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# METHOD OF DRILLING REGIME PARAMETERS SEARCH UNDER CERTAIN GEOTECHNICAL CONDITIONS

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In practice, in the geological cutting of the same well, a sequence of rocks with different physical and mechanical properties can be found, which makes it impossible to drill all the rocks with the same crown bit at high speed. Besides, the crown bit wears quickly because of inadequacy of rocks, and the frequent change of the bits, according to the rocks, leads to the increase of the time spent on additional actions, to the decrease of the work productivity, and the increase in the prime cost of 1m of well drilling. Thus, it can be concluded that in frequently alternating rocks with different physical and mechanical properties, the efficiency of well drilling can be improved based on the comparative analysis of the maintenance indices of diamond rock-breaking tools.

In this paper, based on the investigation of impregnated diamond bit labour capacity indices applied under certain geological and technical conditions, a method of searching for optimal values of the drilling regime parameters of wells with high indices of rock destruction tools is proposed.

In the course of studies, the impregnated diamond bits produced in the RF, and by the leading world-famous western companies (like AtlasCopco, Dimatec, Boart Longyear, Fordia, HARDCORE and Global Getech) have been investigated

To search for the rational values of the well-drilling condition main parameters, theoretical calculations and time-dimensional records have been carried out. As a result of this, it has become possible to increase the maintenance indices of diamond rock-destruction tool by changing the axial load and the rotational speeds of the drill bit.

***Keywords:*** impregnated diamond bit, wear rate, drilling condition parameters, mining and geological conditions, rock.

***Introduction***. In the sphere of exploration drilling, the progress can be implemented in a number of directions, the most modern of which is the intensification of the diamond drilling process under complicated geological and technical conditions. The peculiarity of introducing diamond drilling is conditioned by a great variety of geological and technical conditions characterized by frequent alternation of rocks with both hard abrasive and comparatively low mechanical indices.

In such geological and technical sections, the drilling profitability is mainly determined by the rock destruction tool maintenance indices depending on the structural parameters and the corresponding technological regime [1, 2].

***The goal of the work*** is to improve the efficiency of drilling wells with diamond rock destruction tools. To achieve the mentioned goal, the following problems have been solved:

- revealing the interactions of the main structural and drilling technological parameters of impregnated diamond (ID) bits based on the drilling indices of rocks with different physicomechanical properties;
- revealing the connection between the wear rate of ID bits and the rate of the washing solution;
- decreasing the unnecessary expenditure of different reagents and additives included in the washing solution and its composition and the overloaded operation of the pump.

The results of various investigations carried out in the deposits of Teghut, Amulsar and Hankasar in Republic of Armenia are noteworthy as under the production conditions, drilling rigs and drill bits produced by advanced companies (AtlasCopco, BoartLongyear, Fordia, HardCore and Global Geotech) which have found a wide application all over the world have been applied and studied, which makes the present work universal.

At additional exploration of the Teghut copper-molybdenum deposit (Lori Marz, Armenia), the wells were drilled by Atlas Copco U6 and Cristensen P4 and P6 drilling rigs and the ID bits from SC5-7 up to CS SC 10, KM-3 and Hobic 03-7AC, as by 09-ID diamond bits as well produced by Global Geotech in the rocks of the VIII-IX drillability group.

The drilling was mainly carried out by applying removable extraction receiving borehole tools with N and H diameter ID bits.

The drill bit matrices have been chosen based on the guarantees of the producing organization and the production experience of the drillers.

The parameters of the drilling condition are shown in the range of the values introduced in Table 1.

*Table 1*

*The parameters of the well drilling condition at additional exploration in the Teghut copper-molybdenum deposit*

| Parameters of the condition | Parameters of the drill bit | |
|---|---|---|
| | N (75,6 *mm*) | H (96,1 *mm*) |
| Axial load, *kN* | 7,5...15 | 25...30 |
| Rotational speed, *rot/min* | 400...800 | 300...700 |
| Expenditure of the washing solution *l/min* | 25...30 | 35...40 |

To estimate the optimal values of the drilling condition parameters accurately, drill bits of the grade 09-ID, 03-7AC, KM-3 and of diameter of N and H have been tested in the diorite–porphyrite rocks of the supergene zone. During the tests, the amount of the washing solution was maintained in the range of respectively 28…30 and 31…40 *l/min*.

