The improvement of cementation quality rating method based on compressive strength for low density cement system

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Abstract

In order to prevent the occurrence of cementing fluid leakage in low leakiness formation and protecting reservoir effectively, low density cement system is widely used. As the use of lightening admixture to reduce the density in low density cement system, the cement acoustic impedance of low density cement system is different from conventional density, it can not reflect the real cementing quality when using the criteria of conventional density cement cementing quality evaluation to evaluate the cement job quality of low density cement. Targeted at this problem, this paper conducted a method to improve the criteria of evaluation of cementing for low density cement. Studies have shown that the compressive strength and the acoustic impedance has a good linear relationship in different types of low density cement conserved 24h and 48h, so we put forward a method to improve the evaluation of cementing quality of low density cement based on the compressive strength of low density cement.

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Key words: compressive strength; acoustic impedance; low-density cement; the evaluation of cementing

1. Introduction

With low density cement cementing, the sound coupling is poor compared with conventional density cement [1], this will cause deviation when we use the standard of conventional cementing cement system
quality evaluation, and even cause the wrong evaluation results. The practical application of the field also
shows that the cement bond log interpretation result and the actual cementing quality are not consistent
sometimes. In some wells or hole section, cement bond logging results show that the cementing quality is
high, which means that the effect which cement ring seal between the layers is very good, but it happened
oil, gas, water channeling and even wall collapsed in well in fact; and sometimes cement bond logging
results show that for poor, which mean cement ring seal between the layers is poor, but we found it is
impossible to squeeze cement when we adding squeeze cement after perforation \[^{2}\].

In ChuZehan’s experimental study, he made low density cement slurry only by increasing the
water/cement ratio, the oil well cement compressive strength and the acoustic impedance have a nonlinear
relationship \[^{3}\], but it is by adding lightening admixture and adjusting water/cement ratio while realizing
the purpose of reducing the density of cement slurry in the process of cementing operations, so there
exists some errors in his research. Zhang Chengguang put forward to the method with the corrective chart
and corrective formula to improve the evaluation of low density cement cementing quality \[^{4}\], but due to
the differences of lightening admixture, the acoustic characteristics of each type of low density cement
stone is not completely same. Therefore, this method is not completely suitable for all types of low
density cement.

Through contrasting several conventional low density cements’ relationship between acoustic
impedance and compressive strength, this paper proposes an improved method for cementing quality
evaluation of low density cement.

2. Experimental formula and procedures

2.1 Experimental formula

This experiment mainly studied three kinds of low-density cement slurry, compounds light weight
cementing slurry with floater and micro-silica, low density fly ash cement slurry, hyperfine silica low
density cement slurry. They are all commonly used in field. The density of compounds light weight
cementing slurry with floater and micro-silica is range from 1.09 g/cm\(^3\) to 1.75 g/cm\(^3\), The density of low
density fly ash cement slurry is range from 1.50 g/cm\(^3\) to 1.75 g/cm\(^3\), the density of hyperfine silica low
density cement slurry is range from 1.30 g/cm\(^3\) to 1.62 g/cm\(^3\).

2.2 Experimental procedures:

The main experimental processes are as follows:

(1) For each kind of low-density cement slurry, we separate it into two sets and pour it into moulds
respectively, and then put them into the autoclave curing at ordinary pressure and 75\(^\circ\)C, curing one set for
24h and another for 48h.

(2) We get the mass of the set cements, and get their volume using the displacement method, and then
we calculate the density of the set cement.

(3) We measure the longitudinal wave velocity (v) of the set cements, then we can calculate the
acoustic impedance (z) using the equation \(Z=\rho v\).

(4) Measure the compressive strength of the set cements.

3. The research of the relationship between compressive strength and acoustic impedance

3.1 The relationship of every kind of formulation between compressive strength and acoustic impedance
We can see from Fig1 to Fig3:
(1) There exist a good linear relationship of every kind of cement stone between compressive strength and acoustic impedance, and with the increasing of the compressive strength, the acoustic impedance is increasing.
(2) With the increasing of curing time, the compressive strength and acoustic impedance curing for 48h are all larger than the ones curing for 24h, but the slope is slightly lower.

3.2 The comprehensive analysis of the relationship between compressive strength and acoustic impedance

Although Fig1~Fig3 shows that compressive strength and acoustic impedance have a good linear relationship, but we need to examine whether the relationship can be applied to all common low density cement slurry system.

We can see from Fig.4, acoustic impedance and cement stone compressive strength still have good linear relationship when we put all low density cement stone together to compare.

From Fig.4 we can get the types as follow:
Curing for 24h:  \[ Z = 1.1223G + 21.748 \]  \( R^2 = 0.931 \)  \( (1) \)
Curing for 48h:  \[ Z = 0.9539G + 22.51 \]  \( R^2 = 0.9022 \)  \( (2) \)

In which, \( Z \) stands for acoustic impedance, \( 10^4 \text{g/cm}^2\cdot\text{s} \); \( G \) stands for compressive strength, Mpa.
4. Improvement of the low density cement cementing quality evaluation

4.1 Theoretical analysis

In the cement bond logging, we can simulate the wave propagation of down hole as the processes of reflection and refraction is shown in Fig.5 [8]. The casing wave is often used to evaluate the cementing quality of first interface (the interface of casing and cement).

