Research on Calculation Model of Cutting Bed Thickness of Horizontal Well

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Abstract. Correctly understanding the law of migration of the cuttings bed and the settlement of the cuttings have a great effect on the effect of wellbore purification. According to the flow law of solid-liquid two-phase flow in the wellbore, a model for calculating the height of the cuttings bed and a starting model of the cuttings bed are proposed, and a method for predicting the thickness of the cuttings bed is proposed.

1. Introduction

During drilling operations, if cuttings cannot be removed from the wellbore and the wellbore is kept clean, drilling will not continue. Cuttings migration is generally not a problem in vertical well drilling, but for inclined wells, especially for wells with extended reach and horizontal wells, if the annulus velocity of the drilling fluid is not appropriate, the cuttings will accumulate in the wells with low slopes. Side, a stable rock cutting bed or a flowing rock cutting bed is formed, which causes problems such as stuck drilling, high torque, high friction, and poor cementing quality. Experimental research shows [1, 4] that the drilling fluid carrying capacity of drilling fluid in inclined annulus is affected by drilling fluid displacement, borehole geometry, drilling fluid density, drilling fluid rheology, mechanical drilling speed, cuttings density, cuttings size, and drill string speed, Drill string eccentricity and other factors. In the theoretical study of cuttings migration, theoretical models based on liquid-solid two-phase flow are also continuously developed. In view of the complexity of the movement of cuttings in inclined wells, the author starts by analyzing the law of the movement of cuttings in inclined wells. Through the analysis of the force of cuttings under different types of cuttings migration, the critical point to maintain the cleanliness of inclined wells Annulus velocity calculation model to solve the problem of rock carry in inclined wellbore.

2. Force analysis of cuttings particles

For inclined boreholes, during the process of drilling fluids carrying cuttings from the drill bit to the surface [5], when the cuttings pass through the sensitive area where the cuttings bed is most likely to form, if the velocity of the drilling fluid annulus is lower than the critical cycle under this condition At the air velocity, the cuttings will be separated from the upper return beam and deposited on the lower side of the wellbore. As the thickness of the cuttings bed increases, the velocity of the drilling fluid near the cuttings bed will continue to increase. When the critical annular flow velocity is reached, the cuttings bed thickness no longer increases and reaches equilibrium. Therefore, the critical annular velocity is the minimum annulus velocity that does not form a cuttings bed under certain conditions.


3. Calculation model of cuttings bed thickness

The cuttings will be subjected to gravity $G$ (considering the buoyancy of drilling fluid), drilling fluid lifting force $F_f$, and drilling string rotation lifting force $F_R$, drag force $F_D$, plastic force $F_P$, and axial pressure gradient difference during the movement of the inclined borehole. The resulting pulling force $F_P$. The $y$-axis is parallel to the wellbore axis and is positive upward. The $x$-axis is perpendicular to the wellbore axis and the positive direction points to the high side of the wellbore. Assumptions: The cuttings are spheres; the annulus flow is steady flow; the cuttings do not interfere with the distribution of velocity in the annulus.

3.1. Single-layer cuttings start

Single-layer cuttings start means that the uppermost particles of the cuttings bed are subjected to a force and migrate. The combined force that meets the drag and pressure gradient forces in the horizontal direction is greater than the friction between the cuttings; in the vertical direction, the buoyancy, The combined force of rotary lifting force and mobile lifting force is greater than gravity.

$$
\begin{align*}
G &= \rho_s g \frac{\pi d^3}{6} \\
F_f &= \rho_f g \frac{\pi d^3}{6} \\
F_D &= C_D \frac{\pi \rho_f v^2 d^2}{8} \\
F_L &= C_L \frac{\rho_f A v^2}{2} = C_L \frac{\pi \rho_f v^2 d^2}{8} \\
F_{\Delta P} &= \frac{\pi d^3 G_{\Delta P}}{6} 
\end{align*}
$$

$$
\begin{align*}
F_d + F_{\Delta P} &\geq f \left( G - F_f - F_L - F_R \right) \\
F_f + F_R + F_L &\geq G 
\end{align*}
$$
3.2. Multi-layer cuttings start

If the uppermost cuttings particles meet the single-layer cuttings activation equation above, no cuttings bed deposits will be formed. If the single-layer cuttings activation equations are not satisfied, the cuttings bed sediments will form. There are various arrangements of multi-layered cuttings. For the sake of calculation, it is assumed that the arrangement of the cuttings is oblique. At this moment, there are two types of particle movement in the uppermost layer, one is rolling and the other is transition.