The axial load on the H-diameter drill bit has been changed in the range of 25… 30 *kN*, while in case of N-diameter – in the range of 7,5…15, by a step of 1,5…2 *kN*. The rotational speeds have respectively altered in the range of 400…800 *rot/min* in case of diameter N, and 300…700 *rot/min* in case of diameter H. In the Hankasar copper-molybdenum deposit (Syunik Marz, Armenia) the averaged values of the gabbro, gabbro-diorite and diorite-porphyrite rock drillability fluctuates in the following range:

- the dynamic strength: $F_d = 4{,}08\ldots10{,}5$;
- the abrasion factor: $K_{abr} = 1{,}08\ldots2{,}7$;
- the generalized coefficient of drillability: $\rho_g = 22\ldots34$;
- the average class of the drillability: 8,9.

At drilling, N-diameter ID bits produced by Atlas AtlasCopco SC6 8/4, SC6-8/3, Fordia HERO 7 and HARD CORE 9W have been used.

In the rocks mentioned above, the data obtained on the drilled wells have served as a basis for statistical analysis.

The front view of the tested drill bits (34 pieces) is w-form, the diamond granulation – 20/25 or 30/35 *piece/carat*, the washing paths – 10, the width for AtlasCopco SC6-8/4 and Fordia HERO 7- 3,175 *mm*, AtlasCopco SC6-8/3-4,775 *mm*, the shape-standard, HARD CORE 9W -4,6 *mm* – wedge-shaped respectively.

In the Hankasar copper-molybdenum deposit, the main parameters of the condition at drilling N-diameter wells have altered in the following range:

- the axial load: 4...18 *kN*;
- the rotational speed: 275...700 *rot/min.*

while the amount of the washing solution has been kept in the guaranteed limits.

***The investigation method.*** The ID bits have a number of structural elements which are selected based on concrete geological and technical conditions and the physicomechanical properties of rocks. The rational sphere for the drill bit application is selected taking into account the granulation of its “volume” and “cutting” diamonds, the diamond-containing matrix wear resistance, the scheme of the diamond arrangement, the saturation with diamonds, the front part view, the washing system, etc [3-7]. The next step is the accurate selection of the drilling condition parameters as a result of which, high indices of drilling can be ensured including the increase in the mechanical velocity; the decrease in the specific expenditure of diamonds; the increase in the progress on the drill bit, the decrease in the value of drilling 1*m*.

The insufficient resource of rock-destruction tools and the absence of coordination of the drilling condition parameters restrict the productivity growth of the drilling operations and the prime cost reduction. It is obvious that under the same geological and technical conditions, the drilling rational regimes by drill bits of different wear-resistance ought to be different. For estimating the rational technological parameters, the following directions have been considered as a basis:

- the criterion of the maximal movement velocity taking into account the geological and technical conditions and the maintenance indices of the rock-destruction tool;
- the search for the rational values of the axial load and the rotational speed on the rock-destruction tool ensuring the maximum mechanical velocity for the well drilling in concrete rocks.

To ensure the maximal movement velocity, the increase of the borehole tool rotational speed is a condition, but which is limited by the technical abilities of the rock-destruction tool and drilling equipment (maintenance indices). It is also known that at carrying out any operation, reduction even several times does not lead to the essential rise in productivity [8]. Consequently, more perspective can be regarded at which, an increase in the main criteria (movement progress, mechanical velocity, rock-destruction tool wear resistance, the reduction of the time spent on the auxiliary operations, etc) will be ensured.

Among the mentioned criteria, the most significant ones are the mechanical velocity of drilling and the rock-destruction tool durability. The first criterion is mainly determined by the parameters of the drilling condition (axial load and rotational speed), the second – by the structural parameters and wear-resistance of the applied rock-destruction tool.

