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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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INVESTIGATION OF THE INFLUENCE OF THE MODE PARAMETERS OF THE DRILLING WELLS ON THE BIT SPEED INDICATORS

Abstract. As is known, the prediction of the drilling speed indicators and the determination of the corresponding optimal parameters can be conducted on the basis of rock properties' indicators, and the classification of the geological section. In these cases, homogeneous groups are selected in turn, in each of which intervals are recorded in which bits of the same type are worked out.

According to the aforementioned sequence, in this study, the analysis was conducted, and the corresponding program was developed and implemented using specific examples. As an example of the initial data, previously drilled data in Kazakhstan, Azerbaijan, as well as at one of the fields of the Volga-Ural oil and gas region of wells, which were grouped for a homogeneous group of rocks were used. The provided materials represent the results of joint work of Kazakh and Azerbaijani scientists, implemented within the framework of scientific international cooperation programs.

According to the initially proposed algorithm, through the implementation of the "LOGGING" program, the characteristics of the geological section were calculated: lithology, porosity, permeability, hardness, continuity, abrasiveness, Poisson's ratio, pore pressure and fracture pressure gradients, optimal drilling mud density, and others. In order to compare the results of calculations, the results of Well Survey interpretation were also involved.

Due to the analysis of the change in the mechanical speed of the bit over time, a statistical model of the influence of mode parameters on the values of the initial speed and its rate of decline in time was built. A method is proposed for predicting the run speed, the cost of 1 m of penetration, as well as variant calculations and decision-making on the choice of optimal parameters.

Key words: mode parameters of drilling, rock properties, classification of the geological section, mechanical drilling speed, bit penetration.

Introduction. Currently, considerable experience has been accumulated in the application of actual material regarding the development of various types of drill bits in the construction of models of the drilling process. This is due to the fact that the performance indicators of the bit obtained during bench studies, as a rule, are not performed in real conditions of well drilling. Quite often, comparison of bench and field empirical dependencies illustrates their complete inconsistency with each other. This is due to the appearance of torsional vibrations, hovering of the drill string and other. Therefore, as the initial data for statistical analysis, the results of working bits in real conditions have recently begun to be selected, as has been done in numerous works of recent years [1-8].

The theoretical developments published in recent years have laid the scientific foundations for modeling the dynamic processes occurring in the drill string-bit-rock system. [9-14]. Much attention has been paid to the methods of artificial intelligence in optimizing drilling parameters [15, 16].

The main difficulty in constructing such models is associated with uncertainties in assessing the rock properties, the influence of mood parameters.

An analysis of existing work on optimization of drilling parameters illustrated that when controlling the mechanical process of drilling wells, criteria such as "maximum mechanical speed", "maximum run speed", "maximum penetration per bit" are often used, as well as the global criterion, which in the literature is called also integral, - "the minimum cost of 1 meter penetration" [11, 12, 13, 14].

Optimization is conducted according to the mechanical penetration rate criterion, using the objective function $V_m = k \cdot G^{\delta} \cdot n^{\alpha} \cdot N_d^{m} \rightarrow \max$. The second criterion is the "maximum run speed" criterion, for which the maximum possible speeds and acceleration of the drilling-tool trip for the layers are calculated. The criterion - "the minimum cost of 1 meter of penetration" is calculated as one of the indicators of the drilling process as a whole. In our opinion, in this case, it was possible to take the run speed calculated through the mechanical speed as one of the criteria, and the cost per meter of penetration as the second.

Materials and methods. Summarizing the above, the goal of this study was to make an attempt to plot the dependence of the run speed by analyzing the change in mechanical speed over time, analyzing the influence of various factors on the initial rate of penetration and the rate of decay of the mechanical speed, and when making decisions, the main provisions of the theory of fuzzy sets were applied.

For the analysis and forecasting of indicators, data was collected on the work of bits machined while drilling wells in the marked fields.

The following indicators were analyzed: penetration, mechanical speed, drilling time.

The penetration for other sizes of PDC type bits is in the range of 120÷2250 m, depending on the equipment and the drilling region [5-7].

