# A Study of Factors Influencing Cement Bond Logs[1]

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ABSTRACT

Investigations of cement sheath conditions affecting "bond log" interpretation have been made with respect to the physical properties of various cementing mixtures. These tests indicate that the addition of bulking additives to the cement sheath composition results in higher acoustic transmission.

The nature of the pipe-cement contact necessary to produce minimum acoustic transmission in addition to the effects of instrument calibration were studied to provide a basis for investigation of sheath materials.

## INTRODUCTION

Sound waves are presently being used to provide a method of measuring the degree of contact between casing and cement sheath. The records or "bond logs" produced by the measurements performed are interpreted to indicate the condition of the cement sheath surrounding the casing, the presence of channels, and the location of the cement "top".

A series of laboratory controlled tests for determining the effect of various cementing compositions on the transmission of acoustic waves and related physical properties were conducted. These tests included measurements of acoustic transmission of casing surrounded by cement sheaths of various composition and thickness; however, the test conditions imposed did not include the effects of formation in proximity of the cement sheath. Other measurements to aid in "bond log" evaluation were conducted.

## DESCRIPTION OF TESTS

Acoustic logging tools, used to measure the "bond" between the outer casing wall and the cement sheath surrounding the casing, commonly use a transmitter and a receiver which are acoustically coupled to the well bore fluid. The transmitter emits a pulse at controlled intervals, and this acoustic wave is received by the receiver after a period of time depending on the fluid in the well bore and the dimensions of the pipe and tool.

Acoustic energy transmitted through the casing to the receiver is converted to an electrical signal, and measurements are made on the portion of the wave considered to be pertinent to the bond of the cement sheath to casing.

A logging instrument employing a transmitter separated from the receiver by 4 ft of Teflon was used to determine the effects of various oil well cementing mixtures on acoustic transmission. This instrument measured the first arriving pipe signal and that which was received for 75 microseconds thereafter. The amplitude of the portion of the receiver waveform which arrived during this period was measured, amplified, and sent to the surface to be recorded on a continuous strip chart recorder.

The presence of an API Class A cement sheath which tightly clamps the casing is found to cause a reduction in acoustic transmission and a corresponding reduction in the amplitude of the measured signal.

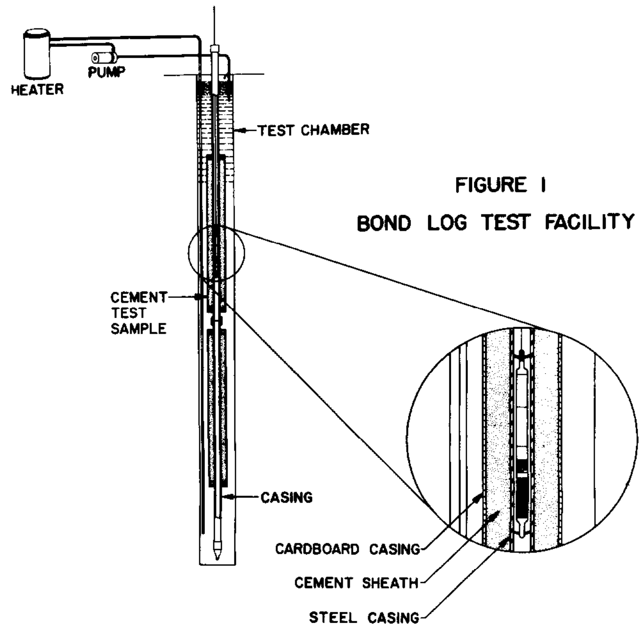


FIGURE I

BOND LOG TEST FACILITY

The various oil well cementing mixtures shown in Table I were used in forming a cement sheath around 5-1/2 in. casing (Fig. 1). These compositions were mixed by using optimum water-cement ratios with standard jet mixing equipment (1). The slurries were circulated with the use of a plunger type pump to simulate displacement in a well prior to placement.