So, the parameters of the drilling condition should be selected so that the intensities of the matrix and diamond wear should be approximately equal. To ensure the mentioned condition, in case of concrete geological and technical conditions, it is necessary to have a great amount of statistical data, whose elaboration will ensure high reliability.

Drill bits have been tested in the Hankasar copper-molybdenum deposit. In Fig. 1, the dependence of the wear rate by the height of the ID bits on the matrix front width is illustrated.

The wear rate ($\gamma$) [9] has been determined by the following formula:

$$\gamma = \kappa G^{m} \mathrm{v}_{l}^{a} v_{i}^{a} ,$$

where K is the coefficient of proportionality; G – the contact pressure; $v_i$ - the linear velocity of the drill bit rotation.

Based on the abovementioned formula, the dependence of the drilling mechanical velocity on the axial load (P) and rotational speed (n) has been chosen as a planned function of the experiment. By inserting P and n into the coordinate system and combining the same values of wear rate, the optimal range of regime parameters is determined as a result of the change in the drilling condition parameters. In that range, the maximum value of the mechanical velocity with the minimum wear rate of the drill bit is ensured.

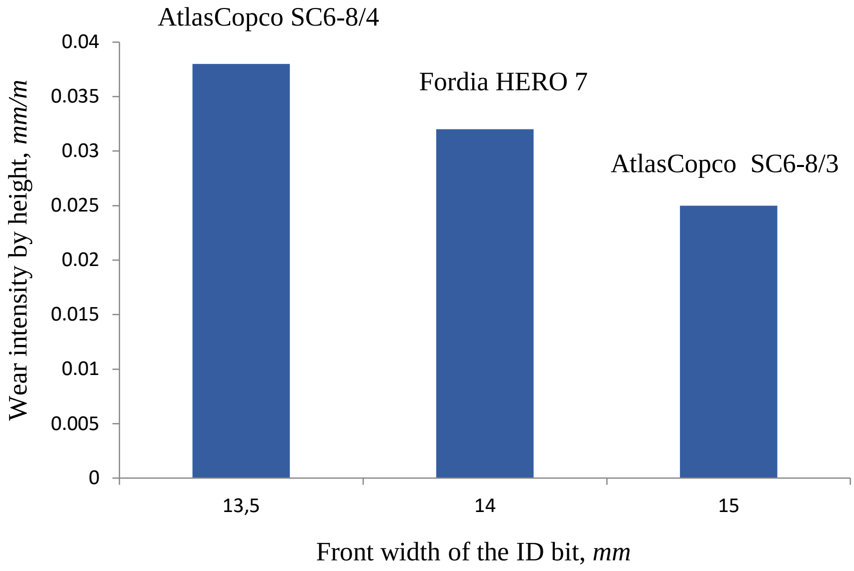


*Fig. 1. The dependence of the wear rate by height of the ID bits on the front width*

***The investigation results.*** Since diamond drilling is implemented by high rotational speeds, the washing solution amount injected into the bore cavity is not always able to clean the formed slime. And the remaining slime in the contact area of the bore cavity-drill bit undergoes further destruction, subjecting both the drill bit front part and the washing paths to abrasive wear.

In strongly cracked secondary quarzites (class IX of borability), HARD CORE 9W PQ (Fig. 2-1) h=10 *mm*, l=5 *mm*, n=12 (the number of washing paths)), the drill bit, after drilling 92 *m* was worn by 7 *mm*. Therefore, the wear rate was 0,076 *mm/m*. In this case, the drilling condition parameters were in the following range: the rotational speeds – 360…500 *rot/min*, the axial load – 15…20 *kN*, and the amount of washing solution – 40 *l/min*. While in very strong cracked sulphites (class IX of borability), the Fordia HERO$^{TM}$ 7 HQ (Fig. 2-2) (h=13 *mm*, l=4,77 *mm*, n=10 (the number of washing paths)) drill bit, wearing out completely, drilled 435 *m*. The drilling condition parameters were in the following range: the rotational speeds – 700 *rot/min*, the axial load – 15…22 *kN*, and the amount of washing solution – 45 *l/min*.

