CSCanada
Advances in Petroleum Exploration and Development
Vol. 8, No. 1, 2014, pp. 55-60
DOI:10.3968/5413

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

An Experimental Study on Cement Sheath Sealing Evaluation

ZHAO Xiaofeng[a],*; MA Wenhao[a]; LIAO Hualin[a]; HE Hongjun[a]

[a] College of Petroleum Engineering, China University of Petroleum, Qingdao, China.
*Corresponding author.

Supported by the National Basic Research Program of China (973 Program) (NO. 2010CB226706); And the fundamental research funds for the central universities (NO. 27R1202015A).

Received 6 August 2014; accepted 16 September 2014
Published online 25 September 2014

Abstract

According to the problem of cement sheath sealing evaluation, a laboratory simulation experiment has been conducted. By making such scaled models, simulate the different cementationconditionsof interfaces, and measured by the logging instrument which is established underthe principle of similarity, then proposed the evaluation method of cement sheath, finally realized the quantitativeevaluationofthe cement sheath seal integrity in the lab.

Key words: Cement sheath; Seal evaluation; Simulated experiment; Fast fourier transform

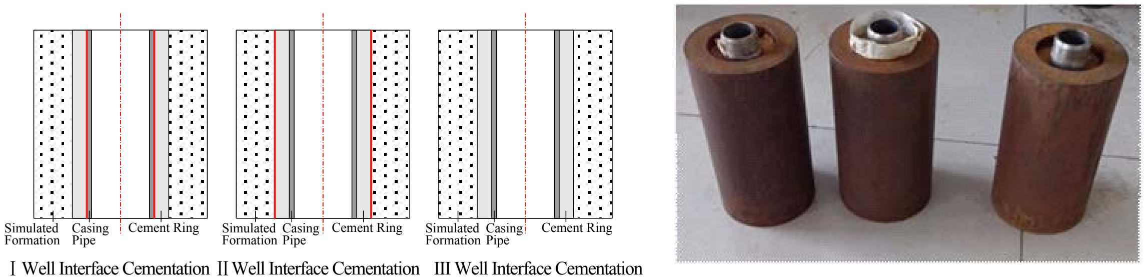
Zhao, X. F., Ma, W. H., Liao, H. L., & He, H. J. (2014). An experimental study on cement sheath sealing evaluation. *Advances in Petroleum Exploration and Development*, *8*(1), 55-60. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/5413
DOI: http://dx.doi.org/10.3968/5413

INTRODUCTION

The seal integrity of the cement sheath can directly influence the well's life and series of subsequent operations like well testing and production, and so on. Also it is an important premise of some measures for increasing production and stimulation such as acid and fracture.Therefore, it is significant to insure the seal integrity of the cement sheath in every section of the well by reinforcing evaluate the seal of the cement sheath[1-3]. Well drilling is a high-investment and high-risk economic activity, and the economic costs of experimental research using oil field well is enormous, so researches aimed at evaluate the seal of the cement sheath mostly use simulated experiments and theoretical methods[4-8], and experimental study with shrunken models is characterized by low cost, fast efficiency and feasible operability, and so forth. In this paperwe fabricated the well section model in the lab, measured with the established acoustic logging instrument, and ultimately proposed a simple but effective method which can evaluate the seal of the cement sheath quantitatively. The method can calculate the casing wave energy and formation wave energy accurately, and by defining the interfacial bond index, finally realized evaluate the seal integrity of the cement sheath quantitatively in the lab.

1. FABRICATION OF WELL SECTION MODEL AND ACOUSTIC LOGGING INSTRUMENT

In order to measure and analyze the well section models with different cementation quality, we made 21 well section models with different cementation quality in this experiment. The structure diagram of well section models are shown in Figure 1a, from left to right, the cementation quality are poor cementation of interface I, poor cementation of interface II, and perfect interfacial cementation respectively.

