Calculation of Ball Jet Drilling Processes in the Optimal Mode of Rock Destruction

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Abstract. This article is devoted to the study of ball jet drilling method, which in the future may increase the mechanical speed and driving of the bit during drilling of solid rocks for various purposes. Ball jet method of drilling wells is to destroy rocks by strikes of metal balls continuously circulating in the near wellbore area by means of a jet system, laid to the basis of ball jet – ejector drilling unit. The main advantages of ball jet drilling include simplicity of drill construction, absence of necessity in the bit rotation and creation of axial load on it. Destruction of rocks by ball strikes can occur in a variety of modes, the most effective of which is the optimal (volumetric), accompanied by the formation of a large chipping funnel. The aim of this work is to develop methods for calculating ball jet drilling processes in the optimal mode of rock destruction.

Method of calculation is based on the results obtained by the authors of theoretical and experimental studies, as well as some provisions of the predecessors. It allows us to determine the optimal geometric parameters of the drilling units, rational technological parameters of drilling mode, and also to make the choice of pumping equipment for specific geological and technical conditions. In the proposed calculation method the values of the washing liquid flow are limited in the presence of intervals intent to erosion of the borehole walls, the ejection rate of the jet device and the pressure drop on the nozzle to prevent its intense wear at the expiration of the drilling fluid.

Keywords: destruction of rocks, rock destruction tool, ball jet drilling, ball jet - ejector drilling unit, jet device, solid rocks.

DOI: 10.18599/grs.18.2.5

For citation: Kovalyov A.V., Ryabchikov S.Ya., Gorbenko V.M., Gorbenko M.V., Saruev L.A. Calculation of Ball Jet Drilling Processes in the Optimal Mode of Rock Destruction. *Georesursy = Georesources*. 2016. V. 18. No. 2. Pp. 102-106. DOI: 10.18599/grs.18.2.5

Introduction

Analysis of technical and economic indicators of drilling exploration, water intake, explosive and technical wells in solid rocks indicate on insufficiently high rate of penetration and headway per bit. Increasing the efficiency of the mechanical drilling in solid rocks can be implemented in two ways: creation of new materials and new structures of rock cutting tools.

Despite the constant improvement of rock cutting tool, drilling by mechanical means in the solid rock is not sufficiently effective. Therefore, it is important to develop alternative methods of rock destruction. According to some researchers (Davidenko, Ignatov, 2013; Kovalev et al., 2015; Kozhevnikov, Davidenko, 1987) one of the most promising methods is the hydrodynamic method implemented by a high-speed jet. By this way it is possible to pass a significant hydraulic power on the bottomhole, while the speed of drilling and headway of the bit can increase multiple times.

However, the method in its conventional form is not promising for drilling in solid rocks. Ball jet method of drilling is of great interest, the essence of which consists in the destruction of rocks at the bottomhole as a result of the impact of steel or carbide balls moving at high speed and continuously circulating in the well bottom zone due to the jet device. This method allows us to solve a number of technical and technological problems in the implementation of the hydrodynamic method of rocks destruction.

Fig. 1 shows a schematic all jet-ejector drilling unit, developed at the Department of drilling wells of the National Research Tomsk Polytechnic University (Kovalyov et al., 2015). Its working principle is as follows: the working fluid supplied through the supply chamber 1 is accelerated in the nozzle 2 and flows therefrom into the mixing chamber 5. In the space surrounding the nozzle exit 2 from the outside, discharge zone is formed. The unit body has inlet ports 4, through which due to discharge, working fluid is sucked with suspended balls from the annulus. Next, the two-phase mixture passes through the mixing chamber 5 and the diffuser 6, followed by hitting the rock, causing its destruction. Delay device 3 is intended to guide the ascending annular cutters balls into the inlet window and to center the drill in the borehole.

The main advantages of ball jet drilling by units of described design are:

- Design simplicity of ball jet-ejector drilling unit;
- There is no need in the rotation of the bit and creating axial load.

