Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 13, No. 1, 2024

Analysis of Cuttings Backflow and Flow Path Erosion of Different Size Core Tools

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Abstract: In the process of rock coring drilling, poor rock-carrying ability and short bit life are the main reasons leading to low drilling efficiency, among which the cuttings deposition at the bottom of the annulus and the abrasive cuttings wear the drilling teeth are the main factors. Therefore, taking an ultra-deep well in the northwest of Sichuan Basin as the research object, a three-dimensional fluid-structure coupling numerical model of coring tool was established to analyze the flow velocity law of bottom hole and annulus under different sizes, and the influence of injection parameters on the flow channel erosion rate was investigated. The results show that: (1) There is a linear positive correlation between bottom hole flow rate and annulus flow rate with different sizes of coring tools. The attenuation rate of flow rate from bottom hole to annulus is about 90%, and both can meet the minimum rock carrying rate. (2) The inner wall of the outlet of the throat is in the area of sudden shrinkage of the fluid channel, and the erosion wear is the most serious; secondly, the fluid channel of the inlet of the throat decreases but does not decrease sharply, and the erosion phenomenon is more serious but relatively weak; (3) The comparison and analysis of Φ140, Φ203 and Φ172 core tools showed that the erosion rate in the erosion area decreased from 10^{-3} to 10^{-4} and 10^{-5} under the same injection displacement, showing an order of magnitude change; However, when the injection rate increases to 35 L/s, the erosion rate in the two areas is of the same order of 10^{-4}. It is concluded that in the process of rock coring, it is necessary to select a larger size coring tool, reasonably increase the injection displacement, optimize the inlet and outlet flow channels and wall structure, avoid excessive increase in erosion rate, and reduce the impact of erosion effect on the fatigue life of drill teeth and wall. The research results can provide technical support for solving practical drilling problems on site.

Keywords: Rock coring; Rock carrying capacity; Erosion rate; Annular velocity; Bottom-hole velocity.

1. Introduction

Global oil and gas exploration and development continue to move towards deep resources, which has become a further important direction for the oil industry. At present, the total proved amount of deep-earth oil and gas resources in China can reach 671×10^8 t, and the exploration of 10,000-meter deep Wells is an opportunity and challenge for China's future oil and gas exploration and development [1]. In the process of oil and gas well exploration, the core samples extracted from the target formation are the basic basis for analyzing the characteristics of the oil reservoir and the physical properties of the fluid, which is of great significance for the oil and gas development after exploration.

The target oil and gas well is mainly drilled in dolomite formation, which is highly abrasive, some strata are loose and broken, and the drilling expansion phenomenon is obvious [2]. Therefore, in the process of drilling coring with PDC bits, the annular flow rate is generally lower than the average, the annular chip removal ability is poor, the bottom debris deposition, the strong abrasive rock particles repeatedly wear the drill teeth at the bottom of the hole, resulting in a sharp shortening of the service life of the bit, and seriously reducing the drilling and coring efficiency. Tang et al. established an annulus expanding model, and found in theoretical study combined with numerical simulation that annulus flow rate presents a curve downward trend with the increase of hole diameter expanding rate [3]. Zhao et al. studied the effects of drilling parameters on the particle size of cuttings and upreturn efficiency, and the results show that the increase of bit weight will increase the particle size of cuttings within a certain range, but beyond the critical value, the particle size of cuttings will decrease and may affect the bit life [4]. Yang et al. studied the erosion damage behavior of manifold in shale gas fracturing and concluded that the impact Angle and flow velocity will seriously affect the erosion wear degree, and the erosion rate increases first and then decreases with the increase of impact Angle [5]. In summary, the annular radius and upturn efficiency of coring tools of different sizes can not be ignored on the wear of tool runner and drill bit.

Therefore, taking an ultra-deep well in the northwest of Sichuan Basin as the research object, a three-dimensional fluid-structure coupling numerical model of coring tool was established, the flow rate laws of bottom hole and annulus under different bit sizes were analyzed, and the influence of injection parameters on the flow channel erosion rate was explored, hoping that the research results will have guiding significance for solving the actual drilling core problem.