In the drill bit washing paths, by the graph of the liquid flow velocity (V) and the path height (h) dependence (Fig. 2), it can be clearly seen that in case of the height of 7 *mm*, the wear-out is comparatively negligible (from 1,19 *m* to 1,94 *m/sec*), then it can grow sharply reaching 4,28 *m/sec*. This is proved by the wear rates (in the case of HARDCORE 9W i=0,076; in the case of Fordia HERO$^{TM}$ 7 i=0,03; and in the case of 02И3 (ВК6+Cu) i=0,52). Consequently, to avoid the hydroabrasive wear, in the case of monolith rocks, it is desirable to keep the flow rate in the washing paths in the limits of 4,05 *m/sec*.

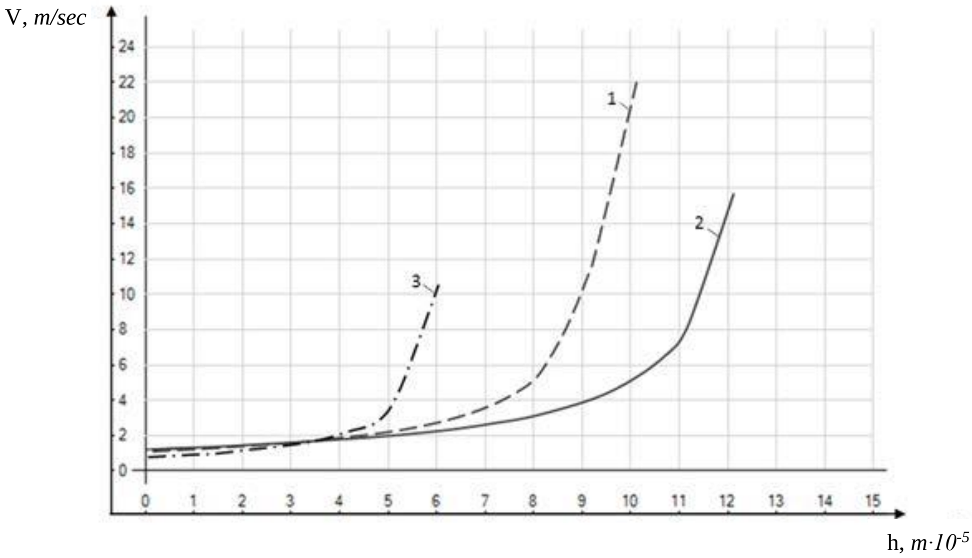


*Fig. 2. Alteration of the flow rate (V) of the washing solution in the washing paths of the drill bit depending on the height (h) of the washing path, the drill bit wear rate $i$ -wear rate of the drill bit mm/m, 1- HARDCORE 9W $i$=0,076, 2 - Fordia $HERO^{TM}$ 7 $i$=0,03, 3 - 02И3 (ВК6+Cu) $i$=0,52*

The dependence of the drilling mechanical velocity $(V_m)$ on the number of rotations of the borehole tool by 09-ID ID bits during the drilling of diorite-porphyrites (drillability group VIII-IX) under different axial loads (P) (maintaining the amount of the washing solution in the range of 20...30 *l/min*) is introduced in Fig. 3.

The analysis of the mentioned dependence shows that in the given range of changing the regime parameters, by increasing the axial load within 26…28 *kN*, the drilling mechanical velocity first increases directly proportional to the axial load and in case of a further increase, the growth rate of the mechanical velocity is observed which is continued even in case of increasing the number of rotations.

Based on the given data of the production testing, the relation of the drilling mechanical velocity ($V_m$) to the axial load *(P)* is expressed by the following pilot formula:

$$V_m = 2{,}3447 \cdot e^{0{,}002n}$$

whose approximation coefficient of reliability is` $R^2$ = 0,8272.