Summarizing the data of all three samples, in accordance with the work [5], we note that the main reasons for the failure of PDC bits in the fields under consideration are:

- galling of teeth - 17%;
- breakage of teeth - 30%;
- spading of teeth -31%;
- tripping of teeth -3%,
- no galling - in 19% cases.

Results. To build the dependences of the rate of penetration on the mode parameters and rock properties, the data on the noted deposits of Kazakhstan and Azerbaijan were analyzed. For the Aktum and Kokmay deposits of Kazakhstan, the processing was conducted according to the usual data of working bits.

As a result of statistical analysis, by means of appropriate transformations, linear models were built, for which the variables are presented in logarithms and transformed into a multiplicative form. At the same time, the following dependencies were obtained, the parameters of which were refined during the processing by the random search method:

- for three-cone bits of Russian production, machined at the Kokmay field (Kazakhstan):

$$V_m = 2,0592 \frac{\left(\frac{G}{d}\right)^{0,18989} \cdot Q^{1,790249} \cdot A^{0,232049}}{n^{0,526293} \cdot p_{ш}^{0,434253}} \quad (1)$$

and the Karamandybas deposit (Kazakhstan):

$$V_m = 542,211 \frac{\left(\frac{G}{d}\right)^{0,2522}}{p_{ш}^{0,3391} A^{1,1319}} \quad (2)$$

- for PDC bits (Aktum field, Kazakhstan):

$$V_m = 43,08 \frac{\left(\frac{G}{d}\right)^{0,3893} \cdot n^{0,7822} \cdot Q^{0,1617}}{p_{ш}^{0,7889} \cdot A^{0,6547}} \quad (3)$$

- for 12 "MXL-1 bits (South Koktau field, Kazakhstan):

$$V_m = 0,06714 \frac{\left(\frac{G}{d}\right)^{0,53509} \cdot p_{ш}^{0,11163} \cdot n^{0,7971} \cdot Q^{0,48108}}{A^{1,1368}} \quad (4)$$

G/d - specific axial load; *G* - axial load on the bit, TP (*Tones Power*); *D* - bit diameter, cm; *n* - bit rotation frequency, min.$^{-1}$; *Q* - drilling mud flow rate, l/s; $p_{ш}$ - rock hardness according to L.A. Schreiner, *MPa*; *A* - abrasiveness category; V_m - mechanical speed, m/hour.

In the above equations, the influence of factors, in particular, indicators of the rock properties, is ambiguous, which is due to the fact that in some cases, in general, there are no significant changes in the values of these indicators of properties in depth.

For the fields of Karabagly and the Volga-Ural oil and gas region, we had disposal geological and technological research data, which more accurately reflects the results of drilling.

The results of these studies are provided below, and the implementation of the decision-making method for previously drilled wells is illustrated on the basis of these results.

At different times, various specialists conducted observations of the change in mechanical speed over time [2, 4, 15, 17, 18]. These dependencies are important for analyzing the impact of drilling conditions on the performance of this process, forecasting for new similar penetration conditions on the bit, run speed, cost of 1 m of penetration and selection, on this basis, of mode parameters that will provide the best drilling efficiency. In addition, such dependencies make it possible to track the process of bit galling over time, to analyze the effect on the rate of damping of rock properties, first of all, abrasiveness, as well as mode parameters.

Taking into account the need for such an analysis, we conducted research to study the influence of rock properties and mode parameters on the initial mechanical speed and its decay rate over time.

Data from geological and technological studies of the drilling wells' process in the Karabagly area (Azerbaijan) and a well drilled in the Volga-Ural oil and gas region were used for the analysis. The calculations were carried out according to the sequence (algorithm) illustrated as a diagram in Figure 1.