2. Mathematical Model

2.1. Mathematical model of flow

The core tool bottom hole and annular flow rate follows the conservation of mass and momentum, and the differential equations are as follows:

Mass conservation means that the increase of mass in the fluid microelement per unit time is equal to the net mass flowing into the microelement at the same time interval. The circulating medium of drilling fluid in the coring tool is a transient three-dimensional incompressible fluid, that is, the fluid density is constant, then the corresponding mass conservation equation is as follows [6,7] :

$$\frac{\partial\rho}{\partial t}+\rho\nabla\bullet V=0$$

Momentum conservation means that the rate of change of momentum of the fluid in the micro body with respect to time is equal to the sum of all external forces acting on the micro body, then the momentum conservation equation for the three coordinate directions of x, y and z is as follows:

$$\begin{cases} x: \dfrac{\partial(\rho u)}{\partial t} + \nabla \bullet (\rho u \mathrm{V}) = -\dfrac{\partial p}{\partial x} + \dfrac{\partial \tau_{xx}}{\partial x} + \dfrac{\partial \tau_{yx}}{\partial y} + \dfrac{\partial \tau_{zx}}{\partial z} + \rho f_x \\ y: \dfrac{\partial(\rho u)}{\partial t} + \nabla \bullet (\rho u \mathrm{V}) = -\dfrac{\partial p}{\partial y} + \dfrac{\partial \tau_{xy}}{\partial x} + \dfrac{\partial \tau_{yy}}{\partial y} + \dfrac{\partial \tau_{zy}}{\partial z} + \rho f_y \\ z: \dfrac{\partial(\rho u)}{\partial t} + \nabla \bullet (\rho u \mathrm{V}) = -\dfrac{\partial p}{\partial y} + \dfrac{\partial \tau_{xz}}{\partial x} + \dfrac{\partial \tau_{yz}}{\partial y} + \dfrac{\partial \tau_{zz}}{\partial z} + \rho f_z \end{cases}$$

ρ is the fluid density, kg/m^3; u is the fluid velocity, m/s, p is the isotropic pressure of the fluid,MPa; f is the volume force, N; τ is the shear stress related to fluid viscosity, MPa.

2.2. Erosion mathematical model

The particle erosion wear model in FLUENT is in the form of [8,9] :

$$\mathrm{ER} = \sum_{p=1}^{N_{particles}} \frac{m_p C(\mathrm{d_p}) \mathrm{F}(\alpha) \mathrm{u}_p^{b(\mathrm{u_p})}}{A_{face}}$$

Where, C(d$_\mathrm{p}$) is a function related to particle diameter; b(u$_\mathrm{p}$) is a function related to particle collision velocity. A_{face} is the area of the wall calculation unit, m^2; $N_{\mathrm{particles}}$ are the number of particles colliding on the unit area. ER is the erosion rate in kg/(m^2·s).

2.3. Calculation model

From the perspective of numerical simulation, the influence laws of different sizes of coring tools on flow rate and erosion were analyzed. Based on the field drilling structure, the fluid simulation software Fluent was used to analyze the flow rate distribution at the bottom of the well and in the annulus, and the flow channel erosion laws avoided by the inlet were shouted out. The three dimensional models of core tools with drill size Φ140, Φ172 and Φ203 are established, and the mesh is divided.

Figure 1. 3D model of coring tool (Taking Φ172 as an example)

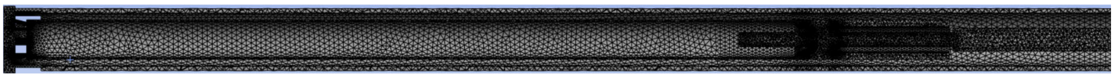

Figure 2. 3D model of coring tool grid model (Taking Φ172 as an example)

3. Results and Discussion

3.1. Rules of cuttings backflow and flow path erosion with Φ140 bit size

According to the actual working conditions on site, the drilling fluid injection capacity of Φ140 coring tool in the process of drilling coring is 10 L/s, 15 L/s, 20 L/s and 25 L/s respectively. Fig 3 and 4 show the distribution of bottomhole flow rate and annulus flow rate of Φ140 bits with different injection rates. According to Bernoulli's principle, when high-speed drilling fluid is injected into the flow channel direction, a higher return rate will be formed in the return annulus and core hole, resulting in a negative pressure cavity. Meanwhile, the higher the injection rate, the stronger the suction capacity and the stronger the migration capacity of cuttings. As can be seen from Fig 5, as the injection rate increases, the bottomhole flow rate of the Φ140 coring tool basically increases linearly, from 18.4 m/s to 46.9m /s, and the annular flow rate increases from 1.75 m/s to 4.39 m/s, with a attenuation rate of about 90%.

