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WELL REHABILITATION IS A PROMISING AREA FOR INCREASING HYDROCARBON PRODUCTION

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Abstract: This article provides a general description of the potential for increasing hydrocarbon production in Ukraine through the restoration of oil and gas wells by drilling sidetracks, based on an analysis of the fields resource potential. The main factors for selecting candidate wells for sidetracking are described. Each stage of well selection set during the design and direct drilling operations is supported by practical results. The main technical and technological solutions for well rehabilitation are described, taking into account the possibility of minimizing the cost of sidetrack drilling. The approaches to selecting and designing a sidetracked well profile are analyzed in detail. The technological scheme for drilling a sidetrack and the layout of the bottom of the drill string are substantiated. An algorithm for calculating the required length of weighted drill pipes and the length of the casing exit for sidetracking is presented. The peculiarities of using drilling fluids for deepening wells with an assessment of the impact on the coefficient of core permeability recovery are presented. The requirements for high-quality well casing are analyzed on the basis of an assessment of the possibility of running the casing in certain areas of sharp changes in the curvature parameters when drilling a well with a small-sized rock-destroying tool. The main functional criteria of the applied buffer systems are characterized and the necessity of using sedimentation-stable dispersion-reinforced grouting systems for high-quality cementing of sidetracks in conditions of small annular gaps is substantiated.

KEYWORDS: Well rehabilitation, wellbore profile, directional drilling, casing exit, wedge deflector, well cementing

1 Introduction

The oil and gas industry is a fundamental component of the country's socio-economic development. For instance, in 2020, Ukrnafta, the largest oil producer in the country with 21,300 employees, paid UAH 47.5 billion in taxes [1]. Domestic hydrocarbon production guarantees price stability in the energy market and reliable oil and gas transit, as well as the operation of underground storage facilities, remain a guarantee of energy stability on the European continent.

The state policy's priority objectives in the field of energy independence include increasing domestic energy production. According to analysts, the share of oil and natural gas in the structure of final consumption remains the highest and has exceeded 50% throughout Ukraine's years of independence [2].

At the enterprises of JSC "Ukrgazvydobuvannya" to ensure the stabilization of hydrocarbon production, various measures are being developed, which are aimed at preventing possible complications, in particular, the accumulation of liquid in the well flowlines, as well as the formation of hydrates. Thus, to prevent the accumulation of liquid

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pollution in the inner cavity of the well flowlines, it is advisable to periodically clean them by creating a high-speed gas flow [3-4], using a surfactant solution [5-6], using foam of different multiplicity [7-8] and other methods . The optimal method should be chosen based on experimental studies. To prevent hydrate formation, it is necessary to take measures in a timely manner [9-10].

Over the 250 years of operation of the oil and 100 years of the gas industries of Ukraine, more than 250 oil and gas fields characterized by complicated mining and geological conditions, tens of thousands of engineering facilities for hydrocarbon production, ranging from primitive (wells, pits, diggings) to complex engineering structures such as deep wells, have become critical energy infrastructure in the oil and gas complex of Ukraine. Most of these facilities, for various reasons, are inactive or inefficiently used, posing a threat of potential pollution of large urbanized areas. First of all, these are the hydrocarbon deposits of Boryslav, Dolyna and Nadvirna oilfield districts, which are directly adjacent to the resorts of Bukovel, Morshyn, Skhidnytsia, and Truskavets. In particular, Ukrnafta has more than 4,300 idle wells on its balance sheet, the lion's share of which, almost 3,100, are located in the Western Oilfield Region (WOR).

The main difficulties faced by industrial producers in the WOR in gathering, treating and transporting oil include:

- intensive accumulation of asphaltene-resinous paraffinic deposits (ARPD) in tubing (pumping and compressor pipes) of wells and pipelines, which reduce the pipeline cross-section and, in some cases completely prevent the operation of the well and transportation of its products;
- formation of stable oil emulsions, which can be stabilized by mechanical impurities, resins, asphaltenes, paraffins, chemical reagents, etc;
- ineffective separation of well products due to the presence of paraffins, resins and asphaltenes that contribute to an increase in the oil pour point (up to + 20 °C);
- ineffective treatment of associated reservoir water produced with oil.

The main complications listed above are mainly related to the properties of oil and the conditions of its collection, treatment and transportation [11]. To eliminate these complications, industrial production companies apply a variety of basic, standard measures, which include: heating of well products, use of chemicals to remove ASPW deposits, use of demulsifiers to demulsify oil, improvement of separation efficiency, etc. The above-mentioned basic measures are not always effective, so companies develop and implement innovative technologies and measures [12-13] including the use of ultrasonic and wave methods of processing well products and chemicals with the use of new high-performance equipment.

The return of emergency, idle or abandoned wells to the fund to obtain additional hydrocarbon production is not a new method. Since the mid-1950s, oil companies have been re-entering old wells and drilling sidetracks to bypass areas of contaminated reservoirs or mechanical obstructions in the well, thus saving material and financial resources [14].

