Numerical Simulation on Cuttings Transport with Drillpipe Rotation in Extended Reach Well

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Abstract Computational Fluid Dynamics (CFD) is used to simulate the solid-liquid two-phase flow in the annulus. The results show that the mixture of liquid and solid moves in spiral in horizontal annulus, and the solid phase distributes asymmetrically in the annulus. The distribution of solid volume fraction and the velocity of liquid phase and solid phase in annulus are given. The thickness of cuttings bed of rotating drill pipe is 1/3 of that of non-rotating drill pipe. Main factors which influence the cuttings transport in the annulus are analyzed, and the following results are got: the thickness of cuttings bed changes sensitively when the rotation speed of drill pipe ranges from 80rpm to 120rpm, the rotation of drill pipe disturbs the flow of liquid and solid in annulus, improving the cleaning of annulus.

1. Introduction
The biggest difference between Extended Reach Wells (ERWs) and conventional wells is that it has a long horizontal displacement. Cuttings take a long time to reach the wellhead from the bottom, which makes it very difficult to remain hole cleaning because of the formation of cuttings bed.

Many scholars have carried out a lot of research on cuttings transport in ERWs [1], and established a number of models [2-3]. These models can be broadly divided into two categories, one is theoretical model including steady models like it in [4-8] and second is the experimental regression model like it in [9]. The regression model is generally based on the experimental data regression, so it can be used to calculate the influence of drill pipe rotation on the cuttings bed height, but it can not explain the mechanism of the impact of drill pipe rotation on the cuttings transport [10]. The theoretical models can be subdivided into two layers steady model like it in [4], three layers steady model like it in [5], two layers dynamic model like it in [6] and three layers dynamic model like it in [7]. Most of these theoretical models ignored or simplified the effect of the drill pipe rotation on cuttings transport. The reason is that the rotation of the drill pipe can make the two-phase flow in annular become more complicated and difficult to solve. As a result, these theoretical models can not be used in the field design because of the big error and cannot be used to analyze the influence of drill pipe rotation on the cuttings transport.

Thus, a numerical model of cuttings transport solved by Fluent software is presented to simulate the cuttings transport in fluid in this paper. The change laws of concentration, velocity and pressure of liquid or cuttings with or without pipe rotation are analyzed. The simulation result has a very great theoretical and engineering value to hole cleaning technology of ERWs.
2. Numerical Model

Euler multiphase flow model is adopted to analyze the problem. The mathematical model is shown as follows.

(1) Continuity equation

\[
\frac{\partial}{\partial t} (\alpha_q \rho_q v_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q) = \sum_{p=1}^{n} \dot{m}_{pq}
\]  

(2) Momentum equation

\[
\frac{\partial}{\partial t} (\alpha_q \rho_q \vec{v}_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q \vec{v}_q) = -\alpha_q \nabla p + \nabla \cdot \tau_q + \sum_{p=1}^{n} (\dot{R}_{pq} + \dot{m}_{pq} \vec{v}_{pq}) + \alpha_q \rho_q (\vec{F}_{q} + \vec{F}_{lift,q} + \vec{F}_{vm,q})
\]

In the above formulas, \( \rho \) is density, \( v \) is velocity, \( \alpha \) is the volume fraction, \( \vec{F} \) is the external volume force, \( \vec{F}_{lift} \) is the lift force, \( \vec{F}_{vm} \) is the virtual mass force, \( \vec{R} \) is the interphase force, \( p \) is the pressure, \( \dot{m} \) represents mass transfer between two phases, \( \tau \) is the pressure strain tensor, subscript \( p \) and \( q \) represents a certain phase respectively.

3. Model Verification

According to the actual situation of extended reach drilling, this paper chooses the 215.9mm diameter of hole and the 127.0mm diameter of drill pipe with an eccentricity of 0.5 as the annular border. Considering the capability of the computer CPU and memory, the axial length is set to 20m. Through a lot of trial, the final grid scheme is determined as 56x8x360=161280. The grid division diagram of annular section is shown in Figure 1 below. After the meshing work done, the software of Fluent was used to complete the rest simulation works.

The comparing result between the numerical model in this paper and Wang’s model [9], which is regressed from experimental data, is shown in Figure 2. The Wang’s experimental parameters are used in the simulation and comparison. We can see that the two calculation results are close. But there are also some differences. The result of Wang’s model is approximate to a straight line, while our numerical model is more like a parabolic curve. The result of cuttings bed height calculated by our model is higher when the flow rate is small and lower when the flow rate is high than it using Wang’s model.