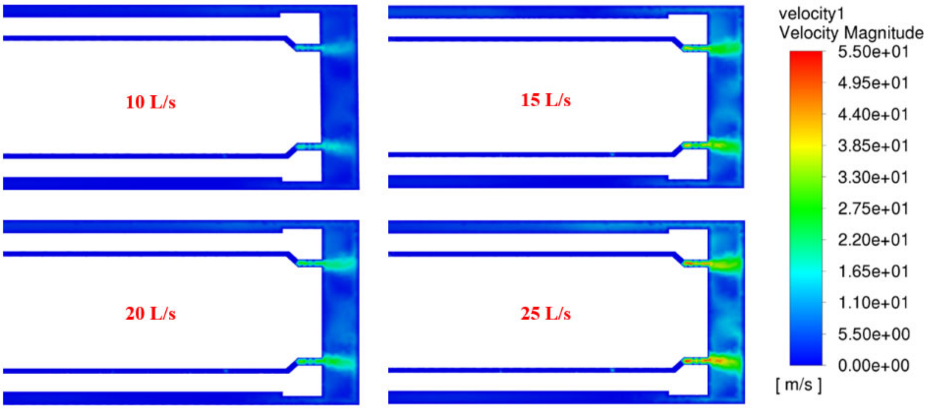

Figure 3. Bottom hole flow rate distribution for a Φ140 coring tool

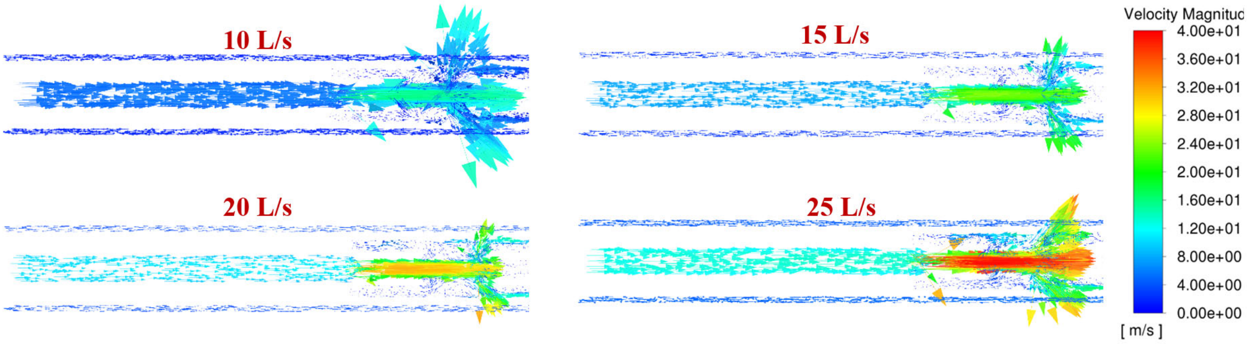

Figure 4. Annular flow velocity distribution for a Φ140 coring tool

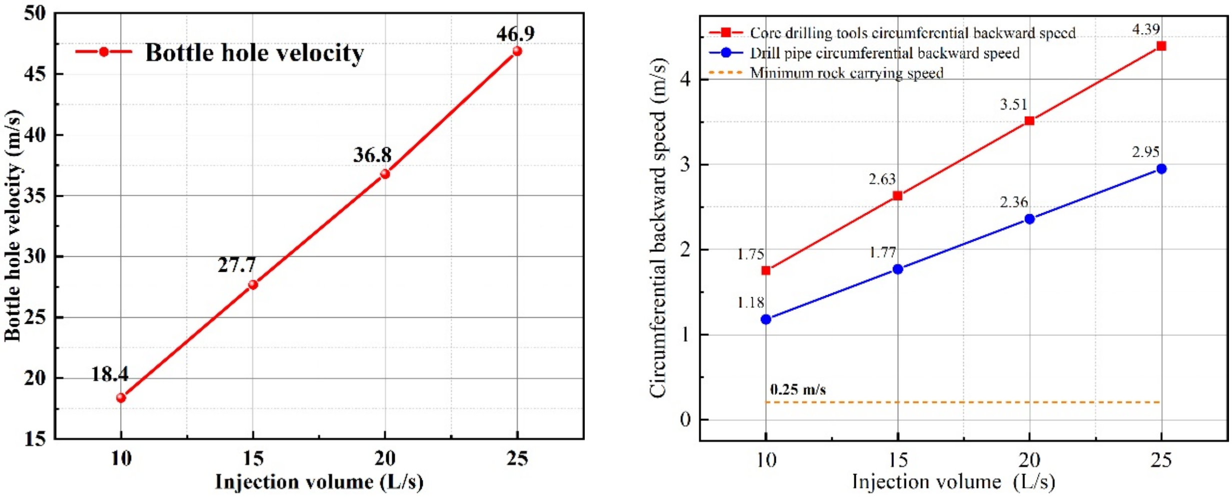

Figure 5. Bottom hole and annular flow rates of Φ140 core tool

It can be seen from Fig6 that obvious erosion is easy to occur in two areas near the orifice surface of the inlet of the throat and the inner wall surface of the outlet of the throat. Among them, the inner wall of the outlet of the throat is in the area of sudden shrinkage of the fluid channel, so the erosion wear is the most serious. Secondly, the fluid channel at the entrance of the throat decreases but does not decrease sharply, so the erosion phenomenon is relatively serious but relatively weak. As can be seen from Fig 7, in all the four injection schemes, the annular flow rate is higher than the minimum rock-carrying flow rate, and the bottom hole flow rate can timely clean the cuttings on the surface of the cutter. However, when the flow rate reaches 25 L/s, the erosion amount on the wall of the core tool presents a nonlinear increase, and the erosion rate increases from 1.49×10^{-3} to 1.49×10^{-3}. The growth rate increased from 53.6% to 231%. In summary, for the Φ140 coring tool, it is recommended to use a lower injection rate while ensuring normal drilling, so as to successfully complete the rock carrying process and reduce the erosion effect of excessive flow rate on the flow channel.

