https://doi.org/10.33271/nvngu/2025-3/065

A. O. Ihnatov[*1],
orcid.org/0000-0002-7653-125X,
O. O. Aziukovskyi[1],
orcid.org/0000-0003-1901-4333,
Y. M. Stavychnyi[2],
orcid.org/0000-0001-8583-2313,
S. A. Rybachuk[2],
orcid.org/0009-0001-8177-204X,
I. K. Askerov[1],
orcid.org/0000-0002-8398-0205,
D. Sala[3],
orcid.org/0000-0003-1246-2045

1 – Dnipro University of Technology, Dnipro, Ukraine
2 – Public Company "Ukrnafta", Kyiv, Ukraine
3 – AGH University of Krakow, Krakow, Republic of Poland
* Corresponding author e-mail: ignatov.a.a@nmu.one

DEVELOPMENT OF PROMISING TECHNOLOGICAL SOLUTIONS IN THE CONSTRUCTION WELLS

Purpose. Setting the parameters of drilling, flushing and cementing cycles of wells constructed in sedimentary rocks that are subject to integrity violations, absorption of drilling fluid and stuck drill pipes, as well as the development, based on these parameters, of effective methods for eliminating well complications.

Methodology. The geological structure of the deposits was studied taking into account geophysical and well studies. Conclusions regarding the complexity of the geological conditions in the well are based on statistical information. The technical and technological parameters of the devices for eliminating complications and cleaning the well were studied on a stand equipped with a ZIF-650M drilling rig, NB-4 and NB-32 pumps, pressure gauges, a flow meter, a tachometer, and a coordinate controller. Studies of the properties of washing liquids were carried out on the basis of standardized methods and instruments. Mathematical and physical modeling was used with results processed in MATHCAD and EXCEL.

Findings. The process of well construction was studied using the example of fields in the Dnipro-Donetsk depression. It has been proven that high quality of drilling, flushing and casing works will allow for efficient hydrocarbon production. Issues of technical and technological support for the elimination of stuck wells are considered. The features of bottomhole and wellbore flushing with a closed circulation system for drilling fluids have been studied. The characteristics of the processes of preparing a well for casing are given and regulations for carrying out work on cleaning complicated sections of the wellbore are proposed.

Originality. Based on the data on the peculiarities of well construction in the Dnipro-Donetsk Basin, it has been proven that a rational scheme for field development is based on the need to implement comprehensive programs for the construction of wells that exclude the occurrence of geological and technical complications.

Practical value. The results presented can serve as the basis for progressive methods for constructing wells that are located in clayey strata prone to the occurrence of sticking and cavities.

Keywords: *well, flushing fluid, stuck drill pipes, rock, fastening*

Introduction. A well construction process relates to several areas of the mining industry, i. e. the extraction of solid, liquid, and gaseous minerals. The main components of a well drilling process include rock mass disintegration in the space limited by the contour of influence of the applied rock-breaking device and the bottomhole surface of the specified working. According to the rock mass properties, a method for its breaking impact is selected, i. e. a drilling method (most often, it is the mechanical one).

The selected drilling method (i. e. mechanical) is implemented with the formed circulation of a cleaning agent, which performs highly complex functions. That is why the technological properties of a cleaning agent are subject to quite strict restrictive requirements, including the ones from the viewpoint of environmental science. Their implementation will ensure the avoidance of complications and accidents in the wellbore under construction as well as contribute to the achievement of competitive technical and economic indicators for the extracted products.

© Ihnatov A. O., Aziukovskyi O. O., Stavychnyi Y. M., Rybachuk S. A., Askerov I. K., Sala D., 2025

Well lining is an indispensable process of the well construction cycle. It is performed mainly with metal casing pipes and the subsequent filling of the annular space with a special cementing solution. However, the effectiveness of the mentioned process will be determined mostly by the quality and perfection of the preparatory operations in the wellbore, preceding the casing string running, and physical and chemical properties of the cementing materials and solutions activated by various reagents.

Literature review. Currently, a problem of obtaining hydrocarbon raw materials (oil and natural gas) is completely connected with the need to construct deeper wells under complex mining-technical [1] and geological [2] conditions or restore the operation of decommissioned and suspended wells [3]. Under these circumstances, the reason for steady growth of financial investments in oil and gas production becomes obvious. Besides, the number of wells completed by the construction with serious deviations from the normative condition, which requires complex and capital-intensive repair and restoration operations, increases consistently as well [4]. Moreover, carrying out the specified type of

operations also requires a significant number of wells, whose life does not exceed just a few years of operation. Certain lagging behind the theory and practice of drilling from the modern needs of the relevant industry along with the increasing rate of complication of well construction tasks are the influential factors of the abovementioned facts [5]. The listed problematic issues have a certain relationship to the processes of exploration and exploitation of deposits of other minerals. These minerals, for example, include the class of so-called solid minerals (coal, iron ore, building materials).

Unsolved aspects of the problem. It should be pointed out that the nominal well diameter, corresponding to the diametric overall size of the rock-break zing tool (i.e. a bit) [6] can be preserved only in the stable rock [7]. Plastic salts and clay rocks are peculiar for the narrowing wellbore; it can also be observed in highly permeable rocks – sandstones, when a thick and loose clay crust is formed on their surface as a result of a drilling fluid filtration process [8]. The wellbore deepening factors we have indicated almost always precede the occurrence of stuck drill strings. It should also be emphasized that well drilling processes in unstable rocks (loose clays, shales, argillites, loose sandstones, and other weakly bound rocks) [9] are quite often accompanied by rather intense cavern formation, sloughing, and rock falls [10].

Basing on the analysis of the geological and technical conditions for constructing oil and gas wells, it can be stated convincingly that unhindered movement of rock-cutting drilling tools at high mechanical speed, cleaning (washing at various stages of construction) and lining (cementing) are among the most influential operations of a well construction cycle [11].

The occurrence of a complication in the form of stuck drill pipes must be classified as a difficult phenomenon from the standpoint of the possibility of elimination. Such complications can lead to accidents with serious consequences. In these circumstances, devices (hydraulic hammers) for creating dynamic loads for tools stuck in the well show significant effectiveness. Such hydraulic machines generate oscillatory pulses. The transmission of such impulses quite often contributes to the release of the drilling tool within a relatively short time without unnecessary technological operations.