The structure of productive formations in most fields and areas of Ukraine includes significant hydrocarbon reserves concentrated in low-permeability reservoirs. At one time, based on Ukrnafta's analysis, the share of hard-to-recover reserves in the structure of current recoverable oil reserves (class 111+121) was about 63%, while reserves in low-permeability reservoirs accounted for more than 60%. In the current recoverable reserves of oil class 122, hard-to-recover reserves accounted for more than 70%, while reserves associated with low-permeability reservoirs accounted for about 97%. Productive reservoirs with low-permeability reservoirs are characterized by complex man-made processes due to the fluidity of filtration and capacitive properties along the section of the productive layer, changes in their saturation parameters and thermobaric conditions, as well as difficult conditions for their recovery. Hydrocarbon production from such reservoirs requires the use of modern technological solutions, among which horizontal well drilling plays an important role. Taking into account the difficulties with land allocation, as a result of all this, wells usually have a special profile and design [15]. The process of drilling a new well requires solving the troublesome issue of land allocation and attracting significant investments for well construction. All mining and geological factors should be analyzed in detail when drilling wells, especially in environmentally sensitive areas [16]. The drilling of wells in thick geological deposits requires a comprehensive solution to drilling problems with ensuring wellbore stability [17]. One of the methods to accelerate the commissioning of wells and increase hydrocarbon production is to drill sidetracks from already drilled wells. In accordance with the Law of Ukraine No. 2314-VIII dated March 1, 2018 "On Amendments to Certain Legislative Acts of Ukraine Regarding Deregulation in the Oil and Gas Industry", there is no need to allocate a land plot, so to speak, from scratch. The work is carried out at existing well sites, to which the territory is brought to accommodate the necessary drilling equipment. This is especially true in the Carpathian region, where the tourism industry is developing rapidly and the area of land in nature reserves is increasing every year.

2 Analysis and research results

Based on the experience of drilling operations, Ukrnafta specialists have developed and implemented the technology of sidetracking and further deepening based on the available resources and drilling rig fleet. In recent years, up to ten wells have been restored by sidetracking, including two wells each at Dolyna and Pivnichna Dolyna fields, three wells at Bytkiv-Babche field, one well at Oriv-Ulychno field, etc. Technical and technological solutions have been developed to restore 11 wells at the Oriv-Ulychno field. Based on the planned number of wells to be rehabilitated, the work will take about three years, provided that two drilling rigs are used.

Implementation of the developed technical solutions at the above wells would increase oil production by 333.305 thousand tons and gas production by 447.304 million m^3. Net profit calculated based on the current cost of energy resources in 2021 would have amounted to UAH 691.51 million [18].

Similar work was carried out on a number of other fields in the WOR, which resulted in 14 wells being recommended for rehabilitation. If we take into account the wells located in the Eastern Oilfield Region (EOR) of Ukraine, this number amounts to 64 wells.

In general, a titanic amount of work was done to select candidates for sidetracking, including analysis of the current state of wells, their construction experience, workovers and stimulation methods, and production performance of not only potential candidates but also the wells in the field. Specialists in various fields were involved, including drilling, geology, geophysics, development, production, stimulation, and economists. In total, we processed data from more than 150 wells.

However, the ambitious sidetracking project was not implemented. One of the biggest obstacles in the implementation of the plans was the fact that the company had the opportunity to use existing heavy drilling rigs, but more appropriately mobile rigs with a lifting capacity of 120 tons – 180 tons, in some cases – 225 tons. The use of these rigs would have been accompanied by significant time and financial costs. Purchasing or contracting mobile rigs is also a significant investment. As a result, these costs are borne by the payback period of the wells, which is estimated to exceed five years. Against the backdrop of then current price environment in the oil market and military operations in the country, the risks of losing the necessary investments to implement the SAFE project were too high, even though this method is a resource-saving direction, since the cost of well recovery does not exceed 60% of the cost of drilling a new well (including savings in land acquisition, infrastructure construction, etc.) [19].

So, what are the main challenges faced by specialists during the design and direct implementation of work on the wells, you may ask. Let us try to systematize and provide short but comprehensive answers.

The first aspect is to find candidate wells for rehabilitation.

Since the main task set for a candidate well for sidetracking is to recover residual hydrocarbon reserves, the selection of candidates is based primarily on this condition.

The selection of wells for sidetrack drilling is based on the geological and hydrodynamic model of field development and the feasibility study based on the expected flow rate, taking into account the technical feasibility of drilling and safe sidetrack installation.

The technical feasibility of these operations is most strongly influenced by the diameter of the production casing run. The best option, in terms of sidetracking work, well casing, cementing, further operation and workovers, is the existing casing with diameters of 177.8 mm, 168.3 mm and 146.0 mm. As for the wells cemented with 146 mm casing, based on the available technical and technological capabilities, it is advisable to consider well recovery at insignificant (within 100 m) design bottomhole deviations from the drilling point in the calculated azimuth using unguided BHAs. In a well where a production casing with a diameter of 139.7 mm has been run, even with a good technical condition of the casing, there are some technical difficulties, especially with pipe wall thicknesses of more than 7 mm. Work in such a well requires the use of small-diameter drilling tools, in particular, 98.4 mm diameter deepening bits. Such a nominal borehole diameter significantly complicates the requirements for the successful implementation of the design profile of the side track, high-quality fastening and further operation.

The second aspect is the selection and construction of the optimal type of sidetrack profile.

The sidetrack profile is selected based on the following criteria:

