Hydraulic Research on Improving Hole Cleaning in Horizontal Wells

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Abstract

The horizontal well is widely used in the global hydrocarbon exploitation. However, due to the effects of the gravity, the cutting bed is likely to form during the horizontal drilling, which possibly harms the whole drilling operation. Given this, it is required to analyze the flow field of the PDC bit in the horizontal well, and propose feasible adjustment plans. This paper numerically simulates the flow field of each flow passage of the PDC bit and the cutting movement path under the effects of the gravity, and two modification plans are proposed to control the cutting deposition.

Keywords

Horizontal well, Hole cleaning, Numerical simulation, Hydraulics, Reverse nozzle.

1. Introduction

As the global oil and gas field exploration and development continuously advance, the applications of the extended-reach well and horizontal well are ever growing (Zhao, 2017; Chen et al., 2018; Bi et al., 2018). However, the deterred transportation of drilling cuttings through the wellbore leads to cutting accumulation at the lower side of the annulus and resultant cutting beds. Under such circumstances, complex downhole issues such as the shooting-up resistance, bit bouncing and sticking are likely to occur (Wang, 1995; Du, 1999; Jiang, 1987). Given the aforementioned, it is of great importance to carry out the hydraulic analysis on the bottomhole flow field so as to improve the hole cleaning. In general, two type of methods are applied to analyzing the bottomhole flow field of the bit (Zhang, 1987; Wang & Shen, 1988; Zhu, Wang, Liu S., & Liu C., 2009): One is to study the hydraulic parameter (Xie, Yang, & Chen, 2002; Liu, 2015), which is constrained by the field equipment capacity and the strength of the borehole wall. The other targets the hydraulic structure of the bit (Sun, 2006; Guan, Chen, & Liu, 1994 and 1996). From the perspective of the bit hydraulic structure, this paper carries out numerical simulation, in which a model is first created for the PDC bit in question and iterative calculation is then conducted after the boundary condition is defined.

2. Bottomhole flow field modelling for horizontal wells

2.1 Physical model

In our simulation of the horizontal well, the five-blade-six-nozzle PDC bit, which is most frequently used in the field practice, is adopted. The created model of the bit has an outside diameter of 215.9 mm, with six 12-mm nozzles. The position and angle of each nozzle are presented in Table 1-1, and the 3D rendering illustration is shown in Fig. 1-1. The subsequent modelling of the wellbore and the meshing of the bottomhole flow field are shown in Fig. 1-2.

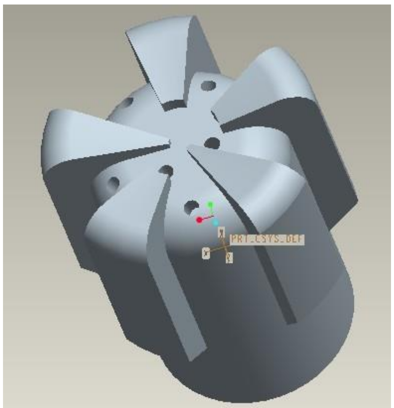

Figure 1-1. Three-dimensional rendering figures of the PDC bit model

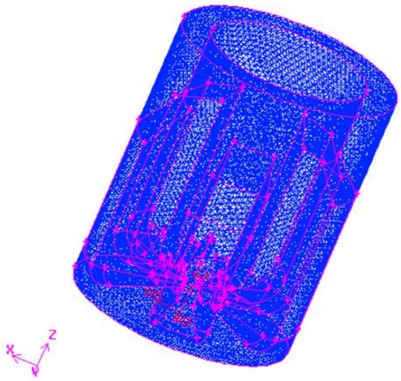

Figure 1-2. The meshed wellbore

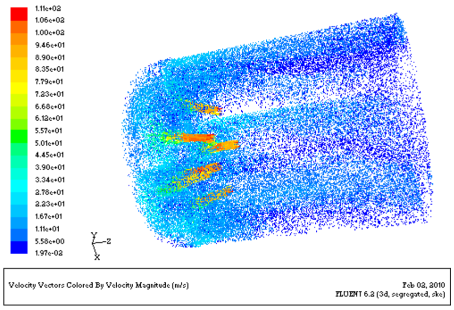

Figure 1-3. Overall flow field at the bottomhole

Table 1-1. Parameters for nozzles

No.	1	2	3	4	5	6
Nozzle Diameter (mm)	12	12	12	12	12	12
Exit Angle (degree)	10	20	15	20	5	15
Rotation Angle θ (degree)	51	123	195	267	303	339
Distance to the Bit Center (mm)	62.4	54.6	27.3	54.6	25	62.4

2.2 Boundary conditions

Pressures are regarded as the initial condition and set prior to the calculation. The pressure at the inlet of the nozzle is set as 16 MPa, and both the confining pressure and the nozzle outlet pressure are 10 MPa. The fluid jetted from the nozzle first reaches the wellbore bottom and then flow upwards through the junk slot.

