Acoustitolog-nuclear Logging in Cased Wells†

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ABSTRACT

The development of a superior Acoustitolog instrument has made it possible to obtain porosity and lithology data from cased wells. At the same time, a valuable evaluation of the cement condition can be made from the data recorded. Recent advancements in electronic technology, as well as improvements in acoustic transducers, made the design of this acoustic equipment feasible.

In most situations, 40 to 50 percent cement bond is adequate for the accurate recording of formation travel times. Under certain fast-velocity formation conditions, accurate interval transit-time logs have been obtained with even a smaller percentage of bonding.

The versatility of the Acoustitolog and the nuclear logging equipment makes it possible to simultaneously record the acoustic, gamma-ray, neutron, caliper, and collar logs. These data are obtained routinely in both open and cased wells.

INTRODUCTION

Shortly after the first acoustic log was introduced, it was noticed that occasionally a good acoustic signal was received which had traveled through the formation even though the well was cased. It was quickly realized that these results were associated with the zones where the cement was completely bonded to the casing and to the formation. In these early days of acoustic logging, some clients, for educational reasons, asked that the log be run over the section of the well that had already been cased. From such logs it was frequently evident that the formation signal could be tracked, and it was possible to produce a cased-hole log that correlated quite well with the open-hole log. These logs were of the single-receiver type and could not be used to determine porosity. As time passed and the dual-receiver log came into existence, many attempts were made to obtain a continuous and accurate acoustic log in the cased hole. Most of the attempts failed for two reasons: First, the cement bonding to the casing and the sidewall was usually not continuous; Second, the acoustic instruments did not have sufficient output signal nor received signal amplification, thus the first compressional signals from the formation could not be logged successfully.

As the electro-acoustic transducers were improved, much knowledge was being gained through constant effort to improve the acoustic tools. The use of this knowledge, along with improved electronic technology, resulted in the development of a superior acoustic tool—one capable of transmitting and receiving a good acoustic signal through the formation behind casing under cementing conditions that are normally considered no better than poor-to-fair. These tools have been used quite successfully during the past year in West Texas. Accurate acoustic-gamma-ray-neutron logs have been obtained in new wells which were cased, because of high gas pressures, bad hole conditions, or for economic reasons, before the acoustic log was run. The tools have also been used with very good results in old wells that were completed before the advent of the acoustic porosity tool.

TOOL DESCRIPTION

The acoustic section consists of one acoustic transmitting transducer positioned above two or more acoustic receiving transducers that send the received signals to the highly refined electronic circuitry. The entire acoustic wave train is amplified in the electronic section and transmitted to the surface via a seven conductor cable. The formation signal, when present in this acoustic wave train, is processed by the complex electronic measuring panel and travel time of the acoustic signal through the formation is recorded on film in microseconds per foot.

The ability to record formation acoustic travel times in a cased well depends upon the amplitude of the formation signal. This signal amplitude, in turn, is dependent upon the bonding of the casing to cement and cement to formation. It is also dependent upon the sophistication and versatility of the logging equipment.

The gamma-neutron section, also a very refined set of down-hole electronics, is capable of operating at 200°C detecting the natural gamma radiation and the induced epithermal-neutron radiation. Neutron charts are available for determining porosity. The response of all epithermal-neutron tools is primarily influenced by the hydrogen present within the section being investigated.

If the porosities calculated from the log using the correct chart are excessive when compared to the porosities obtained for the acoustic informations, an interpretation of the presence of extra hydrogen (fluid) between the casing and the formation can be made. This condition could indicate the existence of channeling.

Thus, the simultaneous recording of the acoustic and epithermal-neutron log through casing makes possible the determination of apparent formation porosity, the identification of lithology, or an evaluation of the cement condition in a cased well.