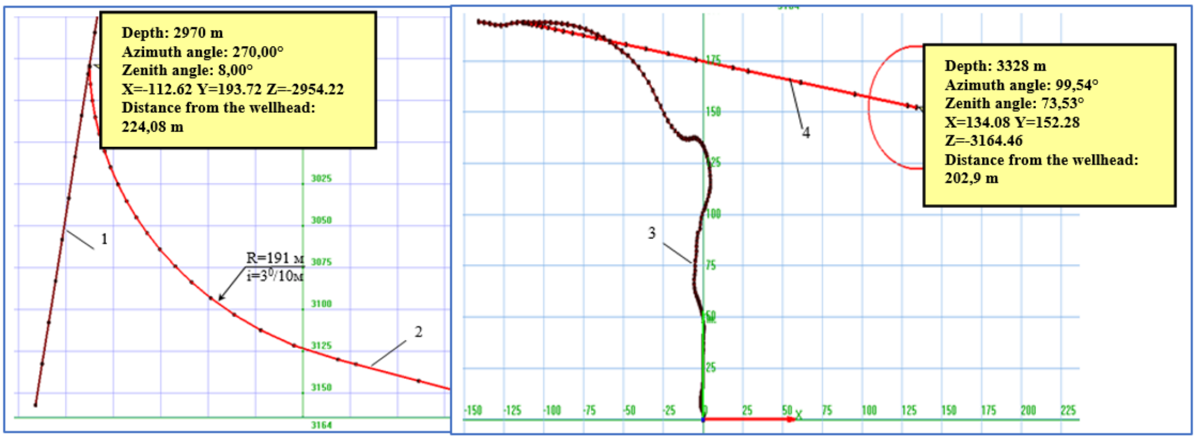
- opening of the productive horizon in accordance with the planned indicators - the required angles of entry into the formation (zenith and azimuthal angles) at a given vertical depth and distance from the wellhead while ensuring the minimum length of the sidetrack;
- the possibility of trouble-free well completion and avoidance of intersection with the wellbore of neighboring wells (anti-collision);
- free passage of the BHA, conducting navigation measurements during drilling with the help of a telecommunication system, geophysical surveys;
- possibility of completion of the side track according to various schemes;
- the ability to run and operate production equipment.

According to [20], casing exit and drilling of a sidetrack is carried out according to the conventional type profiles (in the same plane), which are a curved line with one or more straight and curved (with a certain radius of curvature) sections, or spatial type profiles, which are represented by a spatial curved line. The most common types of sidetrack profiles are flat-type profiles.

The main difference in the design of sidetrack profiles compared to the design of directional or horizontal well profiles is that the curvature parameters of the actual wellbore must be taken into account. The selected casing exit point will be characterized by certain values of zenith and azimuth angles, usually different from zero. Accordingly, the drilling direction (drilling azimuth) must be calculated based on the actual departure of the cutting point from the wellhead at a certain azimuth.

For example, in order to achieve the specified design parameters of the sidetrack in well 53 of the Oriv-Ulychno field, namely, the horizontal displacement of the bottom hole from the wellhead at a depth of 3165 m, at an azimuth of 40° should be at least 200 m, according to analytical calculations and graphical constructions, it is necessary to drill at an azimuth of 99.5° from a certain drilling point of 2970 m, with a radius of curvature of 191 m, the distance from the place of tapping to the design bottom hole will be 244.6 m. The calculated solutions ensure the drilling of the sidetrack with the optimal spatial architecture (the drilling interval consists of areas of curvature gain and stabilization) and satisfies the conditions for the opening of the productive horizon - the angle of entry into the productive formation is 52°, the length of the sidetrack along the trajectory is 358 m, of which 53 m is located in the productive formation.

Fig. 1 shows the actual and design vertical and horizontal projections of the wellbore profiles of well 53 of the Oriv-Ulychno field.



1 – vertical projection of the actual wellbore profile
2 – vertical projection of the design profile of the wellbore
3 – horizontal projection of the actual wellbore profile
4 – horizontal projection of the design profile of the wellbore

Fig. 1. Actual and design vertical and horizontal projections of the wellbore profiles of well 53 of the Oriv-Ulychno field

The main thing in designing the sidetrack profile configuration is to determine the radius of curvature, which is obtained using modern technical means and technologies to ensure the possibility of opening productive formations at a given angle, fixing this wellbore with a casing string and producing hydrocarbon fluid with the necessary underground equipment.

According to [21], the radius of curvature R, in meters, which can be obtained by a BHA that includes a downhole motor with a device with a certain axis skew (AS), is determined by the formula:

$$R = \frac{l_1 + l_2}{2 \cdot \sin(\gamma + \beta)}, \tag{1}$$

where l_1 is the length of the BHA elements located below the AS, m; l_2 is the length of BHA elements located above the AS, m; γ is the angle of skew of the axes, deg; β is the skew angle due to the gap between the bit and the deflector body, deg, determined by the formula:

$$\beta = \mathrm{arctg}\left(\frac{D - d_{dm}}{2 \cdot l_1}\right), \tag{2}$$

where D is the diameter of the bit, mm; d_{dm} is the diameter of the downhole motor, mm.

The radius of curvature R_1, in meters, with a known intensity of the set or decline of the zenith angle of the borehole, is determined by the formula:

$$R_1 = \frac{573}{i_{10}}, \tag{3}$$

where i_{10} is the intensity of the gain or loss of the barrel angle of inclination, degrees per 10 m.

According to [21], the radius of curvature up to 250-280 m and the intensity of curvature change from 2.0º to 2.5º per 10 m of penetration meets all the requirements for drilling and casing directional wells.

With the deterioration of the structure of hydrocarbon reserves and at the late stages of field development, leading foreign oil and gas companies are widely using the horizontal completion sidetrack drilling technology. Cracking a productive formation with a horizontal borehole increases well productivity by increasing the filtration area, the degree of hydrocarbon recovery, and minimizes the possibility of water inflow during operation, which is important for low-permeability horizons and reservoirs with vertical fractures [22]. According to some studies, the productivity of horizontal wells is 4 to 16 times higher than that of vertical wells.

If it is impossible to implement a sidetrack with a horizontal casing, it is advisable to provide an angle of entry into the productive horizon of at least 30°. This will increase the drainage area of the formation (Fig. 2) and, as a result, increase the well flow rate. According to some estimates, an increase in the angle of entry into the formation from 10° to 45° is accompanied by a flow rate increase of up to 30%, and up to 60%, the flow rate increase can be 50%.

An example of a profile implementation with a short radius of curvature and horizontal sidetrack termination according to [23].