Figure 6. Erosion distribution of a Φ140 coring tool

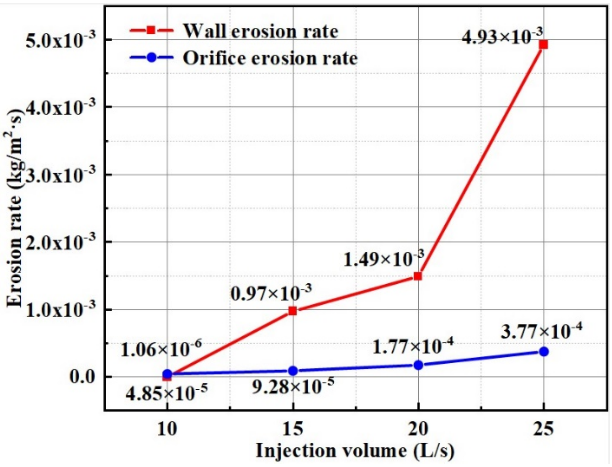

Figure 7. Erosion rule of Φ140 coring tool

3.2. Rules of cuttings backflow and runner erosion with Φ172 bit size

Drilling fluid injection rates for the Φ172 coring tool are 15 L/s, 20 L/s, 25 L/s, 30 L/s, and 35 L/s. FIG8 and 9 show the distribution of bottomhole flow rate and annular flow rate of Φ172 bits at different injection rates. Compared with Fig.3, it can be seen that the distribution rules of bottomhole flow rate and annular flow rate are similar with different sizes of coring tools, but there is no obvious difference, and both meet the minimum rock carrying rate. It is worth noting that by comparing the bottom hole rate and annular rate of the Φ172 core tool and the Φ140 core tool, the bottom hole flow rate of the Φ172 core tool is 12.4 m/s, 16.2 m/s and 20.7 m/s when the injection rate is 15L/s, 20L/s and 25L/s, respectively. The bottomhole flow rate of the Φ140 core tool was 27.7 m/s, 36.8 m/s, and 46.9m /s, respectively. It is not difficult to see that the bottomhole flow rate is negatively correlated with the size of the core tool, and the decrease is about 55.8%.