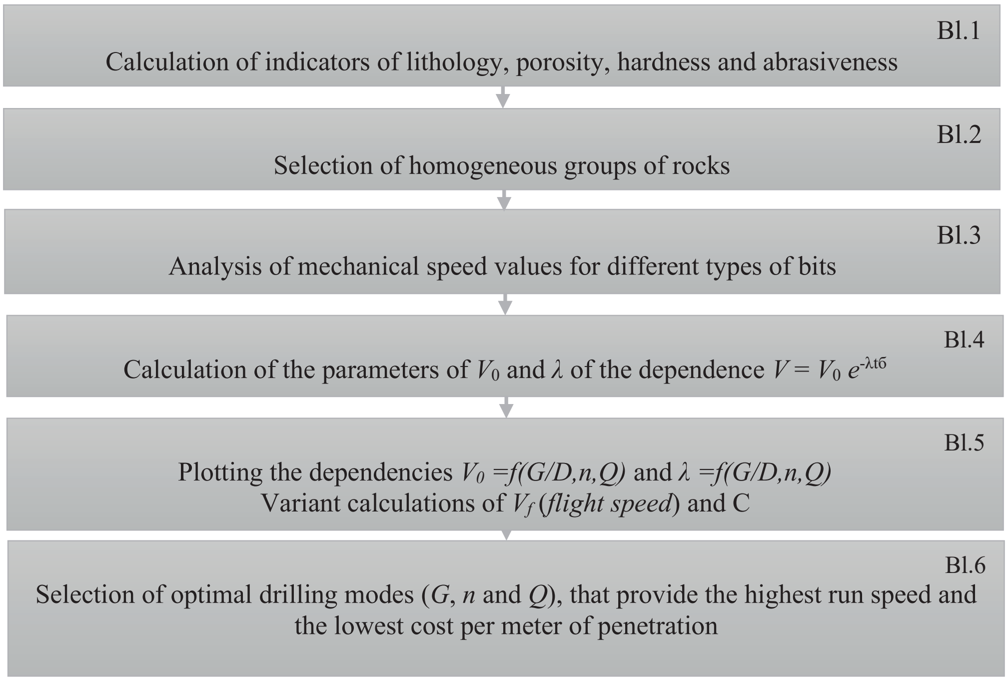

Fig. 1 - Block diagram of the algorithm for calculating drilling indicators and selecting mode parameters according to geological and technical studies of a drilled well.

As illustrated in figure, first, the characteristics of rocks are estimated according to the well drilling data. This is done using the appropriate program.

The analysis of bit development was conducted within the intervals (packs) of homogeneous rock properties, for the selection of which the fuzzy cluster analysis program was used. The noted dependencies were built for the same types of bits.

The intervals of bit development identified according to the well drilling data, as noted, of the same standard size within the considered homogeneous group of rocks, the types of bits and the values of the initial mechanical speed, as well as the rate of its decay are given in Table 1.

Table 1 – Values of V0 and l

Field	Interval		Bit	$V_{0,}$ m/h	*l*
	from	to			
Karabagly	0	351	CR1	77,239	0,1521
	351	1003	MAX-GT1	92,843	0,0715
	1003	1984	MAX-CGT1	60,965	0,0534
	1984	2328	MX-C1	23,374	0,0331
	2328	3303	FS-2643	68,554	0,038
Volga-Ural oil and gas region	396	521	295,3 MC3 GNU	4,1532	0,0244
	536	651	295,3 MC3 GNU	3,6251	0,006
	711	776	295,3 MC3 GNU	4,4557	0,0632
	806	856	295,3 MC3 GNU	4,8789	0,0338

	861	886	215,9 M3 GV	3,037	0,0186
	911	976	215,9 M3 GV	4,295	0,03
	981	1281	215,9 M3 GAU	4,3757	0,0136
	1286	1326	215,9 M3 GAU	3,443	0,0288
	1376	1591	215,9 M3 GAU	4,2069	0,0055

For analytical approximation, a simple exponential function, previously proposed by various researchers, was chosen in the form:

$$V_m = V_0 \times e^{-\lambda t} \quad (5)$$

where V_0 – initial mechanical speed, *m/h*; λ-rate of decrease in mechanical speed over time, h^{-1}.

As a result of statistical processing of the mechanical speed dependences on time, the values V_0 and λ were obtained (Table 1).