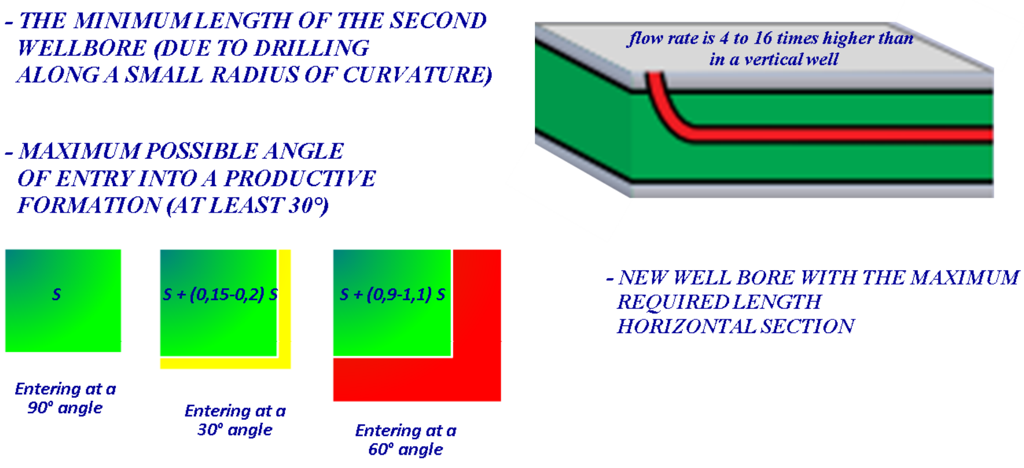


Fig. 2. Basic requirements for sidetracking parameters to increase hydrocarbon production

Production well Alturitas 22, flow rate 47 m^3/d. It was decided to increase the flow rate by drilling an additional horizontal sidetrack. A 6-meter-long casing exit was cut out of a wedge deflector installed at a depth of 3,321 meters, of which 3 meters were drilled partially through the rock. A hydrocarbon-based drilling mud was used. When drilling 26 meters, the zenith angle was 90º. The horizontal section of the second well was located in the interval 3349 – 3354 m in the productive horizon. The length of the drilled horizontal section is 589 meters. After development, the flow rate was 318 m^3/d.

The third aspect was the choice of the technological scheme for sidetrack drilling.

At present, there are three technological schemes for sidetrack drilling:

- cutting a section of the casing and drilling from the cement plug (Fig. 3);
- casing exit and drilling from a wedge deflector (Fig. 4);
- drilling from under the casing shoe.

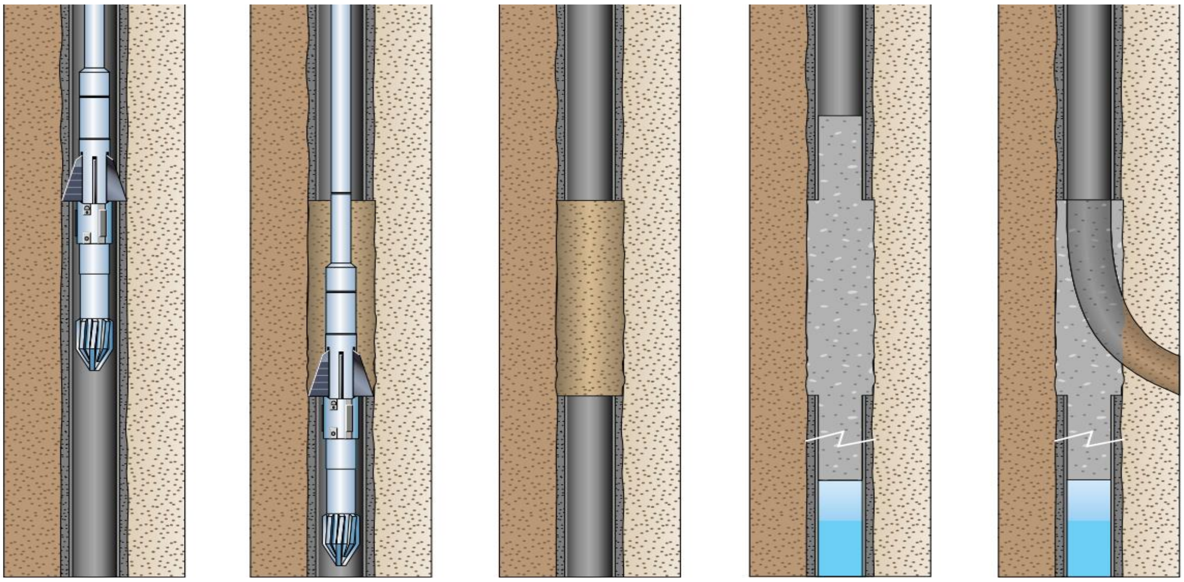


Fig. 3. Scheme of sidetrack drilling from a cut section of casing from a cement plug