2.3 Bottomhole flow field

The simulated bottomhole flow field is shown in Fig. 1-3. The fluid velocity at the nozzle inlet amounts to 109.6 m/s. The fluids from the six nozzles of the bit all present appropriate velocity profiles and velocity decline behaviors. Such a desirable nozzle layout favors the bottomhole cleaning and cutting transportation. In a more comprehensive analysis involving the gravity, the effects of the gravity on the drilling fluid are minor. Nevertheless, in the case of the presence of the cutting, notable settlement of cuttings towards the lower side of the wellbore is observed, which is the main contributor to the formation of the cutting bed.

3. Analysis on the bottomhole movement path of cuttings

In horizontal drilling, the cutting detached from the bottomhole reaches the annulus through the junk slot, and is then carried upward by the drilling fluid to the wellhead. However, the downhole cutting is not only horizontally-loaded, but also vertically-loaded by the gravity. In order to capture the effects of the gravity on the downhole cutting in horizontal drilling, five specific moments during the bit rotation are picked up for analysis. The movement path of the cutting affected by the gravity in the case of one flow passage reaching the lowest position is illustrated in Fig. 2-1.

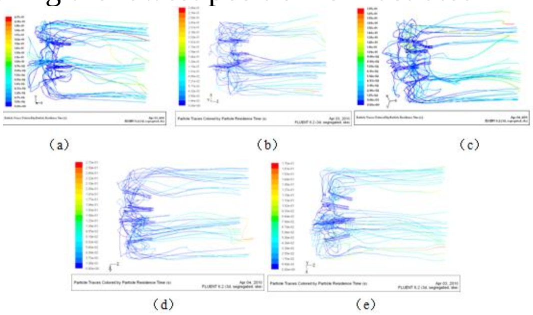

Figure 2-1. Cutting movement paths of five flow passages under the effects of the gravity

By setting different conditions in the numerical simulator, the cutting movement path in the case of each flow passage reaching the lowest position is obtained, as is shown in Fig. 2-1. It is seen that the settlement path of part of cuttings is observed in each case, which indicates that the gravity plays a vital role during the up-returning of the cutting. The gravity leads to the settlement tendency of the cutting towards the lower side of the horizontal wellbore, and this probably boosts the formation of the cutting bed that is unfavorable for the operation in horizontal wells. By accelerating the drilling fluid flow through the junk slot, the velocity of cuttings flowing towards the wellhead is stimulated, the duration of cuttings staying at the bottomhole is reduced, and consequently the formation of the cutting bed is suppressed. Moreover, the high-velocity fluid can impact and erode the cutting bed that has already been formed. In such cases, the deposited cutting moves again and migrates back into the annulus.

4. Measures for improvement

4.1 Adjustments of nozzle positions and angles

The velocity vector mapping comparison of the bottomhole flow field between the adjusted and original bits reveals that by moving the position of Nozzle 4 towards the borehole wall, the distance of the fluid jetted from Nozzle 4 to Junk Slot 1 is reduced. The maximum velocity of fluids from the modified Nozzle 4 reaching the bottomhole amounts to 42.1 m/s, while that prior to the adjustment is 45.9 m/s. The variation is small, so this adjustment has no notable impact upon the nozzle's cleaning the bottomhole cutting.

Owing to the adjustment of Nozzle 4, the flow field inside Junk Slot 1 is changed, as is presented in Figure 3-1 and 3-2. The lowest junk slot in the two figures is Junk Slot 1. It is indicated, the maximum flow velocity through the slot changes from 21.6 m/s to 23.1 m/s, after the adjustment. Moreover, the velocity range of 21.6 m/s greatly expands, thanks to the adjustment. The above two variations significantly contribute to the suspension of the cutting bed formation and cutting bed flushing. An extremely favorable velocity field is generated inside Junk Slot 1, due to the adjustment in the bit, and this can improve the up-returning velocity of cuttings inside this slot and promote cutting transportation. Also, with the rotation of the bit, the junk slot rotates in the wellbore. Under such circumstances, every time Junk Slot 1 passes through the lower side of the horizontal wellbore, a strong flushing is impacted on the borehole wall behind it. Accordingly, the bottomhole flow field of the PDC bit in the horizontal wellbore is well improved, and the risk induced by the cutting bed is reduced (Li, Ma, & Hou, 1996).