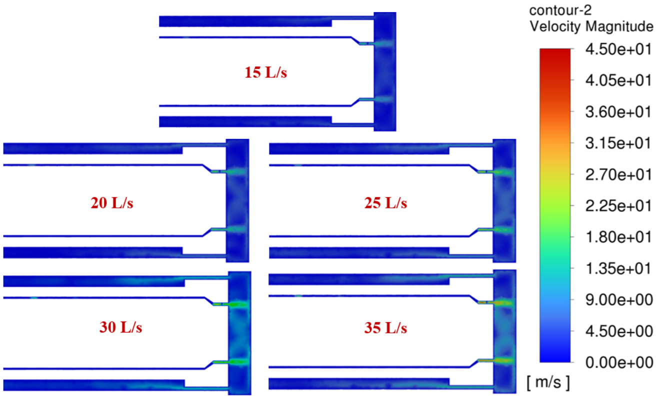

Figure 8. Bottom hole flow rate distribution for a Φ172 coring tool

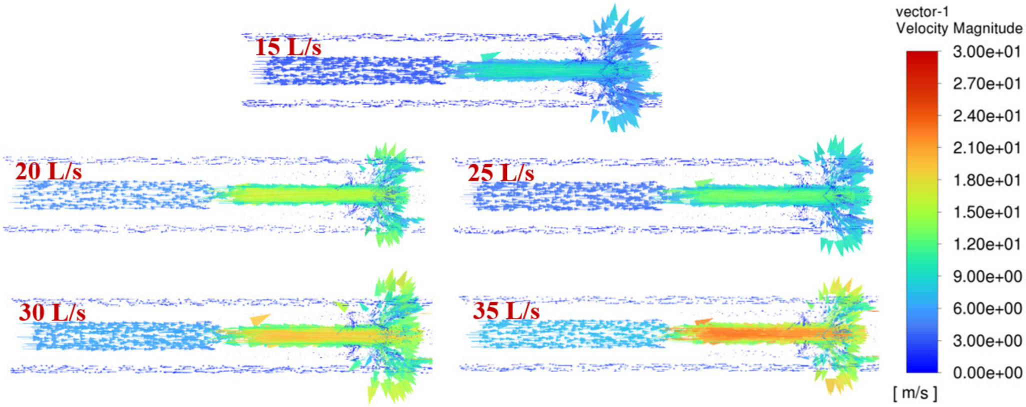

Figure 9. Annular flow velocity distribution for a Φ172 coring tool

As can be seen from Fig.11, compared with the Φ140 coring tool, the Φ172 coring tool has a larger annular area, and the erosion rate of the two areas near the hole surface at the entrance of the pipe and the inner wall at the outlet of the pipe is reduced by a single order of magnitude. When the injection displacement is 15L/s, 20L/s, and 25L/s, respectively. The erosion rates of Φ172 coring tools were 0.88×10^{-4} kg/m^2·s, 3.38×10^{-4} kg/m^2·s and 5.04×10^{-4} kg/m^2·s, respectively. The erosion rates of Φ140 coring tools were 0.97×10^{-3} kg/m^2·s, 1.49×10^{-3} kg/m^2·s and 4.93 kg/m^2·s, respectively. In addition, when the injection displacement is greater than 25 L/s, the increase of Φ172 coring tool is significantly increased. To sum up, in the process of rock coring, if there is no special ground conditions, due to the selection of larger size of core tools, at the same time, for tools of the same size, the tool structure should be reasonably designed to achieve annular diameter expansion, and reduce the impact of erosion effect on drill teeth and wall fatigue life.

