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RESEARCH PAPER

Cement bond quality evaluation based on acoustic variable density logging

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Abstract: A new method of cement bond quality evaluation was proposed by combining numerical simulation and calibrated cased hole acoustic logging data. The effects of the cement channel angle and the quality of the second bond interface (the interface of cement with formation) on acoustic variable density logging data were analyzed. Based on the analysis result, a new cement bond evaluation standard was presented after revising the traditional CBL/VDL method. The axisymmetric acoustic field was simulated by real axis integral method, while the non-axisymmetric acoustic field was simulated by 2.5-D finite differential method. After comparing with the calibrated cased hole acoustic logging data, the research has the below results: the numerical simulation result matches with the calibrated well logging data very well and the new method is reliable; the amplitude of the first acoustic arrival in the case hole decreases as the angle of cement channel decreases, and the denser the cement is, the faster the amplitude of cased hole acoustic waveform decays; the lower limit of cement channel angle is around 45 degrees which can be detected by acoustic logging; the formation acoustic waveform is not easy to be detected in time domain, however it is easy to be detected in frequency domain, especially in limestone formation, the first arrival only can be detected when the annulus width of the second bond interface is small. According to the research result of the numerical simulation of cased hole acoustic field and acoustic variable density logging data, new evaluation criteria of cement bound quality were presented.

Key words: cement bond quality; acoustic variable density logging; acoustic field in cased well; cement channel angel; interface bond index

Introduction

To ensure production safety of oil and gas wells and extend service life of casing, the space between the casing and formation is usually filled by cement, to bind the casing and formation closely. As oil and gas wells are generally more than 1 000 m deep, quick and effective evaluation of cement quality in cased wells is particularly important. Acoustic logging is the main method nowadays used in evaluating the cement quality in oil and gas industry. The evaluation includes bond interface I (the bond interface of casing and cement) and bond interface II (the bond interface of cement and formation). Previous researches have already proved that bond interface I can be evaluated from the casing arrival waveform, while bond interface II can be evaluated from the formation arrival waveform[1–2].

Borehole acoustic field study is the foundation of cement quality evaluation with acoustic logging. A lot of researches and studies on this topic have been conducted at home and abroad[3–11], most of them were theory research based on wave equation. But in the real cased wells, the anisotropy of formation and borehole fluid, and the acoustic logging tool itself will definitely affect the borehole acoustic field. Although some researchers have already studied the effect of logging tool, casing type, fracture, formation dip on the cased well acoustic field with numerical simulation[12–17], limited by experimental conditions, the physical models in the researches normally were only a few meters long, much shorter than the real cased wells in oilfields. That is to say the previous researches had their limitations. In addition, there are a lot of different kinds of acoustic logging tools in the market, though CBL/VDL is the cheapest and quickest acquisition tool widely used in the oilfield to evaluate the cement quality, there aren't much report about its application in evaluating cement channeling and bond interface cement quality.

According to the actual size of oil and gas wells, the non-axisymmetric acoustic field has been numerically simulated with 2.5-D finite differential method and then compared with the casing waveform acquired by acoustic variable den-

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sity logging tool in the calibration wells to evaluate the reliability of the numerical simulation method and analyze the effect of cement channeling angle on the acoustic variable density logging; and the axisymmetric acoustic field has been calculated with real axis integral method to analyze the effect of the annulus width of bond interface II on the casing arrival waveform and formation arrival waveform; based on the analysis of the effect of cement density and cement channeling angle on the CBL/VDL logging quality, a new improved cement bond quality evaluation method with CBL/VDL data has been advanced in this study.

1. Research methods of acoustic field in cased well

Real acoustic logging data and the numerical simulated data in standard calibration wells were used to study acoustic field in cased well. On one hand, the real logging data taken from calibrated wells can validate the reliability and accuracy of the new simulation method, on the other hand, the numerical simulation can compensate the limited number of calibration wells and lower research cost.

1.1. General introduction of the calibration wells

The calibration wells were constructed by Xin Jiang Logging Service Company to calibrate downhole logging tools. There are eight calibration wells named as Well 1–8. The cement density in these calibration wells is from 1.20 to 2.25 g/cm^3 and the formation lithology includes shale, sandstone, limestone and granite. Well 3 and Well 4 were used to model the situation of sector cement channeling. Both of them have a casing diameter of 139.70 mm, casing thickness of 7.72 mm, cement sheath thickness of 38 mm, formation inner diameter of 216 mm and outer diameter of 1216 mm. Five different situations from the well bottom to the top, eccentric casing and different cement channel angles of bond interface I of 22.5°, 45°, 90°, 180° and 360°, (Fig. 1) were simulated. The cement density of Well 3 is 1.89 g/cm^3, while Well 4 is 1.20 g/cm^3. As Fig. 1 shows, the amplitude of the casing arrival becomes smaller with the decrease of the cement channeling angle. The same variation trend of the cement channeling angle and the amplitude of the casing arrival waveform shows that acoustic logging data can be used to evaluate cement channeling angle.

