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TECHNICAL MEANS AND TECHNOLOGIES FOR ELIMINATING STUCK DRILL PIPES IN WELLS

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ТЕХНІЧНІ ЗАСОБИ ТА ТЕХНОЛОГІЇ УСУНЕННЯ ПРИХОПЛЕНЬ БУРИЛЬНИХ ТРУБ У СВЕРДЛОВИНАХ

Purpose. Enhancing the efficiency of drill string sticking elimination under adverse conditions through the analysis of the causes of downhole complications and substantiation of the application of the PGB–3V vacuum-chamber hydraulic hammer.

The methods. A comprehensive analysis of drilling operational data from Well No. 16 of the Kachanivske field, drilling fluid parameters, drilling modes, and the spatial well profile was carried out. To evaluate the performance efficiency of the PGB–3V hydraulic hammer, analytical relationships were used to determine the impact energy E, impact frequency f, impact power N, and friction forces F_{fr}.

Findings. It was established that the greatest influence on the occurrence of drill string sticking is exerted by wellbore curvature, insufficient bottomhole cleaning, deterioration of cuttings transport, and an increase in friction forces between the drill string and the wellbore walls. It was determined that, within problematic intervals, excessive drag of the drill string, deterioration of drill tool passage, and complications in drilling fluid circulation were observed. It was found that the use of hydraulic impact mechanisms improves the passage of the bottom hole assembly and reduces the negative effect of friction forces. The prospects of applying the PGB–3V vacuum-chamber hydraulic hammer for the elimination of downhole complications were demonstrated.

The originality. Approaches to the application of hydraulic impact mechanisms for the elimination of drill string sticking were further developed by establishing the influence of impact parameters, friction forces, and drilling fluid circulation modes on the efficiency of passing problematic well intervals.

Practical implementation. The obtained results make it possible to substantiate rational operating modes for the PGB–3V and to improve the efficiency of eliminating downhole complications. The research results can be used in selecting technological modes for performing remedial and preventive operations under complex well construction conditions.

Keywords: *well drilling, drill string sticking, hydraulic hammer, impact, drill string, pressure, drilling fluid, bottom hole assembly, hydraulic drive, rock.*

Introduction. Drilling of oil, gas, and other types of wells is a complex multifactor process [1]. The efficiency of this process directly depends on the technical equipment of drilling rigs, compliance with technological operating modes, and the specific mining and geological conditions.

The gradual development of the drilling industry is accompanied by the continuous improvement of technical equipment, drilling tools, and drilling technologies [2]. In this regard, particular attention is paid to increasing the efficiency of the use of energy and material resources, as well as ensuring the stable operation of primary and auxiliary equipment.

The drilling results are significantly influenced by the correct selection of technological parameters, properties of drilling fluids, and operating modes of rock-destroying tools [3]. Researchers also focus on methods for increasing the rate of penetration and improving drilling performance. An important area is the improvement of drilling tool designs and auxiliary equipment. Considerable importance is attached to ensuring efficient bottomhole cleaning from drilled cuttings. Increased requirements are also imposed on the reliability of drill string operation and the circulation system [4]. Significant attention is devoted to projects aimed at automating the most important technological processes and monitoring drilling parameters.

Literature analysis. During well construction, ensuring the continuity and reliability of drilling operations becomes of great importance [5]. The stability of various downhole processes directly affects drilling efficiency and the quality of operations. Coordinated operation of drilling equipment and compliance with established technological modes play an important role in this regard. In addition, it is necessary to ensure the proper functioning of drilling and downhole rock-destroying tools throughout the entire well deepening process [6]. This is due to the fact that the occurrence of non-routine situations leads to an increase in well construction time, higher material costs, and deterioration of the technical and economic indicators of drilling.

Modern drilling conditions are characterized by increasing well depths, more complex geological conditions, as well as the necessity to perform operations in unstable and heterogeneous formations [7]. The above-mentioned factors impose increased requirements on technical equipment, drilling tools, and drilling technologies. The efficiency of the drilling process is significantly influenced by drilling fluid parameters, operating modes of drilling tools, the quality of well cleaning, and the overall technical condition of the equipment.

An important direction of the current stage of drilling industry development is the improvement of existing and the creation of new technical equipment and technologies [8]. These approaches are aimed at increasing the reliability of the drilling process, reduction of accident rates and decreasing non-productive time losses. The application of innovative technological solutions makes it possible to improve the efficiency of well construction, ensure stable operation of the corresponding equipment, and minimize the negative impact of complications on the drilling process.

During the drilling of oil and gas wells, one of the most complex and widespread problems remains drill pipe sticking. These phenomena significantly affect the efficiency and safety of drilling operations. The occurrence of sticking leads to considerable time losses, increased demand for material resources, and complications in the technological process of well deepening. It should also be noted that sticking causes a substantial deterioration in the technical and economic indicators of well construction. In some cases, such complications may become a factor leading to serious emergency situations. Certain types of sticking require urgent and rather lengthy and complex remedial operations or may even result in the loss of the well [9].

Despite the considerable number of scientific studies and practical developments in the field of prevention and elimination of drill string sticking, the issue of improving the efficiency of technologies for combating such complications remains relevant. Modern drilling conditions require the application of a comprehensive approach to this issue. Such an approach should combine the use of specialized equipment, optimization of drilling modes, improvement of drilling tool designs, and implementation of advanced technological solutions [10].