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ACOUSTIC CLASSIFICATION OF CASING BONDING

Primarily there are three main classifications of bonding which may exist in the borehole after cementing They are a free casing, b partial bonding, and c complete bonding

A Free Casing

There are several variations of this condition Fig 1A and 2A are oscilloscope displays of the acoustic signal under the two most common conditions In both cases, the acoustilog will record the travel time (57 microseconds) of the acoustic signal in pipe The changes in response are shown on the neutron curve

The first unbonded condition (Fig 1A) is further illustrated in Fig 1B The acoustic curve has recorded casing acoustic travel time of 57 microseconds/ft and the neutron log is indicating extremely high apparent porosity The neutron response also has poor resolution when related to the known formation bedding planes, porosity changes, etc Thus free casing must be the interpretation

An example of the second condition (Fig 2A) is demonstrated by Fig 2B The acoustic log will indicate a time of 57 microseconds/ft The acoustic wave train, as observed on the oscilloscope (Fig 2A), will be very distorted The recorded neutron response will correlate with the formation lithology and will usually be very similar to the open-hole neutron log

B Partial Bonding — Channeling

The condition of partial bonding is the most difficult to accurately record and interpret, but it is the condition in which the greatest degree of advancement has been achieved The improved acoustic instruments can record the formation travel times under poor cement conditions Experience has shown that, frequently, no more than 40 to 50 percent cement coupling of the casing to
the first arrivals of the formation signal. It is also obvious from the oscilloscope presentation that, when the acoustic signal is from high-velocity formation and arrives prior to the casing signal, practically no difficulty is encountered in making an accurate acoustic log.

Fig. 3B is an excellent example of a log over a section of high-velocity formation in a well in which partial bonding is believed to exist. The formation is Ellenburger (depth of 20,000 ft) in the Delaware-Val Verde Basin. The acoustic time curve is quite valid and may be used to predict formation porosity. The neutron curve indicates excessive apparent porosities. This may be interpreted as a possible channel. When all the dense points are connected on the neutron curve (Slope A), the amount and extent of the possible channel becomes quite apparent. The neutron log will not correlate with the acoustic or gamma ray curves. The open-hole caliper log was used to eliminate one possibility of misinterpretation of the neutron indication, which could have been the result of borehole enlargement. Since the caliper showed no enlargement, it must be concluded that an anomaly occurred between the casing and the formation to cause excess hydrogen atoms (fluids) to be present. This condition may be attributed to channeling.
When the cement is well-bonded to centralized casing, but the cement bond to the formation is nonexistent, the acoustic wave train received will appear on the oscilloscope as shown in Fig 4A. The amplitude of the casing signal will depend upon the degree of bonding between the casing and the cement. The example shown in Fig 4A is the condition that existed in the well over section “A” on the acoustic log of Fig 4B.

The entire acoustic wave train is of such low amplitude it is impossible to record an acoustic travel-time log. The neutron curve exhibits poor formation response, again verifying partial-to-nonexistent bonding to the formation. It should be noted that, under conditions of partial bonding, there exist many variables which may affect the acoustic signal. It is recognized that the presence of hydrocarbons, mud cake, types of casing, condition of casing, types of cement, etc. play an important role in the amplitude of the acoustic signal.

C Complete Bonding

Continuously good bonding between casing and cement and cement and formation is the best situation for recording the acoustic-neutron log through casing. The casing signal, although present, is not recorded by the measuring panel because of its extremely low energy level. Thus a valid formation signal of either low or high velocity can be recorded. The neutron response will also be valid and usable for determination of apparent porosity and lithology. The following five case histories demonstrate the usefulness of this combination service.

Case history No. 1 (Fig. 5) is an acoustic-neutron log obtained in a cased well in the McElroy Field, Crane County. The formation is primarily dolomite, with contamination of 18 to 25 percent gypsum by volume.

In this case, the neutron log is a very poor porosity curve because of the large amount of gypsum present. The neutron recording is affected by the chemical composition of gypsum (CaSO₄ 2H₂O) resulting in a very high apparent porosity. This is caused by high hydrogen content in water of hydration.

The acoustic log was verified by the open-hole recording (dotted curve). Casing travel time of 57 microseconds/ft is indicated by the vertical interrupted line. It should be observed that the acoustic log from 3,000 to 3,050 ft is recording the formation signal and not the casing signal, although the travel time is very near casing time.

CONCLUSION The acoustic-gamma-ray-neutron log through casing is valid and equally as good as the open-hole recording. Lithology and porosity are identifiable and determinable from this log.