Analysis of papers devoted to destruction of solid rock using ball jet-ejector drilling unit indicates that this method may be more effective than the conventional ones. Results of trial application of the drilling method (Uvakov, 1969; Strasser, 1966; Zaurbekov, 1995) show that when drilling rocks of VIII drillability category and above, the value of penetration rates increases compared to using a conventional cutter tool. Industrial trials performed by Zaurbekov S.A. have shown excess mechanical speed of oil well drilling with diameter of 215.9 mm by 20%, headway per bit by 43% in comparison with the rock bits (Zaurbekov, 1995).

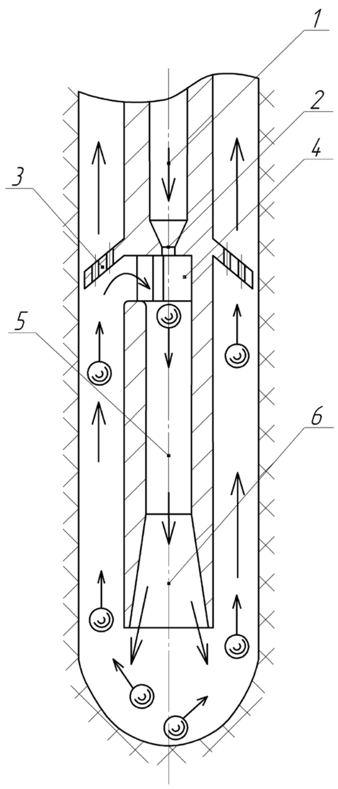

Fig. 1. Structural scheme of ball jet-ejector drilling unit: 1 – chamber supplying a working fluid; 2 – nozzle; 3 – delay device; 4 – inlet windows; 5 – mixing chamber; 6 – diffuser.

Modes of rock destruction

According to the results of theoretical and experimental studies (Uvakov, 1969; Shtrasser, 1966) the destruction of rocks by the impact of steel or carbide balls may occur in different conditions. Rock destruction mode is determined by the contact pressure at the ball interaction with the breed, which depends on the speed of collision.

Fig. 2 shows the modes of rock destruction by hitting balls. Area 1 characterizes rock surface abrasion mode. The relationship between the rate of drilling and magnitude of contact pressure is linear. When the contact pressure exceeds the limit of rock fatigue, destruction process is fatigue. At the same time the growth rate of the drilling speed is higher than

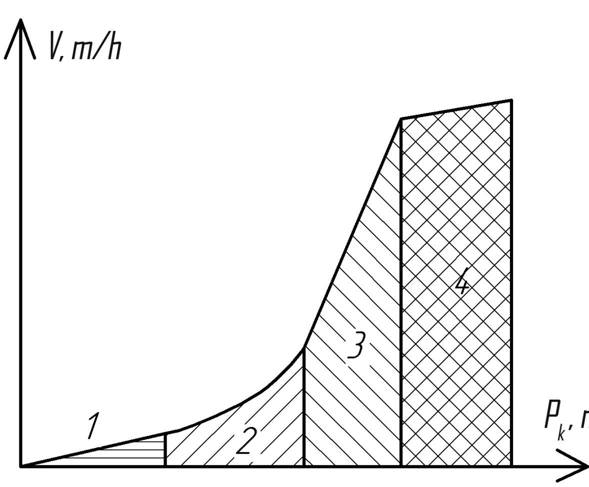

Fig. 2. Modes of rock destruction by hitting balls: 1 – mode of surface abrasion; 2 – fatigue mode of destruction; 3 – initial stage of optimal destruction; 4 – optimal destruction.

the growth rate of contact pressure (area 2). Upon reaching the contact stresses of rock hardness values, effective destruction begins. The dependence of the penetration rate of the contact pressure again becomes linear (area 3), rock destruction mode is close to the optimum – the ball hitting process culminates in the formation of large cleavage along the contour. At the optimum destruction mode (area 4) contact pressures are as sufficient to implement the first jump in the destruction with the formation of a large funnel of chipping. A further increase in contact pressure does not significantly increase rate of penetration (Uvakov, 1969).

