Study on the Mechanism of Enhancing Cementing Quality with the Downhole Shear Swirling Flow Vibration Cementing Tool

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Abstract: Downhole shear swirling flow vibration cementing tool has shear, rotational flow and vibration triple effects. It can improve cementing quality in various aspects. This paper developed discussion in the aspects of the tool to change cementing fluid performance by shear, to realize turbulent displacement and improve the wall shear stress by swirling flow, to change periodically relative position of clearance by casing eccentric revolution, to increase compression strength of cement by vibration and so on. It analyzed the mechanism of enhancing cementing quality of the downhole shear swirling flow vibration cementing tool in detail. It deepened the understanding of the tool. Then the research results help to promote the tool further application in oil and gas well cementing engineering field, and further increase the oil and gas well cementing quality.

1. Introduction
At present, oilfields in old areas have entered the late stage of high-water-cut development, and the output of oilfields is facing the trend of decline. To achieve the goal of stabilizing oil and controlling water, higher requirements are put forward for cementing quality of adjustment Wells in old areas. At present, there are two main problems in cementing adjustment Wells in the old water-flooding oilfield. First, in order to ensure the oilfield production, the old oilfield pays more attention to the development of thin layer and the interval between layers is smaller, which requires cementing operation to provide better inter-layer isolation effect. Second, after years of water injection development in the old oilfield, several pressure systems have been formed longitudinally, and the cementing fluid density window is more narrow, resulting in double risks of pressure leakage and well surge. The displacement efficiency is poor due to the restriction of displacement discharge rate, and the high-pressure layer is prone to gas-water invasion during the temperaturating process, which seriously reduces the cementing quality of adjustment Wells. The shear cyclone vibration cementing tool USES the cementing fluid as the power source to drive the cascade rotation. The tool can improve cementing quality from many aspects. In this paper, the mechanism of improving cementing quality of downhole shear cyclone vibration cementing tool is analyzed, which lays a theoretical foundation for further popularization and application of the tool.
2. Downhole shear cyclone vibration cementing tool structure

The downhole shear cyclone vibration cementing tool is installed at the casing shoe at the bottom of the casing string and is mainly composed of three parts, namely, the guide hole of the supporting plate, the shear cascade and the eccentric cascade, as shown in Figure 1. There is a guide hole on the supporting plate, and the guide hole has a certain inclination angle, which will make the fluid change the flow direction according to the inclination angle of the guide hole and impact the cascade at a certain angle. The structure of the cascade is similar to that of a turbine, which rotates at a high speed under the impact of fluid. The shear cascade mainly acts as a high speed shear for cementing fluid to improve its rheological property. An eccentric block is installed on one side of the eccentric cascade, which makes the cascade apply an ever-changing excitation force in the direction at the bottom of the casing string while rotating. Under the action of this excitation force, the casing tube generates eccentric revolution, which is similar to the motion of conical pendulum. The conical pendulum motion driven by eccentric cascade can play the role of swirl and vibration on annular cementing fluid.

3. Study on the Mechanism of improving cementing quality

3.1. Downhole shear cyclone vibration changes the cementing fluid performance

The downhole shear cyclone vibration cementing tool uses cementing fluid as the power source to drive the downhole cascade to rotate at high speed. According to Bernoulli equation and the law of momentum of momentum, the calculation model of downhole cascade rotation velocity can be obtained:

\[
\eta = \frac{30}{\pi} \frac{1}{\rho_d Q_e} \left( \frac{P_1 - P_2}{\mu_d} + \frac{\alpha_1 V_1^2 - \alpha_2 V_2^2}{2g} \right)
\]

Where, \( Q_e \) is the displacement of the fluid flowing through the eccentric cascade, m³/min; \( D_o \) and \( D_i \) are the outer and inner diameters of the cascade, m; \( \Sigma G \) is the section for the blade bearing retainer plate under above, cascade and the gravity of the fluid, N; \( u \) is friction coefficient, 0.008~0.0012; \( a_1 \) is the inlet design Angle, rad; \( a_2 \) is the absolute velocity Angle when the fluid flows out of the cascade. \( v_{al} \) and \( v_{al2} \) are the annular component of absolute flow velocity when drilling fluid flows into the diversion hole and flows out of the cascade, m/s; \( P_1 \) and \( P_2 \) are respectively the pressure of the fluid at the inlet and outlet of the eccentric cascade, MPa; \( \rho_d \) is fluid density, g/cm³; \( \pi \) is the number of cascade blades; \( \beta_1 \) and \( \beta_2 \) were exit design Angle and exit limit Angle, rad, respectively. \( \eta \) is the efficiency coefficient of fluid kinetic energy to mechanical energy, %; \( r \) the average rotation radius of the cascade, m.
The rotation of downhole cascade produces high speed shear on cementing fluid, which significantly changes the rheological property of cementing fluid and makes it easier to replace\textsuperscript{[1]}. Indoor simulation experiments show that the high speed shear action of downhole cascade will significantly change the cementing fluid performance. The plastic viscosity of drilling fluid decreases by 40% on average, the dynamic shear force decreases by 56.7% on average, and the apparent viscosity decreases by 43.3% on average. The rheological property of drilling fluid can be significantly improved, and it is easier to be replaced. The plastic viscosity of cement slurry decreases by 44.7% and the dynamic shear force by 38.3% on average, which makes it easier to achieve turbulent displacement and reduces the friction of cementing fluid flow, which is beneficial to the control of surface pump pressure and the safety of cementing construction.