Formulation of the unresolved part of the problem and the purpose. The issues of prevention and elimination of drill pipe sticking have long remained one of the important directions in the development of the drilling industry. A significant number of scientific papers under consideration are devoted to investigating the causes of downhole sticking, the conditions of their occurrence, and methods for their elimination [11]. Particular attention is paid by researchers to improving technical equipment, drilling modes, and the properties of drilling fluids. Considerable focus is also placed on increasing the reliability of drill string operation and auxiliary equipment. An important role is occupied by scientific and practical studies related to improving drilling tool designs. Issues concerning the enhancement of circulation system efficiency are also of significant interest. In addition, research is being conducted toward improving well cleaning processes from drilled cuttings.

Despite the significant amount of research carried out, the problem of drill pipe sticking remains relevant. This is associated with the complexity of drilling conditions and the variety of factors affecting the operation of drilling tools. Modern well construction conditions are characterized by increasing drilling depths, the presence of unstable formations, high formation pressures, and complex temperature conditions. These factors complicate the process of ensuring stable operation of drilling equipment. Additional influence is exerted by significant axial loads and complex operating modes of the drill string. The properties of rock formations and drilling fluid parameters also play an important role. In some cases, ensuring proper transportation of drilled cuttings to the surface becomes complicated [12].

Existing technical equipment and technologies do not always provide sufficient efficiency under various mining and geological conditions. Some of the applied technical solutions have a limited field of application. Certain methods for eliminating sticking are characterized by considerable operation time and high resource consumption. In some cases, there is a need to perform complex auxiliary operations, which negatively affects the overall indicators of well construction. Certain technological approaches require the use of additional equipment and specialized tools. At the same time, the efficiency of operations significantly depends on the specific drilling conditions.

Issues related to improving the efficiency of specialized equipment for eliminating sticking require further development. Methods for adapting technological operating modes to changing drilling conditions remain insufficiently studied. An important direction of development is also increasing the efficiency of monitoring the technical condition of the drill string and timely identification of prerequisites for sticking occurrence. Insufficient attention is devoted to the comprehensive assessment of the influence of technological parameters on drilling tool operation. Approaches to the prompt adjustment of drilling modes depending on changing operating conditions require substantial improvement [13].

Particular attention should also be paid to the issue of comprehensive integration of technical, technological, and organizational measures. Under modern conditions, it is important to develop solutions capable of ensuring high operational efficiency under various drilling modes and changing geological conditions. Reducing non-productive time losses, increasing the reliability of drilling operations, and minimizing the risk of emergency situations remain relevant tasks. Considerable importance is also attached to improving the durability of drilling tools and the operational stability of auxiliary equipment [14].

In view of the above, further research aimed at improving technical equipment and technologies for eliminating drill pipe sticking has significant scientific and practical importance and remains relevant for the modern drilling industry.

The methodology selected by the authors [15] is based on a comprehensive analysis of operational drilling data from Well No. 16 of the Kachanivske field, the conditions leading to drill string sticking, and the specific features of applying hydraulic impact mechanisms as part of the BHA. The methodology involves studying drilling fluid parameters, drilling modes, the spatial well profile, and factors affecting the occurrence of drag and sticking. In addition, to evaluate the performance efficiency of the PGB–3V vacuum-chamber hydraulic hammer, analytical relationships are used to determine the main energy, dynamic, and force parameters of its impact action. The justification for the application of this methodology is associated with the necessity for a comprehensive assessment of the conditions leading to downhole complications and the selection of rational operating modes for the PGB–3V under complicated drilling conditions.

Purpose of the article**:** to improve the efficiency of drill string sticking elimination under complicated drilling conditions through investigating the causes of downhole complications, analyzing operational drilling data, and substantiating the specific features of applying a vacuum-chamber hydraulic hammer as an impact tool for improving drill string operating conditions.

Results. It should be emphasized that modern conditions of oil and gas well drilling are characterized by continuously increasing complexity of mining and geological conditions, as well as greater well depths [16]. A similar situation is also typical for the construction of exploration and geotechnological wells. The drilling process is significantly influenced by unstable rock formations, wellbore curvature, high formation pressures, temperature loads, and difficult conditions of bottomhole cleaning from drilled cuttings. These factors substantially complicate drill string operation and considerably increase the risk of various technological complications.

The most complicated conditions arise during drilling of directional and deviated well intervals. Under such conditions, contact loads between the drill string and the wellbore walls increase, cuttings transport deteriorates, and friction forces rise. In addition, significant complications in drilling tool operation are observed in the presence of keyseat formation, accumulation of drilled cuttings in the annular space, and insufficient efficiency of the circulation system.

Drilling fluid parameters have a significant influence on the stability of drill string operation. Insufficient well cleaning efficiency, deterioration of the lubricating properties of the drilling fluid, and disturbances in circulation modes may lead to an increase in torque, as well as the occurrence of sticking and drag of the drilling tool. In this regard, timely monitoring of drilling parameters, drilling fluid condition, and circulation system performance becomes particularly important.

Considering the complexity of modern well construction conditions, the analysis of actual operational drilling data becomes particularly important. The use of factual data makes it possible to investigate in greater detail the causes of technological complications and the specific features of drill string operation. In addition, operational data allow for evaluating the influence of specific technological parameters on the stability of the drilling process and identifying the most problematic intervals of wellbore penetration. Existing drilling modes and the specific features of passing complex well intervals play a fundamental role in this regard.

At the same time, the use of detailed operational drilling data creates opportunities for evaluating the efficiency of technical means for the prevention and elimination of sticking. Of particular interest is the analysis of cases involving drag, tight spots, and sticking of drilling tools. It is also important to investigate the efficiency of gauge runs, reaming, and well flushing under complicated drilling conditions.