Each pair of parameter values given in the table, that is, the initial mechanical rate of drilling and the rate of its decay in time, is a function of the mode parameters, therefore, for the most correct description of the process, it is necessary to conduct a statistical analysis with the construction of models that most fully reflect the influence of the mode parameters.

Using the obtained values of υ_0 and λ, as well as drilling data in the rock under consideration, we conducted a statistical analysis in order to establish dependencies of the form

$$V_0 = f(\frac{G}{d}, n, Q) \quad \text{and} \quad \lambda = f(\frac{G}{d}, n, Q)\,, \quad (6)$$

where $\frac{G}{d}$ – specific axial load (G – axial load, d – bit diameter), n – rotation frequency, Q – drilling fluid consumption.

The analysis was conducted by the random search method [19] by estimating the parameters of the models in the form:

$$V_0 = a(\frac{G}{d})^b n^c Q^d \exp(-e(\frac{G}{d})-f\times n-g\times Q)\,. \quad (7)$$

According to this method, to estimate the parameters of the model (5), another model of the form (7) was adopted; based on the preliminary analysis, as well as generalization of the data of previously performed studies, [2, 3], the following boundaries of their change were set with the corresponding steps:

- for data on wells of the Karabagly field:

$$v_0 \rightarrow \begin{cases} 0 <= a <= 1 \\ 0 <= b <= 1 \\ 0 <= c <= 1 \\ 0 <= d <= 1 \\ 0.0001 <= e <= 0.01 \\ 0.00001 <= f <= 0.01 \\ 0.00001 <= g <= 0.01 \end{cases} \qquad \lambda \rightarrow \begin{cases} 0 <= a <= 1 \\ 0.01 <= b <= 3 \\ 0.01 <= c <= 2 \\ 0.01 <= d <= 2 \\ 0.0001 <= e <= 0.01 \\ 0.00001 <= f <= 0.01 \\ 0.00001 <= g <= 0.01 \end{cases} \quad (8)$$

- for wells in the Volga-Ural oil and gas region:

$$v_0 \rightarrow \begin{cases} 0 <= a <= 1.5 \\ 0.01 <= b <= 3 \\ 0.01 <= c <= 2 \\ 0.01 <= d <= 2 \\ 0.0001 <= e <= 0.01 \\ 0.00001 <= f <= 0.01 \\ 0.00001 <= g <= 0.01 \end{cases} \quad (9)$$

The unknown parameters of the models for υ_0 and λ were found using the implementation of a random search program based on the conditions:

$$\Sigma(V_0 - V_{0p})^2 \rightarrow \min$$
$$\Sigma(\lambda - \lambda_p)^2 \rightarrow \min \quad (10)$$

The parameter values are given in Table 2.

Table 2 – Model parameter values by expression (7)

Field	Parameters / Model	a	b	c	d	e	f	g
Karabagaly	V_0	0,629	0,367	0,892	0,054	0,01	0,0001	0,0079
	l	0,042	0,437	0,206	0,677	0,0092	0,0005	0,0232
Volga-Ural oil and gas region	V_0	1,42	0,13	0,31	0,12	0,0047	0,0034	0,0091

The dependence of λ on the mood parameters for the Volga-Ural oil and gas region is best described using a linear expression:

$$\lambda = a_0 + a_1 \frac{G}{d} + a_2 n + a_3 Q, \qquad (11)$$

where a_0=0,114; a_1=-0,009; a_2=-0,00167; a_3=0,00023.

To calculate the run speed and the cost of 1 m of penetration, according to the results of regression analysis, equations were obtained for the corresponding types of bits in a given rock, expressing the dependence of the drilling time on the mood parameters in the following form [2]:

- for bits 295,3 MC3-GNU:

$$t_б = \frac{25}{\frac{G}{D} \cdot n^{0.18}} \qquad (12)$$

- for bits 215,9 M3-GV, 215,9 M3-GAU, 215,9 C3-GV:

$$t_б = \frac{10}{\left(\frac{G}{D}\right)^{1.15} \cdot n^{0.01}} \qquad (13)$$

The above expressions make it possible to predict the bit operation time depending on the mode parameters for the conditions under consideration.

