As a result there will be no or very weak casing arrivals. The first part of the VDL will be illustrated as very low to non-existent amplitudes. This portion of the VDL will be followed by the formation signal.

The formation will be weak or strong depending upon the acoustic coupling and the ability of the formation to transmit sound. There is means to determine the circumference of cement in contact with the formation. The detection of the sound wave represents only the acoustic coupling of the cement and the formation **not the "bond" of the cement to the formation.**

Factors affecting the Amplitude

A **bond index** may be calculated and presented on the log. This ratio of attenuations is proportional to the lack of energy reflection between the casing and the cement. With omni directional transmitters and receivers, this number will represent the average value over the circumference of the casing. Then a computation of 100% is intended to represent coverage of the entire casing circumference with cement.

Actual zonal isolation may occur at numbers that could be much less than 100% or may not occur at this apparent coverage. It becomes **difficult to predict isolation** based only upon this bond index calculation. The problem is that it represents, at best, an average of the cement coverage. However, more importantly there are a number of factors that will affect the attenuation of the sound wave.

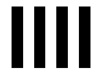
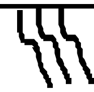
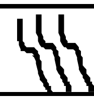
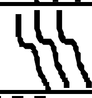
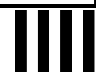
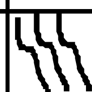
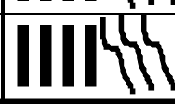
1. **Circumference of the cement (around the casing)**
2. **Compressive strength of the cement**
3. **Density of the cement**
4. **Thickness of the cement**
5. **Other affects**
    - **Tool centralization**
    - **Effects due to micro annulus**
    - **Concentric casing strings**
    - **Fast formations**

Interpretation of the CBL VDL

A proper interpretation of the CBL VDL requires that the amplitude, variable density and the transit time or travel time. Since other factors affect this measurement, it is best to know more data before making an interpretation. The following information will be useful:

- **The type and density of the cement**
- **The curing time of the cement**
- **The density and type of mud displacing the cement**
- **The size and weight of the casing**
- **Any staging of the cement or other cement slurries used**

The following table can be used to aid in the interpretation of acoustic cement logs:

Effect	TT 2	CBL mv (T0 mode)	VDL display	VDL display (Pictorial)	Interpretation
Free Pipe	stable	FP is High	Strong casing arrivals No formation arrivals Chevrons at collars		No cement
Bonded pipe 100% BI	stable … or Stretch / skip	BP is low	Very weak/no casing arrivals, strong formation arrivals		100% CSG circumf. Coverage
Partial bond	stable	BP < X< FP	Medium casing & formation arrivals		
Eccentered sonde	Decrease > ± 4 µs	Anything	Blurred arrivals		B.I not valid. If formation arrivals "some cement is present"
TT stretch	increase up to 13.7µs		No/weak casing arrivals Strong formation arrivals		Good cement. Use T0 (or Tx) amplitude for calculations
TT skip	increase step 33 to 55 µs		No/weak casing arrivals Strong formation arrivals		Good cement. Use only T0 amplitude for calculations
Concentric casings	possible increase 20<X<55µs	High amplitude	Doubling of casing arrivals frequency		Some cement. BI not valid if high mV
Fast Formation arrivals	Decrease or stable	Anything	Formation arrivals before or at ± same time as casing arrivals		Some cement. B.I not valid.
Micro annulus	stable	High (reduced with casing pressure)	Casing & formation arrivals		Some cement is present (B.I not valid)
Channeling	stable	High amplitude	Casing & formation arrivals		Some cement is present

<u>Micro Annulus</u>

It can be seen that a micro annulus and a channel have the same response in the table above. A micro annulus is simply something that has caused an interruption in the transmission through the cement, and minimizes the effect of the attenuation of the sound wave. The micro annulus is generally **less than 0.5 mm** and too small for fluid to move through (perhaps some gas) and essentially is not a problem, but a channel may be a severe problem.