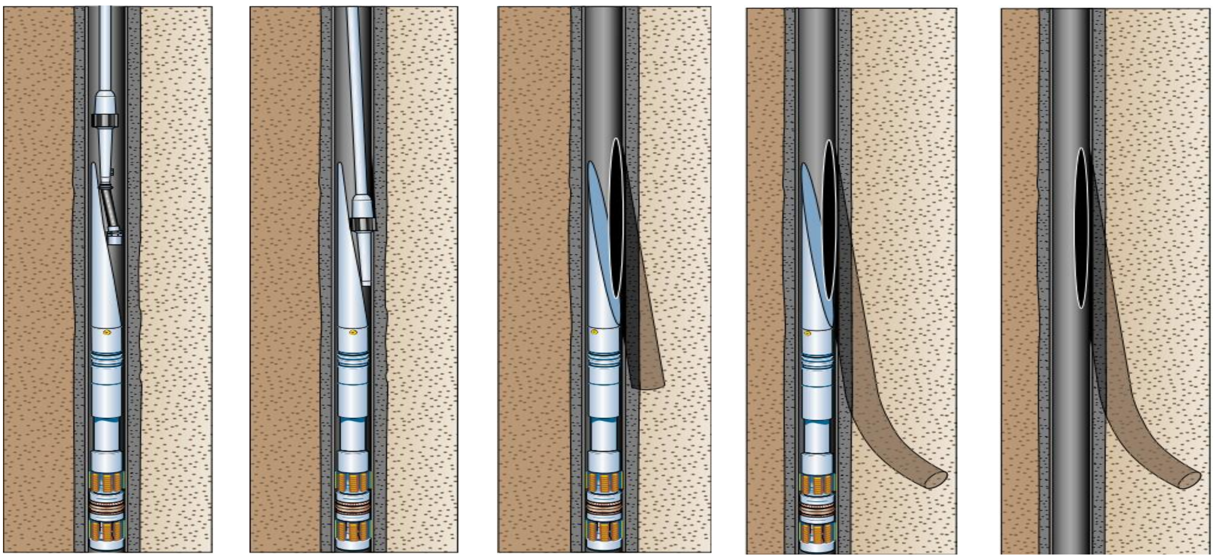


Fig. 4. Schematic of casing exit and sidetrack drilling from a wedge deflector

The choice of a specific drilling scheme is based on the analysis of geological information, the condition of the casing and cement stone behind it, as well as the availability of the necessary equipment and materials for the implementation of a particular option.

At present, the most common variant of the sidertacking scheme is the one with a casing exit. However, Ukrnafta's specialists have implemented the projects of the sidetracking according to all three of the above options.

For the continuous milling of the casing section, a domestic device was used, which was once manufactured at the Karpatnaftoburmash plant in Kalush. The universal cutting device UCD-114 allows for work in casing with a diameter of 140-146 mm. The output of the cutters from the device, which are used to fracture the casing wall, is caused by the pressure drop when the drilling mud is fed through the device. This device has a fairly simple and straightforward design and principle of operation. However, the main drawback of its use is the frequent failure of the cutters (breakage, blunting), and, as a result, a long procedure for cutting the column, which in some cases, such as in well 318 of the Dolyna field, lasted 15 days instead of the planned three. The reason for this is the use of low-efficiency cutting elements (specialized cutters have not been manufactured due to the breakdown of production chains since the mid-1990s).

The technology of casing exit involved the use of a stationary wedge deflector of our own design, which was fixed in the well with a cement plug (Fig. 5). The deflector wedge, assembled according to the image in Fig. 5, was lowered on drill pipes to a predetermined depth (2-3 m above the artificial bottom hole – the roof of the cement plug, the head of the drill pipe or tubing). The deflector wedge was oriented in the required direction, after which it was installed cement plug while creating circulation through the flushing hole. After the plugging mud was pumped into the well in the interval of the wedge deflector location and 12-25 m above it, the screw was cut by lowering the tool and unloading part of the tool weight onto the artificial bottom hole. The transport nozzle was raised above the head of the wedge deflector and the well was flushed to remove the plugging fluid above the required depth to the surface. After that, the tool was lifted to the surface and the well was left for 72 hours of WOC – waiting on cement. After that, we assembled the assembly for casing exit and proceeded with the specified work.

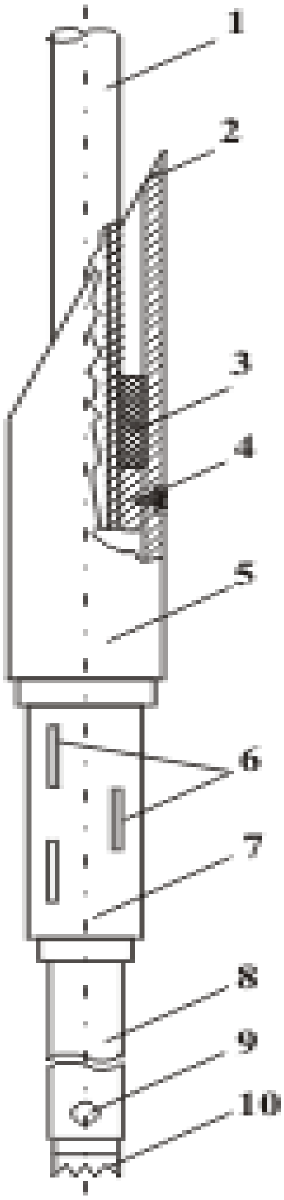
In the world practice, stationary and removable wedge deflectors, the so-called whipstocks, which are fixed in the casing with a special anchor with dies, are widely used.

The technology of sidetrack drilling from under the casing shoe, if mining and geological conditions allow it, is the least expensive. In this case, after drilling the casing equipment (cement plugs, stop clutch, check valves and shoe), the well is deepened to reach the open hole and further drilling is carried out according to the established trajectory.

The fourth aspect is the choice of layouts for drilling from the cut-out section of the casing, casing exit, and drilling the sidetrack.

The technological solutions for drilling the sidetrack from the cut-out section implemented by Ukrnafta were based primarily on the use of existing equipment and material resources and were as follows.

After cutting out the required section of the casing, working out and templating the open hole with a cutting device with slotted cutters, flushing the well until the metal cuttings were completely removed, and determining the actual geometric dimensions of the open hole section using a logging tool, a cement plug was installed. The plug was installed so that its upper level was located 20-25 m above, and the lower level was 30-35 m below the cut-out section of the casing.



