Annulus flow is a phenomenon which is frequently encountered in many industrial processes and has been under investigation for many decades. It is relatively simple to study concentric annulus flow. However, if the annulus is eccentric, calculations become complex due to the asymmetry of the eccentric annulus flow. During drilling operation, the space between the drill stem and the well wall is generally an eccentric annulus. Especially in highly deviated wells and horizontal wells, the drill stem will be located at the low side of the wellbore because of gravitational effects, thus, a fully eccentric annulus is formed. The velocity profile in the eccentric annulus will exert a great impact on the transportation and distribution of the cuttings, which is very important to prevent the drill string from being buried and avert sticking incidents. Based on a single-phase flow model and a solid-liquid two phase mixture drift model, (using the computational fluid dynamics (CFD) software) we analyze the influence of six factors in this paper. These factors are the
- flow rate,
- fluid viscosity,
- the type of fluid,
- eccentricity,
- annulus geometry size and
- cuttings concentration.

According to the results of numerical simulation, we can see that the velocity profile in the eccentric annulus is asymmetrical. There will be a high-speed basin in the wide gap of the annulus while the low-speed basin will lie in the narrow gap. With increasing flow rate, annulus geometry size and a decrease of the eccentricity, the area of the high-speed basin in the annulus will be increased and that of the low-speed basin will be decreased. This will improve the uniformity of the annulus flow. With increasing fluid viscosity and cuttings concentration, the velocity in high-speed basin of the annulus will be increased, at the same time, the velocity in low-speed basin will be decreased and the change of the velocity is not evident. However, the pressure loss in annulus will increase rapidly. Therefore, we have to ensure that the velocity at the low-speed basin is large enough to transport the cuttings and to avoid the debris deposition in the drilling operation. At the same time, the borehole pressure should be taken into consideration when we select the reasonable drilling fluid viscosity.

**Keywords:** eccentric annulus, velocity distribution, influencing factor, numerical simulation.

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**Introduction**

Fluid flow in annulus space is frequently encountered in many industrial processes and has been under investigation for many decades. The flow in concentric annular space can be analyzed without much difficulty. However, if the annular space is eccentric, the flow becomes more complex due to the asymmetry of the eccentric annulus. Unfortunately, the annulus we can see most frequently in the practical production is the eccentric annulus. The velocity profile in the eccentric annulus will exert a great impact on the transportation and distribution of the cuttings, thus affecting wellbore cleaning.

Considerable researches have been conducted to the distribution of velocity in the eccentric annulus, and the main research methods are numerical computation and numerical simulation. In 1965, Roberto and Vaughn [1] studied the axial laminar flow of non-Newtonian fluids in narrow eccentric annulus with the method of numerical calculation and analyzed the feature of the velocity profile in the narrow eccentric annulus. In addition, they also analyzed the influence of velocity on pressure loss, and the influence of slight eccentricity on final results. In 1990, Luo and Peden [2] analyzed the eccentric annular flow of non-Newtonian fluids with a new method where an eccentric annulus represented by an infinite number of concentric annuli with variable outer radius. By using this new method, they obtained more accurate approximations for various profiles and good predictions of the volumetric flow rate and pressure gradient in eccentric annular flow. In 1994, Buckinghm [3] studied the velocity and turbulence intensity profiles for Newtonian annular flow and the effect of mechanical aids on these profiles with the method of numerical computation. In his paper, he analyzed the influence which is exerted by the centering device. In 1995, Manglik and Fang [4] studied the effect of eccentricity on fully developed laminar flow in annular ducts. In order to get a more accurate result, different phase angles were taken into consideration in his paper. In 2006, Ozbayoglu...
and Omurlu [5] analyzed the effect of eccentricity on flow characteristics of annular flow of non-Newtonian fluids by using finite element method. They came to the conclusion that when the eccentricity increase, the frictional pressure drop decrease, and this observation is verified both with simulation results as well as with experimental data. In 2012, Alégría and his fellows [6] point out that during the rotary drilling operation, the oscillations of drill bit change the well cross-section from an expected circular to an elliptic shape. In these cases, the researchers studied the characteristic of viscoplastic fluid when it flows through eccentric elliptical annular pipe.