In the modern practice of constructing various-purpose wells, drill fluids (based on technical water) have become widespread [12] in the form of dispersed systems with dispersed phases of different physical and chemical properties (in most cases, clays of certain mineralogical groups) and with the added reagents of a wide-range nomenclature (e.g. some surface-active substances). Moreover, in some geological and technical conditions and for a certain type of wells, polymer, emulsion, aerated solutions, and aqueous solutions of surface-active substances as well as foams and compressed air have proven themselves positively – here it is appropriate to talk about drilling with blowing.

Our analysis of literature along with the available production experience allows us to conclude the following: for now, the flushing fluid parameters are selected in accordance with the functions they perform. The most important ones are as follows: formation of back pressure on the well walls complicated by geological phenomena, well cleaning to remove rock-breaking products (sludge particles) to the surface, cooling of the operating rock-breaking tool, and acting as a hydraulic energy source [13]. It is logical that flushing liquids have technological properties related to density and rheological, sedimentation, and filtration indicators. The well construction practice has confirmed repeatedly that the density of the applied drilling fluid, being adequate to the existing interval well formation pressures as well as to the pressures of hydraulic fracturing, helps avoid possible complications (fluid manifestations, absorption, blow-ups, and gushing) and rational conditions for rock breaking at the bottomhole [14].

Much attention is paid to the use of complex treatment for washing fluids to obtain the properties that help exclude possibility of their negative physical and chemical interaction with rocks, which may result in sloughing, rock falls, shaft narrowing, cavern formation, sticking etc. [15].

In terms of currently introduced requirements for ensuring the wellbore construction quality, in a certain interval, the lining and cementing operations are carried out. The operations are preceded by determining the shaft curvature and well azimuth; the wellbore cross-section size and shape are also recorded by a section gage log or a caliper log [16]. Certain preparatory operations are carried out in the wellbore; their purpose is to eliminate unreliable placement and hardening of the cement mortar. Recently, there has been a steady trend of intensifying analysis of the issues of technical and technological support of this type of work as well as the development of rational formulations and materials for special well process fluids [17].

High quality of the indicated operations must be confirmed by final technological (pressing the casing string for tightness) and geophysical studies (acoustic control, gamma-gamma control of cementation etc.).

Thus, we have proven convincingly and argumentatively that the most important stages of a well construction cycle include rock mass breaking with simultaneous washing of the formed wellbore and its following lining. The specified work must be carried out to prevent the occurrence of well complications and accompanying accidents [18]. The resulting quality of the specified operations will make it possible to create a rational system of the hydrocarbon (and others) field development in full compliance with the requirements regarding the need to reduce the well construction terms and financial costs.

Methods. Geological factors of the structure of hydrocarbon deposits were studied on the basis of geophysical and direct well survey data [19]. Conclusions about the consequences of the presence of complex geological conditions in the well are made based on the available production statistical information [20]. Impact mechanisms, considered as devices for eliminating sticking in a well, are original developments of the authors. The technical and technological parameters of the devices already mentioned, as well as devices for cleaning the wellbore during cementing, were studied on a special stand equipped with a ZIF-650M drilling rig, NB-4 and NB-32 drilling pumps, pressure gauges, a flow meter, a tachometer, and a coordinate meter. To study the technological properties of drilling fluids, unified methods and devices were used [21]: the density was determined using VRP-1 lever scales, the conditional

viscosity was determined using a VBR-1 viscometer, the filtration rate was determined using a VM-6 device; the static shear stress of the drilling fluid was measured using a VSN-3 rotational viscometer, the friction coefficient for the filter cake was determined using a KTK-2 device; the concentration of foreign solid impurities was determined using an OM-2 device. To determine the concentration of Ca and Mg ions, a complexometric method was used, which is based on the ability of "Trilon B" to extract calcium from its soluble colored complex with murexide, as a result of which the pink color of the solution changes to purple. The basis for determining the concentration of colloidal particles is an express method for determining bentonite based on the adsorption value of "methylene blue" [22]. The study of the features of the flushing process during various well operations was carried out using modern methods of experimental laboratory and industrial research [23]. In addition to the above, methods of mathematical and physical modeling were used, as well as methods for processing and interpreting research results in the SolidWorks, MATHCAD, EXCEL environment.

Results and discussion. It should be noted that the Dnipro-Donetsk depression, as the main region of hydrocarbon production in our country, is an internal platform structure of the avlacogenic type. From the viewpoint of stratigraphic science [24], the depression consists of Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary deposits. According to the definitions of lithological science [25], a section of the depression is represented mainly by terrigenous deposits, i.e. fragmental rocks and their classic representatives – clayey differences. Salt-bearing strata also experienced their development in the geological section of the depression. Typical stratigraphic and lithological characteristics of the geological section of the Dnipro-Donetsk depression as well as the conditions for well construction are shown in Table 1.

According to the represented data (Table 1), the following conclusions can be drawn. A process of well drilling in terms of Dnipro-Donets depressions is characterized by significant difficulties associated with disturbed wellbore, drilling fluid absorption, cavern formations, sticking of drill pipes etc., which requires the use of special washing liquids with adequate physical and chemical properties, and technical and technological methods to eliminate the consequences of the specified complications [26]. To eliminate sticking of the drill string in a well under construction, the method for inducing shock-oscillatory movements has proven itself to be quite effective. The indicated movements in the stuck tool are generated using special impact mechanisms of various modifications. Such mechanisms can be mechanical or hydraulic. According to the specified features of well construction, the authors of the work developed and proposed for use a series of downhole devices. These devices are designed, in addition to drilling wells, to create shock pulses in a stuck drill string. A schematic representation of the design and operating principle of these devices is shown in Fig. 1.

