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Modeling pellet impact drilling process

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Abstract. The paper describes pellet impact drilling which could be used to increase the drilling speed and the rate of penetration when drilling hard rocks. Pellet impact drilling implies rock destruction by metal pellets with high kinetic energy in the immediate vicinity of the earth formation encountered. The pellets are circulated in the bottom hole by a high velocity fluid jet, which is the principle component of the ejector pellet impact drill bit. The experiments conducted has allowed modeling the process of pellet impact drilling, which creates the scientific and methodological basis for engineering design of drilling operations under different geo-technical conditions.

1. Introduction

Currently, there is a global trend to drill hard rock for various purposes. Hard rock drilling is characterized by low drilling rate and low rate of penetration. New materials and new design of drill bits for mechanical drilling can improve drilling efficiency. Despite the continuous improvement, the enhanced hard rock drilling is still a challenge.

Therefore, new alternative methods for rock drilling are urgent now. According to some researchers [1, 4, 6], one of the most promising drilling methods is hydro-dynamic drilling by high-speed fluid. This method ensures transmission of significant energy to the bottom hole with the multifold increase in the drilling rate, as well as the rate of penetration. Furthermore, this method is easy to apply within the current mechanical drilling technology where mud is used for cutting transport. However, hydro-dynamic drilling in its traditional version is not enough efficient for hard rock drilling.

Pellet impact drilling implies rock destruction by metal pellets circulating constantly in the bottom hole, which will solve a number of engineering problems connected with hydro-dynamic drilling. This method is characterized by a number of significant advantages: simplicity of drill bit design, no need for drill bit rotation and axial load. According to the data on drilling performance [3, 9] pellet impact drilling is associated with the increase in the drilling rate and the rate of penetration in comparison with the traditional drill bits.

We have proved that the most effective method to drill hard rock is to use ejector pellet impact drill bit with the nozzle and the tubular mixing chamber arranged consequently in line [5]. The efficiency of this drill bit is connected with the accuracy of geometric bit design and drilling parameters. The existing methods of pellet impact drill bit engineering design are limited in application and appropriate to design a particular drill bit only. Therefore, designing a specified model of pellet impact drilling process is currently urgent since it would create a scientific and methodological basis for engineering design under different geological and technical conditions.

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2. Designing a pellet impact drilling process

Designing a pellet impact drilling process was made on the basis of experimental data, in a particular, high-speed photography. A hydrodynamic layout of drill bit performance is shown in Figure 1.

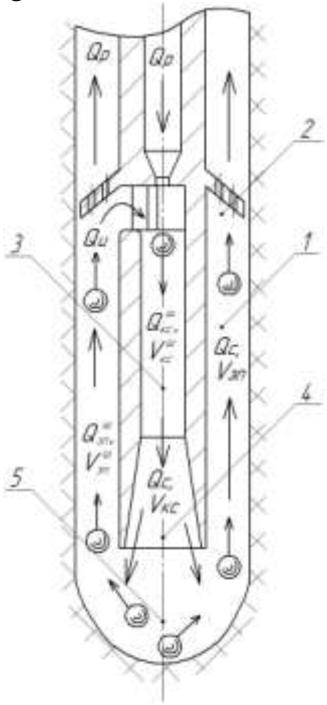

Figure 1 A hydrodynamic layout of drill bit performance:
1 – annular space; 2 – suction zone; 3 – mixing chamber; 4 – diffuser; 5 – a space between drill bit and bottom hole;
Q_{dm} – consumption of drilling mud supplying to the drill bit;
Q_i – injected drilling mud consumption;
Q_{mc} – mixed mud consumption;
V_{as}, V_{mch} – mud velocity in annulus space and drill bit;
Q^p_{mch}, V^p_{mch} – pellet consumption and pellet velocity in mixing chamber;
Q^p_{as}, V^p_{as} – pellet consumption and pellet velocity in annulus space.

Pellets are used in the following operations:

1) pellets are lifted in annular space 1 up to suction zone 2;
2) pellet are sent to mixing chamber 3 from suction zone 2;
3) pellets move in mixing chamber 3 and diffuser 4;
4) pellets move between the drill bit and bottom hole 5

A distinctive feature of a fluid jet is circulation of drilling mud and pellets. [3]. Thus, the circulation of drilling mud (Q_{dm}) and pellets (Q^p_{db}, Q^p_{as}) is observed in the process of drilling by the drill bit. It is necessary to note that operation mode of a fluid jet is changed by adding pellets in drilling mud.

3. Hoisting pellets in annulus space

The analysis of pellet movement in annulus space (Figure 2) obviously shows its unequal character.

Figure 2. Stroboscopic image of pellet movement in annulus space.