In spite of the numerical computation, researchers also study this problem with the method of the numerical simulation. In 1992, Azouz [7] studied the flow of Newtonian and non-Newtonian fluids in conduits of arbitrary cross-section. And they also studied the characteristics of laminar flow of the Bingham fluid and the power law fluid in annulus by using the CFD software. In 2001, with the method of numerical simulation, Escudier [8] studied the fully developed laminar flow of purely viscous non-Newtonian liquids through annuli, including the effects of eccentricity and inner-cylinder rotation. The result showed that the viscosity index exerted a great influence on the feature of the velocity profile. At the same time, in this paper, they also proposed a new method to analyze the result. In 2008, Duan and his fellows [9] studied the effect of eccentricity, the power law index of viscoplastic fluid when it flows through eccentric annulus. In 2012, Mokhtari [10] studied the influence rule and mechanism influenced the velocity profile in eccentric annulus. In 2014, Alegría and his fellows [6] studied how the eccentricity, the power law index, the type of the fluid, annulus of each factor. These factors include the flow rate, and analyzed the influence rule and mechanism of velocity profile in foam drilling operation. By using the CFD software, they came to the conclusion that the drill fluid drill rate and velocity profile.

In this paper, based on single-phase flow model and solid-liquid two phase mixture drift model, by using CFD software, they came to the conclusion that the drill pipe rotation can slightly increase the pressure drop only in the eccentric annulus, and this effect is caused by the changing of the velocity distribution in the eccentric annulus. In 2012, Mokhtari [10] studied the computational modeling of drilling fluids dynamics in casing drilling. With the help of the CFD software, they tried to study how the eccentricity, the power law index and the wellbore geometric size influenced the pressure and velocity profile.

In this paper, based on single-phase flow model and solid-liquid two phase mixture drift model, by using CFD software, we studied the six main factors which influenced the velocity profile in eccentric annulus and analyzed the influence rule and mechanism of each factor. These factors include the flow rate, eccentricity, fluid viscosity, type of the fluid, annulus geometry size and cuttings concentration.

1. Mathematical model
1.1. Single-phase flow control equations in annulus

Assuming the flow in annulus is stationary and isothermal, we can get single-phase flow control equations:

1. Equation of continuity

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u_r \right) + \frac{1}{r} \frac{\partial}{\partial \theta} \left( r \rho u_\theta \right) + \frac{\partial \rho u_z}{\partial z} = 0
\]  

(1)

2. Momentum equation

\[
\rho \left( \frac{Du_r}{Dt} + \frac{u_r u_r}{r} \right) = \rho g_r + \frac{1}{r} \frac{\partial}{\partial r} \left( r \sigma_{rr} \right) + \frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{\partial \sigma_{rz}}{\partial z} + \frac{\partial \left( r \sigma_{rr} \right)}{\partial z} \]

(2)

\[
\rho \frac{Du_\theta}{Dt} = \rho g_\theta + \frac{1}{r} \frac{\partial}{\partial r} \left( r \sigma_{\theta\theta} \right) + \frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{\partial \sigma_{\theta z}}{\partial z} + \frac{\partial \left( r \sigma_{r\theta} \right)}{\partial z} \]

(3)

\[
\rho \frac{Du_z}{Dt} = \rho g_z + \frac{1}{r} \frac{\partial}{\partial r} \left( r \sigma_{rz} \right) + \frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{\partial \sigma_{\theta z}}{\partial z} + \frac{\partial \left( r \sigma_{rz} \right)}{\partial z} \]

(4)

where

\[
\frac{D}{Dt} = \frac{\partial}{\partial r} \left( r \frac{u_r}{r} \right) + \frac{1}{r} \frac{\partial}{\partial \theta} \left( r \frac{u_\theta}{r} \right) + \frac{\partial u_z}{\partial z}
\]