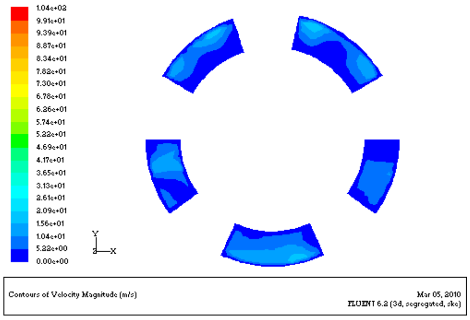

Figure 3-1. Flow field inside junk slots after adjustments

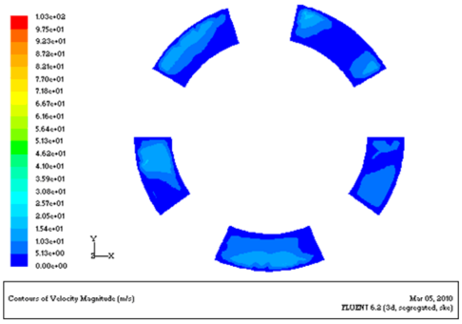

Figure 3-2. Flow field inside junk slots before adjustments

4.2 Setting a reverse nozzle at Junk Slot 1

A reverse nozzle, having a 60° angle from the bit body axis, is set at original Junk Slot 1 in order to boost the fluid flow velocity inside this slot, as is shown in Fig. 3-3. With other numerical simulation parameters unchanged, the simulated overall flow field of this new bit is presented in Fig. 3-4. The presence of the reverse nozzle tremendously alters the flow field of such a five-blade PDC bit in the horizontal wellbore (Li, X., 2018; Guo T., 2016).

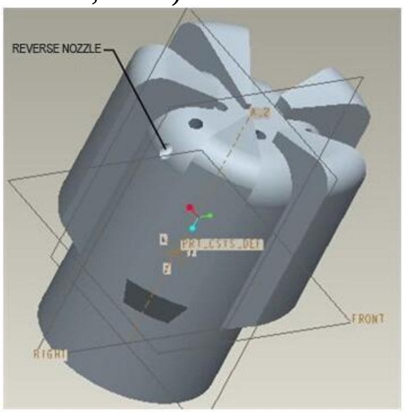

Figure 3-3. 3D rendering illustration of the modified PDC bit

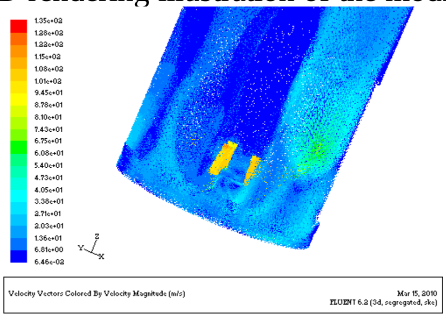

Figure 3-4. Overall flow field of the modified bit

As is shown in Fig. 3-5, Junk Slot 1 presents velocities superior to those of all other four slots. Moreover, the fluid that flows along the borehole wall has a large high-velocity region (Guo T., 2017), which promotes the cutting transportation.