In view of the above, it is advisable to consider the operational drilling data obtained during the drilling of the sidetrack of Well No. 16 of the Kachanivske field. The objective of this project was to drill a sidetrack toward Well No. 107 through the restoration of Well No. 16 and the penetration of the V-17v and V-17n horizons. The implementation of the project was aimed at refining the reservoir filtration and storage properties, increasing hydrocarbon production volumes, accelerating oil and gas reserve recovery rates, and improving the oil recovery factor within the investigated area.

Well No. 16 had been abandoned for geological reasons and remained filled with drilling fluid. The well design included a conductor casing and subsequent well deepening with the sequential running of intermediate and production casing strings. The new project envisaged drilling operations in two stages. The first stage involved drilling for the running of the intermediate casing string, while the second stage involved drilling for the production casing string. However, the actual well construction conditions necessitated adjustments to the well design and drilling technology. As a result, the drilling operations were carried out in three stages. Additionally, further well deepening was performed for the installation of a smaller-diameter liner. Accordingly, the well design included several casing strings of different diameters and separate drilling intervals (Fig. 1).

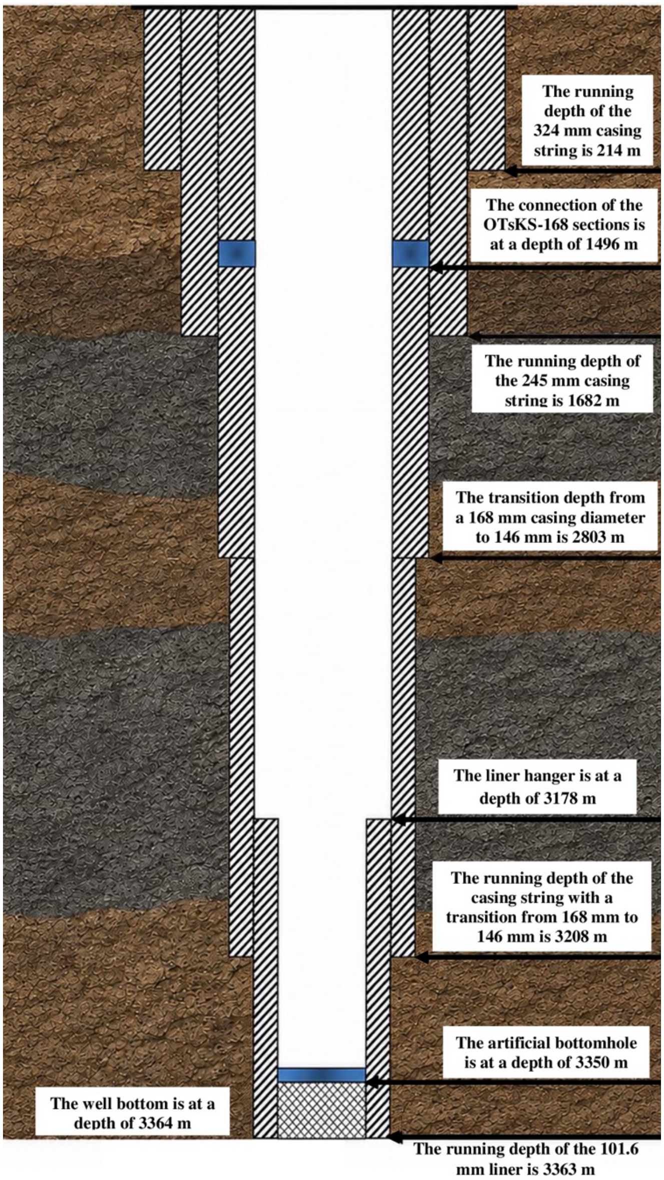

Fig. 1. Implemented design of Well No. 16 of the Kachanivske field after sidetrack drilling

The well design presented in Fig. 1 includes conductor, intermediate, and production casing strings. A smaller-diameter liner is installed in the lower part of the well. The diagram shows the setting depths of the casing strings and the transition intervals between strings of different diameters. In addition, the connection point of the production casing sections using the OTsKS–168 device is indicated. The position of the artificial bottomhole is also shown.

The presented well design characterizes the challenging conditions encountered during the construction of the sidetrack wellbore. This necessitated the staged deepening and casing of the wellbore.

For a more detailed study of the construction features of the considered well, it is advisable to examine the drilling schedule presented in Fig. 2. The presented schedule makes it possible to analyze the variation in wellbore deepening rates at different stages of the drilling operations. In addition, it allows the assessment of the impact of technological complications and auxiliary operations on the overall well construction duration.