The acoustic intensity (or amplitude) of casing wave is related to the cementing quality, when we neglect the absorption decay of sonic, the acoustic intensity \( J \) received is:

\[
J = J_0 \alpha_{12} \beta_{23} \alpha_{21} = J_0 \alpha_{12}^2 \beta_{23}
\]

When analyzing the standard of cementing quality evaluation, we assume the mud and casing’s material is fixed and the casing mode is fixed. If the cementing quality is good, we can conclude that the acoustic impedance of mud \( (Z_1) \) and the acoustic impedance of casing \( (Z_2) \) are fixed value, so the refractive factor \( \alpha_{12} \) is a fixed value. Then the acoustic intensity is only related to the reflection factor \( \beta_{23} \), meaning it is only related to the acoustic impedance of cement \( (Z_3) \).

We also know that the acoustic intensity proportional to the square of acoustic amplitude, so the acoustic intensity can also be expressed as:

\[
J = kA^2
\]

In which, \( A \) stands for the acoustic amplitude, \( k \) is a factor, which is related to the density of media and the speed of sound.

Depending on the above analysis, we can get the acoustic amplitude expression as follow:

\[
A = \frac{m}{Z_3 + n} - c
\]

In which, \( m = 2cZ_2 \), constant; \( n = Z_2 \), constant; \( c \), constant.

We can see from type5, when other conditions as a fixed value and only consider the acoustic impedance of cement \( (Z_3) \), the amplitude of casing wave’s head wave is related to \( Z_3 \), with the increase of \( Z_3 \), the acoustic amplitude \( A \) is decreasing. And the value of the acoustic impedance of low density cement is less than the one of conventional cement. So, when we use low density cement to cementing, the value of acoustic amplitude is lower than the conventional cement, if we evaluate the quality of cementing with the conventional evaluation standard, there will be deviation. Therefore, we need to check the standard of cementing quality evaluation and fix it. By type 5, it can be known that, if we know the value of the acoustic impedance of cement, we can get the theoretical value of the acoustic amplitude.

4.2 The calculation method of casing wave based on the compressive strength of cement

Because the logging time is often 24h, so choose type1 to calculate the value of the acoustic impedance and the theoretical value of fully cemented casing wave amplitude.

Putting type1 into the type5, we can get the theoretical value of casing wave amplitude when the first interface’s cementation quality is good. The equation is in the form of:
2.1223 21.748
\[ A = \frac{m}{1.1223G + 21.748 + n} - c \]  

Where \( m, n, c \) are all fixed value. Therefore, the casing wave amplitude is only related with compressive strength of low density cement. In well logging, if the value of the compressive strength of cement stone is known, then the theoretical value of received casing wave amplitude can be calculated when the first interface cementation quality is good.

4.3 The improvement of low density cement cementing evaluation

The relative amplitude method and the cement bond index method are generally used to evaluate the quality of cementing in CBL/VDL. In this paper, the improvement measure which we proposed aim at the relative method.

The relative amplitude method:

\[ A_f = \frac{A}{A_o} \times 100 \]  

In which, \( A_f \)--relative amplitude, \%;
\( A \)--the acoustic amplitude of casing wave’s head wave in intended interval, mV;
\( A_o \)--the acoustic amplitude of casing wave’s head wave in free hole section, mV.

The general evaluation criteria is as follow, \( A_f \leq 20\% \) means a good cement bond; \( 20\% < A_f \leq 40\% \) means a middle cement bond; \( A_f > 40\% \) means a poor cement bond. (This criteria is only for reference, the concrete criteria should be decided base on the actual situation of each oil field)

Due to the value of low density cement’s acoustic impedance is less than the value of conventional density cement’s acoustic impedance, as well as poorly of the sound coupling, so the acoustic amplitude is higher. So according type6 and type7, we can get the theoretical value of low density cement’s relative amplitude \( (A_{f1}) \) when the first interface cementation quality is good. We can also work out the theoretical value of conventional density cement’s relative amplitude \( (A_{f2}) \) when the first interface cementation quality is good. We define the amplitude increase coefficient \( (l) \) as the ratio of theoretical value of low density cement’s relative amplitude \( (A_{f1}) \) and the theoretical value of conventional density cement’s relative amplitude \( (A_{f2}) \).

\[ l = \frac{A_{f1}}{A_{f2}} \]  

So we can improve the standard of low density cement’s cementing quality evaluation by get the value of \( l \). So the evaluation standard becomes: \( A_f \leq l \times 20\% \) means a good cement bond; \( 20\% < A_f \leq 40\% \) means a middle cement bond; \( A_f > 40\% \) means a poor cement bond.

Conclusion

Through theoretical analysis and experiment research we obtained the following conclusions:

(1) For the compounds low density cement slurry with floater and micro-silica, low density fly ash cement slurry and hyperfine silica low density cement slurry, the compressive strength of the set cements has a good linear relationship with the impedance of acoustic.

(2) Using the geometric acoustical analysis and the experimental rules, considering that when the first interface cement well, we can known that the amplitude of casing waves depend on the value of cement's
acoustical impedance when the first interface cementation quality is good, we get the equation to calculate the amplitude of casing waves based on compressive strength of low-density cement.

(3) We put forward the improvement methods of the first interface cementing quality evaluation standards of low-density cement based on the compressive strength under the down hole condition, and this provide basis for the overall improvement of the cementing quality evaluation standards of low-density cement.

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