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**Fig. 5 — Case History No. 1**

Case history No. 2 (Fig. 6) is a recording of a typical San Andres dolomite in Andrews County, Texas. The top of the San Andres is marked with a radioactive silstone at 4,465 ft.

The acoustic log through casing was compared to the open-hole recording (dotted curve). In the interval indicated at 4,400 ft, the acoustic log in casing is reading 57 microseconds/ft rather than following the open-hole recording. This indicates probably less than 40 to 50 percent cement bonding between the casing and the formation. This lack of cement is verified by the neutron curve (Slope C) which shows an increase in the apparent porosity. The neutron response exhibits poor formation resolution and indicates false boundaries. The borehole was in gage over the entire interval (5-1/2-in casing/7-7/8-in open hole).
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Slopes A and B indicate the amount and extent of possible channeling. The acoustic log over both of these sections is confirmed by the open-hole acoustic log. Therefore, the cement bond can be assumed to be probably greater than 40 to 50 percent.

**CONCLUSION** The acoustic log through casing over the main zones of interest is valid and usable for porosity determinations. The neutron indicates possible channeling and verifies a lack of cement bond at 4,400 ft. This cased-hole log produced an abundance of information with one trip in the hole.

Case history No 3 (Fig 7) is another situation in which the acoustic-neutron log through casing added a great deal of information.

This well was drilled and logged in Andrews County, Texas in 1953. A standard electrical survey was recorded from total depth to the surface. The Minitlog was only recorded over selected zones at the bottom of the well.

Normally, a gamma ray-neutron log would have been the only method of determining porosities behind the casing over the unlogged sections. Slope A emphasizes the poor results that would have been obtained from the neutron curve for porosity determination. The neutron response may have been affected by hole-size enlargement, casing centralization, formation gas, cement channeling, etc. No matter what possible unknown

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**Fig 6 – Case History No. 2**

**Fig. 7 – Case History No. 3**
caused these results, the neutron log by itself, in this case, would have been no more than a fair correlation curve.

The acoustic recording in general is valid. The acoustic coupling of the casing to formation was sufficient and the acoustic log was successfully recorded for several thousand feet. Using the matrix velocity normally assumed for this area, porosities were calculated and used to determine water saturations.

CONCLUSION The acoustic curve gave the best results for formation porosity determination, but some calculated values were optimistic because of unfavorable cement and casing conditions.

Case history No. 4 (Fig. 8) is the recording through a dolomite formation in Lea County, New Mexico. The acoustic-neutron through casing log was compared and verified with the open-hole acoustic log.

CONCLUSION The open-hole Acoustilog and the cased-hole acoustic-neutron log were equally good.

Case history No. 5 (Fig. 9) is an acoustic-neutron through casing log in the Ellenburger formation, Delaware-Val Verde Basin.

The acoustic log through casing was compared and verified by the open-hole recordings.

The neutron log shows no indication of channeling over this interval. The neutron porosities emphasize the optimistic total porosities resulting from the non-interconnecting vugs and fractures, as compared to the pessimistic porosities read from the acoustic recording.

Fig. 8 - Case History No. 4

Fig. 9 - Case History No. 5
CONCLUSION If bad open-hole conditions had existed, the cased-hole recording of the acoustic-neutron would have been the safest and the most economical approach.

SUMMARY AND CONCLUSION
The value and advantages of the acoustic-neutron through casing log are
A Obtaining valuable log information in wells that were cased prematurely because of bad hole conditions
B Obtaining valuable porosity information in wells that are to be recompleted for secondary-type production that were first completed before the advent of the acoustic log
C The economical advantages of both A and B are obvious Continued success in obtaining this log could result in the development of other economical logging procedures
The interpretation of channeling or cement absence is based on empirical conclusions derived from the recorded data. The primary purpose of this up-to-date method of evaluating cased wells is to determine porosity and formation lithology. Eventually the limitations, advantages, and disadvantages of acoustic-neutron logging in cased wells will be established. In the meantime, an important new service is available to the oil industry.

BIBLIOGRAPHY