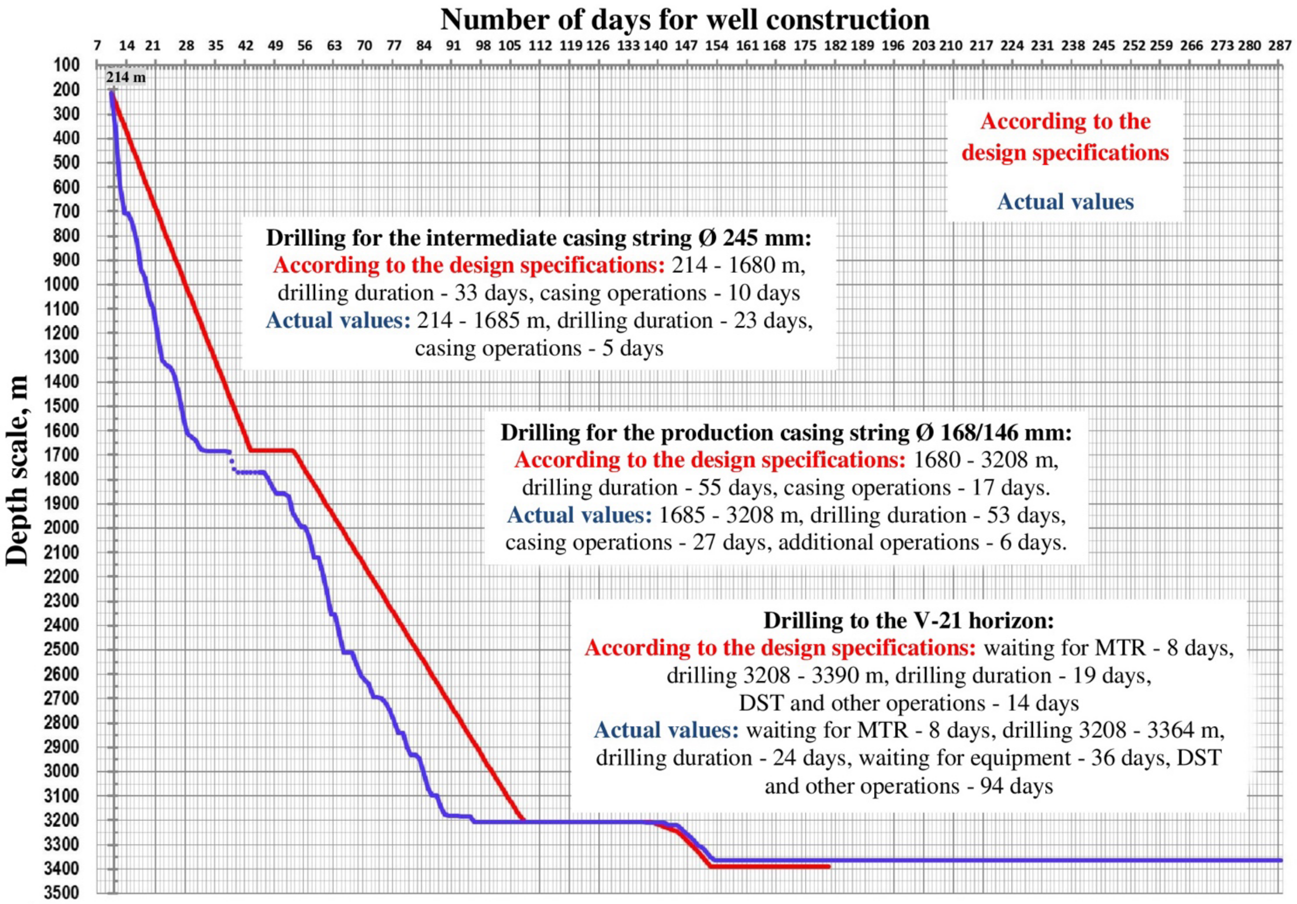

Fig. 2. Drilling schedule of Well No. 16 of the Kachanivske field

The schedule presented in Fig. 2 makes it possible to evaluate the relationship between the planned and actual drilling performance indicators. Based on this schedule, the most challenging wellbore intervals can be identified, as well as the influence of auxiliary, remedial, and preventive operations on the overall well construction duration can be analyzed.

The schedule analysis showed that the most difficult drilling conditions were encountered while drilling the intervals for the production casing and the smaller-diameter liner. It was within these intervals that a reduction in well deepening rates, an increase in the duration of auxiliary operations, and occurrences of drill string drag were observed. In addition, the results of the schedule analysis confirm the significant impact of technological complications on the actual well construction time.

It should be noted that particular importance is attached to the study of drilling fluid parameters, which directly affect the efficiency of well cleaning, the operating conditions of the drilling tool, and the risk of drag and sticking occurrences. Analysis of the drilling records indicates that different types of drilling fluids were used during well construction, with their properties varying depending on the drilling depth, geological conditions, and the specific features of drilling individual wellbore intervals. The main parameters of the mentioned fluids used during drilling are presented in Table 1.

Table 1

Technological parameters of drilling fluids used during the drilling of Well No. 16 of the Kachanivske field

Characteristic complicated application interval, m	Type of drilling fluid	Technological parameters of the drilling fluid					
		Density, g/cm^3	Viscosity, s	pH	SSS_1/SSS_{10}, dPa	Filtration, cm^3/30 min	Lubricant additive content”
1681–1856	Sodium humate-based drilling fluid / Potassium-polymer drilling fluid	1.10–1.13	22–28	9–10.5	15/28–31/59	5–6	up to 7%
1856–1936	Potassium-polymer drilling fluid	1.11–1.14	28–33	9–9.5	16/43–16/55	4–5	7–8%
1920–1994	Potassium-polymer drilling fluid	1.14	33	9	16/55	4	7–8%
1994–2695	Potassium-polymer drilling fluid	1.15–1.16	32–37	9.5–10	10/31–36/60	4–4.5	8–10%
2695–2840	Potassium-polymer drilling fluid	1.16	32–33	10	10/31–15/35	3.5–4	8–10%
2840–3180	Potassium-polymer drilling fluid	1.15–1.16	33–36	9–10	15/38–29/78	3.5	8–10%
3180–3208	Potassium-polymer drilling fluid	1.15–1.18	33–98	9.5–10.5	15/38–53/92	3.5–5	8–10%

The analysis of the data presented in Table 1 shows that certain intervals of Well No. 16 were characterized by difficult drilling conditions and deterioration in drill string movement. These sections were marked by increased values of drilling fluid viscosity, static shear stress, and outlet mud temperature. In addition, a gradual increase in drilling fluid density was observed with increasing well depth.