![Figure 1. Grid division diagram](image1)

![Figure 2. Comparison with Wang’s model](image2)
4. Simulation Result
The default values used by simulation are as follows. The pump rate is 30 L/s, the drillpipe rotation speed is 100 rpm, the eccentricity is 0.5, the viscosity of fluid is 25cP, the inlet volume fraction of cuttings is 5%, and the cuttings diameter is 1mm. The section where the cuttings volume fraction is bigger than 70% is defined as fixed bed area and the section where the cuttings volume fraction is between 10% and 70% is defined as mobile bed area.

4.1. Cuttings Distribution in Annular
Cuttings distribution with drillpipe rotation and without rotation are shown in Figure 3. It can be seen that the distribution of cuttings is not symmetrical because of the drillpipe rotation. In the right side of annular, the fluid flows upward driven by rotating drillpipe and carries more cuttings into the upper flow area, which leads to a loose cuttings bed in large range. But the left side is the opposite. In comparison with the integration of cuttings volume fraction without rotation, the cuttings amount is reduced by nearly 1/3 with drillpipe rotation, which shows the important effect of drillpipe rotation on cuttings transport.

![Figure 3. Cuttings volume fraction distribution with (left) and without (right) pipe rotation](image)

The solid velocity distribution in the annular space with and without pipe rotation are shown in Figure 4. It can be seen from the figures, due to the rotation the cuttings bed in lower part of annular becomes loose and part of the cuttings jump into the upper liquid flow area, which makes the cuttings concentration of upper liquid flow region increases and the fluid flow energy decreases. As a result, the velocity of solid phase in upper layer decreases, but the velocity of solids in cuttings bed of lower region increases significantly, which makes the average velocity of solids in annular increases.
4.2. Effect of Pipe Rotation and Eccentricity on Cuttings Bed Height and Velocity

Curves of the height of cuttings bed and the average velocities of each area of the annular at different rotation speeds are shown in Figure 5. As can be seen, with the increase of rotation speed, more cuttings are carried into the upper part of the liquid flow area and taken away. As a result, the cuttings bed height is declined, the velocity of fixed cuttings bed and mobile cuttings bed is increased, while the rate of upper area of liquid flow is decreased. It can also be seen that the decreasing speed becomes small when the rotation speed is more than 100 rpm. From Figure 6 it can be seen that, with the rising of eccentricity, the height of the cutting bed increases. But the influence of eccentricity is more complex, which is related to the height of the bed height and the geometrical size of the annular.

4.3. Effect of Flow Rate and Fluid Properties on Cuttings Bed Height and Velocity

Curves of the height of cuttings bed height and the average velocities of each area of the annular at different flow rates are shown in Figure 7. As can be seen, the bed height declines and the velocities increases with the increase of flow rate. The changing speeds reach maximum while the flow rate is between 30—40L/s. When the flow rate reach 50 L/s, almost all the cuttings are moved up and there is no cuttings deposited. The influence of fluid viscosity and density on the height of cuttings bed is shown in Figure 8. It can be seen that, with the increase of the viscosity and density of the fluid, the height of the cutting bed is reduced.
4.4. Effect of Cuttings Diameter and Inlet Concentration on Cuttings Bed Height

The influence of cuttings diameter on the height of cuttings bed is shown in Figure 9. It can be seen that with the increase of cuttings diameter the height of the cutting bed is increased. The ROP increases with the rising of inlet concentration of cuttings, and thus the inlet concentration of cuttings is used instead of ROP in this paper. From Figure 10, it can be seen that the height of the cuttings bed increases with the rising of the inlet concentration of cuttings.

5. Conclusion

(1) Drillpipe rotation turns the axial motion of cuttings in annular into the helical motion and the distribution of cuttings concentration and velocity become symmetrical in annular.

(2) Drillpipe rotation can not only reduce the cuttings concentration in annular, but also increase the cuttings velocity, and thus promotes the hole cleaning condition. But it also increases the annular pressure drop.

(3) The cuttings bed height decreases effectively with the rising of flow rate. There is a sharply declination of cuttings bed at the rotation speed of 80 to 120 rpm. When the rotation speed is more than 120 rpm, the cuttings bed height does not change obviously. Thereby, the speed of more than 80 rpm is recommended in fields to enhance the important role of drillpipe rotation on hole cleaning.

(4) With the increase of the viscosity and density of the fluid, the cuttings bed height decreases. With the rising of cutting diameter, ROP and eccentricity, the cuttings bed height increases.

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