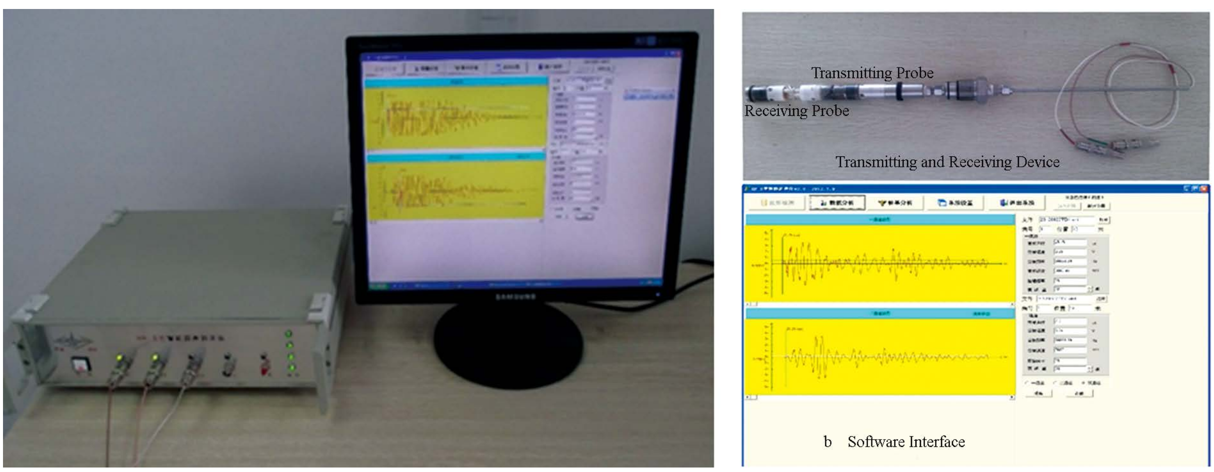


(a) (b)

Figure 1
(a) Structure Diagram of Well Section Models, (b) Well Section Models

According to the similarity criterion and the actual wellbore size, the well section models are shrunk by 4:1, the models are cylindrical (Figure 1b), 21 cm total in height, choose 304 stainless steel tubes (inner diameter 32 mm, wall thickness 2 mm) to simulate casing, and circular cast iron (inner diameter 60 mm, wall thickness 20 mm) is used to simulate formation. Insert the simulated casing into the center of the simulated formation and center the casing with designed pedestal. Then cement slurry is injected into the annular space between casing and formation, the cement slurry (50% water/cement ratio) is made of G-class cement, 0.2% fluid loss agent and 0.2% foam breaker. During fabricating the model, we adhere pieces of paper to the external casing wall (internal circular cast iron wall) to simulate the poor cementation of interface I (interface II). After injected the cement slurry into the annular space, curing the model by 48 h under the conditions of normal temperature and pressure. During waiting on cement, we should inject water to the surface of the cement sheath every 8 hours to prevent cracks from appearing due to the loss of water.

Based on the relevant information, we got the propagating velocity of sound wave in the well section model: Water 1,500 m/s, stainless steel casing 5,900 m/s, G-class cement 3,000 m/s, cast iron formation 5,000 m/s. Both the transmitter and receiver of the logging instrument use piezoelectric ceramic transducer. The center frequency of sound source is 80 KHz, which is equivalent to 4 times of actual instrument. The external diameter of logging instrument is 22.60 mm, and the source spacing is 104 mm. It needs to carve sound insulation groove on the shell of the instrument to prevent the sound wave from spreading in the instrument. The signal generator is shown in Figure 2a. The logging instrument and data-collecting software interface is shown in Figure 2b.



(a) (b)

Figure 2
(a) Signal Generator, (b) Logging Instrument and Data-Collecting Software Interface

2. PRINCIPLES OF THE EXPERIMENT

2.1 Measurement Method and Principle

The whole well section model needs to be fully immersed in water when measuring, and the instrument should be placed into the model and centered. Acoustic wave from transmitter can spread to receiver by the paththrough four kinds of medium, from water into the casing, cement and formation (Figure 3).