It was established that, within the most problematic intervals, the use of a potassium-polymer drilling fluid with an increased content of lubricant additives is advisable. This is associated with the necessity of reducing friction forces between the drill string and the wellbore walls. At the same time, even with adjustments to the drilling fluid parameters, drag occurrences and deterioration of drilling tool movement conditions were still observed in certain intervals.

The occurrence of drill pipe sticking during the construction of Well No. 16 had a complex multifactor nature and was determined by a combination of technical, technological, and geological factors. One of the main causes complicating drill string operation was insufficiently effective well cleaning from drilled cuttings. During the drilling process, repeated accumulation of cuttings in the annular space was observed, which was accompanied by an increase in torque, the occurrence of drag during tripping operations, and deterioration in the movement of the drilling tool.

The most difficult conditions were observed in the deviated well intervals (Fig. 3) and in keyseat formation zones. These circumstances led to increased contact loads between the drill string and the wellbore walls, as well as to an increase in friction forces.

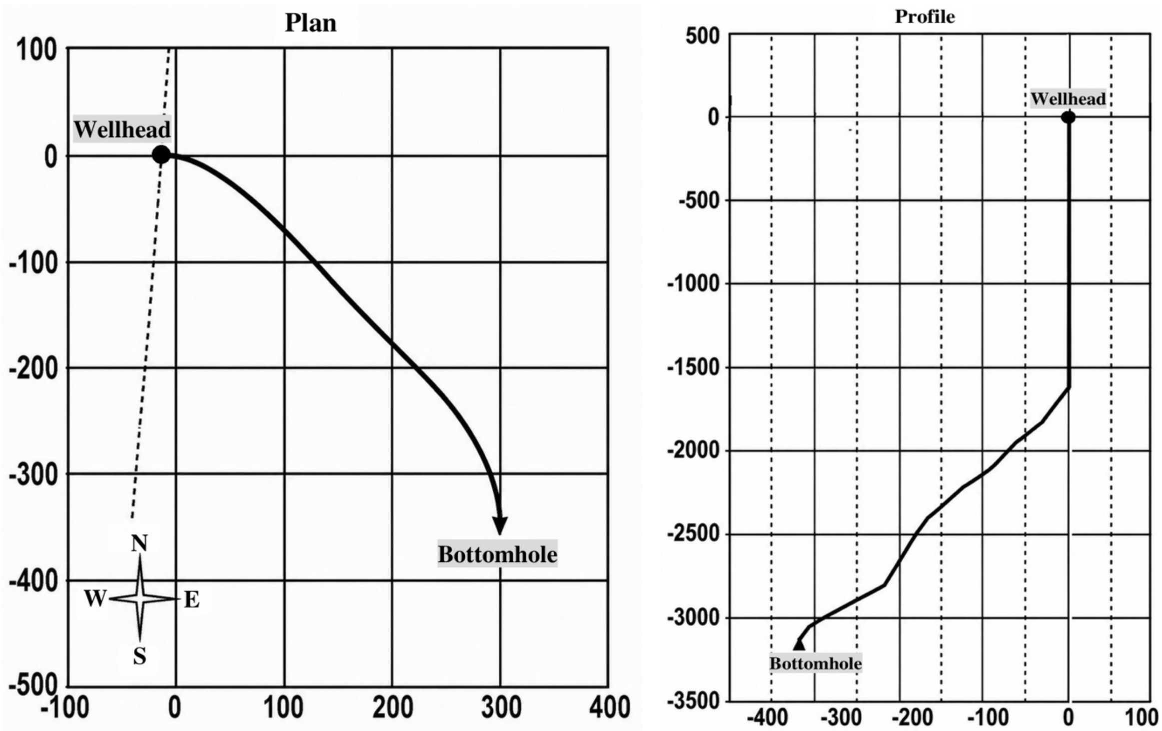

Fig. 3. Plan and profile of the wellbore of Well No. 16 of the Kachanivske field

The study of the well plan and profile (see fig. 3) indicates the presence of a directional wellbore trajectory. With increasing depth, the deviation intensity gradually increases. As a result, the well bottomhole has a significant horizontal displacement relative to the wellhead. The greatest wellbore deviation is observed in the middle and lower intervals of the well. Within these intervals, contact loads between the drill string and the wellbore walls increase. This leads to higher friction forces and deterioration in tool movement conditions. In addition, the transportation of drilled cuttings becomes more complicated in the deviated intervals. Such conditions promote cuttings accumulation and increase the risk of drag and drill string sticking.

During the drilling of Well No. 16, wellbore reaming and gauge-checking operations were repeatedly performed. These measures were aimed at improving drill string passability, reducing friction forces, and preventing sticking incidents. To enhance well cleaning efficiency, flocculants were used, simultaneous operation of two mud pumps was ensured, and additional wellbore flushing operations were carried out (Table 2). Special attention was paid to the use of technical means for sticking prevention. The bottomhole assembly (BHA) included hydraulic impact mechanisms (HIM), anti-sticking equipment, and check valves installed above the downhole motors. The application of these technical means was intended to improve drill string movement conditions, reduce the risk of downhole motor plugging by cuttings, and increase the efficiency of drag and sticking elimination.