(5)

\[
\rho \text{ - dense, } \text{kg/m}^3; \quad u \text{ - velocity, } \text{m/s}; \quad \sigma_{ij} \text{ - component of the surface force, N;} \quad t \text{ - time, s;} \quad g \text{ - gravite, } \text{m}^2/\text{s}.
\]

1.2 Two-phase flow control equations in annulus

When we study the effect of cuttings for annulus, we try to study how the eccentricity, the power law index, the type of the fluid, annulus of each factor. These factors include the flow rate, eccentricity, fluid viscosity, type of the fluid, annulus geometry size and cuttings concentration.

1.1. Single-phase flow control equations in annulus

Assuming the flow in annulus is stationary and isothermal, we can get single-phase flow control equations:

1. Equation of continuity

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u_r \right) + \frac{1}{r} \frac{\partial}{\partial \theta} \left( r \rho u_\theta \right) + \frac{\partial \rho u_z}{\partial z} = 0
\]

(6)

where

\[
\rho_n = \sum_{k=1}^{2} C_k \rho_k
\]

\[
\rho_m = \sum_{k=1}^{2} C_k \rho_m
\]

\[
\rho_m = \sum_{k=1}^{2} C_k \rho_m
\]

(7)

(3) Relative velocity equation

For the solid phase

\[
U_s \frac{\partial U_{sr}}{\partial r} + U_s \frac{\partial U_{s\theta}}{\partial \theta} + U_s \frac{\partial U_{sz}}{\partial z} = \frac{U_s^2}{r}
\]

(8)

\[
= F_s - \frac{1}{\rho_s} \frac{\partial p}{\partial r} + \frac{1}{C_s \rho_s} F_s + \frac{1}{C_s \rho_s} F_s = 0
\]

\[
U_s \frac{\partial U_{sr}}{\partial r} + U_s \frac{\partial U_{s\theta}}{\partial \theta} + U_s \frac{\partial U_{sz}}{\partial z} = \frac{U_s^2}{r}
\]

(9)

\[
= F_s - \frac{1}{\rho_s} \frac{\partial p}{\partial r} + \frac{1}{C_s \rho_s} F_s + \frac{1}{C_s \rho_s} F_s = 0
\]

\[
U_s \frac{\partial U_{sr}}{\partial r} + U_s \frac{\partial U_{s\theta}}{\partial \theta} + U_s \frac{\partial U_{sz}}{\partial z} = \frac{U_s^2}{r}
\]

(10)

For the fluid phase

\[
U_f \frac{\partial U_{gf}}{\partial r} + U_f \frac{\partial U_{g\theta}}{\partial \theta} + U_f \frac{\partial U_{gz}}{\partial z} = \frac{U_f^2}{r}
\]

(11)

\[
= F_f - \frac{1}{\rho_f} \frac{\partial p}{\partial r} + \frac{1}{C_f \rho_f} F_f + \frac{1}{C_f \rho_f} F_f = 0
\]
\[ U_{p} \frac{\partial U_{f}}{\partial r} + U_{p} \frac{\partial U_{s}}{\partial \theta} + U_{p} \frac{\partial U_{m}}{\partial z} = \frac{1}{r} \left( F_{f} - \frac{1}{\rho_{f}} \frac{\partial P}{\partial r} \right) + \frac{1}{\rho_{f}} F_{fs} \]

where
\[ f, s - \text{subscript, fluid and solid}; \]
\[ t - \text{time, s}; \]
\[ \rho - \text{mixed phase density, kg/m}^3; \]
\[ m - \text{total mass flux, kg}; \]
\[ u_{m} - \text{velocity of mixture phase, m/s}; \]
\[ U - \text{relative velocity of each phase, m/s}; \]
\[ C_{f}, C_{s} - \text{the volume fraction of each phase}; \]
\[ F_{a} - \text{added mass force, N}; \]
\[ F_{sf}, F_{fs} - \text{interaction between the two phases, N/m}^3; \]
\[ \nu - \text{molecular viscosity coefficient of the fluid}; \]
\[ \tau_{0} - \text{wall friction stress, N/m}^2; \]
\[ \gamma - \text{pipe circumference, m}; \]
\[ A - \text{cross-sectional area of annulus, m}^2; \]
\[ F_{fr}, F_{fz}, F_{f\theta} - \text{liquid mass force component along different directions, N/kg}; \]
\[ F_{sr}, F_{sz}, F_{s\theta} - \text{solid mass force component along different directions, N/kg}; \]