Table 1

Stratigraphy, lithology, and drilling conditions for a typical hydrocarbon deposit of the Dnipro-Donetsk depression

System	Index	Typical representatives	Possible complications while well drilling
$Q+N+P$	Kz	Clays, marls	Rock sloughing, rock falls, shaft narrowing, drilling fluid absorption, sticking
Cretaceous	K_2	Clays, marls, sands, chalk	Disturbed wellbore integrity (sloughing and rock falls), drilling fluid absorption, sticking
	K_1	Sands, slightly cemented sandstones, argillite-like clays	
Jurassic	J_3	Argillite-like clays, slightly cemented sandstones, clay-like argillites, limestone	
	J_2	Slightly cemented sandstones, clay-like argillites	
Triassic	T_2	Clay-like argillites with separate (up to 5–6 m) layers of slightly cemented clayey sandstone, slightly cemented sandstones (clay in places), limestones	
	T_1	Aleurolites, clayey sandstones, sandstones	
Permian	P_2	Clayey sandstones, in some places aleurolites, argillites	Rock sloughing and falls, trough formations, cavern formations, drilling fluid absorption
	P_1	Clayey sandstones, argillites (with individual layers up to 5–7 m of clayey sandstone), sandstones	
Carboniferous	C_3	Clayey sandstones (with layers of up to 4–5 m of argillites, sandstones, aleurolites, argillite aleurolites, argillites	Disturbed wellbore integrity, drilling fluid absorption, fluid manifestations
	C_{2m}	Sandstones, clayey sandstones, aleurolite argillite, argillites (with up to 3 m layers of aleurolites and clayey sandstones), argillites	
	C_{2b}	Aleurolites, argillites, aleurolites with argillite layers, clayey sandstones, limestones, sandstones	
	C_{1s}	Aleurolites, layering (from 1 to 3 m) of aleurolites, sandstones, and argillites, clayey sandstones, sandstones	
	C_1V_1	Argillite aleurolites, sandy aleurolites, clayey sandstones, argillites, dense sandstones, aleurolites	

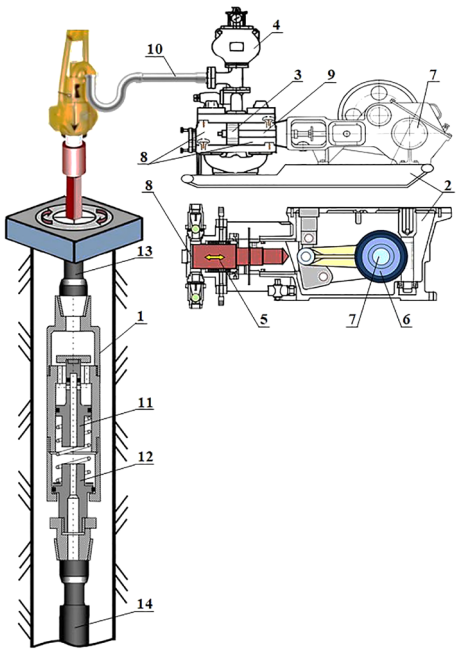

Fig. 1. The procedure for installing a downhole impact machine:

1 – impact machine; 2 – mud pumps; 3 – piston; 4 – compensator; 5 – plunger; 6 – crank mechanism; 7 – drive shaft; 8 – working chamber; 9 – rod; 10 – discharge line; 11 – striker; 12 – anvil; 13 – drill pipe; 14 – drill bit

A peculiar feature of the device for generating shock (or vibration) loads shown in Fig. 1 is its specific operating principle. This principle lies in the need to create a pulsed supply of working fluid for the impact machine *1*. It is this mode that will ensure stability and adjustability of the operating parameters of the hydraulic hammer. The implementation of pulse feed makes it possible to significantly simplify the design of the impact mechanism and eliminate wear parts from it. Also, such a mechanism is less susceptible to the wide range of physical properties of circulating fluids.

Pulse circulation of the flushing fluid can be achieved through fairly simple technical techniques for modernizing mud pumps *2* [27]. Such an upgrade consists of disconnecting one piston *3* (with stroke length x) of a double-acting disc piston pump, with parallel insulation of the compensator *4*, on discharge line *10* (to enhance the pulsation mode, one suction and discharge valve can be taken out of operation), or disconnecting one (if necessary, two) plungers *5* (also with stroke length x) of a rocker piston pump. The specified technical transformations, for drive pumps with a crank mechanism *6*, make it possible to obtain systematic intermittent supply with strictly defined time intervals, the value of which is determined by the rotational speed of the drive shaft *7* located in the pump housing [23]. Here it should be noted that the speed u of the stroke of the piston *3* (connected to the rod *9*) or the plunger *5* of the pump is the first derivative of the path x with respect to time

$$u = \frac{dx}{dt} = r\sin\varphi\frac{d\varphi}{dt} = r\omega\sin\varphi, \qquad (1)$$

provided that the stroke length of the piston or plunger will be

$$x = r(1 - \cos\varphi), \qquad (2)$$

where r is the radius of the crank; φ is the angle of rotation of the crank; ω is the angular speed of rotation of the crank.

Taking $\varphi = 0°$ for a piston or plunger for its extreme left position, we can state the end of the liquid injection cycle in the rodless working chamber 8 of a piston pump, and the end of the suction cycle in the rod end of the suction cycle, with $u = 0$; for a plunger pump, such a characteristic will also mean the end of the pumping cycle in the working chamber. At $\varphi = 180°$ the opposite situation occurs, but $u = 0$, as in the previous case. These explanations are very important to justify the mode of movement of the working fluid through the pump. For a piston pump, pulsating flow is due to several reasons. This is the unevenness of the pump piston speed u, which is zero at $\varphi = 0°$, and reaches its maximum value at $\varphi = 90°$ and then drops to zero again. For one full revolution of the crank, the indicated cycle of changing the speed u occurs twice. Speed pulsations are also caused by a reduced amount of liquid in the rod working chamber due to the presence of a rod. The reasons mentioned are also the factors in pressure pulsations in the injected liquid. For a plunger pump, when the middle plunger is turned off, uneven flow occurs due to the influence of the design features of the crank mechanism. To obtain a completely intermittent flow, two plungers must be turned off.

The procedure for eliminating stuckness of a drilling tool (when it is stuck by a filter cake) includes the following. The impact machine *1*, on drill pipes *13*, is lowered into the well to connect with the stuck part of the drill string *14*. When pump *2* is turned on, the striker *11* of the impact machine begins to deliver periodic blows to the anvil *12*, which is rigidly connected to the stuck part of the column. The resulting vibrations in the drill string promote the release of free water in the contact zone between the pipes and the filter cake. This circumstance is accompanied by a decrease in the friction coefficient and a violation of the contact of the drill pipes with the walls of the well. The presence of supply and pressure pulsations in the flushing fluid flow serves as an additional source of high-frequency oscillations in a stuck drilling tool.