Table 2

Main factors causing drill string sticking and technological measures for its prevention

Factor causing drill string sticking	Manifestation of the impact	Technological measure	Purpose of the measure
Reduction in the carrying capacity of the drilling fluid	Cuttings accumulation and increase in torque	Use of two pumps	Improvement of well cleaning
Insufficient well cleaning	Deterioration of drilled cuttings transport	Use of flocculants	Improvement of drilling fluid cleaning efficiency
Insufficient content of lubricant additives	Increase in friction forces and drag occurrences	Addition of lubricant additives to the drilling fluid	Improvement of lubricating properties
Keyseat formation	Complication of drill string movement	Reaming of problematic intervals	Elimination of local restrictions and keyseats
Wellbore deviation	Increase in contact loads	Wellbore gauge checking	Reduction of drag occurrences and improvement of passability
Plugging of the downhole motor by cuttings	Deterioration of circulation and BHA operation	Use of flocculants and flushing operations	Improvement of circulation system cleaning
Wear of the drilling tool	Deterioration of drill string operational stability	Application of anti-sticking equipment	Reduction of the risk of drill string sticking

The performed analysis of operational data (see table 2) confirms that the occurrence of drill string sticking is associated with the combined influence of technical and technological factors. The greatest influence is exerted by insufficient well cleaning, deterioration of the lubricating properties of the drilling fluid, and wellbore curvature. In addition, keyseat formation, plugging of the downhole motor by cuttings, and deterioration of the technical condition of the drilling tool also play a significant role. To reduce the risk of sticking, it is advisable to apply a set of preventive measures aimed at improving well cleaning and drill string operating conditions.

Under the influence of the above-mentioned factors, the application of specialized technical means for the prevention and elimination of drill string drag and sticking becomes particularly important. One of such means is hydraulic impact mechanisms [17], the use of which improves drilling tool passage conditions and reduces the negative influence of increased friction forces. In this regard, it is advisable to analyze the specific features of applying hydraulic impact mechanisms as part of the BHA during the drilling of problematic well intervals (Table 3).

Table 3

Some specific features of the application of hydraulic impact mechanisms as part of the BHA

BHA designation	Operating interval, m	Type of HIM	Nature of operations	Specific drilling conditions
Reaming BHA	1681–1856	HIM Ø165	Reaming and gauge run	Initial wellbore deviation, deterioration of tool passage
BHA No. 6	1856–1936	HIM Ø162	Drilling	Drill string drag, increased friction forces
Reaming BHA	1920–1936	HIM Ø162	Interval reaming	Necessity to improve wellbore passability
BHA No. 8	1936–2695	HIM Ø162	Drilling	Deterioration of well cleaning, increase in torque
BHA No. 9	2695–2840	HIM Ø162	Drilling	Keyseat formation and difficult cuttings transport conditions
BHA No. 10	2840–3180	HIM Ø162	Drilling	Significant contact loads and drill string drag
BHA No. 10 (reaming and deepening)	3180–3208	HIM Ø162	Reaming and deepening	Wellbore preparation before casing running

The performed analysis of the data presented in Table 3 shows that hydraulic impact mechanisms should be used primarily in the most complicated drilling intervals. The main reasons for their application are drill string drag, deterioration of well cleaning, wellbore curvature, and increased friction forces [18]. In addition, the use of hydraulic impact mechanisms is associated with the necessity of performing reaming, gauge runs, and wellbore preparation prior to casing running.

The study of a wide range of operational data and modern technical solutions shows that hydraulic impact mechanisms (HIM) are effective means of reducing the risk of drill string sticking under complicated drilling conditions. The use of such devices makes it possible to generate additional impulse loads on the drilling tool. In addition, their application improves drill string passage and reduces the negative influence of friction forces within deviated well intervals.

At the same time, modern well construction conditions require the development of more multifunctional impact technical devices [19]. Such devices should be suitable not only for improving drilling efficiency, but also for performing auxiliary and remedial operations. Of particular importance is the possibility of their application during the elimination of drill string drag and sticking. Reaming of problematic intervals, improvement of bottom hole assembly (BHA) passage, and performance of other technological operations under complicated conditions are also important.

For this reason, the proposed PGB–3V vacuum-chamber hydraulic hammer (Fig. 4) is of considerable practical interest. The design of this device is aimed at providing controlled impact action. In addition, it ensures improved efficiency of hydraulic energy utilization and enables rapid adjustment of operating modes depending on well penetration conditions. A separate advantage of the PGB–3V is the possibility of its application not only directly during the drilling process. The device can also be used during remedial, preventive, and auxiliary operations associated with the elimination of sticking and the improvement of drill string operating conditions.

Considering the design and technological features of the PGB–3V vacuum-chamber hydraulic hammer (Fig. 4), its application is promising not only directly during the drilling process, but also during operations aimed at eliminating downhole complications. The device design ensures the generation of impact impulses of various amplitudes and frequencies. This makes it possible to adapt its operating modes to specific well penetration conditions [20].

The main structural elements of the PGB–3V include the upper threaded adapter 1, splined sleeve 2, and hollow housing 5. Important design elements also include the stepped valve-striker 6 with a distribution circulation rod 7, vacuum chamber 15, and impact chamber 17. The impact system of the device includes hammer 18 and anvil 20. In addition, the PGB–3V is equipped with a system of bypass circulation channels 23 and 24. The design also includes the bottomhole central circulation channel 27 and jet discharge channels 28.