An annular space was formed by an inner casing of 5-1/2 in. 17 lb/ft J-55 casing 26 ft long and an outer cardboard casing 18 ft in length. Because of its ability to become water wet and still retain sufficient strength

TABLE I

CEMENTING COMPOSITIONS

1. API Class A Cement
2. API Class A Cement - 4 % Bentonite
3. API Class A Cement - 4 % Bentonite - 0.3 % Lignin Retarder
4. API Class A Cement - 8 % Bentonite
5. API Class A Cement - 12 % Bentonite - 0.3% Lignin Retarder
6. API Class A Cement - Pozzolan X - 0 % Bentonite
7. API Class A Cement - Pozzolan X - 2 % Bentonite
8. API Class A Cement - Pozzolan X - 2 % Bentonite - 0.4 % Lignin Retarder
9. API Class A Cement - Pozzolan Y - 0 % Bentonite
10. API Class A Cement - Pozzolan Y - 2 % Bentonite
11. API Class A Cement - Pozzolan Y - 2 % Bentonite - 0.4 % Lignin Retarder
12. Pozzolan X - 15 % Hydrated Lime - 4 % Activator
13. Pozzolan X - 15 % Hydrated Lime - 4 % Activator - 25 lbs. Gilsonite
14. API Class A Cement - 0.9 gal. Latex

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to support the cement column commercial cardboard tubing suitable for forming the desired sheath thickness was selected for the outer casing. Wooden spacer rings were used at each end of the cardboard casing to hold it concentric with the inner casing.

The annulus was filled through a hose extending to the bottom of the form. As the annular space filled with cement, the test specimen was lowered into a water-filled curing chamber.

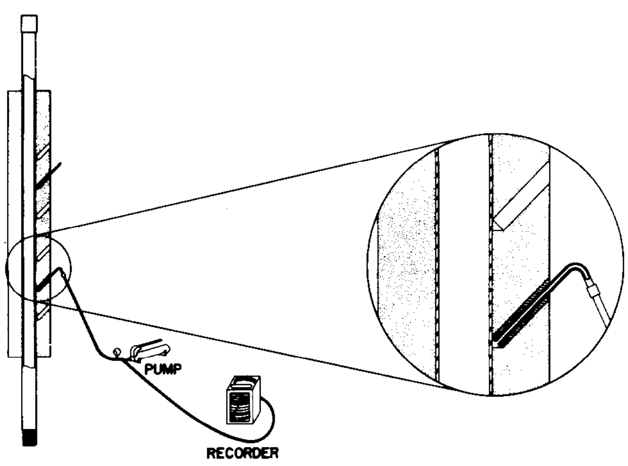
A drilled hole, 60 ft deep and 34 in. in diameter and filled with water, was used as a curing chamber for the test specimens. A water temperature suitable for the samples under test was maintained throughout the logging period.

During cement curing, logs were made on each sample at one or two hour intervals depending upon the rate of acoustic transmission decrease. And logging of test specimens continued until minimum transmission was reached and for various periods of time afterwards up to 30 days.

After logging was discontinued each specimen was raised and subjected to a test to measure the pressure necessary to bring about hydraulic separation of the cement sheath and pipe. The pressure required to cause this separation was measured by applying hydraulic force to the cement-pipe interface (Fig. 2), and recording the minimum pressure required to establish communication. This pressure is hereafter termed the "resistance to communication."

FIGURE 2

RESISTANCE TO COMMUNICATION TEST




A portion of the mixture used to fabricate the test specimens was retained to determine the compressive strength and support coefficient. These measurements were made at the time when minimum acoustic transmission was reached, and also at the time when the resistance to communication was determined.

The support coefficient was measured by filling the annular space between 2 in. and 4 in. line pipe sections, 10 in. long, with the slurry under test and by allowing the sample to cure in the test chamber with the logging specimens. A shearing force was applied to the cement-pipe interface, and the mechanical force at which failure occurred was recorded. The support coefficient was then derived by dividing this force by the area of the inner pipe that was in contact with the cement, since the failure will occur at the surface having the least area. These tests were made in a manner similar to those performed by Bearden and Lane (2;3).

PRELIMINARY TESTS

Test specimens of 5-1/2 in. casing with no cement sheath and with 40 per cent of the circumference of the casing covered with an API Class A cement 2 in. thick were prepared for logging instrument calibration. Tests on all subsequent specimens employed two logging instrument sensitivities. In the less sensitive position the receiver saturated at that signal received in the casing with no cement sheath. In the more sensitive position the receiver saturated and produced a full scale reading when 40 per cent of the circumference of the casing was covered by a cement sheath. Data obtained by using these sensitivities indicate that sonic transmission correlation could be obtained with the reduced sensitivity as indicated by previous work (4).