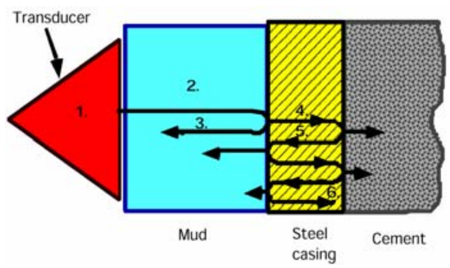
In order to identify a channel from a micro annulus two logging passes must be made. One is ran without putting any pressure inside the casing and the amplitude is compared to a second pass that has some pressure applied inside the casing. This slight change in the casing diameter increases the contact with the cement and the casing. The result is a **reduction of the amplitude**. When an amplitude change is observed the results are considered to be a micro annulus.

A micro annulus is rarely a problem and is not a problem that can be repaired. The size of the micro annulus is generally too small to accept cement particles. Therefore, a **squeeze would have no effect**.

Ultrasonic Cement Evaluation Tools

The ultrasonic tools investigate the casing radially. Older technologies like the CET and PET measure 8 spots around the casing. The newer technology of the **USIT** from **Schlumberger** has either 36 or 72 measurements or **Halliburton's CAST-V** has 100 measurements. The response reacts to the acoustic impedance difference between two materials; just as the reflection of seismic waves reflect off two layers of lithology. The results are an acoustic impedance of the cement that can be correlated to the quality of cement.

The reflection from the first layer of the casing inside and the fluid inside the casing yields the radius between the tool and the casing. A radius measurement on the other side is added with the first to determine a **diameter** of the casing. This same method is used as a **caliper** in open hole while drilling with LWD equipment. The next interface of the outside of the casing and the cement is used to determine the thickness of the casing.



The resulting exponential decay of the energy is evaluated to determine the acoustic impedance. Acoustic impedance is the product of the density of a material and the velocity of the ultrasonic wave. The acoustic impedance of cement is a function of the **type of cement, its density and the time** it has cured. The following table shows the acoustic impedance of common materials in the reactions that take place:

Material		**Impedance**
Z_{gas}	=	**0.3**
Z_{water}	=	**1.5**
Z_{mud}	=	**2.5**
Z_{slurry}	=	**2.6**
Z_{cement}	=	**3.5 – 9**

Ultrasonic technologies are plagued by the presence of gas. A gas filled micro annulus may appear to be casing that may not have any cement behind it. It is difficult to determine the cement integrity of lightweight cements since their acoustic impedance may be very similar to that of mud. In these circumstances it is best to include the cement bond log along with the ultrasonic log. New techniques have been developed to evaluate the ultrasonic logs in a low acoustic impedance environment.

Cement Bond Logs vs Ultrasonic Logs

Both the **cement bond logs** and ultrasonic logs like the **USIT** from Schlumberger and **CAST-V** from Halliburton have their limitations. No technologies looks beyond the casing to determine the placement of cement in the annulus and on the formation. The acoustic logs give only an idea of acoustic coupling due to cement somewhere around the borehole, **not whether it is cement all the way around the formation of not.**

The conventional cement bond logs have several factors that cause interpretation problems:

1. **360^0 Averaging** (Other technology will average over 60^0 or 45^0)
2. **Micro Annulus and Tool Centering**
3. **Cement Property Effects**
4. **Concentric Casing Strings**
5. **Fast Formations**

Ultrasonic logs can also have factors that create problems for their interpretation:

1. **Gas in the Cement** (Contaminated or foamed)
2. **Very Small Channels**
3. **No Information Concerning the Formation**
4. **Micro Annulus filled with Gas**
5. **Mud with too many Solids (or gas cut)**
6. **Lightweight Cement** (Acoustic Impedance too Low)
7. **Need to Correct for Fluid Type and Density**

Light Weight Cement Evaluation

Both Schlumberger and Halliburton are offering a method to evaluation cement that is lightweight or gas cut or foam cement. All of these cause ultrasonic devices to read too low acoustic impedance. However, the **characteristic of the acoustic impedance curves is different** from liquid cement or mud. These new techniques utilize this phenomenon and are better able to determine the placement of these type of cements.

Currently Schlumberger is offering this service each time they run a USIT log while Halliburton is offering it as a separate service. However, **Halliburton** has developed **techniques to use on the CBL** log also. Halliburton will, upon request, use their techniques with Schlumberger logs.