1 – transport pipe;

2 – inclined plane;

3 – gland seal;

4 – shear screw;

5 – wedge-deflector;

6 – centralizers;

7 – drill collar;

8 – support pipes (drill pipe, tubing);

9 – flushing hole;

10 – support (ring cutter, oblique cut)

Fig. 5. Design of a stationary wedge deflector

After 72 hours of WOC, a roller cutter bit (e.g., 120.6 ST-CV) or a milling cutter designed to drill cement stone was lowered into the well. The cement plug was drilled to the depth of the upper part of the cut-out section of the casing and its strength was checked by unloading part of the weight of the drilling tool.

Work practice has established that the cement plug can be used for sidetracking if the bearing capacity of the plug is tested with an axial load of 50 kN on a bit with a diameter of 120.6 mm and 70 kN on a bit with a diameter of 139.7 mm, which meets the established requirements.

To directly drill the sidetrack, a BHA was run into the well, including a downhole motor with an axle skewing mechanism, a tele-system (to ensure the tool orientation), spiral drill collar (length according to calculations) and drill pipes.

After removing the influence of magnetic interference by pulling the assembly out of the well for a length of at least 30 meters, the first measurement of the borehole curvature parameters was performed and, if necessary, adjustments were made. To stabilize the zenith angle, a calibrator (centerer) with a diameter of 1 to 2 mm smaller than the bit was included in the assembly above the downhole motor.

The calculation of the required cutting length of the casing section is carried out according to the All-Union Research Institute of Drilling Equipment methodology [24].

For casing exit, Ukrnafta specialists used a setup that included a reamer or window mill, drill collar, and drill pipes. The geometric dimensions of the assembly elements were determined depending on the diameter of the casing string in which the work was performed.

In order to maximize the curvature, the maximum length lDC, m, was determined by the formula according to [25]:

$$l_{DC} = \sqrt{\frac{k \cdot E \cdot d_{DC} \cdot D_в}{[\sigma_T]}} \tag{4}$$

where k is a coefficient that takes into account the actual curvature of the well (for casing strings k = 2); E – elastic limit, N/m^2 (for steel $E = 2{,}1 \cdot 10^{11}$, N/m^2); d_{DC} – outer diameter of the DC, m; D_i – the inner diameter of the casing, m; $[\sigma_T]$ – yield strength of the drill collar material, N/m2 (for steel grades 40X and 40XH [σ_T] = $3{,}4 \cdot 10^8$, N/m^2).

During milling, the drillstring rotation torque was monitored by torque meter readings (optimal torque Mkr = 4.0 – 7.0 kN·m). An increase in the axial load above the recommended 5-12 kN on the reamer/window mill led to premature wear of the cutting elements and an increase in torque. As a result, it is possible to obtain a hole of a shorter length than required.

The maximum length of the hole l_h, m, that can be obtained when milling the casing with reamers, is determined by the formula according to [25]:

$$l_h = \frac{D_r + d_r}{2 \cdot tg\alpha_0} + \frac{D_r - d_r}{2 \cdot tg\frac{\alpha_r}{2}} + b \tag{5}$$

where D_r, d_r – the largest and smallest diameters of the reamer, m; α_0 – the angle of inclination of the inclined plane of the deflector wedge, deg; α_r – the angle of conicity of the reamer, deg; b – the length of the cylindrical part of the reamer, m.

If necessary, based on the results of geophysical surveys (coupling locator), the length of the borehole was increased by a configuration that included a bit, a short DC nozzle, a cylindrical pumpkin-shaped reamer, and drill pipes. The length of the tubing with the DC is equal to the required length of the slot enlargement.

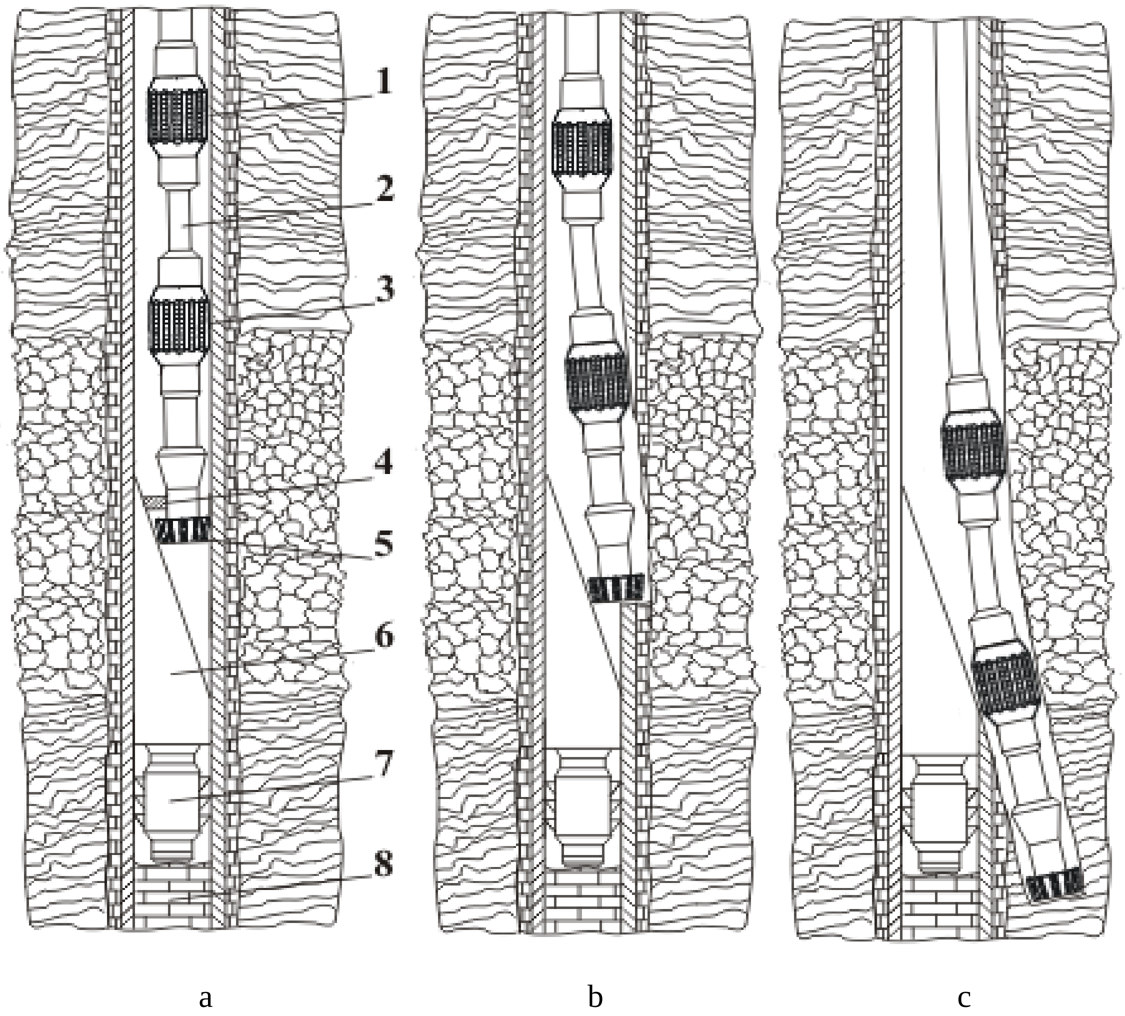
After the casing exit was cut, the sidetrack was drilled with a downhole motor and navigation systems, or with a standard rotary BHA in case of non-oriented drilling.