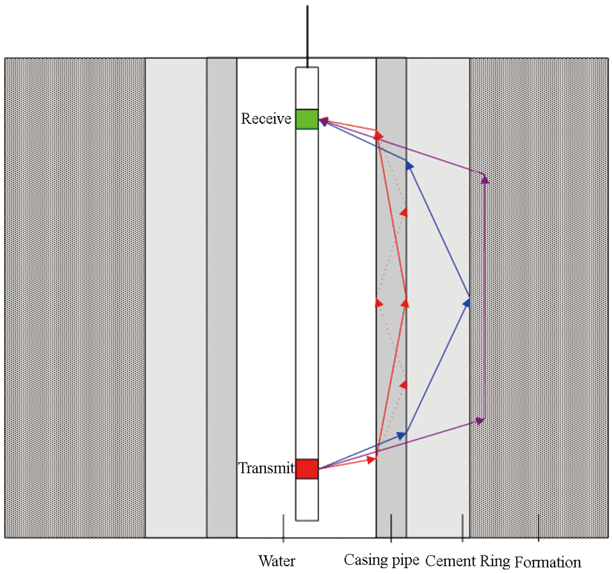


Figure 3
Transmission Path of Acoustic Wave in Well Section Model

Therefore, the receiver can detect four kinds of waveform: water wave, casing wave, cement sheath wave and formation wave. However, due to the serious attenuation of acoustic wave in the cement, cement sheath wave is weak which can be neglected. Finally, we evaluate the sealing conditions of cement sheath interfaces by identifying the energy of casing wave and formation wave.

2.2 Evaluation Method on the Sealing of Cement Sheath Interface

2.2.1 Confirmation of Formation Wave Arrival Time

Through determined the systematic error of the logging instrument (the difference between calculated value and actual measured value), and combined with the theory arrival time of formation wave which is calculated from the theory of wave velocity in different mediums and propagation path, then formation wave arrival time which is measured can be estimated.

In the systematic error confirmation experiment, we measured the head wave arrival time of casings with different diameter. Figure 4 shows the casings, as is shown, diameter decreases from left to right. Theoretical head wave arrival time of simulated casing can be calculated by the following formula:

$$T_1 = T_w + T_c \tag{1}$$

Type: T_1 - Arrival time of casing wave, μs; T_w - Time of acoustic wave propagating in water, μs; T_c - Time of acoustic wave sliding in the casing, μs.

Figure 4
Simulated Casings With Different Diameter

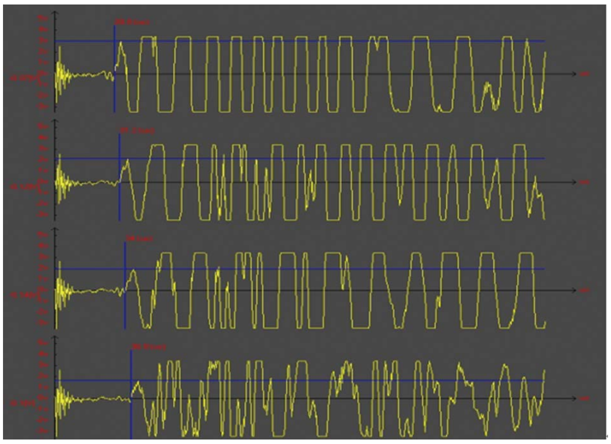


Figure 5
Measured Waveforms of Casings With Different Diameter

Figure 5 shows the measured waveforms of simulated casings with different diameter. After measurement, compared the measured wave arrival time with the theoretical calculated value, the results are shown in Figure 6. As we can see from the figure, head wave arrival time increases as casing diameter increases, and the differencesare almost constant between theoretical values and measured values, finally we got the systematic error 9 μs by calculating the average value.

By using the obtained systematic error, the measured arrival time of formation wave can be estimated by the following formula, and then the formation wave can be identified in the time-domain graph.

$$T_2 = T_w + T_c + T_{ce} + T_f + \Delta t \tag{2}$$

Type: T_2 - Arrival time of formation wave head wave, μs; T_w - Time of acoustic wave propagating in water, μs; T_c - Time of acoustic wave sliding in casing, μs; T_{ce} - Time of acoustic wave propagating in cement sheath, μs; T_f - Time of acoustic wave sliding in the formation, μs; Δt - Systematic error of instrument, μs.