3.2. Annular cyclone replacement is realized with downhole shear cyclone vibration cementing tool

When the cementing fluid enters the eccentric cascade, it drives the cascade to rotate at a high speed. The eccentric block on the cascade generates an eccentric force for the whole device and applies it to the casing string at the bottom of the well. The excitation force at the bottom of the casing string changes constantly in the direction, which causes the casing string to generate eccentric revolution vibration, which is similar to the motion of conical pendulum. In the vibration process, the excitation force comes from the eccentric rotation of the eccentric block, and its size is determined by the following formula:

\[
P = \frac{W}{g} \left( \frac{2\pi n}{60} \right)^2 R
\]

Where, \( W \) is the gravity of the eccentric block, N; \( n \) is the rotation speed, r/min; \( R \) is the radius of rotation, m.

Under the action of eccentric revolution of the casing string, the annular fluid will be driven to generate swirling flow, and the annular swirl flow field is shown in Fig.2. Driven by the eccentric rotation of the casing, the cyclone velocity at the wide and narrow clearance will increase obviously, but the annular cyclone velocity at the narrow clearance is obviously higher than that at the wide clearance, which is conducive to flushing the drilling fluid at the narrow clearance. Annular rotating flow increases fluid flow velocity\textsuperscript{[2]}, achieves turbulent displacement (Fig.3), improves wall shear force (Fig.4), and is conducive to improving displacement efficiency\textsuperscript{[3-4]} and activates static cuttings to effectively clean boreholes.

![Fig. 2 Circumferential velocity cloud map of fluid under 10mm revolution amplitude](image-url)
The results show that the eccentric rotation amplitude at the bottom of casing is the largest, which is beneficial to improve the cementing quality of local sealing section at the bottom hole. Eccentrically rotating vibration intensity of the casing pipe increases with the increase of the entering position. The deeper the well, the more obvious the vibration effect is and the longer the effective action distance is. This technique can be applied to cementing of the long sealing section of medium and deep Wells.

3.3. The shear cyclone vibration cementing tool changes the relative positions of wide and narrow gaps

When the casing rotates eccentrically, the casing rotates and vibrates periodically in the borehole, causing periodic changes in any annular section in the borehole, as shown in Fig. 5.
At $t_0$ time, casing and borehole combination as shown in figure 5, located on the $x$ axis of the annulus clearance to $d_0$, after a quarter of a cycle, at time $t_1$, borehole wall and the outer wall of casing annulus clearance on the $x$ axis for $d_1$, repass arrive 1/4 cycle time $t_2$, borehole wall and the outer wall of casing annulus clearance on the $x$ axis for the $d_2$, after the initial $t_0$ time distance 3/4 cycle, borehole wall and the outer wall of casing annulus clearance on the $x$ axis by changing for $d_1$, and after 1 cycle, sleeve located on the $x$ axis moment back to the initial position to make the annular clearance to $d_0$.

And the maximum velocity at these two moments is:

$$u_{z max}^0 = -\frac{d_0^2}{8\mu} \frac{dp}{dx}$$

$$u_{z max}^2 = -\frac{d_2^2}{8\mu} \frac{dp}{dx}$$

Since the pressure gradient remains unchanged and $d_2 > d_0$ is obviously true, during hydrocyclone cementing, the casing rotates and vibrates periodically in the borehole. As the narrow gap widens, the displacement velocity increases, thus improving the displacement efficiency of the annular narrow gap \[5\]. At the same time, the swirling action caused by the eccentric rotation of the casing has the most obvious effect at the narrow gap \[6\]. which can carry the drilling fluid at the narrow gap into the wide gap and be replaced.

3.4. Shear cyclone vibration cementing tools can improve the interface cementing capacity
During drilling, mud cake will be formed on the borehole wall. If the mud cake is not removed during cementing, an uncurable layer will be formed on the borehole wall \[7\].The shear force of vibration wave generated by vibration cementing on the mud cake is greater than that generated by annular flow, which is beneficial to clear the drilling fluid film and filter cake on the casing wall, reduce the viscosity and shear force of liquid.

Vibration can reduce the static shear force of cement paste, and the density becomes even, is conducive to the formation of a solid cement ring. At the same time, vibration is helpful to destroy the cement slurry particle bond, and improve the cementing strength of the first and second interfaces, prevent formation fluid from escaping into the annulus, and thus inhibit the oil, gas and water flowing after cementing. The eccentric rotation vibration of shear swirl vibration cementing tool reduces the initial setting time by 5.9% and the transition time of initial and final setting by 15.1% on average. The vibration speeds up the early hydration speed of cement slurry and reduces the conversion time of cement slurry from liquid to solid, which is beneficial to prevent the early annular oil and gas water flowing after cementing. The vibration significantly improves the compressive strength of cement and the cementing quality.

4. Conclusions
(1) Under the action of eccentric cascade, the casing pipe produces eccentric revolution vibration, which is similar to the motion of conical pendulum. Compared with the rotating casing, this vibration mode has the following obvious advantages: ① Under the action of eccentric cascade, the annular rotation flow strength caused by it is greater; ② Eccentrically rotating borehole casing vibration not only has the effect of annular flow formation, but also has the effect of vibration cementing; ③ Eccentric rotational vibration of the casing keeps changing the relative position of the wide and narrow gap.

(2) The influence of shear vibration of eccentric cascade on cementing interface: ① The high-speed shear agitation of eccentric cascade can significantly reduce the viscosity and dynamic shear force of drilling fluid; ② The vibration reduces the initial setting time of cement paste by 5.9% on average and the transition time of initial final setting by 15.1% on average, which speeds up the early hydration speed of cement paste.

(3) Mechanism of eccentrically rotating vibration of downhole casing to improve displacement efficiency: ① Annular rotating flow increases annular fluid flow velocity and wall shear stress, which is conducive to the removal of retained drilling fluid and wall mud cake; ② Eccentric rotation of casing makes the position of wide and narrow clearance change continuously, which is conducive to drilling
fluid displacement at the narrow clearance.

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