The application of the PGB–3V becomes particularly important in cases of drill string drag and sticking. The generation of impulse loads makes it possible to reduce friction forces between the drilling tool and the wellbore walls. In addition, the passage of the bottomhole assembly is improved. The efficiency of reaming problematic intervals is also increased. Another important advantage is the possibility of rapid adjustment of the device energy parameters. This creates prerequisites for the use of different impact modes depending on the nature of the complication.

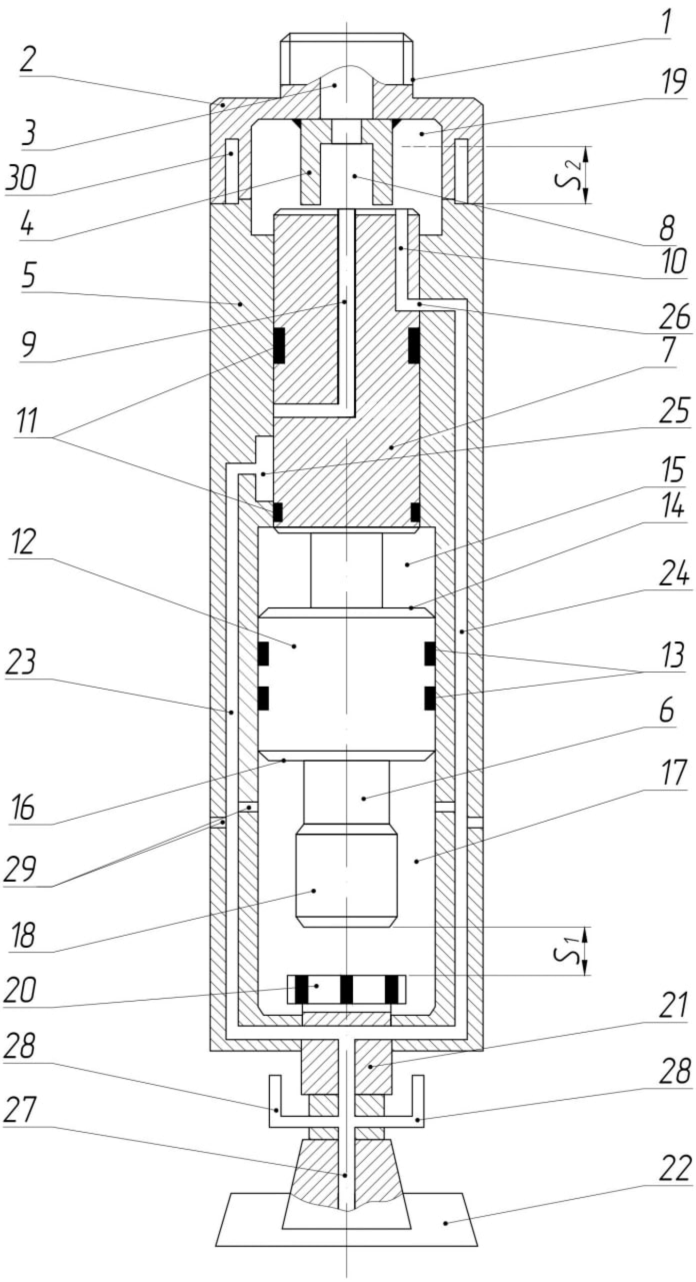

Fig. 4. Design of the PGB–3V vacuum-chamber hydraulic hammer

An important feature of the PGB–3V is the presence of a system of circulation and jet discharge channels. The use of discharge channels provides additional suction of the drilling fluid. At the same time, turbulent disturbances are generated within the bottomhole zone. This contributes to intensified cuttings removal and improved well cleaning. Such a feature is especially important under conditions of bottomhole cuttings accumulation and deterioration of drilling fluid circulation. These conditions often accompany the occurrence of drilling tool sticking. The device design makes it possible to rapidly change its operating modes by regulating the parameters of the impact cycle. The listed design features of the PGB–3V determine the broad technological capabilities of its application under complicated drilling conditions. The main design and technological features of the PGB–3V vacuum-chamber hydraulic hammer are presented in Table 4.

Table 4

Some technical and technological features
and application capabilities of the PGB–3V device

Feature of the PGB–3V device	Design implementation	Technological effect	Significance under complicated conditions
Impact action regulation	Vacuum and impact chambers	Variation of impulse energy	Elimination of drill string drag
Impact frequency adjustment	Splined connection	Adaptation of operating modes	Operation in various intervals
Controlled impact cycle	Stepped valve-striker	Stable operation	Reduction of sticking risk
Improved circulation	Bypass channels	Flow stabilization	Reduction of cuttings accumulation
Flow turbulization	Jet channels	Intensification of cleaning	Improved cuttings removal
Closed circulation	Channel system	Efficient energy utilization	Operational stability
Transition between operating modes	Impact cycle regulation	Expansion of functional capabilities	Performance of auxiliary operations
Operation in deviated intervals	Impulse action	Reduction of friction forces	Improved BHA passage
Application during emergency situations	Impact loading	Release of the drill string	Elimination of sticking

It should be noted that the PGB–3V vacuum-chamber hydraulic hammer is characterized by broad technological capabilities for application under complicated drilling conditions. The device design provides the possibility of regulating impact action parameters, improving bottomhole zone cleaning, and reducing friction forces between the drill string and the wellbore walls. In addition, the use of the PGB–3V makes it possible to increase the efficiency of eliminating drill string drag and sticking, as well as to improve the passage conditions of the bottom hole assembly within deviated well intervals.