An important element of progressive well construction technology is also the prevention of sticking. Here, special drilling fluids have proven themselves positively. For these liquids, the targeted formation of certain physical and chemical properties is carried out. These properties include helping to reduce the coefficient of friction between the walls of the well and the drill pipes, as well as reducing the stickiness of the filter cake. The listed characteristics for clayey washing liquids can be obtained based on their treatment with surfactants (Fig. 2). However, such treatment naturally affects the other technological properties of the washing liquids, which is clearly shown by the studies carried out.

By analyzing the obtained graphical dependencies (Fig. 2), several important conclusions can be drawn. Surfactants, although on different scales, contribute to a change in the viscosity parameter of the clay drilling fluid. The determining factors here are: the type of surfactant used, its concentration, and the presence of other chemical additives. For an unambiguous understanding of what was formulated, we note that hydromica was

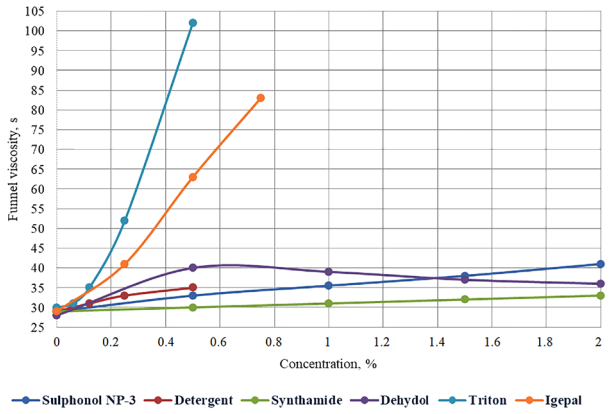

Fig. 2. Values of funnel viscosity for drilling clay solutions treated with different surfactants

used as the dispersed phase of the clayey drilling fluid. The density of this solution was 1,100 kg/m^3. The solution in question was additionally treated with a carbon-alkaline reagent.

The application of the indicated techniques in practice will significantly reduce the time and money spent on constructing wells in difficult conditions. Maintaining the wellbore walls in a stable condition will make it possible to carry out effective cementing work. This circumstance is a factor in preserving a long period of maintenance-free operation for the wellbore. Moreover, it will be accompanied by high quality indicators for the resulting hydrocarbons.

Detailed industrial and laboratory studies have proven the following. The productivity of widely used mechanical methods for drilling various-purpose wells, with a closed circulation of various-type flushing fluids (Fig. 3), depends greatly on the quality of flushing fluids circulating through the wellbore and their technological parameters (density as well as rheological, thixotropic, and filtration parameters). The parameters are determined mainly by the flushing liquid composition. In the process of well drilling, a flushing fluid is saturated with particles of the drilled-out rock (slurry); as a result, its rheological and structural-mechanical indicators increase [28].

The intensity of growth rate of the rheological and structural-mechanical indicators [29] of the applied flushing fluid depends on the following: volume of the drilled-out rock particles, their fractional composition, and colloidal-chemical activity [23]; cleaning degree of the washing liquid; nature of chemical processing and properties of the applied chemical reagents [30]. Other physicochemical factors also have certain influence. In accordance with the above, rational control of the flushing fluid properties is, first of all, effective regulation of the solid phase content in the fluid as well as quantitative and qualitative composition of chemical reagents [31].

The amount of solid phase in the washing liquid affects significantly the service life and reliability of the elements in the circulation system [32], its hydrodynamic characteristics. Correlation of the specified parameter with the values of the mechanical velocity of drilling and stability term of rock-breaking tools (drill bits, crowns) is also rather noticeable. According to the data of the leading USA researchers, even 1 % reduction of the solid phase content in a drill fluid improves well performance on average by 7–10 %. Some industrial-laboratory studies have also shown that when the solid phase content in a washing liquid is reduced by 42–33 %, the bit life can increase potentially by about two times, and the mechanical velocity can increase as well. When diamond tool is used, the development of flushing fluid formulations should provide the need to reduce the solid phase content (up to the complete exclusion) in a flushing fluid (in case of technological possibility and effectiveness of such a procedure). For example, in order to achieve the best technical and economic indicators of core diamond drilling and drilling with the help of systems with removable core receivers, it is suggested to use flushing fluids with a low solid phase content (from 3 to 7 %). Such solutions can also be widely recommended for drilling wells for oil and gas (Table 2).

Flushing fluids indicated in Table 2 in practice (for deep oil and gas drilling conditions) ensure normal passage of clayey rock layers. For such flushing fluids, the circulation regime is maintained without affecting the integrity of the wellbore and the accumulation of cuttings at its bottom.

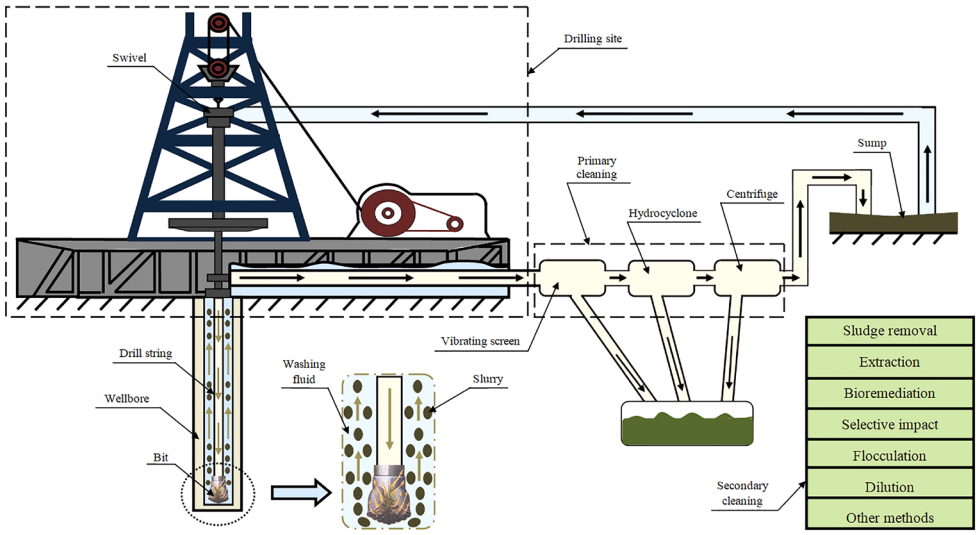

Fig. 3. Example of a schematic representation of the closed flushing fluid circulation within the drilling site