The surface condition of the inner casing was considered to be of great importance for uniform test results. Identical sheaths were formed on clean sandblasted pipe and on casing which was sandblasted and allowed to accumulate a thin uniform layer of rust. The time to reach minimum acoustic transmission for both samples proved comparable. Subsequent samples, with the exception of tests on surface coatings, were prepared using the rusty casing.

TEST RESULTS

Figure 3 illustrates the acoustic transmission properties with respect, to curing time of the materials tested when using the least sensitive calibration. A comparison of the acoustic and support properties of these materials show that they may be divided into two groups.

Group 1, which consisted primarily of cement slurries without bulking additives, attained very low ultimate acoustic transmission and reached this ultimate in a relatively short time. The compositions in this group also develop a moderate compressive strength in a relatively short time.

A comparison of the average acoustic transmission and the average support coefficient of Group 1 materials is shown in Figure 4. During the early stages of cement curing, acoustic transmission decreased and support coefficient values increased at comparable rates. However, during the later stages of curing, the support coefficient values exhibited a rapid increase which was not accompanied by a proportional lowering of acoustic transmission.

Cementing materials containing bulking additives generally show a higher degree of acoustic transmission than do those in Group 1. The average behavior of these Group 2 materials is illustrated in Figure 5. The average support coefficient developed more slowly in this group and is comparable to the acoustic measure over the time shown.

API Class A cements containing up to 40 per cent diatomaceous earth also exhibited acoustic properties similar to Group 2 materials. As the percentage of this bulking additive was increased, the ultimate acoustic transmission was also increased.

Pozzolan-lime compositions exhibited acoustic and support properties similar to Group 2 materials during earlier stages of curing and later exhibited properties of Group 1 materials. Transfer of a pozzolan-lime sample to another location in the curing chamber resulted in damage and a subsequent gain in acoustic transmission. A period of 6 hr was required for restoration to the original transmission level, as shown in Figure 3.