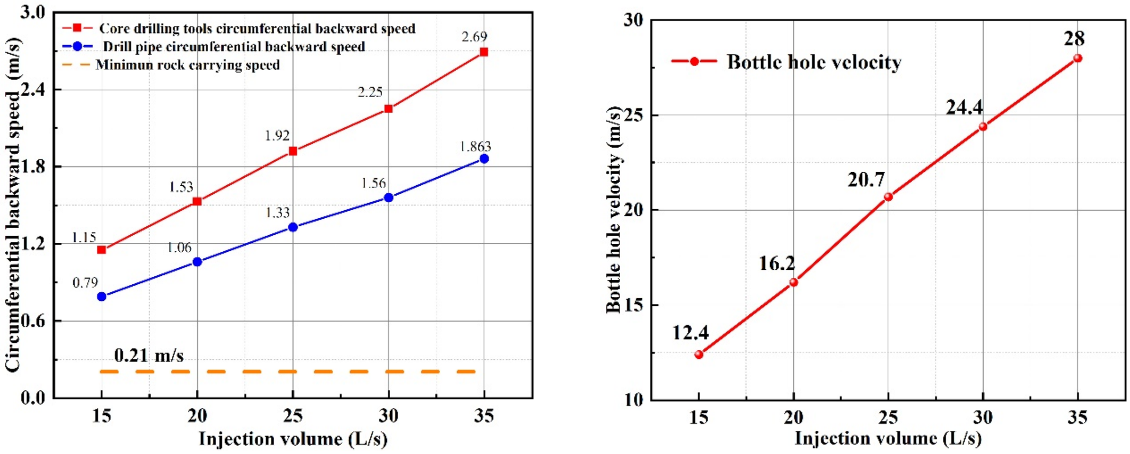

Figure 10. Bottom hole and annular flow rates of Φ172 core tool

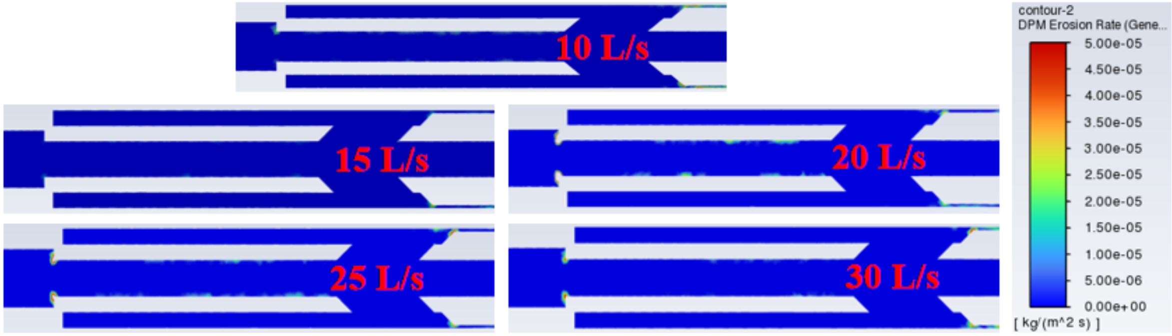

Figure 11. Erosion distribution of a Φ172 coring tool

3.3. The rule of cuttings backflow and runner erosion with the size of Φ203 bit

Depending on the site conditions, the drilling fluid injection rate of the Φ203 coring tool was increased to 25 L/s, 30 L/s, 35 L/s and 40 L/s to ensure rock carrying. When drilling fluid displacement increases, the flow rate at the bottom hole is continuous with the annular flow rate, except for the area where the flow path is reduced. The comparison of Fig.5, 10 and 15 shows that with the increase of the size of the coring tool, when the injection rate is 25 L/s, the bottomhole flow rate of the Φ140, Φ172 and Φ203 coring tools is 46.9m /s, 20.7m /s and 18.4m /s, respectively. The annular flow rates were 4.39 m/s, 1.92 m/s and 1.84 m/s, respectively. The bottom hole flow rate and annular flow rate are negatively correlated with the core tool size, which is consistent with the above rules. It is worth noting that when Φ140 increased to Φ172, the bottom hole flow rate and annular flow rate changed greatly; when Φ172 increased to Φ203, the bottom hole flow rate and annular flow rate changed slightly, with a decrease of only 11.1%, far less than the decrease of 55%.

