Study on cuttings removal effect of Effective HydroClean Drill Pipe under different deviation conditions of drill pipe

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Abstract. In order to solve the problem of cuttings bed in the drilling process of highly deviated sections in directional wells, horizontal wells and extended reach wells, an Effective HydroClean Drill Pipe(EHCDP) was designed, using computational fluid dynamics (CFD) simulation techniques, the flow characteristics of the annular flow field under the action of EHCDP were analyzed, the cuttings removal efficiency of this kind of EHCDP under different deviation conditions is studied, thus providing the relevant basis for using this EHCDP to remove cuttings more efficiently. The results show that the EHCDP can effectively remove cuttings under different deviation conditions. However, the larger the inclination angle of the well, the more likely the cuttings is to accumulate on the lower edge of the wellbore due to gravity, forming cuttings bed. In highly inclined wellbore above 60°, EHCDP can be combined with traditional cuttings removal methods to more effectively remove cuttings near the low side of the wellbore.

Keywords: Highly deviated wells; Cuttings bed; Wellbore angle; Hole cleaning.

1. Introduction

In recent years, directional drilling technology has been increasingly utilized in oil and gas development. Directional wells, especially those with large inclinations, displacements, and difficult directional requirements, have become more prevalent in major oilfields[1]. However, during the drilling process of the horizontal and highly inclined well sections, cuttings tend to accumulate on the low side of the wellbore due to gravity. This accumulation forms a cuttings bed that is difficult to remove, significantly impacting drilling safety and efficiency. According to statistics, nearly 70% of the accidents causing loss of drilling time are related to stuck drilling[2], and one-third of the stuck drilling accidents are caused by inadequate hole cleaning[3].

The traditional methods[4–8] for removing cuttings beds are: improving drilling fluid performance; increasing drilling tool rotational speed; increasing annulus return speed; and mechanical removal methods. Drilling fluids with a high dynamic-to-plastic ratio can improve their performance and increase the ability to suspend cuttings. However, this effect is limited, and the cost is high. Increasing the rotational speed of drilling tools can enhance the disturbance of drilling fluids in the wellbore annulus, allowing cuttings to be brought into the high-speed zone of the annulus and carried out of the wellbore with the drilling fluids. However, some tools may malfunction at high speeds during drilling, leading to potential failure of the drilling column. Increasing the annular return speed can improve the cleaning of the cuttings at the lower side of the wellbore, but it can lead to the collapse of the soft formation above the wellbore and cause material to fall off the block. Mechanical removal methods mainly include short-range up-and-down drilling and drilling of the wellbore, but these methods often require extensive auxiliary operations, leading to increased time consumption. Frequent usage of those methods can significantly impact drilling efficiency.

The cuttings bed removal tool is an effective tool for destroying cuttings bed, utilizing both hydraulic and mechanical effects, which can significantly improve the removal of cuttings bed. This tool enhances the transportation state of cutting particles during drilling, effectively addressing the issues of cuttings bed accumulation in horizontal wells and extended reach wells[9–11]. At present, companies[12-16] such as VAM, DBS, HaiLong and others have developed cuttings bed removal tools that demonstrate promising cuttings removal effects. However, there is limited research on analyzing the rock removal efficiency of these cuttings bed removal tools under different working conditions.

To enhance the efficiency of cuttings bed removal, it is necessary to analyze its effectiveness under different well inclination conditions. This paper examines the operational mechanism of the Effective HydroClean Drill Pipe (EHCDP) through flow field simulation technology and investigates its impact on cuttings bed removal across different well inclination conditions. The aim is to provide a relevant basis for optimizing cuttings removal by EHCDP under diverse working conditions.

2. Structural design and working principle

2.1 Structural design and the parameters

Compared with an ordinary drill pipe, the EHCDP is characterized by a spiral groove structure arranged on its outer surface. Fig. 1 shows the structural features of the EHCDP, which includes 5 spiral grooves, an arrangement length of 1.43 m, with a maximum diameter of 166 mm, and the outer diameter of the pipe body is 127 mm.