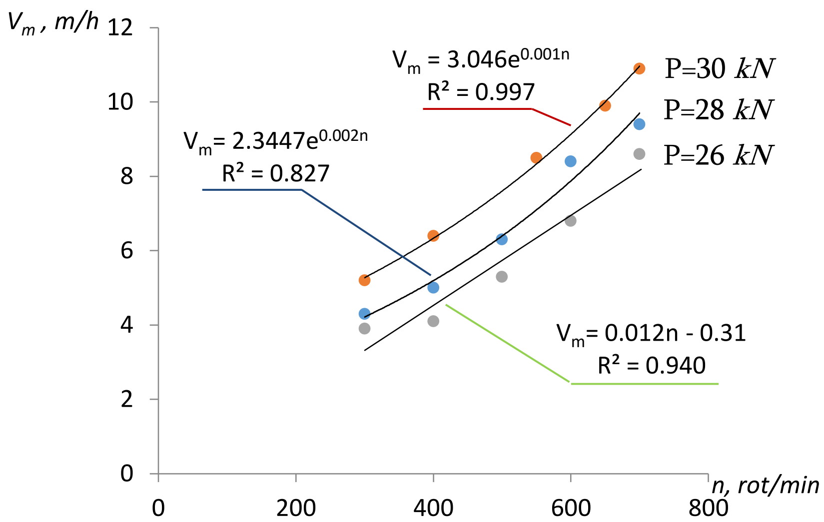


*Fig. 3. Dependence of the drilling mechanical velocity ($V_m$) on the number of rotations of the borehole tool (n): ID bits - 09-ID H (96,1 mm), rock - diorite-porphyrite, drillability group -VIII-IX*

The analysis of the obtained data shows that for the maximum mechanical speed, along with increasing the number of rotations, it is necessary to increase also the axial load up to a certain limit. In case of the abovementioned example, to provide the maximum mechanical velocity of $V_m = 10\ m/h$, in case of the borehole tool rate of 800 *rot/min*, the axial load should be increased up to 30 *kN*.

In Fig. 4, the relation of the drilling mechanical velocity ($V_m$) to the axial load ($P$) is introduced. All measurements show that with the increase of the axial load, a growth of the mechanical velocity up to a certain limit is observed.

Let us use the following method [7] to obtain the response surface of the drilling mechanical velocity. For convenience, the response surface of the drilling mechanical velocity is presented in the form of a topographic plan (Fig. 5). In the *P* and *n* coordinate system, the known values of *Vm* are noted (for both P and n technological parameters): The points of equal mechanical velocities are connected by the isolines. As a result of building the isolines, we receive a response surface whose top point value corresponds to the maximum value of the mechanical velocity. In this case, the maximum value of the top point of response surface is 6,1 *m/h*.

The revelation of the optimal combination of the axial load (P) and the rotation number (n) (18 *kN* and 780 *rot/min* respectively) ensures the maximum mechanical velocity (6,1 *m/h*). From the dependence introduced in Fig. 5 it can be seen that if the axial load in the given conditions exceeds the critical value of 18 *kN*, the sludging of the front part of the diamond drill bit takes place preventing from the introduction of the diamonds into the rocks. On the other hand, because of the sludging, the matrix wear is intensified leading to great exposure of the diamond thus reducing their durability.

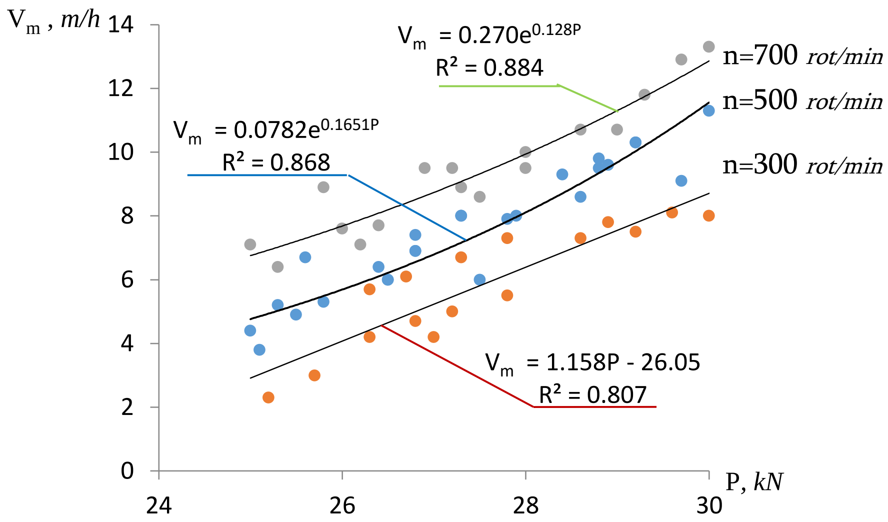


*Fig. 4. Dependence of the drilling mechanical velocity ($V_m$) on the axial load (P) diamond drill bit - KM-3, H (96,1 mm), rock – porphyrites, drillability group V-VII*