As shown in Figure 2, the cuttings are rolled forward along the flow direction of the drilling fluid at the support point with point A as the support point. At this time, the supporting force is applied. The condition for the rollover is to take a moment at the support point A and move the cuttings the dynamic torque is greater than or equal to the resistance torque, and the relationship is expressed as:

\[
\left( F_{D} + F_{D} \right) \frac{d}{2} \cos \phi + \left( F_{L} + F_{R} \right) \frac{d}{2} \sin \phi - G \frac{d}{2} \sin(\phi + \frac{\pi}{2} - \alpha) - F_{F} \frac{d}{2} \sin \phi = 0
\]

(7)

\[
F_{L} + F_{R} + F_{f} \geq G
\]

(8)

Substituting the formulas (1), (2), (3), (4), (5) into the formula (7) for cuttings rolling drilling Critical fluid velocity:

3.3. Calculation model of cutting bed thickness of horizontal well

![Figure 3. Cuttings bed without contact with drilling tools](image)
In Figure 3, the thickness of the cuttings bed is $H$, and the annulus can be divided into two parts. The upper part is clean liquid flow, and the lower part is a uniformly stacked cuttings bed.

$$R_0 = \frac{R_2^2 - R_1^2 + e^2 + 2R_e \cos \phi}{2(R_2 - R_1 + e \cos \phi)}$$  \hspace{1cm} (9)

$$\beta = \arctan \left( \frac{(R_2 - R_1) \sin \phi}{e + (R_2 - R_1) \sin \phi} \right)$$  \hspace{1cm} (10)

$$\Psi = \pi - \phi + \beta$$  \hspace{1cm} (11)

$$A_b = R_2^2 \phi - R_1^2 \beta + e \left( R_2 - R_1 \right) \sin \phi + R_2^2 \Psi$$  \hspace{1cm} (12)

The flow equation of the cuttings bed is:

$$v_s C_s A_b = v_c C_c \left( R_2^2 - R_1^2 \right)$$  \hspace{1cm} (13)

$$v_c \pi \left( R_2^2 - R_1^2 \right) = v_s A_s + A_b v_{id}$$  \hspace{1cm} (14)

Where $v_s$ is the average velocity of two phases of drilling fluid and cuttings in the mainstream area. $C_s$ is the average volume concentration of cuttings in the mainstream area. $v_c$ is the average velocity of the cross section of the wellbore. $C_c$ is the average volume concentration of the cross section of the wellbore.

The left side of the equation is the drilling fluid circulation pressure gradient, which is unknown:

$$\frac{\Delta P}{L} = \frac{4f \cdot v^2}{2gD} \left[ \frac{\rho_\mu + (1 - k) S_i (\rho_\mu - \rho_\mu)}{\rho_\mu} \right] \cdot \eta + k \cdot S_p \cdot \frac{\rho_\mu - \rho_\mu}{\rho_\mu} \cdot \mu_s$$  \hspace{1cm} (15)

The equilibrium equation of force under critical conditions is:

$$F_n = F_{dv}$$  \hspace{1cm} (16)

The first term on the right represents the component force of the gravity of the cuttings particles along the slope; the second term represents the frictional resistance of the cuttings particles along the slope under the action of gravity and dissipation force.

$$F_n = (\rho_\mu - \rho_\mu) g \cdot A_b \cdot \Delta z \cdot C_b \cdot \cos \alpha + \left( (\rho_\mu - \rho_\mu) g \cdot A_b \cdot \Delta z \cdot C_b \cdot \sin \alpha \right) + 2 \tau \left[ R_0 \Psi + R_1 (\phi - \beta) \right] \Delta z / (g \theta) \mu_s$$  \hspace{1cm} (17)

$$F_{dv} = 2 \tau \left[ R_0 \Psi + R_1 (\phi - \beta) \right] \Delta z + \frac{\Delta P}{L} A_b \Delta z$$  \hspace{1cm} (18)

4. Conclusion
From the perspective of microscopic rock debris particle migration, based on the theory of force balance, two-phase flow in the annulus, and material balance, a new method for calculating the thickness of sliding rock beds is established.
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