To evaluate the operational efficiency of the device, determining its main energy, dynamic, and hydraulic parameters becomes particularly important. In this regard, it is advisable to consider the methodology for calculating the main operating parameters of the PGB–3V and the specific features of its impact action.

Taking into account that the PGB–3V device includes stepped valve-striker 6, hammer 18, anvil 20, vacuum chamber 15, and impact chamber 17, determining the impact impulse energy E transmitted to the drill string becomes particularly important:

$$E = \frac{1}{2} m \cdot v^2, \qquad (1)$$

where m is the hammer mass, kg; v is the hammer velocity before contact with the anvil, m/s.

Considering that the design of the PGB–3V provides the possibility of regulating the impact frequency by changing the parameters of the splined connection and the impact cycle, the average impact power of the device is determined by the following relationship:

$$N = E \cdot f, \qquad (2)$$

where N is the impact power, W; f is the impact frequency, Hz.

Evaluation of friction forces between the drill string and the wellbore walls is of great importance during the elimination of sticking:

$$F_{fr} = \mu \cdot N_p, \qquad (3)$$

where F_{fr} is the friction force, N; μ is the friction coefficient; N_p is the normal force pressing the drill string against the wellbore wall, N.

To evaluate the oscillatory operating mode of the drill string under the influence of the PGB–3V, the following dynamic equation may be used:

$$m_{DS} \frac{d^2x}{dt^2} + c_d \frac{dx}{dt} + kx = F_0 \sin(\omega t), \qquad (4)$$

where m_{DS} is the equivalent mass of the drill string, kg; c_d is the damping coefficient; k is the system stiffness, N/m; x is the longitudinal displacement of the drill string, m; $\frac{d^2x}{dt^2}$ is the acceleration of oscillatory motion, m/s^2; $\frac{dx}{dt}$ is the drill string velocity, m/s; F_0 is the amplitude of the impact force, N; ω is the angular frequency, rad/s; t is time, s.

The presented relationships make it possible to evaluate the main energy, dynamic, and force parameters of the PGB–3V vacuum-chamber hydraulic hammer operation. In addition, the analytical relationships allow analysis of the oscillatory operating mode of the drill string and the influence of the device design parameters on the efficiency of sticking elimination. This creates prerequisites for selecting rational operating modes of the PGB–3V under complicated drilling conditions.

Conclusions. The conducted study showed that drill string sticking during the construction of Well No. 16 of the Kachanivske field had a complex multifactor nature. The greatest influence on the occurrence of complications was exerted by wellbore curvature, insufficient bottomhole cleaning, and increased friction forces between the drill string and the wellbore walls. The analysis of operational drilling data confirmed that, within the most problematic intervals, drill string drag, deterioration of tool passage, and increased torque were observed. It was established that the efficiency of sticking prevention depends on controlling drilling fluid parameters, improving well cleaning, and applying additional technological measures. The use of hydraulic impact mechanisms as part of the BHA confirmed the efficiency of impulse action under complicated drilling conditions. The application of hydraulic impact mechanisms makes it possible to improve drill string passage and reduce the negative influence of friction forces. The prospects of applying the PGB–3V vacuum-chamber hydraulic hammer for eliminating downhole complications were substantiated. The device design provides regulation of impact action parameters, improvement of bottomhole zone cleaning, and increased efficiency of drill string sticking elimination. The proposed analytical relationships make it possible to evaluate the main energy, dynamic, and force parameters of the PGB–3V operation and create prerequisites for selecting rational operating modes of the device.

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АНОТАЦІЯ

Мета. Підвищення ефективності ліквідації прихоплень бурильної колони в несприятливих умовах шляхом аналізу причин виникнення свердловинних ускладнень та обґрунтування застосування вакуумкамерного гідроударника ПГБ–3В.

Методика. Використано комплексний аналіз виробничих матеріалів буріння свердловини № 16 Качанівського родовища, параметрів промивальних рідин, режимів буріння та просторового профілю свердловини. Для оцінки ефективності роботи ПГБ–3В використано розрахункові залежності визначення енергії удару E, частоти ударів f, ударної потужності N та сил тертя $F_{тр}$.

Результати. Встановлено, що найбільший вплив на виникнення прихоплень бурильної колони мають викривлення стовбура свердловини, недостатнє очищення вибою, погіршення транспортування шламу та зростання сил тертя між бурильною колоною і стінками свердловини. Визначено, що в проблемних інтервалах спостерігались затяжки бурильної колони, погіршення проходження бурильного інструменту та ускладнення циркуляції промивальної рідини. З'ясовано, що використання гідравлічних ударних механізмів дозволяє покращити проходження компоновки низу бурильної колони та зменшити негативний вплив сил тертя. Показано перспективність застосування вакуумкамерного гідроударника ПГБ–3В для ліквідації свердловинних ускладнень.

Наукова новизна. Набули подальшого розвитку підходи до застосування гідравлічних ударних механізмів для ліквідації прихоплень бурильної колони із встановленням впливу параметрів ударної дії, сил тертя та режимів циркуляції промивальної рідини на ефективність проходження проблемних інтервалів свердловини.

Практична значимість. Отримані результати дозволяють обґрунтувати раціональні режими застосування ПГБ–3В та підвищити ефективність ліквідації свердловинних ускладнень. Результати дослідження можуть бути використані під час вибору технологічних режимів виконання аварійно-профілактичних робіт у складних умовах спорудження свердловин.

Ключові слова: *буріння свердловин, прихоплення бурильної колони, гідроударник, удар, бурильна колона, тиск, промивальна рідина, компоновка низу бурильної колони, гідравлічний привід, гірська порода.*

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