2. Physical model

In this paper, we use the smooth pipe which the external diameter is 5 in (127 mm) to simulate the drill stem, and use the other one which the internal diameter is 7 in (177.8 mm) to simulate the wellbore. We employ the structured grid and the size of the mesh is 100 (circumference) x 15 (radius) x 250 (axis). The boundary condition of the entry is the velocity inlet, and the export use the natural outflow boundary condition. Due to the assumption that wellbore and inner pipe are smooth string which without slipping, so we use the fixed wall boundary condition to close the computational domain.

Boundary conditions are set as follows:

Inlet boundary condition: Annular inlet boundary condition is velocity inlet, so that we can change the flow rate of the inlet. Meanwhile, in order to improve calculation accuracy and convergence speed, turbulent kinetic energy and turbulent dissipation rate at the annulus entrance are appropriate settings. Since the turbulence calculation model is used, we need to set the values of turbulence intensity and hydraulic diameter. In this paper, turbulence intensity is set to 10% and the hydraulic equivalent diameter is 0.0873 m.

Outlet boundary condition: Annular outlet boundary condition is set to the outflow. Its physical meaning is the full development of the border. Meanwhile, in order to improve the convergence speed of the calculation, we set up the appropriate hydraulic equivalent diameter and turbulence intensity values.

Solid wall boundary conditions: Assuming the wellbore and tubing string are no-slip smooth columns, thus the simulation space was closed by the solid wall boundary conditions.

3. The results of numerical simulation and analysis

In this paper, we applied the variable control method. Therefore, there is only one variable in a particular simulation calculations. The others are set in terms of the table.

<table>
<thead>
<tr>
<th>Flow rate, L/s</th>
<th>Eccentricity</th>
<th>Viscosity, mPa's</th>
<th>Type of fluid</th>
<th>Annulus geometry size, in</th>
<th>Cuttings concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0</td>
<td>0.2</td>
<td>10</td>
<td>7</td>
<td>3%</td>
</tr>
<tr>
<td>12</td>
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<td>0.4</td>
<td>20</td>
<td>8.5</td>
<td>5%</td>
</tr>
<tr>
<td>18</td>
<td>0.4</td>
<td>0.6</td>
<td>30</td>
<td>9.5</td>
<td>15%</td>
</tr>
<tr>
<td>24</td>
<td>0.6</td>
<td>0.8</td>
<td>40</td>
<td>0</td>
<td>5%</td>
</tr>
</tbody>
</table>

3.1. Flow Rate

Flow rate is the most important influencing factor which affects the flow velocity profile in annulus. By changing the flow rate of the inlet, we can get the different flow velocity distribution nephogram of the outlet as shown in figure 2. From the figure 2, we can find that the flow velocity is higher at the wide gap of the annulus and the flow velocity is low at the narrow gap of the annulus. With the increase of flow rate, the high velocity area at the wide gap of eccentric annulus becomes bigger and low
velocity area becomes smaller. The main reason is that: when the fluid rheological feature and hydrodynamic radius is constant, with the increase of the velocity, the Reynolds number will increase, at the same time, the turbulence intensity of the annular flow increases gradually. This is beneficial to overcome the eccentric annulus flow resistance at the narrow gap and improve the flow velocity in the annulus markedly.

At each process of numerical simulation, we extract 50 points from the symmetrical line of the velocity distribution nephogram. In this way, we can know how the annulus maximum velocity at the wide/narrow gap and the ratio of them vary with the change of the flow, as shown in figure 3. As flow rate increases, both of the maximum velocities at wide and narrow gap increase, but the ratio of them is reduced gradually. This is mainly because that with the increase of flow rate, the turbulence intensity of the flow in annulus increases and makes the uniformity of annulus flow to increase.