Table 2

Technological properties of drilling fluids for a typical hydrocarbon deposit of the Dnipro-Donetsk depression

Type of a drilling flush fluid	Density ρ, kg/m^3	Viscosity *T*, s	Hydrogen index pH	Static shear stress SSS Θ_1/Θ_{10} (per 1 min/per 10 min), dPa	Filtration *V*, cm^3/30 min	Thickness of a filter cake *K*, mm	Cake friction coefficient CFC
Humate-natrium	1.14	25	8.5	17/39	5.5	0.5	0.048
Polymer-potassium	1.10	28	9.5	31/59	5	0.5	0.052

The potential effectiveness of low-solid flushing fluids increases sharply with the decreasing concentration of solids, and disappears almost completely if the solid content exceeds 7 %. It is because of the fact that in recent years, for certain drilling conditions, so-called low-clay and polymeric flushing fluids with a solid phase content in the initial solution of no more than 6 % have been developed and implemented in the well construction practice. However, use of such flushing fluids turned out to be not as effective as expected, which is dictated by the rapid enrichment of the flushing fluid with the drilled-out rock particles. Due to the mentioned circumstances, it is easy to see that wide implementation of modern composite formulations of flushing fluids into the well construction practice will be effective only when the problem of regulating the number of drilled-out rock particles in them during cleaning and regeneration of circulation systems will be solved. Thus, we emphasize that cleaning of a washing fluid from sludge is an important measure that makes it possible to increase significantly the main technical and economic indicators of drilling various wells [33].

The systems currently used in drilling to clean flushing fluids from sludge do not always meet the above-mentioned requirements. Thus, there is a logical task of developing a method for cleaning washing liquids, which ensures reliable regulation of the solid phase amount in these liquids [26].

In recent years, in connection with the increasing average depth of the constructed wells and worsening drilling conditions, higher requirements have been placed on the flushing fluids, i.e. regarding flotation, inhibition, and lubrication properties. For these conditions, flushing fluids that partially meet the specified requirements were partially developed and successfully implemented (Table 3).

Analysis of the data given in Table 3 allows us to conclude that the drilling fluids proposed for use are of fair-

Table 3

Results of the analysis of technological properties of a drill fluid from a well for a typical hydrocarbon deposit of the Dnipro-Donetsk depression

No.	Parameters of a drill flushing fluid	Design values	Measured index values
1	Density, kg/m^3	1,140	1,165
2	Relative viscosity, s	25–70	48
3	Static shear stress SSS per 1 min and per 10 min, dPa (SSS-2)	30–50/50–90	14/29
4	Static shear stress SSS (GEL) (in 10 s/1 min/10 min), dPa (Ofite 800) at 20 °C	–	10/19/67
5	Filtration index per 30 min, cm^3	6–7	3
6	Filtration index AHI per 30 min, cm^3	–	3.2
7	Cake friction coefficient, mm	1.0	“film”
8	Cake friction coefficient	–	0.0549
9	Hydrogen index of a solution, pH	8.0–10.0	11.4
10	General mineralization, %	–	6.49
11	Concentration of potassium ions, mg/l	–	350
12	Concentration of magnesium ions, mg/l	–	122
13	Colloidal phase content, %	1.9–2.4	1.65
14	Concentration of CO_3^{-2} carbonates, mg/l	–	480
15	Concentration of HCO_3^- bicarbonates, mg/l	–	2,318
16	Content of a hydrocarbon phase, %	–	7
17	Solid phase content, %	14	11
18	Sand content, %	1.0	0.8
19	Potassium chloride content, %	3.0–4.5	5.5
20	Plastic viscosity (*t* °C 20/40/60), mPa · s	–	27/19/16
21	Dynamic shear stress (*t* °C 20/40/60), dPa	–	91/82/53

ly high quality. Such fluids create conditions in the well to eliminate losses, prevent rock falls, swelling of the well walls, and also reduce power consumption for rotating the drill string.

Further expansion of the area of effective use and increase in the volumes of industrial application of new flushing fluids in drilling various-purpose wells is restrained due to the lack of reliable methods and means for cleaning the defined dispersed systems from sludge. Therefore, the main goal of further research is the development of methods for cleaning and chemical treatment of flushing fluids to increase technical and economic indicators of well drilling.

Cleaning in chutes and sumps (separation of dispersed systems in the gravity field) is the most widespread method in the practice of drilling various-purpose wells [8]. In this context, a cleaning process proceeds better, the larger the size and density of the separating particles are, and the lower the viscosity of a washing liquid is. At the same time, the intensity of sludge deposition is influenced by other factors, such as concentration of solid particles, coagulation etc. Our in-depth research along with the studies by other authors testifies to a very unstable operation of cleaning devices, chuting systems, and sedimentation tanks.

A process of removing solid particles from a washing liquid can be accelerated significantly if the latter is strengthened by the application of a field of centrifugal forces. To do that, when drilling wells for oil and gas, hydrocyclones and centrifuges are used, which centrifugal acceleration is hundreds of times greater than the Earth's gravity one. This allows, with high cleaning performance, to ensure the removal of very small particles with sizes of 5 μm and more. As a result, this cleaning method is classified as a fine cleaning of washing fluids from the solid phase. Washing fluid cleaning in such mechanical devices as vibrating screens provides effective cleaning only of large particles with a size of 0.2 mm and larger. However, as our research has shown, when drilling wells with diamond-hard alloy tools, fine-dispersed sludge of two particle size classes is mainly formed, being 80–100 and 1–10 μm. Accumulation of such thin sludge in a washing liquid leads to an increase in both density and viscosity. To remove this sludge from a washing liquid and restore its properties, the methods discussed above are unsuitable or insufficiently effective. Therefore, we analyzed such non-traditional cleaning methods in drilling as filtering, treatment of the solution in a constant electric field, and precipitation of particles due to the introduction of flocculent reagents into the washing liquid. A distinctive feature of these methods is that they help clean a washing liquid to remove even a colloidal-size solid particles.