In foreign practice, sets of special equipment have been widely used to drill the BS in one trip in casing with a diameter of 140 mm to 168 mm. The tool set includes an anchor, a wedge deflector, a window mill, a lower reamer, a flexible nozzle, an upper reamer, DC, an orientation device, and drill pipes.

The scheme of sidetracking in one trip using a stationary wedge deflector is shown in Fig. 6.

When using the above-mentioned tool set, the work is performed in the following sequence.

Installation of the liquidation and supporting cement plugs is performed. After the WOC and checking the supporting plug for bearing capacity, proceed to assemble and lower the set on drill pipes to the artificial face. Orientation is carried out – setting the inclined plane of the deflector in a certain direction (azimuth). By applying a load (or in another way provided for in the operating instructions for the technical means used), the wedge-deflector is fixed in the casing, the starting cutter is disconnected from it and the casing exit is cut. The declared average mechanical speed of cutting the casing exit is 0.5-1.0 m/h, the optimal torque Mkr = 3.0 – 7.0 kN·m at a load of up to 20 kN.



a – orienting and fixing the wedge; b – cutting the screw and starting to cut the slot;
c – cutting the second barrel; 1 – upper reamer; 2 – flexible pipe; 3 – lower reamer;
4 – shear screw; 5 – starting mill; 6 – wedge deflector; 7 – anchor; 8 – cement plug

Fig. 6. Scheme of sidetracking in one trip

The work is carried out until the upper reamer comes out of the column by 1 to 2 meters. The interval is worked through until the tool is free to move (no seating and tightening), and the well is flushed to remove the remnants of drilled rock and metal chips. Then lift the tool to the surface.

Further deepening of the well is carried out using the classical technology, the BHA, which includes a downhole motor with an axle skewing mechanism, a tele-system, spiral DC or weighted drill pipes.

The fifth aspect is choosing the type and parameters of drilling fluids.

When drilling a sidetrack, the quality of drilling fluids is subject to requirements that meet the mining and geological conditions of drilling and the reservoir properties of productive horizons (low formation pressure anomaly coefficient, low porosity and permeability). In conditions of limited annular gaps, the factors related to the well flushing regime should also be analyzed in detail, taking into account the particle size composition of the drilled rock, the peculiarities of the joint movement of polydisperse sludge, the complex dynamics of the drillstring, and the properties of the flushing fluid [26].

To this end, dual-inhibition drilling fluids based on a polyamine-based organic inhibitor and potassium chloride are widely used in the world practice [27]. Hydrocarbon-based drilling fluids and biopolymer clay-free systems has proven to be very effective in fields with low reservoir pressure.

Ukrnafta specialists also did not stand aside and successfully developed a double-inhibited low-foaming emulsion flushing fluid (LFEFF). The LFEFF was tested during the sidetrack drilling in well 318 of the Dolyna field. To improve the structural and rheological, inhibitory and other technological properties of the drilling fluid, the organocolloid "Premix O" – a fine-grained environmentally friendly composite mixture of carbon and an additive of plant origin and "Premix D" – a mixture of surfactants, polyatomic and monoatomic alcohols, alcohols [28] were introduced into the basic component composition.

During the drilling of the entire sidetrack interval, the drilling mud parameters were stable and met the design parameters, and an integrated approach to the preparation and processing of LFEFF ensured that there were no complications associated with the occurrence of clay swelling, landslides and collapses of the well walls.

These drilling fluids cause the formation of a protective screen in the pay zone. The coefficient of core permeability recovery is more than 90%, which contributes to the expected hydrocarbon production rate.

The sixth aspect is the casing of small diameter wells.

Sidetracking with a continuous production casing or filter-tail is an extremely important and technically challenging process at the final stage of well recovery. The peculiarity lies in the need to run a complex spatial architecture with nominal diameters of 120.6 mm, 139.7 mm, 152.4 mm into the sidetrack with corresponding casing (mostly sleeveless) diameters of 101.6 mm, 114.3 mm, 127.0 mm. And if cementing is required, significant hydraulic loads arise due to the extremely small gaps between the well wall and the casing, which can affect the success of the well casing in general and its further development.