At drilling with the diamond drill bit, the mechanical velocity greatly depends on the rotation frequency as well. As a result of the production testing conducted by us, it was confirmed that the drilling mechanical speed up to 800 *rot/min* is directly proportional to the rotation frequency. This method enables to determine the optimal values of the axial load and the rotation frequency for concrete rocks and ID bits of concrete structure by using the maximum drilling mechanical speed values (the average values of the drilling mechanical speed).

By comparing the values of the drilling mechanical speeds and wear intensities in case of the same velocities of the regime, we come to the conclusion that it is profitable to apply those ID bits, which can provide the maximum mechanical speed with minimum wear values at the given drilling regime. Accepting the ratio of the drilling mechanical speed ($V_m$) and the wear intensity ($i$) an efficiency criterion of the diamond drill bit operation, we can consider the results introduced in Table 2.

Comparing the matrix width of the ID bits, as well as the drilling mechanical speeds and the wear intensities in case of the respective parameters of the regime, it becomes evident that it is more profitable to drill with the ID bits SC6-8/3 produced by AtlasCopco company.

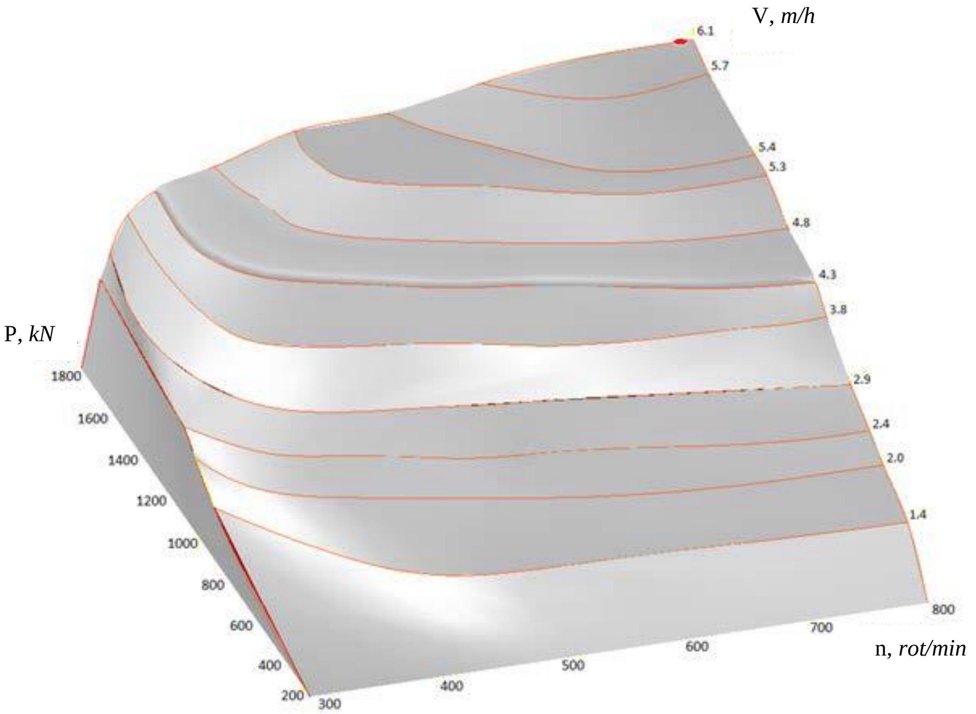


*Fig. 5. The dependence of the drilling mechanical speed ($V_m$) on the axial load (P) and the rotation frequency of the borehole tool (n): type of diamond drill bit - AtlasCopco CBT CF SC6-8/4, diameter - N, average drillability group of the rocks - 8,9, amount of washing solution – 30…40 l/min*