To achieve the required cleaning indicators of washing liquids, it is necessary to solve a number of problems formulated by following general definitions. The solid phase content in the flushing fluids when drilling wells within the areas with different degrees of rock metamorphism differs significantly. A fractional composition of the solid phase is different when drilling wells in different conditions. For effective rationalization of cleaning systems and regeneration of washing liquids, it is necessary to have comprehensive information about the cleaning capacity of the used chuting systems and sumps. From the viewpoint of their cleaning capacity, the requirements for cleaning devices of drilling rigs should be clearly formulated. Electrochemical cleaning methods are promising as for removing finely dispersed solid phase from drilling fluids; according to their essence, specialized cleaning installations should be offered, and appropriate formulations of washing liquids should be developed [21].

Here it is important to highlight the ecological aspects of the implementation of the hydraulic programme for well flushing. Regardless of the availability of a flushing-fluid cleaning system at the drilling site, formation of significant volumes of broken rock sludge, substandard flushing fluids (they are saturated with the colloidal-size clay particles that cannot be separated by conventional cleaning agents), drilling wastewater etc. will be completely natural.

To isolate colloidal clay from the drill washing fluids, it is necessary to use special chemical reagents – coagulants and flocculants, which are harmless to the environment and allow effective separation of the used cleaning agents into technical water and sludge. Moreover, all the resulting sludge must be properly disposed of in compliance with the requirements for its conversion to an inert state (by mixing the sludge with powdered absorbents and obtaining mineral soil).

The process of cavern formation and subsequent sludge accumulation in the complicated intervals is one of the most difficult types of complications during well construction. It affects fundamentally not only the implementation of drilling operations but also the duration of its maintenance-free service.

When constructing oil and gas wells in clayey layers, it is necessary to provide a set of measures that ensures prevention of intensive cavern formation. When mixing the cementing solution with clay-sludge pastes, there is a sharp drop in the performance indicators of the cement stone in the annular space of a well. That may result in different accidents and its loss. Therefore, the search for ways to eliminate the mentioned shortcomings of existing technologies is a necessary component of a set of measures to increase the reliability of drilling operations. Our research makes it possible to assess the technological features of a well construction cycle at a qualitatively new level from the standpoint of ensuring the exclusion of the negative impact of cavern formation and the processes that accompany it on the quality indicators of drilling operations.

By the detailed laboratory and theoretical studies, the authors of the article established the regularities of the formation of clay-sludge accumulations and their influence on the condition of the cementing solution and the stone formed by them. According to the content of the received data and at the level of inventions, a design of devices for interval treatment of the wellbore constructed in the complicated geological and technical conditions is proposed (Fig. 4).

The device we studied (Fig. 4) includes the following [34]: cylindrical body *1* and elastic mechanisms *2* with blades *4*. Two diametrically opposite grooves *3* are made in the outer surface of the walls of the cylindrical body for placing the corresponding elastic mechanisms with blades. The upper ends of the elastic mechanisms are connected to springs *5*, designed to open and close the

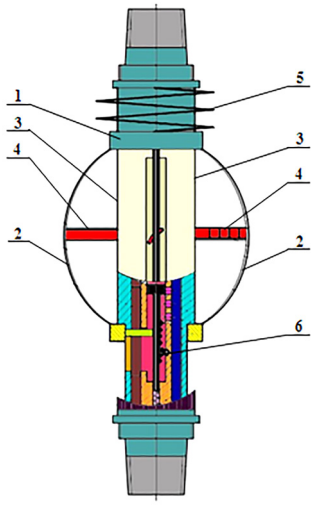

Fig. 4. Schematic of an experimental sample of a wellbore processing device:

1 – cylindrical body; 2 – elastic mechanisms; 3 – grooves; 4 – blades; 5 – spring; 6 – locking element

considered mechanisms relative to the device body. Two sliders are placed in locking element *6*, connected rigidly to the lower ends of the elastic mechanisms, which are capable of moving along the inner wall of the corresponding groove.

The research results were determination of the hydrodynamic characteristics of the model of the interval cleaning device – the speed parameters of active flow (formed due to the operation of a blade organ of the device) and recording of the features of a sludge removal mechanism (Table 4).

While analyzing the received data, the following can be stated. When processing a wellbore complicated by cavernous expansions, reliable removal of sludge accumulations is ensured. In particular, we can observe an increase of 30–40 % in the percentage of C_s in the upward washing liquid flow and an increase of 15–20 % in density ρ and viscosity T. Stability of the mode of sludge accumulation removal from cavernous intervals (expressed in the fact that the controlled indicators of the upward flow of washing liquid C_s, ρ, and T reach their maximum values) is provided at the rotation frequency of the interval cleaning device n = 100–200 min^{-1}. The inclusion of devices for cleaning the wellbore into the drill string will significantly improve the quality of filling the wellbore with cement mortar. In practice, this will make it possible to avoid the occurrence of interlayer migrations of fluids, a decrease in the technological properties of cement stone, and active corrosion destruction of metal casing pipes. Thus, we have substantiated the technological parameters of the device for processing a cavernous zone of the well, basing on the established dependencies of the formation and removal of clay-sludge accumulations, and their influence on the results of well cementing. In addition, the basic principles of the formation of active jets when flowing around the blade element of the device and the nature of their influence on the objects of processing have been identified. Specific recommendations have been also provided for the design of well drilling modes that reduce significantly the intensity of sludge accumulation in cavernous intervals. Among other things, it has been proven objectively that a reliability indicator of the device for wellbore processing is the observance of certain geometric ratios in its design, which correspond to a stable mode of removal of cavernous accumulations. The obtained results of theoretical and laboratory studies are an integral part of the effective technology of wellbore lining and cementing with high technical and economic indicators. Data from the study of sludge accumulation in caverns are basic for the development of rational mode parameters of a well drilling process.