FIGURE 3

ACOUSTIC TRANSMISSION PROPERTIES
OF CEMENTING COMPOSITIONS

CALIBRATION: 0% SHEATH = FULL SCALE

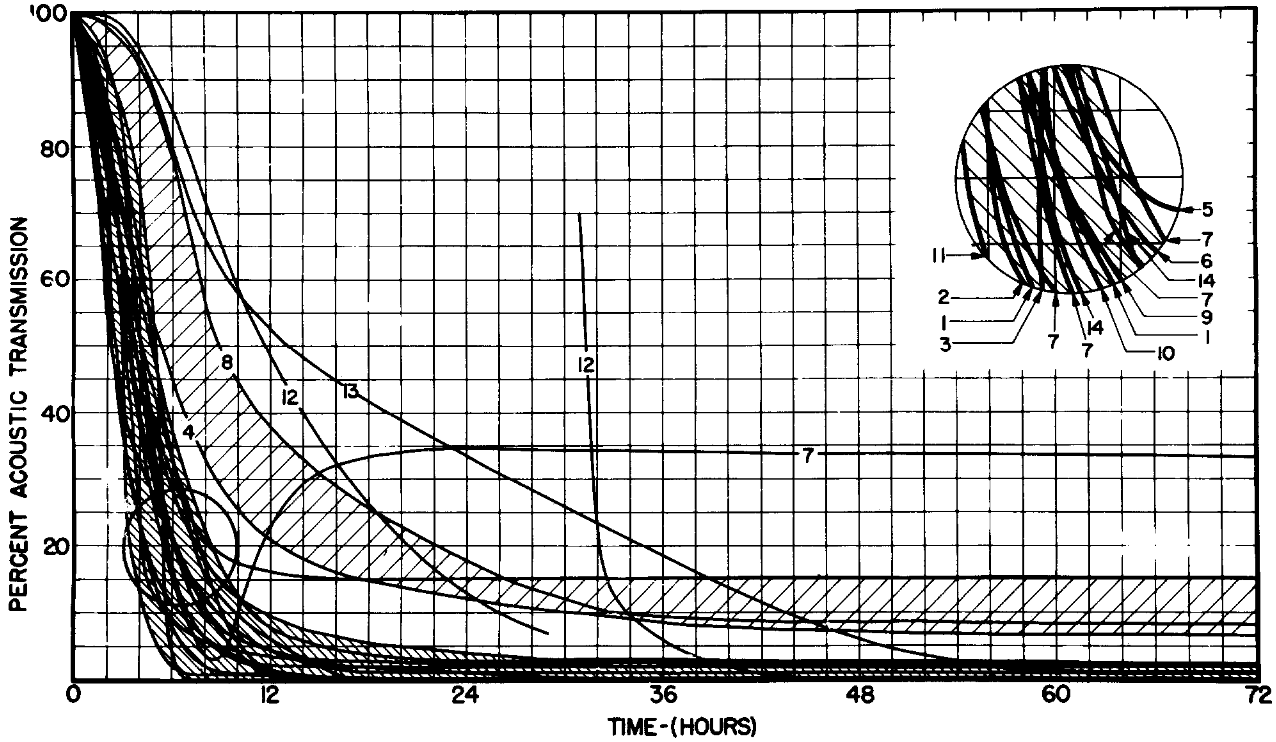



FIGURE 4
GROUP I

ACOUSTIC TRANSMISSION AND SUPPORT COEFFICIENT
(AVERAGE VALUES)

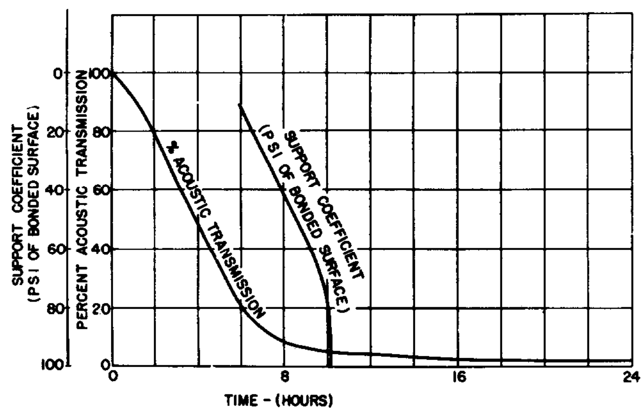
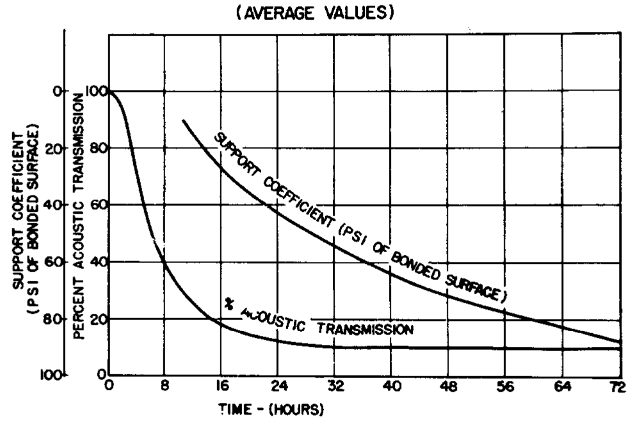



FIGURE 5
GROUP 2

ACOUSTIC TRANSMISSION AND SUPPORT COEFFICIENT
(AVERAGE VALUES)




## PIPE COATINGS

A limited evaluation of the influence of protective mill coatings on the acoustic measurement was made. Investigation included newly coated pipe for comparison to previous tests, and the same type coated casing was evaluated after being in contact with drilling mud. In order to determine the abrasive effect on the protective coating of running casing, the sample was run 1000 ft in a test well containing 9.8 lb/gal water base drilling mud. This casing remained in contact with the drilling mud until cement sheath placement.

The acoustic transmission reached by both these specimens corresponded to that of the same cement formed on uncoated casing; however, the time required to reach this value was slightly longer. A reduction of all physical values measured was shown by both samples when compared to rusted pipe as shown in Table 2. The added effect of mud contact prior to cement placement further reduced the physical measurements.