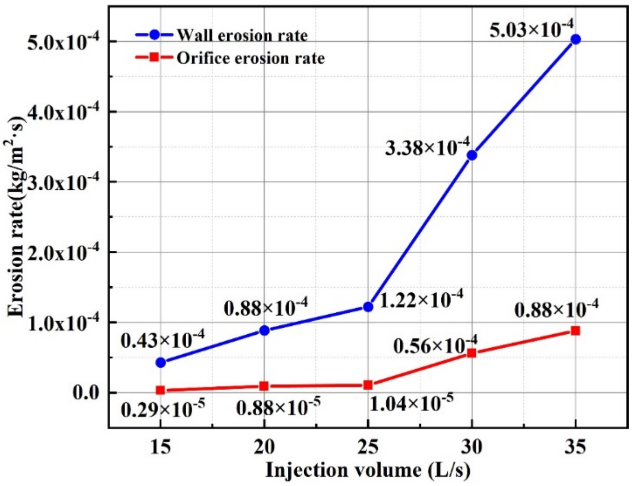

Figure 12. Erosion rule of Φ172 coring tool

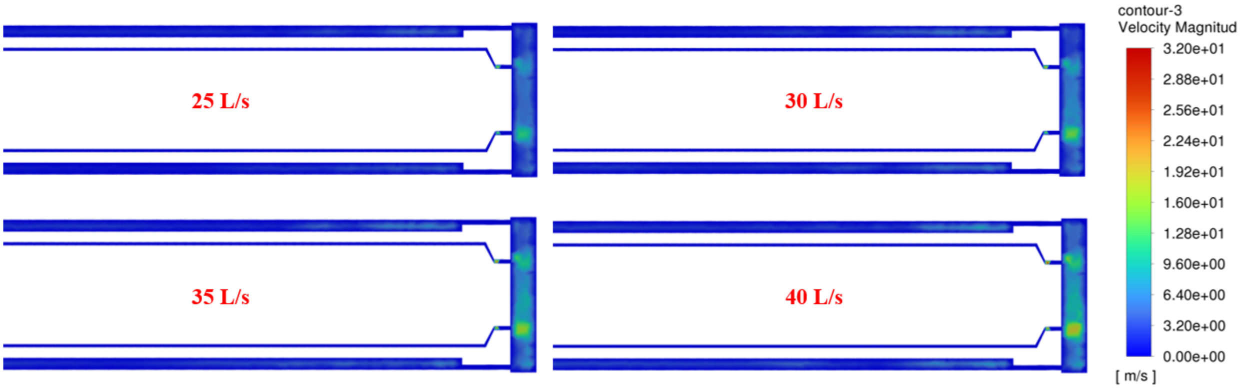

Figure 13. Bottom hole flow rate distribution for a Φ203 coring tool

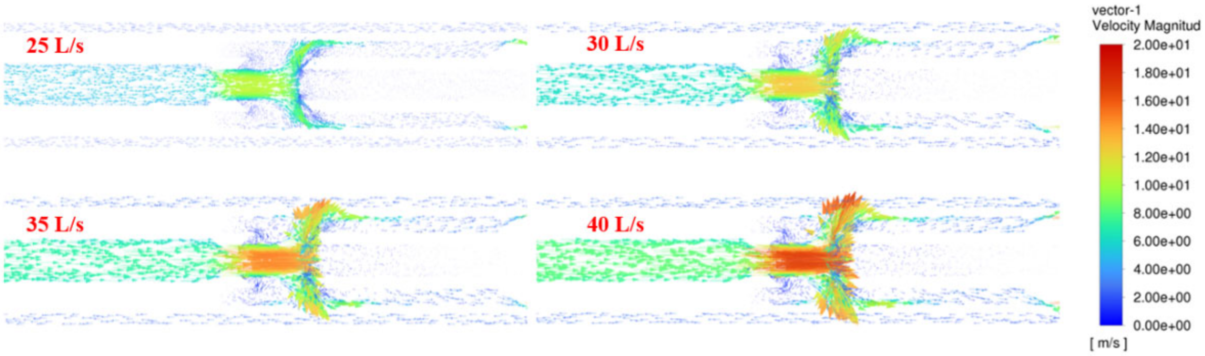

Figure 14. Annular flow velocity distribution for a Φ203 coring tool

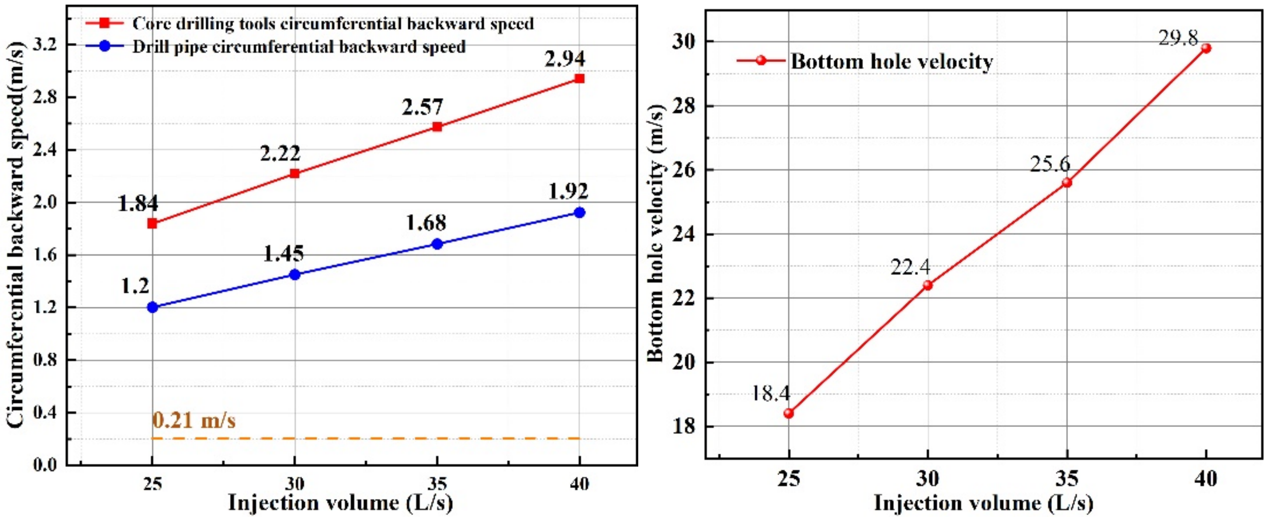

Figure 15. Bottom hole and annular flow rates of Φ203 core tool

As can be seen from Fig.16 and 17, compared with the Φ203 coring tool, the annular area of the Φ203 coring tool increases due to the influence of the tool structure, and when the injection displacement is 25 L/s and 30 L/s respectively, the erosion rate of the two areas near the inner wall of the throat entrance hole and the throat outlet decreases by a single order of magnitude, which is similar to the above rule. However, when the injection displacement is increased to 35 L/s, the erosion rate of the two tools is in the same order of magnitude, the erosion rate of the Φ172 core tool is 5.03×10^{-4} kg/m^2·s, and the erosion rate of the Φ203 core tool is 1.23×10^{-4} kg/m^2·s. Therefore, for the Φ203 coring tool, the drilling fluid injection rate should be less than 35 L/s in the actual operation of the field application, in order to improve the bit life and drilling efficiency.