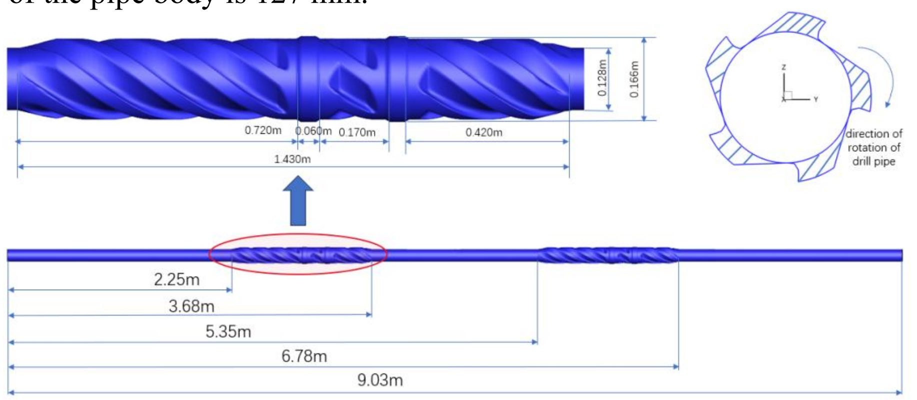


Fig. 1 Schematic diagram of EHCDP structure

2.2 Operational principle

During drilling, the spiral channel structure on the EHCDP rotates to achieve mechanical cuttings clearance. At the same time, the drilling fluid is a vortex in the circulation field of the wellbore and around the outer surface of the drill pipe. The cutting is trapped by the drilling fluid and enters the circulation field with increased flow velocity, facilitating hydraulic cuttings clearance.

3. Numerical simulation of the annular flow field under EHCDP

3.1 Physical model

The spiral groove channel structure of the EHCDP exerts the most significant influence on the surrounding drilling fluid flow field, while other parts of the outer surface remain smooth and have less influence on the flow field. Therefore, the model can be simplified for numerical simulation, as depicted in Fig. 2. Fig. 3 illustrates the initial distribution of cuttings in the annulus flow field. Cuttings are introduced within the length region of 0-3.68 m, divided into three equal parts. The bottom portion (red region), constituting 80% of the cuttings volume fraction, represents the cuttings bed on the lower side of the wellbore. The middle portion (green region) depicts uniformly suspended cuttings particles with a volume fraction of 40%, representing the middle layer of suspended cuttings. The top portion (blue area) indicates no cuttings addition, representing a pure drilling fluid layer in the annulus on the upper side of the wellbore.

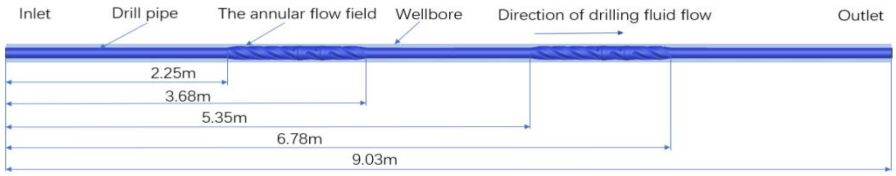


Fig. 2 The physical model

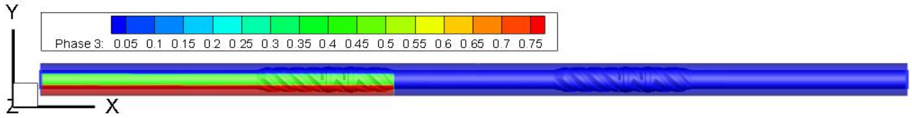


Fig. 3 Initial moment cuttings distribution map

3.2 Mesh partitioning of the model

Given the rotational motion of the EHCDP during operation and the continuous variation of its solid boundary over time, the calculation of annular flow fluid considers it as a non-stationary flow. Solving this type of flow problem using an integrated mesh is challenging. Therefore, this study employs the slip mesh method for numerical simulation of the flow field. This method involves dividing the mesh into distinct regions with mutual motion between them. Interpolation methods facilitate the transfer of flow field data at the intersection interface. The slip mesh technique partitions the fluid near the drill pipe's surface and the peripheral fluid into separate computational domains. This allows solving flow control equations within each subdomain, with flow information exchanged through velocity conversion at subdomain interfaces. Furthermore, the entire fluid region is subdivided using a full hexahedral mesh, as depicted in Fig. 4a, while Fig. 4b illustrates the mesh on the tool's outer surface. Different colors denote various computational domains. The total number of cells after meshing is 2,790,480, with a total of 2,613,600 nodes.

a. Meshing of the fluid domain

b. Meshing of the outer surface of the EHCDP

Fig. 4 Meshing division

3.3 Turbulence model

In this paper, we need to have high accuracy for the calculation of wellbore pipe flow and strong rotating flow, so we choose the model Realizable k-ε, which introduces an equation about turbulent dissipation rate ε, based on the standard model k-ε, which is suitable for a wide range of flow types, including rotating homogeneous shear flow, free flow, cavity flow, boundary layer flow and flow with separation.