## TABLE 2

## BONDING PROPERTIES OF COATED PIPE
## VS.
## UNCOATED PIPE

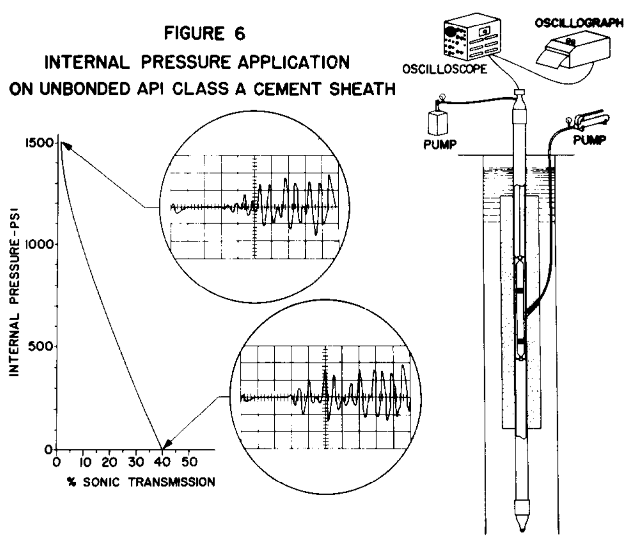
| TYPE CASING | TIME HOURS | RESISTANCE TO COMMUNICATION (HYDRAULIC) P S I | SUPPORT COEFFICIENT P S I OF BONDED SURFACE |
|---|---|---|---|
| CASING SIZE - $5\frac{1}{2}$ INCH CEMENT SHEATH THICKNESS-4.0 INCHES | | | |
| NEW (COATED) | 48 | 375 - 425 | 72.0 |
| NEW (COATED)* | 48 | 175 - 225 | 54.0 |
| NEW (COATING REMOVED) | 192 | 500 - 700 | 395.2 |
| OLD (RUSTED) | 48 | 500 - 700 | 230.0 |
| CASING SIZE - 2 INCH INSIDE 4 INCH CEMENT SHEATH THICKNESS - 0.812 INCHES | | | |
| NEW (COATED) | 8 | | 9.86 |
| OLD (RUSTED) | 8 | | 52.7 |

* CASING WET WITH WATER BASE DRILLING MUD.

### PIPE-CEMENT CONTACT

A study was initiated to determine whether a reduction of acoustic transmission by the pipe-cement contact was due to adhesion or physical clamping. For this study, hydraulic pressure was applied to the pipe-cement interface of a set sample (Fig. 6). This application of pressure caused the acoustic transmission of the sample to increase to 40 per cent of that in free pipe. With separation of pipe and cement sheath established, pressure was then applied to the inside of the casing with the logging device in place. This increase in internal pressure and the corresponding increase in casing diameter caused a significant reduction in acoustic transmission. This test illustrates that intimate contact or adequate acoustical coupling is required for a reduction of sonic transmission. The application of internal pressure cannot create adhesion of the cement to the casing.

FIGURE 6
INTERNAL PRESSURE APPLICATION
ON UNBONDED API CLASS A CEMENT SHEATH




To further this investigation, the effect of excessive closed-in pressure under laboratory conditions during cement curing was studied. A 4 in. thick sheath of API Class A cement was allowed to cure for 2 days with a pressure of 5000 psi applied internally on the casing. Maximum acoustic transmission was recorded after the release of pressure and corresponding contraction of the pipe as noted in a previous publication (2, 3). With the reapplication of internal pressure, acoustic transmission was partically reduced; however, equipment limitations prevented reaching an internal pressure sufficient to restore the acoustic value to minimum.

### RESISTANCE TO COMMUNICATION

The tests of resistance to communication provide a means of comparison of the various cementing materials' ability to help prevent fluid migration along the pipe-cement interface. However, the values obtained under the tests outlined are not necessarily the values which would be obtained were formation loading present. Comparison of the resistance to communication and acoustic transmission has yielded little correlation (Fig. 7). A single pozzolan-cement sample, illustrated in Figure 7, showed high acoustic transmission but had excellent hydraulic properties. During the early stages of curing, this sample exhibited low transmission and then reverted to a higher final value as illustrated in Figure 3. Subsequent tests of this material produced low final acoustic transmission.

### INFLUENCE OF INSTRUMENT SENSITIVITY

The data produced by the reduced logging instrument sensitivity are used in all illustrations discussed. And when compared with the data produced by the higher sensitivity previously described, the acoustic transmission values recorded for all samples containing bulking additives show a marked increase. In tests reported in a prior paper (5) sheath thicknesses below 2 in. also produced an apparent increase in acoustic transmission. Acoustic characteristics of cementing materials used, hole conditions present, and instrument sensitivity must be taken into account for cement "bond log" analysis.