To predict the run speed based on the values of the initial mechanical speed of penetration (v_0) and the rate of decay of mechanical speed over time (λ), first, according to a well – known expression, the penetration is calculated:

$$H = \frac{v_0}{\lambda}(1 - e^{-\lambda t}). \qquad (14)$$

Further, the run speed is calculated according to the well-known expression, taking into account the time spent on the drilling-tool trip operations.

In order to conduct variant calculations, the boundaries of the change in the value of the mode parameters and their steps were set. For all these options, the calculations of the run speed and the cost of 1 m of penetration were conducted, the results of which were summarized in a table, which, due to its large volume, is given here. The best predicted mode parameters were determined with the help of two noted criteria using the theory of fuzzy sets [20, 21].

According to this, the set of solutions is the intersection of the sets of goals (to achieve the highest run speed) and restrictions (at the lowest cost of 1 meter of penetration). The form of the membership function of the goal sets and the constraints in the form were chosen for this purpose

$$\mu = ae^{bx}, \qquad (15)$$

where x – in one case is the cost of 1 m of penetration and in the other – the run speed.

Taking into account the parameters for evaluating the value of the membership function of the run speed, expression (15) takes the form:

$$\mu_{v_p} = 0{,}104e^{0{,}05 v_p}, \qquad (16)$$

and to assess the membership function of the cost of 1 m of penetration, this expression will look like as following:

$$\mu_C = 0{,}97e^{-0{,}0015C} \qquad (17)$$

Discussion. For all the design options (with different combinations of mode parameters), the values of the run speeds and the corresponding values of the cost per meter of penetration were calculated; functions of membership of the target and restrictions were calculated using expressions (16) and (17). The membership function of the set of decisions according to [20, 21] was estimated as min (m).

The largest value of the membership function of the set of solutions in the set of calculated data corresponds to the best solution.

As a result of calculations based on the models, the surface of distribution of the values of the run speed and the cost per meter of penetration was also constructed depending on the mode parameters at constant values of the flow rate of the drilling fluid. These surfaces are illustrated as an example in Figures 2 and 3. With the help of the figures, one can track the change in drilling performance in three-dimensional space, and also establish their optimal values. The surfaces were built using the SURFER program.