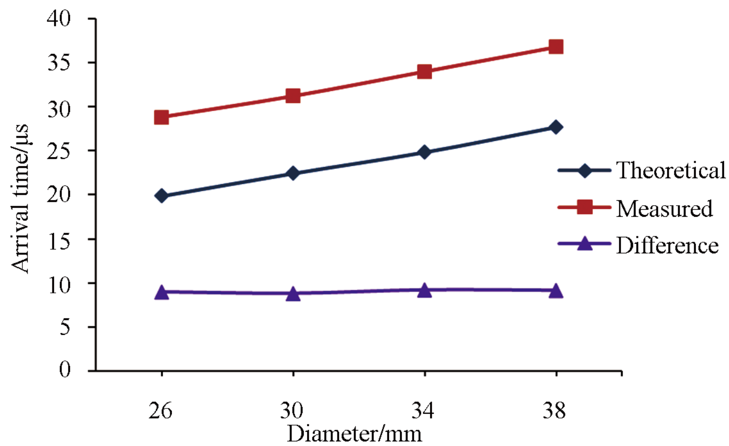


Figure 6
Comparison of Head Wave Arrival Time of Different Diameter Casings

2.2.2 Quantitative Evaluation Method on the Seal of the Cement Sheath

We can get the arrival time of various kinds of waves on the time-domain graph accurately, but because of some degree of interference exists among formation wave, casing wave and water wave, the energy of various waves calculated by integration on time-domain graph is inaccuracy. So we need to make Fast Fourier Transformation to the waveforms on time-domain graph, eliminate the influence of casing wave to formation wave in frequency-domain graph, then calculate the casing wave energy and the formation wave energy, evaluate the seal of the cement sheath interface quantitatively.

The steps to calculate the interfacial cementation index are as follows:

(a) Estimate the arrival time of formation wave by using Formula 2, and open a window from the head wave. (Opening window means to elect some waveform over a period of time, the principle is that it should contains full information of casing wave and formation wave, but no various subsequent interference waves);

(b) Make Fast Fourier Transformation for the waveform in the window and get the amplitude spectrum *A*(*f*);

(c) Recognizedthe dominant frequency of casing wave and formation wave, and integrate the casing wave and formation wave, then get the corresponding casing wave energy and formation wave energy. The formula is as follows:

$$E_1 = \int_{f_1}^{f_2} A(f)df \quad (3)$$

$$E_2 = \int_{f_3}^{f_4} A(f)df \quad (4)$$

Type: E_1 is casing wave energy, V•Hz; f_1 is the start frequency of casing wave, KHz; f_2 is the stop frequency of casing wave, KHz; E_2 is formation wave energy, V•Hz; f_3 is the start frequency of formation wave, KHz; f_4 is the stop frequency of formation wave, KHz.

(d) Calculate the bond index after obtained casing wave energy and formation wave energy. The bond indexes of two interfaces are defined as Formulas 5 and 6:

$$BI_1 = 1 - \frac{B - B_{\min}}{B_{\max} - B_{\min}} \quad (5)$$

$$BI_2 = \frac{A}{A_{\max}} \quad (6)$$

Type: BI_1 is the bond index of interface I, dimensionless; $BI_2$is the bond index of interface II, dimensionless; B is casing wave energy measured in the well section model, V•Hz; $B_{\max}$ is the maximum of measured casing wave energy, that is casing wave energy in the free casing section, V•Hz; $B_{\min}$ is the minimum of measured casing wave energy, that is casing wave energy in perfect cementation well section model, V•Hz; A is formation wave energy measured in well section model, V•Hz; $A_{\max}$ is the maximum of formation wave energy measured in the experiment, V•Hz.

Through the definition of cement sheath interfacial bond index we can see that: the smaller the interface I bond index, the worse the cementation, the worse the sealing effects; On the contrary, the bond index is closer to 1, the better the cementation, the better the sealing effects. The interface II bond index is positively correlated with measured formation wave energy. The bigger the BI_2, the better the cementation, the better the sealing effects.

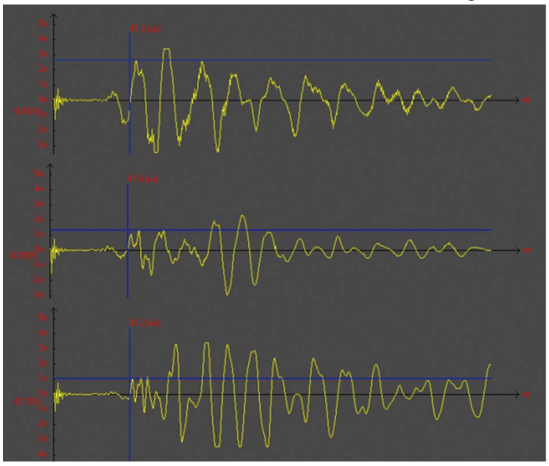


Figure 8
The Waveforms of Different Well Section Models

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Experimental Results

The measurement waveforms of different well section models were showed in Figure 8, from top to bottom in order: Poor cementation of interface I, poor cementation of interface II, perfect interface cementation. As we can see from the figure, the energy of casing wave is powerful when the interface I has a poor cementation, and the amplitude is much larger than the conditions of interface I cementation perfectly. If both interfaces has perfect cementation, the amplitude of formation wave is larger than the conditions of poor cementation of interface II, the results are consistent with the basic theory.