Average velocity of pellets hoisting (m/s) in the case of even movement can be defined by:

$$V^{p}_{as} = V_{as} - U \quad , \qquad (1)$$

where V_{as} – velocity of drilling mud circulation in annulus space, defined by the equality of mixed mud consumption in mixing chamber and annulus space

(2)

where d_{mch} – diameter of a mixing chamber; D_{well} – well diameter; d_{db} – outer diameter of the drill bit.

U – free-falling velocity of pellets in drilling mud for transient and turbulent regime of flow (m/s), defined by Rittinger's formula

(3)

where ω - Rittinger's constant for pellet in average 5,11 , d_p – pellet diameter, ρ_p – density of pellets, ρ_{dm} – density of drilling mud.

The maximum number of pellets in annulus space (N^{p}_{asmax}) is defined using our derived formula, based on the continuous motion of pellets. It is assumed that pellets are arranged in several rows.

(4)

where l_{db} – length of the drill bit.

According to the results of high-speed photography, it is possible to observe that within a pellet portion supply, there are gaps between pellets within a row, as well as between rows, even if the number of pellets is optimal. Therefore, the number of pellets can be defined by the following formula:

, (5)

where C_1 – coefficient of a gap between rows; C_2 – coefficient of a gap between pellets in a row.

Formula (5) is appropriate for calculation of an optimal portion of pellets supply. Validity of the formula is testified by the results of experimental research of the influence of the length of the mixing chamber on pellet impact drilling efficiency. The increase in length of the mixing chamber necessitates a greater number of pellets, which is shown in the mentioned-above formula.

It should be noted that efficient cutting transport may be ensured through:
- increasing the capacity of an arrestor;
- choosing the optimal coefficient of ejection that ensures the appropriate velocity of pellets in the mixing chamber.

4. Pellet supply to the drill bit
In upper part of the drill bit, pellets lifted up by rising current interact with the arrestor and then are sent to the mixing chamber through the process windows.

To prevent pellets jamming under the arrestor the following condition should be satisfied:

(6)

According to the tests, formula (6) is valid if the coefficients of ejection are more than 2.

5. Pellet movement in the mixing chamber and the diffuser
Pellet movement trajectory from the mixing chamber to the diffuser (figure 3) has been studied with high-speed photography. It was revealed that pellets in the mixing chamber do not move parallel to its

axis due to the fact that velocity vector is directed at the angle to an axis of a well at the point of pellets' entrance in a mixing chamber.

Figure 3. Stroboscopic image of pellet movement in the drill bit.

Therefore, the ricochet of pellets after hitting a wall is observed in the mixing chamber. At the same time, the trajectory deviation of pellets is not detected in the diffuser.

Furthermore, the analysis of video sequences shows when the pellets enter the mixing chamber; they are accelerated by the drilling mud flowing from a nozzle. At a distance from the inlet section of the mixing chamber the velocity profile of the fluid jet becomes equal; pellet velocity reduces to velocity V^{p}_{mch} and remains constant.

Pellet velocity in the mixing chamber is defined as:

(7)

where θ – coefficient depending on the ratio of the mixing chamber diameter to the pellet diameter, pellet consumption in a mixing chamber and drilling mud properties [7].

V_{mch} – velocity of drilling mud in the mixing chamber defined as:

—— (8)

where n_e – coefficient of ejection of the fluid jet.

The maximum number of pellets in the drill bit is defined as:

— (9)

Pellets consumption is equal to

, 10)

where t – the time of drilling.

Substituting (9) into (10) in case of even movement, we will obtain:

— —, (11)

In fact, not all pellet in the drill bit move in a row and there is a certain distance between the rows. In this regard, formula (11) should be corrected by adding coefficient C_3 taking into account the gaps between pellets in a row and the rows.

—, (12)

It should be noted that the empirical dependence of pellets consumption in the mixing chamber on pellets velocity is confirmed by the American researchers as well [2].

6. Pellet movement in bottom-hole zone

After leaving the diffuser pellets hit the rock and crush it. Figure 2 shows that the distance between the drill bit and bottom hole is gradually filled up with pellets because of considerable flow turbulence of drilling mud after its interaction with the bottom hole and pellets encounter as well. In addition, a comparison of the actual geometric dimensions of the bit, pellets and the distance between the drill bit and the bottom hole, as well as trajectory analysis show that the marginal zone of bottom hole is crashed mostly by ricocheted pellets and supplied pellets. This once again confirms the justification of a minimum distance between the drill bit and bottom-hole in drilling of a well.

7. Conclusion

The suggested model of pellet impact drilling process creates a scientific and methodological basis for engineering design of drilling operations under different geo-technical conditions, and ensures through:

- to calculate pellet consumption and pellet movement velocity in annulus space and the drill bit;
- to ensure the efficient cutting transport from bottom hole;
- to prevent pellets jamming under the arrestor of the drill bit;
- to calculate the optimal portion of pellet supply for the drill bit.

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