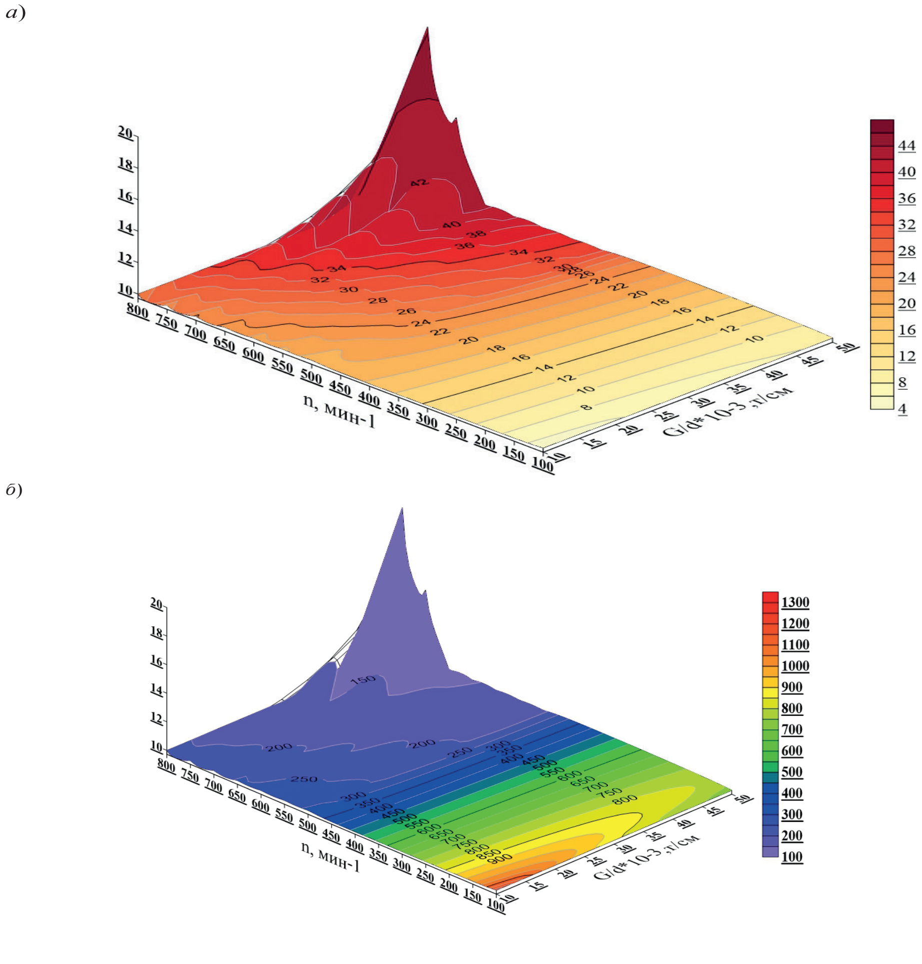

Fig. 2 – The surface of the distribution of the run speed (a) and the cost of 1 m of penetration (b), depending on the mode parameters (The vertical coordinate on the left shows the values of the drilling fluid flow *Q* in the range of 10-20 *l/s*)

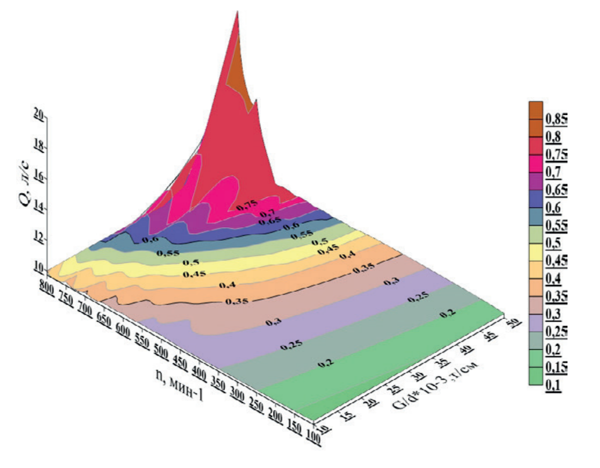

Fig. 3 – Generalized mechanical speed distribution model (The vertical coordinate on the left shows the values of the drilling fluid flow *Q* in the range of 10÷20 *l/s*)

Conclusion. Based on the above results, we can conclude the following:

1. The analysis of the change in mechanical speed in time is conducted, estimates are given to the parameters of this dependence – the initial mechanical speed and the rate of decay of the mechanical speed in time by considering them as functions of mode parameters. The dependences of the initial mechanical speed and the rate of decay of the mechanical speed in time on the mode parameters – axial load on the bit, the frequency of rotation of the tool and the flow rate of the drilling fluid are built.

2. Based on the results of statistical analysis, models have been built that allow predicting the mechanical speed, run speed and the cost per meter of penetration when drilling with this type of bit in the rock under consideration.

3. An algorithm has been developed and implemented for evaluating the optimal mode parameters based on two criteria – run speed and cost per meter of penetration based on information about drilled wells.

4. Surfaces have been obtained that enable to trace the change in drilling performance in three-dimensional space.

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ҰҢҒЫМАЛАРДЫ БҰРҒЫЛАУДЫҢ РЕЖІМДІК ПАРАМЕТРЛЕРІНІҢ ҚАШАУДЫҢ ЖЫЛДАМДЫҚ КӨРСЕТКІШТЕРІНЕ ТИГІЗЕТІН ӘСЕРІН ЗЕРТТЕУ

Аннотация. Бұрғылаудың жылдамдық көрсеткіштерін болжау және оларға сәйкес оңтайлы параметрлерді анықтау тау жыныстарының қасиеттері мен геологиялық қиманың жіктелуі негізінде жүзеге асырылуы мүмкін. Мұндай жағдайларда жыныстардың кезектесіп біртекті топтары таңдалады, олардың шегінде бір типті қашау өңделген аралықтар белгіленеді.