3.2. Eccentricity

We can see from the figure 4 that when the eccentricity is 0, a concentric annulus, the velocity distribution is symmetric. The annulus center velocity is the maximum and the velocity near the wall is relatively small. However, in the eccentric annulus, due to the fact that the pressure loss and energy loss in the wide gap is small, the fluid tends to flow through the wide gap and forms a high speed basin obviously. Correspondingly, as the flow resistance at the narrow gap of eccentric annulus is big, there will be a low speed basin.

As shown in figure 5, from low to high speed zone areas, with the change of the azimuth angle $\psi$, the velocity increases gradually. For annuluses with different eccentricity, the entire flow field is divided into two regions by the dividing line at the $\psi=110-120^\circ$: the region of velocity increasing and the region of velocity decreasing. In the high-speed basin ($\psi=180^\circ$), velocity increases with the eccentricity, however, in the low-speed basin ($\psi=0^\circ$), the velocity decreases with the increase of eccentricity. When the eccentricity increases, the thickness of fluid film formed at the wall does not change, while the effective flow area at the narrow gap is reduced. At the same time, due to the influence of the fluid viscosity, the flow resistance at the narrow gap increases, thereby the velocity at the narrow gap of the annulus reduces with the increase of eccentricity. And the change at wide gap is opposite.

3.3. Fluid viscosity

The viscosity of the fluid is another important factor. Different viscosity means different fluid turbulence intensity which will affect the velocity profile distribution in the annulus. Under the conditions of different fluid viscosity, includeing 10, 20, 30, 40, 50 mPa·s, we can use the numerical simulation software, FLUENT, to simulate. As shown in figure 6, we can find that as the fluid viscosity increase, the velocity at the wide gap of the annulus will rise while the velocity at the narrow gap of the annulus will decrease. This is mainly because that the Reynolds number will decrease which means the turbulence intensity will decrease as the viscosity.
increases. This leads to the increase of film thickness on the wall. As a result, the effective flow area of the narrow gap is reduced, the velocity of the narrow gap decreases. Since the total flow rate does not change, the decrease of velocity at the narrow gap must result in the increase of velocity at the wide gap.

At the same time, with the increase of the fluid viscosity, the friction between the fluid and rough wall surface will increase which will lead to the increase of fluid flow energy loss. The energy loss can be expressed in the form of pressure loss. As shown in figure 8, with the increase of the fluid viscosity, the pressure loss is increasing sharply. The energy loss is more obviously in the narrow gap and the flow resistance is bigger, resulting in the decrease of the velocity at the narrow gap.
3.4. Type of fluid

When the other variables is constant, by changing the type of the fluid, for example the Newtonian fluid, the Power-law fluid and the Bingham fluid, we can study how the type of the fluid effect the velocity distribution in the eccentric annulus. We can get the velocity distribution nephogram and the three-dimensional graph about the velocity gradient vs. location when we change the type of the fluid, just as shown in the figure 9. Compared to the Newtonian fluid, the area of high-speed basin of the Bingham fluid is bigger while the value of velocity at the narrow gap is relatively low. For the power-law fluid, from the velocity distribution nephogram, we can find that the high-speed basin is similar to the Newtonian fluid, but the velocity at the low-speed basin is relatively high.

By extracting the point from the 3-D curves of the velocity along the axis of symmetry, we can obtain the velocity profile of different fluids, as is shown in the figure 10. For Newtonian fluid, the velocity profile consists of two velocity gradient regions and a potential core due to its constitutive equations, and these are more obviously at the wide gap of the annulus. However, at the narrow gap of the annulus, as the sum of the width of the two velocity gradient regions is bigger than the width of the narrow gap, there is not a potential core. For the reason that the constitutive equations of the Bingham fluid and the Power-low fluid are relatively complex, the width of the velocity gradient regions is wider than that of the Newtonian fluid. Therefore, the potential core is relatively narrower and the velocity near the wall increases slowly. As a result, there will form a velocity penetration, just as shown in the figure 10. At the same time, for the shear thinning effect, the velocity of the Bingham fluid is bigger than the Power-low fluid. Accordingly, the velocity at the narrow gap is smaller than that of the power-low fluid under the same conditions.