Based on the results of the logging, the possibility of running the casing in certain areas of sharp changes in the curvature parameters is assessed. According to [25, 29], casing possibility when running into a wellbore with a large zenith angle (more than 45°) is ensured under the following conditions:

$$\sum F - B \leq [G] \leq G_{CL} \tag{6}$$

where $\sum F$ is the total force of resistance to the movement of the column in a curved borehole of length H, m; B is the axial component of the casing dead weight located below the curvature area, under the influence of which the casing moves in the inclined borehole; [G] is the permissible load on the casing to ensure its movement in an inclined borehole; G_{CL} is the critical load on the casing by the weight of the pipes located above the curved section of the wellbore, at which the first-order longitudinal deflection of the pipe string begins, determined by the formula:

$$G_{CL} = 1{,}94 \cdot \sqrt[3]{E \cdot I \cdot g^2} \tag{7}$$

where E is the Young's modulus, Pa, for steel $E = 2.1 \cdot 10^{11}$ Pa; I – axial moment of inertia of pipes, m^4; g is the mass of one meter of casing, kg.

The total resistance force $\sum F$ is generally determined during the BHA run with a stiffness identical to the stiffness of the intended casing string.

If it is necessary to increase the casing unloading beyond G_{CL}, the threaded connections of the pipes located in the curved section are checked for the combined effect of compression and bending stresses according to the formula:

$$n \geq \frac{\delta_p}{\delta_c + \delta_b} \tag{8}$$

where n is the safety factor (for imported pipes and pipes with a trapezoidal cut, n = 1.8);

$$\delta_c = \frac{\sum F}{S} \tag{9}$$

where S is the cross-sectional area of the pipe body, m^2;

$$\delta_b = \frac{EI}{RW} \tag{10}$$

where R is the radius of curvature, m; W is the axial moment of resistance of the hazardous section, m^3.

For high-quality isolation of horizons, it is necessary to properly prepare the wellbore and cement it in accordance with the established requirements [30, 31]. Before running the casing string, it is mandatory to calibrate/process the BHA sidetrack with a stiffness commensurate with the casing stiffness (usually BHA when drilling the last interval), as well as to treat the drilling mud, including the introduction of lubricants.

Depending on the geological conditions, the run of the shanks involves the use of modern casing equipment (shoes with check valves, centralizers for efficient replacement of process fluids during cementing, and anchor-packer-type shank suspensions).

A generally recognized approach to improving the quality of well cementing in wells with complex spatial architecture and in casing with small annular gaps (less than 12 mm per side) is the integrated use of special buffer fluids and cementing materials with the required performance properties. In the absence of effective buffer systems, the area of mixing of process fluids in the well increases in the range from 33% to 75% of the volume of injected cementing fluid [32].

The main functional criteria that characterize the efficiency of buffer fluids include

- reliable separation of the flushing fluid and cementing mud to prevent their mixing in the pipes and annulus;
- effective flushing of the flushing fluid from the annular space of the well and its displacement from cavities and extended sections;
- destruction of the filtration crust, if necessary, and bringing its parts to the surface;
- creating conditions for reliable contact of the plugging stone with the well walls and casing;
- reducing the size of fluid mixing zones and, accordingly, the consumption of cementing mud.

The developed and tested buffer systems, depending on the geological and technological conditions of use, are characterized by increased stability at zero water separation, minimal water loss, good technological parameters, in particular, flowability, washing ability and satisfactory rheological properties [33-34].

An important factor in the completion a sidetrack well with cementing of the shank, to improve the quality of cementing, in general, is the mandatory use of stabilized sedimentation-resistant expandable dispersion-reinforced grouting systems with reduced water loss. These systems are obtained based on composite grouting materials with the introduction of special additives to optimize the properties of the grouting solution and provide modification of the stone structure at the micro level to give the materials high physical, mechanical and operational properties. These properties are achieved, including through nanotechnology, which provides a type of stone synthesis [35-37].

In the case of shanks fastening with a filter column, the use of specialized shank suspensions is envisaged, which allow for the descent and flushing of the open filter part through the column shoe using the filter part isolation unit when using a polished pipe. Such technological solutions make it possible to obtain an equal-passage column without additional time spent on drilling/technological passage of the equipment to the artificial face.

It should be noted that the specialists of Ukrnafta have developed both appropriate technological solutions and a software package for modeling hydraulic loads during the cementing process. This is especially important when cementing a sidetrack with minimum annular gaps of less than 10 mm and under conditions of reduced reservoir pressure. This has enabled the minimization of potential risks and successful running of casing into the sidetrack and cementing it in all wells that were rehabilitated by means of sidetracking.

CONCLUSION

1. The potential for increasing hydrocarbon production in Ukraine through the restoration of idle oil and gas wells by drilling and sidetracking is substantiated.
2. The article outlines the issues that must be addressed during preparation and implementation of drilling and sidetracking operations.
3. The technical and technological solutions developed and implemented by PJSC Ukrnafta for well recovery are described, taking into account the minimization of costs and complications during sidetracking.
4. The main criteria for the selection of candidate wells for rehabilitation and design of sidetrack profile parameters are identified.
5. The fundamental technological schemes for sidetracking are presented.
6. Emphasis is placed on the importance of using high-quality drilling fluids that meet the geological conditions of drilling and minimize the negative impact on productive horizons.
7. Technical and technological solutions for the successful implementation of small diameter sidetracking are proposed.
8. Attention is drawn to the need for clear collaboration between all departments of the company, based on experience, results, and analysis of completed work, involving the scientific component and leading technical and technological solutions for successful sidetracking projects.

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