Аталған жұмыста, талдау жүргізіліп, компьютерлік есептеулерге арналған тиісті бағдарлама әзірленіп, олар нақты мысалдармен іске асырылды. Бастапқы деректердің мысалы ретінде Қазақстанда, Әзірбайжанда, сондай-ақ тау жыныстарының біртекті тобы үшін топтастырылған Еділ-Орал мұнай-газ ауданының кен орындарының бірінде бұрын бұрғыланған ұңғымалардың деректері пайдаланылды. Ұсынылған материалдар халықаралық ғылыми ынтымақтастық бағдарламалары шеңберінде іске асырылған қазақстандық және әзірбайжандық ғалымдардың бірлескен жұмысының нәтижелері болып табылады.

Ұсынылған алгоритмге сәйкес алдымен "КАРОТАЖ" бағдарламасын жүзеге асыру арқылы геологиялық бөлімнің сипаттамалары, яғни: литологиясы, кеуектілігі, өткізгіштігі, қаттылығы, абразивтілігі, Пуассон коэффициенті, кеуек қысымы мен гидравликалық сыну қысымының градиенттері, бұрғылау ерітіндісінің оңтайлы тығыздығы және т.б. қажетті параметрлер есептеліп көрсетілді. Есептеу нәтижелерін салыстыру мақсатында және тұжырымдар келтіру кезінде ГАЖ интерпретациясының қортындылары қолданылды.

Қашаудың механикалық жылдамдығының уақыт аралығында өзгеруіне жүргізілген талдаудың арқасында режімдік параметрлердің бастапқы жылдамдық мәндеріне және оның уақыт бойынша төмендеу қарқынына әсер етуінің статистикалық моделі жасалды. Рейстік жылдамдық пен 1 м ұңғыманың құнын болжау әдістемесі, сонымен қатар оңтайлы параметрлерді таңдаудың нұсқаулық есептеулері мен олар жөніндегі шешімдер қабылдау ұсынылды.

Түйінді сөздер: бұрғылаудың режімдік параметрлері, тау жыныстарының қасиеттері, геологиялық қиманың жіктелуі, бұрғылаудың механикалық жылдамдығы, қашаудың ұңғылауы.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ РЕЖИМНЫХ ПАРАМЕТРОВ БУРЕНИЯ СКВАЖИН НА СКОРОСТНЫЕ ПОКАЗАТЕЛИ ДОЛОТА

Аннотация. Как известно, прогнозирование скоростных показателей бурения и определение соответствующих им оптимальные параметры можно осуществлять на основании показателей свойств горных пород и классификации геологического разреза. В этих случаях выбираются поочередно однородные группы пород, в пределах которых фиксируются интервалы, в которых отрабатывались долота одного типа.

В данной работе проведён соответствующий анализ, разработана и реализована на конкретных примерах программа для расчета и компьютерных вычислений. В качестве примера исходных данных использованы данные ранее пробуренных в Казахстане, Азербайджане, а также на одном из скважин месторождений Волго-Уральского нефтегазового района, которые были сгруппированы для однородной группы пород. Представленные материалы представляют результаты совместной работы казахстанских и азербайджанских ученых, реализованных в рамках программ научного международного сотрудничества.

Согласно предложенному алгоритму вначале путем реализации программы «КАРОТАЖ» были рассчитаны характеристики геологического разреза: литология, пористость, проницаемость, твердость, сплошность, абразивность, коэффициент Пуассона, градиенты порового давления и давления гидроразрыва, оптимальная плотность бурового раствора, а также другие параметры. Для сравнения результатов расчетов, а также для обоснования выводов были привлечены также результаты интерпретации ГИС.

Благодаря проведенному анализу изменения механической скорости долота во времени построена статистическая модель влияния режимных параметров на значения начальной скорости и ее темп снижения во времени. Предложена методика прогнозирования рейсовой скорости, стоимости 1 м проходки, а также вариантные расчеты и принятие решений по выбору оптимальных параметров.

Ключевые слова: режимные параметры бурения, свойства горной породы, классификации геологического разреза, механическая скорость бурения, проходка долота.

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