The transport equations for the turbulent kinetic energy k and turbulent dissipation rate ε of the model Realizable k-ε are as follows [17–18]:

$$\frac{\partial}{\partial t}(\rho_m k)+\frac{\partial}{\partial x_j}(\rho_m k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu_m+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho_m\varepsilon-Y_M+S_k \quad (1)$$

$$\frac{\partial}{\partial t}\left(\rho_m\varepsilon\right)+\frac{\partial}{\partial x_j}\left(\rho_m\varepsilon u_j\right)=\frac{\partial}{\partial x_j}\left[\left(\mu_m+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\rho_m C_1 S_\varepsilon-\rho_m C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \quad (2)$$

where k is the turbulent kinetic energy, m2/s2; ε is the turbulent dissipation rate, m2/s3; u_j is the time-averaged velocity, m/s; v is the kinematic viscosity coefficient, m2/s; G_k is the term for the generation of the turbulent kinetic energy K due to the mean velocity gradient; G_b is the generation of turbulent kinetic energy induced by the action of the buoyancy force; Y_M is the effect of the pulsating expansion of the compressible turbulence on the total dissipation rate; S_k, S_ε is the mean rate of change; μ_t is the turbulent viscosity, kg/(m-s); C_1, C_2, $C_{1\varepsilon}$, and $C_{3\varepsilon}$ are the computational constants; σ_ε is the turbulent energy turbulence Prandtl number, and σ_k is the turbulent dissipation rate turbulence Prandtl number.

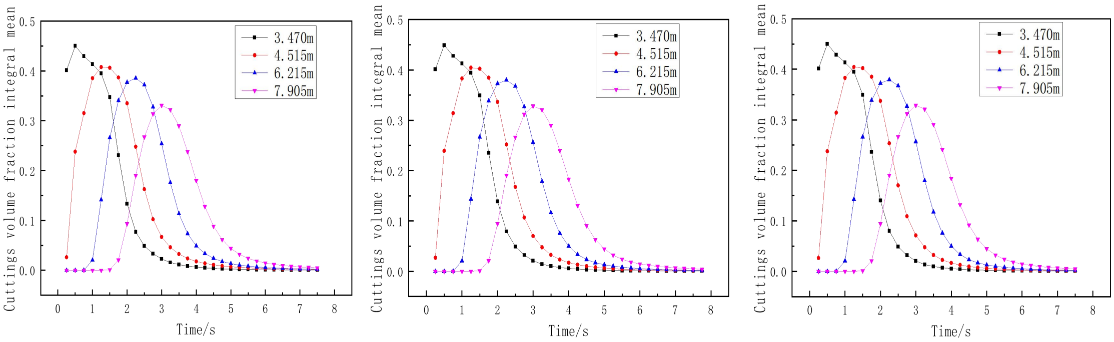
3.4 Boundary conditions

In this paper, we mainly analyze the cuttings removal effect of EHCDP under well inclination angles of 30°, 60°, and 90°, respectively. The working conditions remain consistent, except for variations in the well inclination angles. The drilling fluid density is 1200 kg/m3, with a viscosity of 0.03Pa•s, and an average particle size of 0.1mm, with a density of 3000 kg/m3. Velocity inlet and pressure outlet boundaries are utilized. The inlet fluid velocity is set at 2m/s (corresponding to the fluid displacement of about 40L/s), while the outlet pressure equals the ambient pressure of 30 MPa. The wellbore remains fixed, and the outer surface of the drill pipe functions as a rotating wall. The wellbore remains fixed, and the outer surface of the drill pipe functions as a rotating wall. The drill pipe's rotational speed is set at 90 r/min.

4. Analysis of the cuttings removal effect of EHCDP

As shown in Fig.2, the main cross sections were analyzed at axial distances of 3.470 m, 4.515 m, 6.215 m, and 7.905 m from the inlet, respectively.

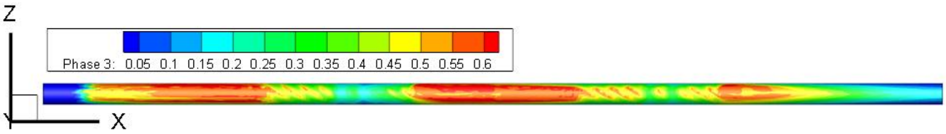
As shown in Fig. 5, the variation rule of the average value of cuttings volume fraction within the cross-section with time under different well inclination conditions is depicted. It can be observed that under the joint action of EHCDP and drilling fluid, the cuttings are constantly transported backward as a whole. Taking the 30° well inclination angle as an example, at the time of 1.25s, the concentration of cuttings at the axial distance of 4.515m reaches the maximum value, and then it decreases until it is close to 0, indicating that a large number of cuttings will be transported to the rear position after that time. At the time of 3.00s, a significant amount of cuttings will be transported to the vicinity of the axial distance of 7.905m. The results indicate that as the axial distance keeps increasing, the peak value of the volume fraction of cuttings over time decreases, and the area enclosed with the horizontal coordinate axis also decreases, indicating that not all of the cuttings move backward with the drilling fluid and exit the wellbore. In other words, the cuttings are not completely removed; instead, a part of the cuttings remains upstream. As shown in Fig. 6, a small portion of the cuttings in the upstream area still adheres to the low side wall of the wellbore, while most of the cuttings have been removed, leaving the other annulus free of cuttings.