Despite the availability of a natural negative impact on the natural environment during well development of deposits, i. e. soil cover disturbance due to land mineralization, vegetation removal over large areas, disturbance of a hydrological regime of the territories etc., works on

Table 4

Results of studying the interval cleaning device operation

Schematic of the bottomhole assembly of a tool string	Velocity of the upward flow of a flushing fluid in the wellbore, m/s	Rotation frequency of the drill string/device n, min^{-1}	Technological properties of a flushing liquid at the outlet from the circulation system		
			Density ρ, kg/m^3	Viscosity T, s	Sludge content C_s, %
Drill pipes with a bit	0.8	140	1,050	20	0.5
		225	1,050	20	0.6
	1.0	140	1,050	21	0.5
		225	1,050	22	0.6
	1.2	140	1,060	22	0.7
		225	1,060	22	0.7
Drill pipes with a bit and an interval cleaning device	0.8	140	1,230	25	1.4
		225	1,210	26	1.6
	1.0	140	1,190	25	1.3
		225	1,200	25	1.2
	1.2	140	1,180	24	1.0
		225	1,190	24	1.1

the hydrocarbon deposit development must be continued. However, the operations should be accompanied by the development and application of technological measures adequate to the existing conditions to prevent large-scale impact of the considered operations on the environment and localization of such an impact within small areas.

Therefore, the authors of the paper have carried out analytical, laboratory, and partially industrial studies of the main factors (i.e. rationalization of a hydraulic programme of the washing liquid circulation and cleaning; processes of lining and cementing of wells constructed on hydrocarbon deposits). That has made it possible to propose innovative technical and technological methods and techniques for improving quality indicators of the specified operations of the cycle of obtaining products in such specific mine workings as wells.

Conclusions. According to the obtained results of the considered studies, the following can be noted. In order to describe the properties of the drilled-out rock, carry out sludge analysis, control the drilling parameters, control the solid phase content in the drilling fluid, and preserve the environmental balance, it is necessary to involve geological and technological research in a well. The developed impact devices can be successfully used when performing operations to eliminate complications in the form of stuck drilling tools. Moreover, the operation of such devices is adjusted using surface mud pumps. It has been shown that by introducing surfactants into the flushing fluids, it is possible to avoid the appearance of drill pipes sticking to the walls of the well. The latter circumstance helps prevent sticking. Being used in the complex mining and geological conditions, drilling fluids contain active sludge, which contributes to the increase in viscosity and static shear stress of these fluids; moreover, the sludge can become a soil and groundwater pollutant. The reliability of operations in a well, as a channel intended for exploration or environmentally safe development of mineral deposits, is determined almost entirely by the quality of the work on washing, lining, and cementing in its shaft. The measures related to the processing of a wellbore, i.e. its cavernous intervals (in the more general case of local expansions) – objects of intensive sludge accumulation with all the following consequences make up a particularly significant stage in the cycle of these operations. The above applies equally to oil and gas, hydrogeological and geotechnological wells, which is often not given due attention. Consequently, the search for ways to improve the scheme of preparatory operations is a very relevant and promising trend.

References.

1. Ouadfeul, S.-A., & Aliouane, L. (2020). *Oil and Gas Wells*. IntechOpen. ISBN 978-1-78984-631-7.

2. Pavlychenko, A.V., Ihnatov, A.O., Koroviaka, Y.A., Ratov, B.T., & Zakenov, S.T. (2022). Problematics of the issues concerning development of energy-saving and environmentally efficient technologies of well construction. *Paper presented at the IOP Conference Series: Earth and Environmental Science*, *1049*(1), 012031. https://doi.org/10.1088/1755-1315/1049/1/012031

3. Hapich, H., Zahrytsenko, A., Sudakov, A., Pavlychenko, A., Yurchenko, S., Sudakova, D., & Chushkina, I. (2024). Prospects of alternative water supply for the population of Ukraine during wartime and post-war reconstruction. *International Journal of Environmental Studies*, 1-12. https://doi.org/10.1080/00207233.2023.2296781

4. Caenn, R., Darley, H.C.H., & Gray, G.R. (2017). *Composition and Properties of Drilling and Completion Fluids*. Elsevier Science & Technology. ISBN: 978-0-12-804751-4.

5. Liu, G. (2021). *Applied well cementing engineering*. Gulf Professional Publishing. ISBN: 978-0128219560.

6. Skinner, L. (2021). *Well Integrity for workovers and recompletions* Gulf Professional Publishing. ISBN: 978-0128182086.

7. Sudakov, A., Dreus, A., Ratov, B., Sudakova, O., Khomenko, O., Dziuba, S., Sudakova, D., Muratova, S., & Ayazbay, M. (2020). Substantiation of thermomechanical technology parameters of absorbing levels isolation of the boreholes. *NEWS of National Academy of Sciences of the Republic of Kazakhstan*, *2*(440), 63-71. https://doi.org/10.32014/2020.2518-170x.32

8. Guan, Z., Chen, T., & Liao, H. (2021). *Theory and technology of drilling engineering*. Springer Singapore. ISBN: 978-981-15-9326-0.

9. Speight, J.G. (2017). *Rules of Thumb for Petroleum Engineers*. John Wiley & Sons, Inc. ISBN 978-1-118-59526-8.

10. Islam, M.R., & Hossain, M.E. (2020). *Drilling Engineering*. Elsevier Science & Technology Books. ISBN: 9780128201930.

11. Ramsey, M.S. (2019). *Practical wellbore hydraulics and hole cleaning*. Gulf Professional Publishing. ISBN: 978-0-12-817088-5.

12. Ma, Y., & Xu, Y. (2022). Research into technology for precision directional drilling of gas-drainage boreholes. *Mining of Mineral Deposits*, *16*(2), 27-32. https://doi.org/10.33271/mining16.02.027

13. Skalle, P. (2015). *Drilling fluid engineering*. bookboon.com. ISBN 978-87-403-1139-6.

14. Ihnatov, A.O., Koroviaka, Y.A., Haddad, J., Tershak, B.A., Kaliuzhna, T.M., & Yavorska, V.V. (2022). Experimental and theoretical studies on the operating parameters of hydromechanical drilling. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (1), 20-27. https://doi.org/10.33271/nvngu/2022-1/020

15. Sweatman, R. (2015). *Well cementing operations*. International Association of Drilling Contactors. ISBN: 978-0-9909049-8-4.