Development of the calculation method of technological processes in an optimum mode of rocks destruction

The purpose of this paper is to provide a method for calculating ball jet drilling processes in the optimal mode of rocks destruction at the bottomhole.

Presented below calculation method for ball jet drilling process in the optimal mode of rocks destruction determines the optimal geometric parameters of the drilling units, rational technological parameters of drilling mode, and also allows making a choice of pumping equipment for specific geotechnical drilling conditions.

The proposed method of calculation is based on the results obtained by the authors from theoretical and experimental studies (Isaev et al., 2014; Kovalev et al., 2015; Konstantinov

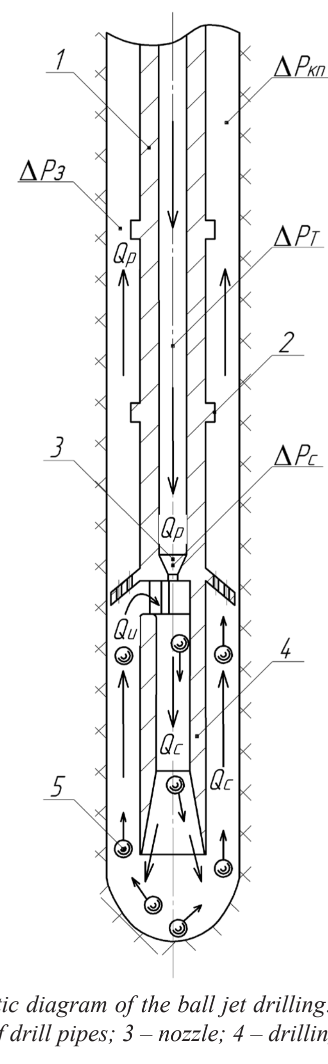

Fig. 3. Schematic diagram of the ball jet drilling: 1 – drill string; 2 – interlocks of drill pipes; 3 – nozzle; 4 – drilling unit; 5 – balls.

et al., 2015), as well as certain provisions of the A.B. Uvakov, V.V. Strasser, L.V. Ledgerwood, etc. (Ledgerwood, 1961; Uvakov, 1969; Strasser, 1966).

The concept of ball jet drilling method is shown in Fig. 3.

Initial data for calculation are as follows: rock properties (dynamic hardness P_c, modulus of elasticity E_1, Poisson's ratio μ_1); well parameters (diameter $D_{скв}$, maximum drilling depth $L_{скв max}$); drilling fluid properties (density $\rho_{бр}$, dynamic shear stress τ_0, dynamic viscosity η), geometric parameters of the drill pipe column (outer $d_н$ and inner $d_в$ diameter of drill pipe, outer diameter of interlock $d_з$, average length of drill pipe $l_{1Т}$); 5. Properties of rock destructing balls (density $\rho_ш$, modulus of elasticity E_2, Poisson's ratio μ_2).