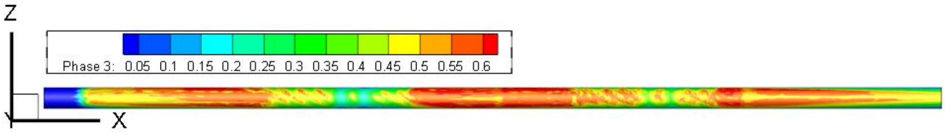
a.Well inclination angle of 30° b.Well inclination angle of 60° c.Well inclination angle of 90°

Fig. 5 Variation of cuttings volume fraction of cross section with time for different well inclination conditions

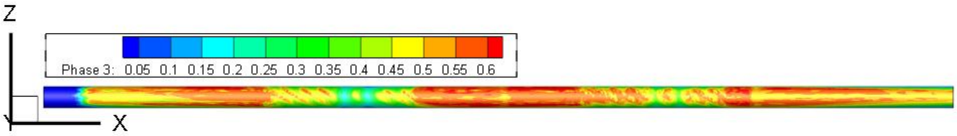
Fig. 6 illustrates the distribution of cuttings near the low side of the wellbore. It is evident that a layer of dense cuttings remains, formed due to continuous gravitational deposition. The results indicate minimal accumulation of cuttings in the section of the well with the spiral channel. Additionally, compared to cases with well inclination angles of 60° and 90°, a 30° well inclination, including the spiral groove, exhibits the least accumulation of cuttings across the entire well section. Moreover, the effectiveness of cuttings removal is relatively higher, suggesting that it is easier to form a cuttings bed in wells with inclination angles exceeding 60°.



a.Cuttings distribution at the wellbore at 30° well inclination angle



b.Cuttings distribution at the wellbore at 60° well inclination angle



c.Cuttings distribution at the wellbore at 30° well inclination angle

Fig. 6 Cloud map of cuttings distribution at the low side of the wellbore at the moment t=6s

As depicted in Fig. 7, the axial cuttings distribution curves at the low side of the wellbore under different inclination conditions at 3.00s are presented. It can observed that at t = 3.00 s, most of the cuttings in the annulus at the low side of the wellbore are transported to a position of 8m away in the axial distance. When comparing the cuttings distribution under different well inclination conditions, it is evident that the volume fraction of cuttings at the low side of the wellbore is relatively larger with an increase in the well inclination angle from 4m to 6m, and the value is the smallest under the 30° well inclination, suggesting that the accumulation of cuttings at the low side of the wellbore gradually increases with the increase in well inclination. In addition, the fluctuation of the volume fraction of cuttings is relatively larger in the annular flow field area attached to the spiral channel. This also indicates that the stirring effect of the spiral channel on the annular flow field increases the turbulence intensity of the annular flow field, aiding in the removal of the cuttings bed at the low side of the wellbore.

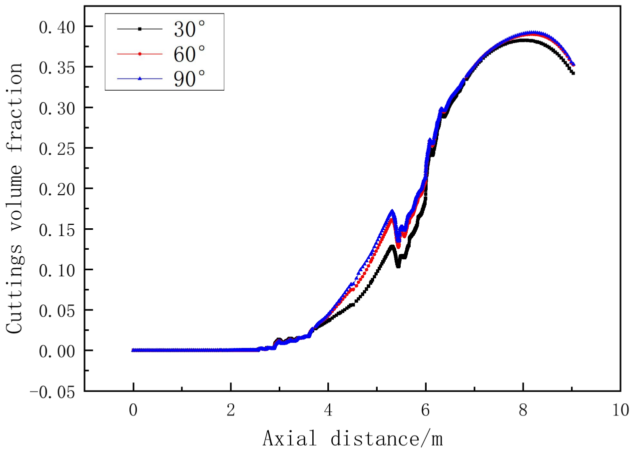


Fig. 7 Axial cuttings distribution at the low side annulus of the wellbore at the moment t=3.00s

5. Conclusion

(1) EHCDP can effectively transport cuttings particles deposited on the lower side of the wellbore to the higher side, where they are discharged with the upward returning drilling fluid.
(2) As the well inclination angle increases to 30°, 60°, and 90°, respectively, cuttings are more likely to accumulate due to gravity on the lower side of the wellbore wall, thereby forming a cuttings bed.
(3) EHCDP is highly effective in removing cuttings in small inclined wellbores and can be combined with traditional cuttings removal methods in large inclined wellbores over 60° to enhance the removal of cuttings near the low side of the wellbore.

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