### CONCLUSIONS

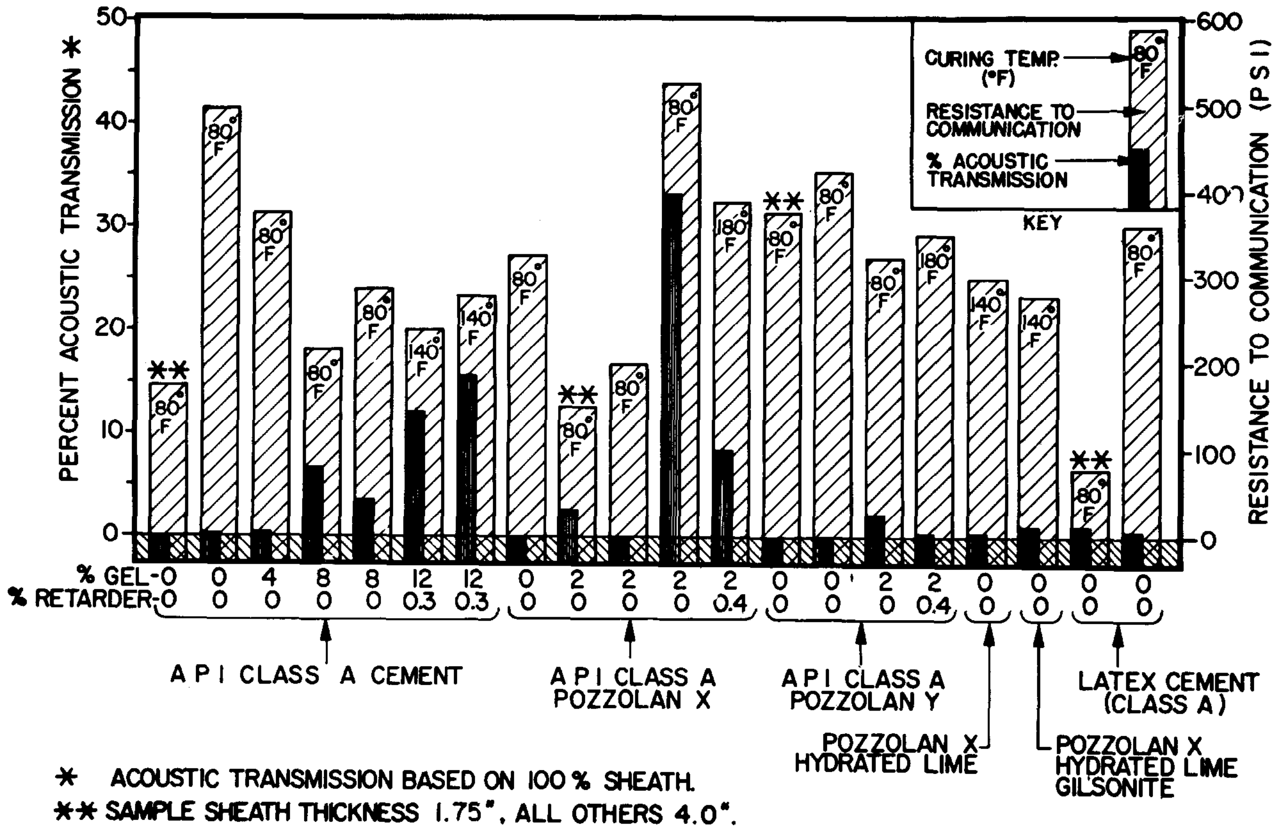
The following conclusions are subject to the limitation that the imposed test condition disregard the influence of formation on the cement sheath and the accompanying effect on acoustic transmission

Within this limitation it is concluded:

(1) The adhesion of the cement sheath to casing was not necessary for a satisfactory "bond log" reading. Intimate physical contact by the cement sheath is all that is required for lowering the acoustic transmission of the pipe signal.
(2) Those cementing compositions, containing no bulking additives (bentonite, diatomaceous earth and pearlites), show, in general, better properties (acoustic and physical) than do those containing these additives.
(3) Log analysis should include the effect of cement sheath thickness and composition.
(4) Protective pipe coating caused a lowering of physical values; however, the acoustic measure was only slightly affected.
(5) Excessive closed-in pressure under the specified laboratory conditions during cement curing may be detrimental to the "bonding" of cement to casing.

FIGURE 7

COMPARISON OF ACOUSTIC TRANSMISSION
AND HYDRAULIC PROPERTIES OF CEMENTING MATERIALS

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