3.5. Annulus Geometry Size

In the practice of drilling operation, based on the casing program design, different depths means different wellbore geometry, and the changing of the annulus geometry size will exert influence on the flow velocity profile. In this paper, we use the FLUENT to simulate the flow when the out diameter of the wellbore is respectively 7 in, 8.5 in and 9.5 in. We can obtain the velocity distribution nephogram as shown in figure 11. As shown in figure 12, the velocity profile...
can be get by extracting point from the nehogram along the axis of symmetry.

From the figure 12, we can see that, with the increase of the wellbore size, the velocity penetration at the high speed basin will become more and more unobvious, and the potential core will become bigger while the maximum value of the velocity is declining. This is mainly because that the width of the velocity gradient regions is the same when the type of the fluid and the inlet velocity is constant, in this case, bigger wellbore size means a bigger potential core. However, at the narrow gap of the annulus, the maximum value of the velocity will increase with the wellbore size. The main reason is that when the eccentricity is constant, with the increase of the wellbore size, the narrow gap will become wider, so that the energy loss will decline and the flow velocity will increase obviously.

3.6. Cuttings Concentration

In drilling operations, the annular flow is often solid/liquid two-phase flow. In this case, the cuttings concentration is an important factor that influences the velocity profile. As the safe upper limit of the cuttings concentration is 5% in drilling operations, we studied the velocity profile when the flow rate was 30 L/S and the cuttings concentration was 0% and 5% respectively by using the CFD software, as shown in figure 13. We can see that when the annular flow is solid/liquid two-phase flow, the maximum value of the high-speed basin at the wide gap will increase while the maximum value of the low-speed basin at the narrow gap will decrease. This is likely due to the presence of the cuttings increases the energy loss when the two-phase fluid flows through the narrow gap of the eccentric annulus and diminishes the velocity value at the narrow gap. Then the fluid tends to pass from the wide gap of the annulus and the velocity of high-speed basin increases.

At the same time, when the flow rate is 30 L/S, with the help of the CFD software, we can get the distribution of cuttings volume concentration, as shown in figure 14. There are little cuttings in the upper part of the eccentric annulus but a lot at the bottom of the annulus which form a cuttings bed. This is likely due to the velocity with flow rate 30 L/S is not high enough to transport the cuttings, cuttings will gradually accumulate at the bottom of the eccentric annulus under the action of gravity and form a cuttings bed. Usually, there will be a stationary bed of drilled cuttings at the bottom, a moving-bed layer above it, and a heterogeneous suspension layer at the top. The cuttings bed will diminish the effective flow area at the narrow gap and fluid tends to pass through the wide gap and the velocity at high-speed basin increases. Therefore, in the drilling operations, especially the high-angle and horizontal well, we have to make sure that the flow rate is big enough to ensure the cuttings can be transported at the narrow gap of the annulus to prevent the drill string from being buried and avert sand sticking accidents.
4. Conclusion

The velocity profile in the eccentric annulus is not symmetrical. There will be a high-speed basin at the wide gap of the annulus and a low-speed basin at the narrow gap. There are six main factors which influence the velocity distribution in the eccentric annulus. These factors consist of the flow rate, fluid viscosity, the type of fluid, eccentricity, annulus geometry size and cuttings concentration.