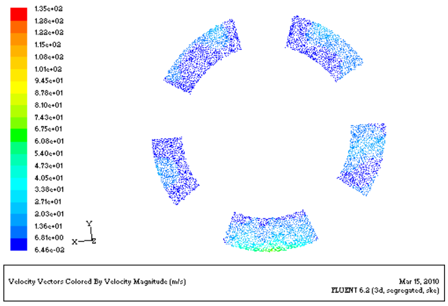

Figure 3-5. Velocity vector mapping of flow fields inside junk slots

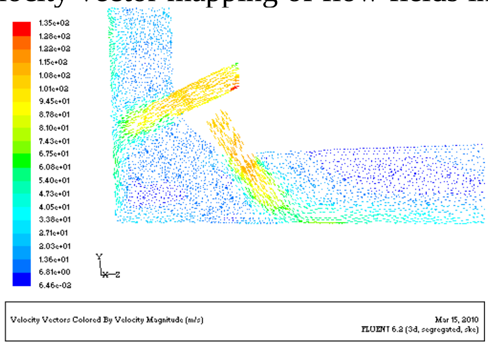

Figure 3-6. Velocity vector mapping of the reverse nozzle

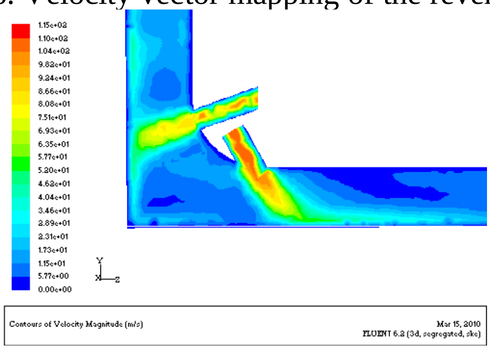

Figure 3-7. Velocity contour mapping of the reverse nozzle

The fluid ejected from the reverse nozzle arrives at the borehole wall at the rate of 64.2 m/s, as is illustrated in Figures 3-4 and 3-5. The fluid then rapidly flows towards the wellhead along the borehole wall, which accelerates the fluid inside the whole junk slot. Thus the fluid velocity inside this junk slot is maximum, and this imposes a great lateral impact on the up-returning cutting, effectively prevents cuttings from deposition and disturbs the formation of the cutting bed (Zhigang, Y, 2012).

The effects of this reverse nozzle can be concluded into two aspects. First, Junk Slot 1 stimulates the velocity of the fluid in its vicinity, regardless its rotation position, and this can improve the cutting transportation throughout the whole flow field and efficiently suppress the formation of the cutting bed. Moreover, every time Junk Slot 1 rotates to the lower side of the wellbore, it will generate strong impacts upon the wellbore section behind the bit. Such high-speed flow forms water jets flushing the formed cutting bed, which pushes the deposited cuttings back into the annulus from the lower side of the wellbore. The cuttings are then carried up to the wellhead by the drilling fluid. It is seen from Figures 3-6 and 3-7 that the minimum velocity of the fluid flowing from the junk slot has reached 14.4 m/s, while the minimum flow velocity is only 2.5 m/s in the case without the reverse nozzle. The fluid flow velocity growth by 5.76 times indicates that the application performance of the reverse nozzle is remarkable. By adding cuttings in the wellbore, the effects of the reserve nozzle is shown more vividly, as is shown in Fig. 3-8.

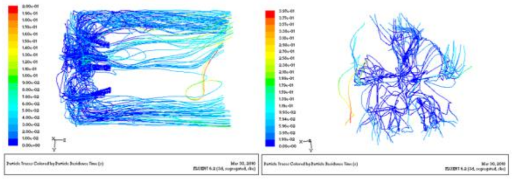
(a) (b)

Figure 3-8. Cutting movement paths under the effects of the gravity along the y axis

The cutting movement path is captured at the moment the gravity is along the axis and Junk Slot 1 just arrives at the highest position. Fig. 3-8 reveals that the cuttings from Junk Slots 3 and 4 tend to deposit at the lower side of the wellbore due to the gravity (Michler, C, 2009). However, as for cuttings from Junk Slots 2 and 5, they overcome the gravity and migrate towards the upper side of the wellbore, thanks to the high-speed drilling fluid ejected from Junk Slot 1. Thus, the formation of the cutting bed is suppressed. It is also observed that the flow through Junk Slot 1 is seen with the most transported cuttings, and attracts the cuttings discharged through other junk slots. In such cases, Junk Slot 1 is capable of accelerating the flow rates of as many cuttings as possible, reducing the duration of cuttings staying in the horizontal section and mitigating the cutting bed formation.

5. Conclusion

(1) The simulation result indicates that the flow field generated by the pure drilling fluid under the effects of the gravity in horizontal wellbores is similar to that in vertical wells, owing to the extremely fast drilling fluid jet. However, the cutting deposition in the drilling fluid caused by the gravity is considerable.

(2) In horizontal drilling, the velocity of the drilling fluid arriving at the bottomhole grows with the decreasing exit angle of the drilling fluid and the narrowing distance between the nozzle and the bit center. The maximum flow velocity of the spreading flow in front of the nozzle also rises, which is favor of cleaning the cuttings at the bottomhole and on the bit surface. A large high-speed fluid flow area is formed inside the junk slot, with a higher nozzle exit angle and an extended distance between the bit center and the nozzle, which helps the cutting flow upwards to the wellhead.

(3)By adjusting the position and exit angle of nozzles in the PDC bit, the flow field of the PDC bit in horizontal drilling is improved, which helps accelerates the cutting movement and ease the formation of the cutting bed.

(4) The analysis on the flow field generated by the PDC bit in horizontal wells reveals that an extra reverse nozzle can significantly stimulate the flow velocities of all fluid through the junk slots. In the meantime, it flushes the formed cutting bed, every time it rotates to the lower side of the wellbore. Thus, the deposition of cuttings is suppressed, and the duration of cuttings staying in the horizontal section is reduced.

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