*Table 2*

*The relations of the drilling mechanical speeds(V m/h) and the wear intensity (i mm/m) of the ID bits under different axial loads*

| The brand of the diamond drill bit | V/i for different axial loads , *kN* | | | |
|---|---|---|---|---|
| | 6 | 10 | 14 | 18 |
| AtlasCopco SC6-8/4 | 2,1/0,043 | 3,9/0,045 | 4,95/0,0484 | 5/0,0538 |
| AtlasCopco SC6-8/3 | 1,9/0,022 | 3,71/0,025 | 4,8/0,0293 | 5,2/0,0347 |
| Fordia HERO 7 | 1,8/0,031 | 3,42/0,0324 | 4,6/0,0362 | 5,1/0,0421 |
| HARD CORE 9w | 2,3/0,069 | 4/0,073 | 5,1/0,0772 | 5,4/0,0816 |

The results of the abovementioned studies can be used by the production and design companies to develop the drilling technology of exploring the wells and selecting the rock-destruction tools.

***Main conclusions***

1. Increasing the efficincy of the rock-destruction tool allows to reduce the time spent on the non-production procedures, to increase the labor process continuity, and to reduce material and energy costs.

2. Based on the analysis of the experimental data, the boundary values of the axial loads and rotation frequency at drilling in cracked rocks are substantiated considering the condition P·n=const.

3. Based on the experimental investigations, the quantitative evaluation method for the rational combination of the axial load and borehole tool rotation frequency providing the maximum mechanical velocity is determined using the indicial function $V_m = a \cdot e^{bP(n)}$.

4. To increase the efficiency of the well drilling, the combination of the technologically rational regime parameters (axial load and rotation frequency) under the concrete geological-technical conditions is determined by applying target function (response surface) method and taking into account the parameters of the diamond drill bit.

5. During the experimental-practical investigations carried out in Kashen copper deposit, it was revealed that the ID bits KM-3, Hobic 03-7AC (matrix hardness - HRC 20…25) produced by AtlasCopco company provide higher drilling mechanical speed, than the ID bits produccd by AtlasCopcoSC-8-3/9 and Global Getech 09-ID (HRC 30…35) conditioned by the hardness of matrices and the physical and mechanical properties of the rocks.

6. As a result of analysing the scientific-experimental data obtained in the Hankasar copper-molybdenum deposit, it is revealed that in the cracked gabbro, gabbro-diorites and diorite –porphirites, the wear intensity of the AtlasCopco CBT CF SC6-8/4, N-diameter diamond drill bit matrix within the limits of the same axial load (14…16 *kN*) intensely increases along with the increase in the rotation frequency (in case of 300…500 *rot/min*, the wear intensity is 0,033 *mm/m*, while in case of 600…800 *rot/min* - 0,064 *mm/m*).

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## ՀՈՐԱՏՄԱՆ ՌԵԺԻՄԻ ՊԱՐԱՄԵՏՐԵՐԻ ՈՐՈՆՄԱՆ ՄԵԹՈԴԸ ԿՈՆԿՐԵՏ ԵՐԿՐԱԲԱՆԱՏԵԽՆԻԿԱԿԱՆ ՊԱՅՄԱՆՆԵՐՈՒՄ