With the change of the flow rate, viscosity and the type of the fluid, the velocity profile in the annulus can be changed. When the flow rate is increasing, the high-speed basin at the wide gap of the annulus will become bigger while the low-speed basin will become smaller. The maximum speeds of both the high-speed basin and the low-speed basin are increasing, however, the ratio of them is gradually declining. This is mainly because that larger flow rate means greater turbulence intensity, in this case, the fluid flow through the narrow gap more easily and the uniformity of the flow will be promoted. With the increase of the fluid viscosity, the velocity has been increased at the wide gap while reduced at the narrow gap, and the change is not obvious. However, the viscosity has a great influence on the pressure loss, and the pressure loss increase rapidly with viscosity. Therefore, even though high viscosity is good for cuttings suspension, we should take the pressure loss into account and chose a reasonable fluid viscosity. As different fluids have different constitutive equations, the velocity profiles will be different when they flow through the eccentric annulus. Compared with the Newtonian fluid, the area of high-speed basin of the Bingham fluid is bigger, but the maximum velocity of the low-speed basin is lower. The high-speed basin of the Power-low fluid is similar to that of the Newtonian fluid, but the maximum velocity of the low-speed basin is higher and the flow of Power-low fluid in eccentric annulus has a greater uniformity.

The influences of annulus geometric characteristics on the velocity profile are outstandingly shown in two aspects: the eccentricity and the annulus geometry size. The increase of the eccentricity will decline the uniformity of the flow. By the boundary that $\psi = 110-120^\circ$, the whole flow field can be divided into two parts: velocity increasing region and velocity decreasing region. With the increase of the eccentricity, the flow velocity increase in velocity increasing region, but there is an opposite tendency in velocity decreasing region. When the annulus geometry size increase, the velocity penetration at the high-speed basin will become unobvious and the maximum velocity is smaller. However, the velocity increases at the narrow gap and the uniformity of the flow will be promoted.

In drilling operations, the annular flow is often solid/liquid two-phase flow. In this case, the cuttings concentration is an important factor that influences the velocity profile. With the presence of cuttings, the velocity will increase at the wide gap of the annulus while decline at the narrow gap. If the velocity in the low-speed basin is too low to transport the cuttings, cuttings will gradually accumulate at the bottom of the eccentric annulus and form a cuttings bed. Therefore, in drilling operations, especially the high-angle and horizontal wells, we have to make sure that the flow rate is big enough to ensure the cuttings can be transported at the narrow gap of the annulus to prevent the drill string from being buried and avert sand sticking accidents.

References

Численное моделирование профиля скоростей в эксцентрическом кольцевом пространстве

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Реферат

Кольцевой поток – это часто наблюдаемое во многих производственных процессах и исследуемое на протяжении многих десятилетий явление. Относительно просто изучать концентрический кольцевой поток. Однако, если кольцевое пространство - эксцентрическое, вычисления усложняются по причине асимметрии эксцентрического кольцевого потока. При проведении буровых работ пространство между бурильной колонной и стенкой скважины в основном эксцентрическое кольцевое. В наклонно-направленных и горизонтальных скважинах бурильная колонна располагается в нижней части ствola скважины таким образом, что формирует в силу гравитационных эффектов полностью эксцентрическое кольцевое пространство. Профиль скоростей в эксцентрическом кольцевом пространстве оказывает большое влияние на вынос бурового шлама, что очень важно для предотвращения случаев прихвата колонны бурильных труб.

В статье, на основе моделей однофазного потока и твердо-жидкостного двухфазного смешанного сдвига, анализируются влияние шести факторов, таких как: расход потока, вязкость флюида, тип флюида, эксцентрицитет, геометрические размеры кольцевого пространства, концентрация бурового шлама.

Результаты численного моделирования показали, что профиль скоростей в эксцентрическом кольцевом пространстве ассиметричен. При этом высокоскоростное пространство располагается в широкой части кольцевого пространства, а низкоскоростное - в узкой части. С увеличением расхода потока геометрических размеров кольцевого пространства и уменьшением эксцентрицитета, область высокоскоростного пространства в кольцевом пространстве будет увеличиваться, а область низкоскоростного пространства сокращаться. Это улучшит однородность (равномерность) кольцевого потока. С увеличением вязкости флюида и концентрации бурового шлама скорость в высокоскоростном пространстве кольцевого пространства будет увеличиваться, в то время как в низкоскоростном - уменьшаться, и это изменение скорости не будет ясным. Однако, снижение давления в кольцевом пространстве будет быстро увеличиваться. Поэтому, необходимо следить за тем, чтобы скорость в низкоскоростном пространстве была достаточно большой для выноса бурового шлама при проведении буровых работ. В то же самое время, необходимо учитывать скважинное давление при выборе приемлемой вязкости промывочной жидкости.