16. Ighnatov, A. (2016). Research into parameters characterizing the process of withdrawing clay-mud formations from bore hole vuggy zones. *Mining of Mineral Deposits*, *10*(1), 63-68. https://doi.org/10.15407/mining10.01.063

17. Ratov, B., Fedorov, B., Sudakov, A., Taibergenova, I., & Kozbakarova, S. (2021). Specific features of drilling mode with extendable working elements. *E3S Web of Conferences*, *230*, 01013. https://doi.org/10.1051/e3sconf/202123001013

18. Guo, B., Liu, X., & Tan, X. (2017). *Petroleum production engineering*. Gulf Professional Publishing. ISBN: 9780128096123.

19. Ratov, B.T., Chudik, I.A., Fedorov, B.V., Sudakov, A.K., & Borash, B.R. (2023). Results of production tests of an experimental diamond crown during exploratory drilling in Kazakhstan. *SOCAR Proceedings*, (2), 025-031. https://doi.org/10.5510/ogp20230200842

20. Khosravanian, R., & Aadnoy, B.S. (2022). *Methods for petroleum well optimization*. Gulf Professional Publishing. ISBN: 9780323902311.

21. Carter, T.S., Lyons, W.C., & Lapeyrouse, N.J. (2023). *Formulas and Calculations for Drilling, Production, and Workover*. Gulf Professional Publishing. ISBN: 978-0-323-90549-7.

22. Sharma, K.K., & Sharma, L.K. (2016). *Physical chemistry*. Vikas Publishing House Pvt Ltd. ISBN: 978-93-5259-042-1.

23. Modi, P.N., & Seth, S.M. (2019). *Hydraulics and fluid mechanics including hydraulics machines* Amit Publisher and Distributors. ISBN 978-81-89401-26-9.

24. Haldar, S.K. (2020) *Introduction to mineralogy and petrology*. Elsevier Inc. ISBN: 978-0-12-820585-3.

25. Ihnatov, A.O., Haddad, J., Stavychnyi, Y.M., & Plytus, M.M. (2022). Development and Implementation of Innovative Approaches to Fixing Wells in Difficult Conditions. *Journal of The Institution of Engineers (India): Series D*. https://doi.org/10.1007/s40033-022-00402-5

26. Ping, W.L. (2016). *Foam drilling cycle theory and practice*. Petroleum Industry Press. ISBN: 978-7518310777.

27. Longo, S., Tanda, M.G., & Chiapponi, L. (2020). *Problems in hydraulics and fluid mechanics*. Springer, Cham. ISBN: 978-3-030-51386-3.

28. Walter, H.J. (2017). *Deep Well Drilling*. Forgotten Books. ISBN: 978-0265728048.

29. Birdi, K.S. (2020). *Surface and Colloid Chemistry* CRC Press. ISBN: 978-0367515973.

30. Don, W.D. (2019). *Oilwell Drilling Engineering*. ASME Press. ISBN: 978-0791861875.

31. Rahul, S., Pankaj, T., Ramgopal, V., & Uppaluri, S. (2021). *Chemical Nanofluids in Enhanced Oil Recovery* Publisher: CRC Press. ISBN: 9781003010937.

32. Lutchmedial, C. C. (2016). *Safety & Health for the Oil & Gas Industry*. Oshe Consultants. ISBN: 978-0692514825.
33. Jadhav, S. (2015). *Oil & Gas Production*. Scitus Academics Llc. ISBN: 978-1681174259.
34. Ighnatov, A. (2016). Technological characteristics of the device for bore hole cleaning. *Mining of Mineral Deposits*, *10*(2), 85-90. https://doi.org/10.15407/mining10.02.085

Розробка перспективних технологічних рішень у процесах спорудження свердловин

А. О. Ігнатов[*1], *О. О. Азюковський*[1], *Є. М. Ставичний*[2], *С. А. Рибачук*[2], *І. К. Аскеров*[1], *Д. Сала*[3]

1 – Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна
2 – Публічне акціонерне товариство «Укрнафта», м. Київ, Україна
3 – Гірничо-металургійна академія імені Станіслава Сташиця, м. Краків, Республіка Польща
[*] Автор-кореспондент e-mail: ignatov.a.a@nmu.one

Мета. Встановлення параметрів циклів буріння, промивання та кріплення свердловин, споруджуваних в осадових породах, що схильні до порушень цілісності свердловини, поглинань промивальної рідини та прихватів бурильних труб, а також розробка на базі вказаних параметрів ефективних прийомів ліквідації свердловинних ускладнень.

Методика. Геологічна будова родовищ вивчалася з урахуванням результатів геофізичних і прямих свердловинних досліджень. Висновки щодо складності геологічних умов у свердловині базуються на статистичній інформації. Технічні й технологічні параметри пристроїв для ліквідації ускладнень і очищення свердловини вивчались на стенді, оснащеному буровим верстатом ЗІФ-650М, насосами НБ-4 і НБ-32, манометрами, витратоміром, тахометром, координатником. Для дослідження технологічних властивостей промивальних рідин застосовувалися уніфіковані методики й прилади. Також застосовувалось математичне й фізичне моделювання з обробкою результатів досліджень у середовищі MATHCAD і EXCEL.

Результати. Виконано комплексне дослідження складових процесу спорудження свердловин на прикладі родовищ Дніпровсько-Донецької западини. Доведено, що виключно висока якість робіт із буріння, промивання та кріплення свердловини дозволить проводити видобуток вуглеводнів із максимальними якісними показниками. В окремому порядку розглянуте питання технічного й технологічного супроводження робіт із ліквідації свердловинних прихватів. Вивчені особливості організації промивання вибою та стовбуру свердловини за замкнутої системи циркуляції спеціальних бурових промивальних рідин. Надана характеристика процесам підготовки свердловини до кріплення й запропоновано регламент проведення робіт з очищення ускладнених ділянок стовбура свердловини від глинисто-шламових паст.

Наукова новизна. На підставі даних щодо особливостей спорудження свердловин в умовах Дніпровсько-Донецької западини доведено, що створення раціональної схеми розробки родовищ базується на необхідності реалізації комплексних програм із буріння, промивання та кріплення свердловин, які виключають можливий прояв геолого-технічних ускладнень.

Практична значимість. Наведені результати можуть слугувати основою прогресивних методик спорудження свердловин, що розташовуються у глинистих товщах, схильних до виникнення прихватів і каверн.

Ключові слова: *свердловина, промивальна рідина, прихват бурильних труб, гірська порода, кріплення*

The manuscript was submitted 23.12.24.