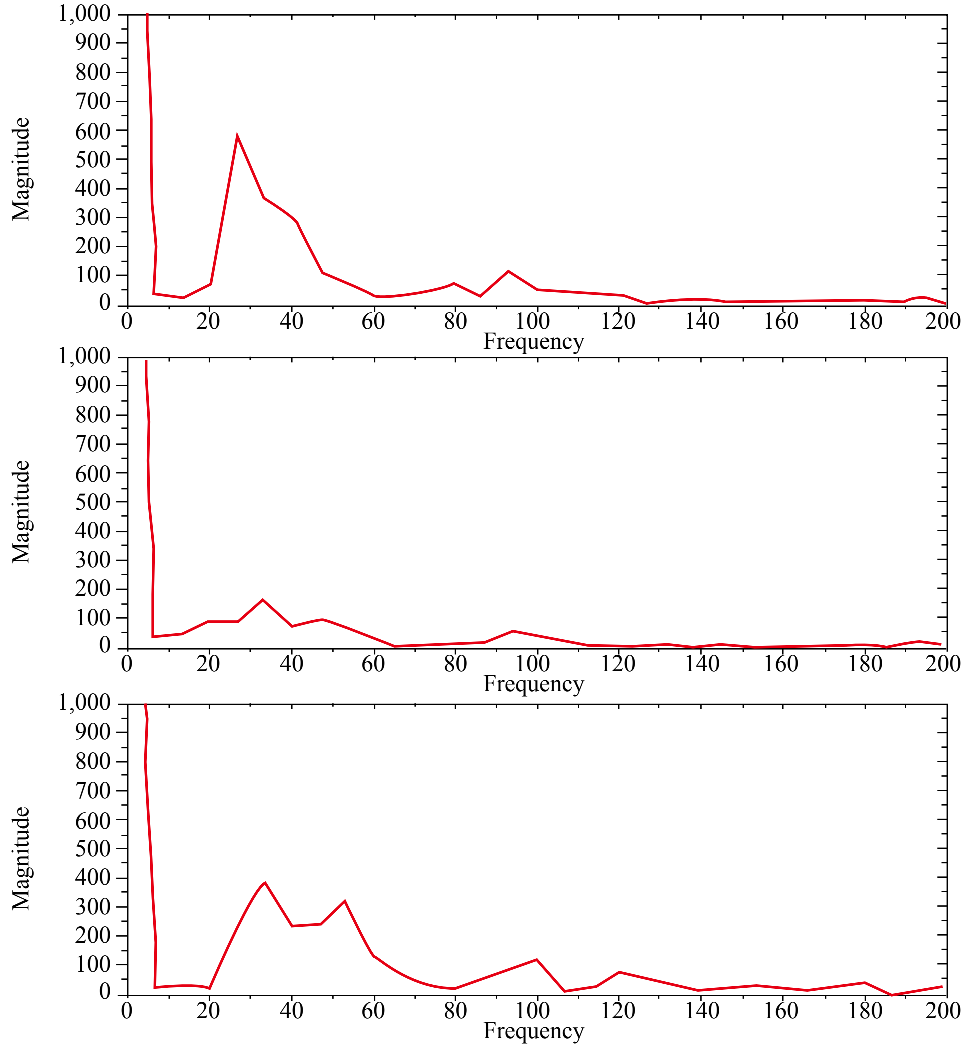


Figure 9
The Frequency Spectrogram of the Waveforms

3.2 Data Analysis

Then export the experiment data, and pick the waveform data from time 25 μs to 100 μs calculated by Fast Fourier Transform, we got the frequency spectrogram of the data shown in Figure 9, plotted by frequency (KHz) on the horizontal axis and amplitude (mV) on the vertical, by comparing the three waveforms in Figure 8, we can see the range of casing wave dominant frequency are 27 KHz to 40 KHz, the range of formation wave dominant frequency are 47 KHz to 60 KHz, and there are some clutter of certain frequency at the same time.

After that, integrate the casing wave and formation wave on the frequency range respectively, get the energy values of the casing wave and formation wave in different cementation, and calculate the interfacial bond index by using Formulas 5 & 6. The Table 1 shows the calculated results. According to the data provided by the table, we can see that under conditions of poor cementation of interface I, the energy value of casing wave is much larger than the conditions of interface Icementation perfectly. If both interfaces has perfect cementation, the amplitude of formation wave is larger than the first two cases, indicate that the wave energy passed the interface II smoothly, and spread to the receiving transducer by sliding in the formation.