Экссентрическое кольцевое сечение скоростных профилей моделировано

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Xülasə

Голяви ахин - бир өзри иштешал проесләрдә төз-тез мүшәхәда эдилән өөн илләкәр бойунча тәддәш эдилән таъжәүдир. Консертлингә хәләғә ахин тәддәш итә була ясандар.

Ландин, хәләғә фаза экссентрикдир, экссентрик хәләғә ахин асимириятиси сәбәбенән һәсләмәләр мүрәккәблашыр. ฉาңа иләрнән апарылышы мәңә, өзәмә көмәри өла өлүй дирав ираандарды фаза асән экссентрик хәләғә фазадыр. Маали-истиқамотлы ви--horizontal сыялмаларды өзәмә камәри өла өлүй ләүәсинә ашык һисәсәнә өла өлүй иләрләр өлләш, грavitация иләрләренә тәсирә аңысоңса там сурәтта экссентрик хәләғә фаза формалашыр. Экссентрик хәләғә фазада үәрләр өзәмә өзәшмәнән бөйүк тәсир гәстрәр өз, бу да өзәмә бураны камарларынын тутулма һәләрләренә өзәшмәнән алынмаși үүнүң өзәшмән алынмаși үүнүң өзәрөөдөр. Мәкаләдә бирфазалы ахин ви- baik-mayе икіфазалы ғарыш өрдәййөмә моделләринән асаанда ашык һисәсәнә алынмаși алты факторун тәсирә тоһил эдиләр: ахин серфи, өлүйдүү өзәлүү, өлүйдүү нөвү, экссентрикдисет, хәләғә фазаны өндәй өлүйдәр, өзәмә өзәшмәнән өзәрөөдө.

Рақәмсәл моделдәрдән әтәнчәләр өзәрөөдөрдө көстәрмәштәр дыр, экссентрик хәләғә фазада үәрләр өзәмә асимириятиси кешеләр. Бүнәлә ыаңыз эшкәсүрәтләр фаза хәләғә фазаның өзәшмән, ашык һисәсәнә ишәдә дар өзәсәнән өлләш. Ахин серфии, хәләғә фазаны өндәй өлүйдәрләр армасы ва экссентрикдисетizin азымләнмә илә хәләғә фаза эшкәсүрәтләр эшкәсүрәтләр фазада өзәшмә артака, ашык һисәсәнә өзәшмә ишә илә азкамаака. Бу хәләғә ахиннән хәйәнсәлиләй (борборлылты) ыаңызләңдерәчә. Өлүйдүү өзәлүүлүүн ви- өзәмә өзәшмәнән өзәрөөдөр армасы ва хәләғә фазаның эшкәсүрәтләр эшкәсүрәтләрнән өзәрөөдөр артака, нәче ки, һәмин ашык һисәсәнәләрдә нәкәлга, ва бу өзәрөө дыйышылйыл ашык һисәсәнән алынмаака. Ландин хәләғә фазада өзәрөөдөр ашык душмән артака. Буна өгә дә өзәрөөдөр эмдәк вакыктәр дыр, ашык һисәсәнә дүүрүү артыгы ихасынын үүнүң бүрүү олын. Ейни заманда ыылүү мәхлүлүңүл өзәлүүлүңүл өшөө өзәмә кыйымын кўйи өзәрөөдө ыйык бўйдир олсун. Ейни заманда ыылүү мәхлүлүңүл өзәлүүлүңүл өшөө өзәмә кыйымын кўйи өзәрөөдө ыйык бўйдир олсун.