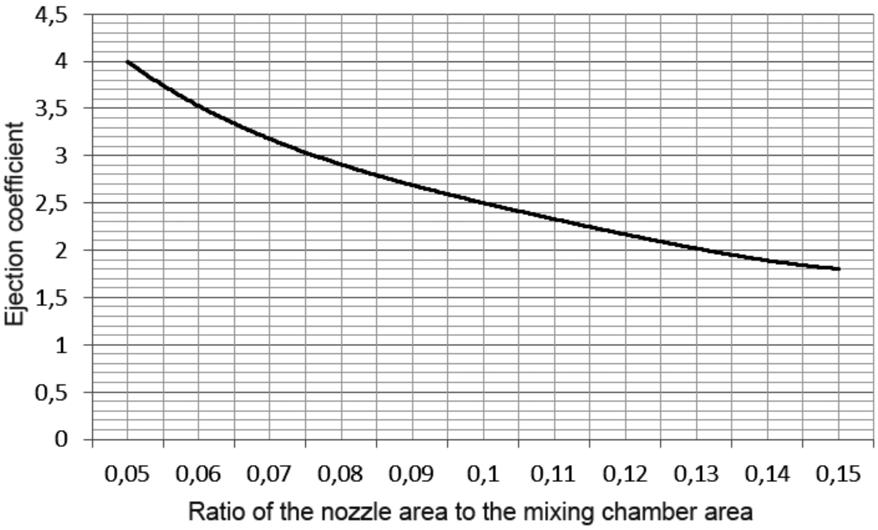

Fig. 4. Dependence of the ejection coefficient and the ratio of the nozzle area to the mixing chamber area (Eckel et al., 1956).

The sequence of engineering calculation of ball jet drilling in the optimal mode of rocks destruction is as follows.

1. Determine the rational diameter of the balls

$$d_ш = \frac{D_{скв}}{6,6}. \quad (1)$$

2. Calculate the diameter and area of the mixing chamber section

$$d_{кс} = 2,2 d_ш, \quad (2)$$

$$S_{КС} = \frac{\pi d_{кс}^2}{4}. \quad (3)$$

3. Calculate the outer diameter of the drilling unit

$$d_{бсн} = D_{скв} - 2,2 d_ш. \quad (4)$$

4. Determine the length of the mixing chamber

$$l_{кс} = 8 d_{кс}. \quad (5)$$

5. Calculate the height of technological windows

$$h_{то} = 1,25 d_ш. \quad (6)$$

6. Calculate the optimum mass portions of balls

$$m_ш = m_{1ш} \cdot N_ш = \frac{\rho_ш \pi d_ш^3 N_ш}{6}, \quad (7)$$

where $N_ш$ – number of rising balls in the annulus, calculated according to the formula:

$$N_ш = \frac{l_{бс}}{d_ш C_1} \cdot \frac{\pi (d_{бс} + D_{скв})}{2 d_ш C_2}, \quad (8)$$

where C_1 – coefficient taking into account the gap between the rows of balls C_1 = 1.5; C – coefficient taking into account the gap between the rows of balls C_2 = 1.5.

Equations (1) – (8) were obtained based on the results of studies conducted by the authors.

7. Determine the velocity of the balls necessary for breaking rock in the optimal mode (Uvakov, 1969; Strasser, 1966):

$$v_{опт} = 2,15 \cdot \left(\frac{4(1-\mu_1^2)}{E_1} + \frac{4(1-\mu_2^2)}{E_2}\right)^2 \cdot \sqrt{\frac{g P_c^5}{\rho_ш d_ш^3 \left(\frac{4}{d_ш} - \frac{4}{0,78 D_{скв}}\right)^2}} \quad (9)$$

8. When penetrating wells at intervals tend to erosion, calculate the maximum possible flow of drilling Q_{pmax}:

$$Q_{p\max} = S_{сквбт} v_{кп\max}, \quad (10)$$

where $S_{сквбт}$ – sectional area of the annulus between the drill pipes and well walls; $V_{кпmax}$ – maximum allowable speed of fluid flow in the annulus, which is equal to 1.5 m/s.

9. According to the technical characteristics of the mud pump, flow rate Q_p is selected, the value of which must be less than the maximum possible flow rate Q_{pmax}.

10. The magnitude of the required average velocity of washing liquid in the drilling unit is defined by the formula:

$$V_{бс} = V_{опт} / \varepsilon, \quad (11)$$

where ε – the ratio of ball speed to the fluid velocity in the drilling unit, taken as equal to 0.7 (Eckel et al., 1956).