Table 1
The Calculated Results of Experiment

Cementation	Energy value of casing wave / V•Hz	Energy value of formation wave / V•Hz	Bond index of interface I BI_1	Bond index of interface II BI_2
Poor cementation of interface I & perfect cementation of interface II	509.35	171.00	0.22	0.50
	538.64	153.91	0.15	0.45
	608.59	188.30	0	0.55
	493.46	141.19	0.25	0.41
	519.17	139.54	0.19	0.40
	492.45	163.30	0.25	0.48
	599.99	153.75	0.02	0.45
Perfect cementation of interface I & poor cementation of interface II	263.61	114.36	0.75	0.33
	173.28	96.01	0.94	0.28
	206.78	135.24	0.87	0.40
	197.82	135.32	0.89	0.40
	181.58	128.25	0.93	0.37
	147.28	100.77	1.00	0.29
	176.97	137.81	0.94	0.40
Perfect interface cementation	314.46	342.22	0.64	1.00
	257.11	277.84	0.76	0.81
	350.02	319.20	0.56	0.93
	347.52	299.60	0.57	0.88
	329.56	290.46	0.60	0.85
	341.91	315.78	0.58	0.92
	335.61	263.18	0.59	0.77

Based on the multiple sets of data of the experiment, define the laboratorial valuation criterion of cement sheath interfacial sealing, as shown in Table 2.

Table 2
The Laboratorial Evaluation Criterion of Cement Sheath Interfacial Sealing

Interface	Cementation factor	Cementation quality
I	$0 < BI_1 < 0.25$	Poor
	$0.25 < BI_1 < 0.56$	Medium
	$0.56 < BI_1 < 1$	Good
II ($BI_1 > 0.56$)	$0 < BI_2 < 0.40$	Poor
	$0.40 < BI_2 < 0.77$	Medium
	$0.77 < BI_2 < 1$	Good

CONCLUSION

(a) Through fabricated well section models in the lab, measured with the created acoustic logging instrument, finally we realized evaluate the seal integrity of the cement sheath quantitatively in the lab. Characterized for its low cost, fast efficiency and feasible operability, the experiment has a certain guiding significance for field work.

(b) When evaluating the sealing of cement sheath in the lab, some degree of interference exists among formation wave, casing wave and water wave, so we can make Fast Fourier Transformation to the waveforms on time-domain graph, then recognize various waveforms in frequency-domain graph more accurately.

(c) By integration on the frequency-domain graph, calculate the casing wave energy and the formation wave energy, and combined with the definition of cementation index. We can evaluate the sealing of the cement sheath interface quantitatively.

REFERENCES

[1] Diao, S. (2003). Influence of microannulus' thickness on capacity ofacoustic wave-logging tool. *Oil Geophysical Prospecting*, *38*(5), 540-542.

[2] Guan, B., Xue, G. Y., & Gao, H. Z. (2002). A method for cementing quality evaluation with full-wave acoustic log data. *Well Logging Technology*, *26*(5), 383-386.

[3] Qiang, Y. M., Li, C. W., Song, Y. H., & Li, G. J. (2004). Principle of multi-parameter ultrasonic engineering logging tool and its application. *Well Logging Technology*, *28*, 28-30.

[4] Tubman, K. M., Cheng, C. H., & Toksoz, M. N. (1984, June). *Determination of formation properties in cased boreholes using full waveform acoustic logs*. SPWLA Twenty-Fifth Annual Logging Symposium.

[5] Che, X. H., Qiao, W. X., & Yan, X. H. (2005). Simulated experimental investigation about effects of different bondings on cement bond quality. *Well Logging Technology*, *29*(3), 185-187.

[6] Hu, W. X., & Shi, X. L. (1997). An experimental study on short spacing acoustic fullwaveform log in cased hole. *Well Logging Technology*, *21*(5), 329-334.

[7] Hu, W. X., & Liu, Y. B. (1997). Experimental model ling for cement bond logging in cased wells. *Journal of Jianghan Petroleum Stitute*, *19*(3), 51-55.

[8] Sun, J. M., Su, Y. D., & Li, Z. C. (2004). On Quantitative Evaluation of Second Interface Cementing Quality. *Well Logging Technology*, *28*(3), 199-202.