**Ռ.Ջ. Հակոբյան, Վ.Ս. Հովհաննիսյան**

Գործնականում միևնույն հորատանցքի երկրաբանական կտրվածքում հաճախ նկատվում է տարբեր ֆիզիկամեխանիկական հատկություններով ապարների հերթագայում, ինչը հնարավորություն չի տալիս միևնույն թագագլխիգկով հորատել բոլոր ապարները մեխանիկական բարձր արագությամբ, և բացի դրանից, տեղի է ունենում թագագլխիկի արագ մաշում անհամապատասխանության հետևանքով, իսկ թագագլխիկի հաճախակի փոփոխությունը, ելնելով ապարների փոփոխությունից, հանգեցնում է օժանդակ գործողությունների իրականացման վրա ծախսվող ժամանակի մեծացմանը և աշխատանքի արտադրողականության փոքրացմանն ու 1*մ* հորատման ինքնարժեքի մեծացմանը: Այսպիսով, կարելի է եզրակացնել, որ տարբեր ֆիզիկամեխանիկական հատկություններով և հաճախ հերթագայվող ապարներում հորատանցքի հորատման արդյունավետությունը կարելի է բարձրացնել՝ հիմնվելով ալմաստային ապարաքայքայիչ գործիքների շահագործման ցուցանիշների համեմատական վերլուծության վրա: Այս աշխատանքում, կոնկրետ երկրաբանատեխնիկական պայմաններում կիրառված իմպրեգնացված ալմաստային թագագլխիկների աշխատունակության ցուցանիշների ուսումնասի-րությունների հիման վրա, առաջարկվում է ապարաքայքայիչ գործիքների շահագործման բարձր ցուցանիշներով հորատանցքերի հորատման ռեժիմի պարամետրերի օպտիմալ արժեքների որոնման մեթոդիկա:

Հետազոտվել են ՌԴ-ում և ոլորտում համաշխարային ճանաչում ունեցող արևմտյան առաջատար ֆիրմաներում (ինչպիսիք են՝ AtlasCopco, Dimatec, Boart Longyear, Fordia, HARDCORE և Global Getech) արտադրվող ալմաստային թագագլխիկները:

Հորատանցքերի հորատման ռեժիմի հիմնական պարամետրերի ռացիոնալ արժեքների որոնման նպատակով կատարվել են տեսական հաշվարկներ և ժամանակաչափային գրառումներ: Արդյունքում՝ հնարավորություն է ընձեռվել ավելացնելու ալմաստային ապարաքայքայիչ գործիքի շահագործական ցուցանիշները՝ փոփոխելով առանցքային բեռնվածությունը և թագագլխիկի պտուտաթվերը:

***Առանցքային բառեր.*** իմպրեգնացված ալմաստե թագագլխիկ, մաշման ինտենսիվություն, հորատման ռեժիմի պարամետրեր, լեռնաերկրաբանական պայմաններ, ապար:

## МЕТОД ПОИСКА ПАРАМЕТРОВ РЕЖИМА БУРЕНИЯ В КОНКРЕТНЫХ ГЕОЛОГО-ТЕХНИЧЕСКИХ УСЛОВИЯХ

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На практике при бурении одной скважины часто наблюдается чередование пород с различными физико-механическими свойствами, что не дает возможность бурить все породы с высокой механической скоростью с использованием коронок одного типа. Кроме того, происходит быстрое изнашивание коронки, а частая замена породоразрушающих инструментов, исходя из чередования пород, приводит к увеличению затраты времени на вспомогательные работы, снижению производительности и повышению затрат на бурение 1 *м* скважины. Таким образом, основываясь на сравнительном анализе эксплуатационных показателей импрегнированных алмазных породоразрушающих инструментов, можем утверждать, что эффективность бурения скважины с различными физико-механическими свойствами и с чередующимися горными породами можно повысить. В процессе исследования были изучены алмазные коронки, производимые в РФ и всемирно известными в этой сфере западными лидирующими фирмами (например, AtlasCopso, Dimatec, Boart Longyear, Fordia, HARDCORE и Global Getech).

В статье на основе изучения показателей работоспособности алмазных коронок, применяемых в конкретных геолого-технических условиях, предлагается метод поиска оптимальных значений параметров режима бурения скважин с высокими эксплуатационными показателями породоразрушающих инструментов.

С целью поиска рационального значения основных параметров режима бурения скважин были выполнены теоретические расчеты и хронометражные записи. В итоге была предоставлена возможность увеличить эксплуатационные показатели алмазного породоразрушающего инструмента путем изменения осевой нагрузки и числа оборотов коронки.

***Ключевые слова*:** импрегнированная алмазная коронка, интенсивность износа, параметры режима бурения, геолого-технические условия, порода.