11. Determine the desired ejection rate:

$$n = \frac{S_{кс} v_{бс}}{Q_p} - 1. \quad (12)$$

12. Verify that the balls rise in the gap between the bit and the well wall, i.e. compare the velocity of the fluid in its flow between the drilling unit and the well wall with balls falling at a rate of transitional and turbulent flow regimes of balls, calculated according to the formula of Rittinger:

$$v_{кп} = \frac{Q_c}{S_{кcвбс}} = \frac{4(1+n)Q_p}{\pi (D_{скв}^2 - d_{бс}^2)} \geq 5,11 \sqrt{\frac{d_ш (\rho_ш - \rho_{бр})}{\rho_{бр}}}. \quad (13)$$

13. According to the dependence scheme of ejection coefficient and the ratio of ejection nozzle area to the area of mixing chamber (Fig. 4) with a constant diameter of the mixing chamber, the desired ratio of $\alpha = S_c/S_{кс}$ is determined.

It is found that the values of the ejection rate in the range from 2 to 4 are the most suitable. In case of its excess, sludge removal is deteriorating, thereby reducing the efficiency of the jet device, and additional energy is expended on its grinding.

14. Determine the diameter and cross-sectional area of the nozzle outlet (

$$S_c = \alpha \cdot S_{кс}, \quad (14)$$

$$d_c = \sqrt{\frac{4 \cdot S_{кс} \cdot \alpha}{\pi}}. \quad (15)$$

15. The pressure drop in the nozzle is calculated by the formula (Popov et al., 2003)

$$\Delta P_c = \frac{Q_р^2 \cdot \rho_{бр}}{\gamma^2 \cdot 2 \cdot S_c^2}, \tag{16}$$

where γ – nozzle discharge coefficient, for conoidal nozzles equal to 0.985.

According to (Kirsanov et al., 1981; Popov et al., 2003) calculated pressure drop in the nozzle should not exceed 13 MPa for preventing intensive nozzle wear for flow of drilling mud.

16. According to well-known techniques, pressure loss is calculated in the circulation system $\Sigma(\Delta P_i)$

$$\sum(\Delta P_i) = \Delta P_T + \Delta P_{КП} + \Delta P_З, \tag{17}$$

where $\Delta P_Т$ – pressure losses in the drill column, $\Delta P_{КП}$ – pressure losses in the annulus, $\Delta P_з$– pressure drop in the gap between the interlock and the well wall.

Due to the low values do not take into account the loss of pressure in the circulation system of the following elements: the riser, the drilling arm, swivel, lead pipe and drill delay device.

17. Based on the values of $Q_р$, ΔP_c, $\Sigma(\Delta P_i)$ the parameters of the mud pump are selected. It should be guided by the following conditions:

$$Q_H \geq Q, \tag{18}$$

$$kP_H > \sum(\Delta P_i) + \Delta P_C, \tag{19}$$

where $Q_н$ and $P_н$ – flow and pressure developed of one or more drill pumps; k – coefficient taking into account the fact that operating pressure of the mud pump discharge should be, according to the rules of drilling operations, fewer the rated pressure by 20-30 %, k = 0.7-0.8 (Popov et al., 2003).

Conclusions

The following conclusions can be drawn on the results of the work conducted.

1. The calculation method of ball jet drilling at an optimum mode of rocks destruction at the bottom is calculated, which allows us to determine the optimal geometric parameters of the drilling units, rational technological parameters of drilling mode, and also to make the choice of pumping equipment for specific geological and technical conditions.

2. In the proposed calculation method of ball jet drilling following restrictions must be considered:

- In the penetration of wells at intervals tend to erosion it is necessary to limit the upward flow rate through the introduction of the limit values of the washing liquid flow;

- To improve cuttings transport conditions, drilling units should be designed with the ejection ratio of not more than 4;

- Calculated pressure drop in the nozzle should not be more than 13 MPa for preventing intensive nozzle wear for flow of drilling mud.

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Manuscript received February 25, 2016