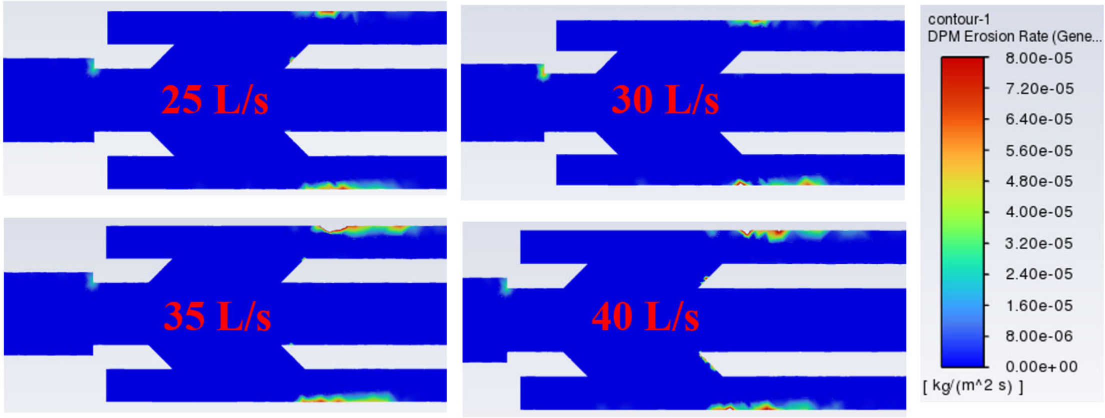

Figure 16. Erosion distribution of a Φ203 coring tool

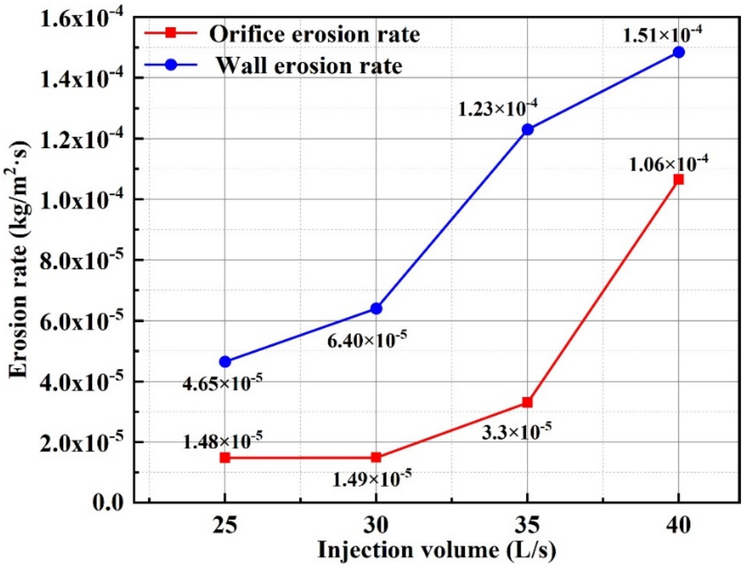

Figure 17. Erosion rule of Φ203 coring tool

4. Conclusion

(1) In the coring process of different sizes of coring tools (Φ140, Φ172, Φ203), with the increase of injection displacement, the bottomhole flow rate of coring tools is linearly positive correlated with the annular flow rate. During the process of drilling fluid flowing into the annulus from the bottom hole, the flow rate distribution is similar, and the attenuation rate is about 90%, and all can meet the minimum rock carrying rate.

(2) Corer tools of different sizes are prone to obvious erosion in two areas near the hole surface of the throat entrance and the inner wall surface of the throat outlet. Among them, the inner wall of the throat outlet is in the area of sudden shrinkage of the fluid channel, so the erosion wear is the most serious. Secondly, the fluid channel of the throat inlet hole decreases but does not decrease sharply, so the erosion phenomenon is more serious but relatively weak. Therefore, the structural optimization of the two areas should be emphasized in the design of coring tools.

(3) Compared with the Φ140 core tool, the core tool presents annular diameter expansion at the same injection displacement (15, 20 and 25L/s), and the erosion rate of the inlet hole and the outlet inner wall of the pipe decreases from 10^{-3} to 10^{-4}, showing a single order of magnitude change; Compared with the Φ172 coring tool, when the injection displacement of Φ203 is 25 L/s and 30 L/s, the erosion rate of the two regions shows the same rule, but when the injection displacement of 35 L/s, the erosion rate of the two regions changes relatively little. To sum up, in the process of rock coring, large size corer tools should be selected, and injection displacement should be reasonably increased to avoid excessive erosion rate increase and reduce the impact of erosion effect on drill teeth and wall fatigue life.

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