1.2. Numerical simulation of acoustic field in cased well

Poor cementation between casing and formation can be separated into two different types, non-cementation of annulus and partial cementation of annulus. Non-cementation means there is no cement between casing and formation. Partial cementation means there is cement in part of the annulus between casing and formation. The former would result in axisymmetric acoustic field, while the latter non-axisymmetric acoustic field.

1.2.1. Axisymmetric acoustic field

The axisymmetric acoustic field was numerically simulated

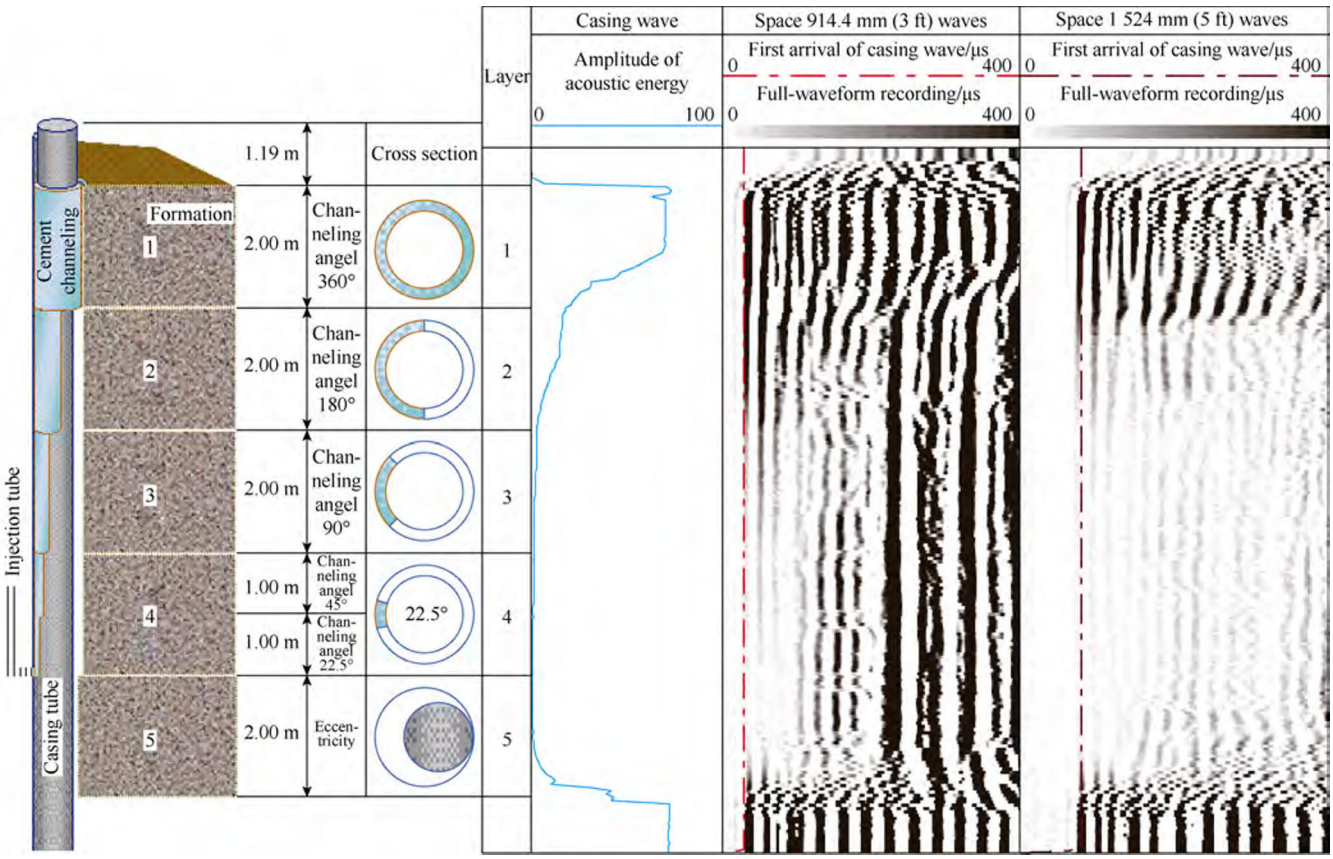

Fig. 1. The model of No.3 calibration well and waveform from CBL/VDL.