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Specific features and prospects of well recovery by sidetracking based on the example of the Stynava field

Specyficzne cechy i perspektywy eksploatacji odwiertów metodą bocznego otworu poziomego na przykładzie złoża Stynava

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ABSTRACT: The article provides a brief overview of the recovery of well No. 47 of the Stynava field by horizontal sidetrack drilling. Based on the analysis of the works, it is established that successful implementation of sidetracking projects with a complex profile can only be achieved through clear interaction of all involved contractors, based on the experience, results, and analysis of carried works, in close cooperation with specialists in the research industry, to implement leading technical and technological solutions. It presents the results of a detailed analysis of geophysical surveys and correlates the geological structure of the field with neighboring wells, which allowed us to design the optimal architecture and spatial placement of the sidetrack. The main technological stages of work on sidetracking and the technical difficulties that occurred are briefly described. The reasons for their occurrence and ways to overcome them are analyzed. The influence of a wide range of loads experienced by a drill string during operation in a directional section is considered, taking into account its geometric characteristics limited relative to the diameter of the sidetrack. The operability of the drill string before the onset of the limit state is calculated and the peak criteria beyond which emergency situations can potentially occur are determined. The influence of the applied drilling mud on the reservoir properties of the productive horizon of the Vygoda formation of the Eocene sediments of the Folded Carpathians (impact evaluation on the core permeability recovery factor) is analyzed. The structural, rheological, tribotechnical, inhibitory, and filtration properties of the drilling mud are presented, which ensure the stability of the near-borehole rock mass and accident-free deepening of the well sidetrack. On the basis of system analysis and calculations, the risks that arise during the lowering of the filter-liner in the complex spatial architecture sidetrack with a nonlinear indicator of the intensity of the zenith angle change are identified. On the basis of the calculations, generalized conclusions are drawn and ways to solve problematic issues regarding the possibility of successful descent of the liner to the bottom hole are presented. A graphical interpretation of the study of the plugging fluid and its formulation are presented. The necessity of using extensive stabilized plugging materials and specialized buffer fluids is established. The main practical criteria of the applied buffer systems are described. The example of the implementation of the project of the sidetracking in well No. 47 of the Stynava field and the initial oil production rate obtained confirms the need to carry out work on the well recovery by drilling a sidetrack in the late stage of exploitation of Ukrainian fields to increase hydrocarbon production.

Key words: drilling, sidetrack, well, casing, cementing.

STRESZCZENIE: W artykule dokonano krótkiego przeglądu rekonstrukcji odwiertu nr 47 złoża Stynava poprzez wykonanie bocznego otworu poziomego. Na podstawie analizy prac ustalono, że powodzenie realizacji projektów wiercenia odwiertów bocznych o złożonym profilu możliwe jest do osiągnięcia jedynie w oparciu o zdecydowaną współpracę wszystkich zaangażowanych firm wykonawczych, w oparciu o doświadczenie, wyniki i analizę przeprowadzonych prac, w ścisłej współpracy ze specjalistami branży naukowo-badawczej, na rzecz wdrożenia wiodących rozwiązań technicznych i technologicznych. Pokazano wyniki szczegółowej analizy badań geofizycznych oraz wykazano korelację budowy geologicznej złoża z sąsiednimi otworami, co pozwoliło zaprojektować optymalną architekturę i rozmieszczenie przestrzenne otworu bocznego. Pokrótce opisano główne etapy technologiczne prac przy wierceniu otworu bocznego oraz powstałe trudności techniczne. Przeanalizowano przyczyny ich występowania oraz sposoby ich przezwyciężania. Rozważono wpływ szerokiego zakresu obciążeń, jakim poddawany jest przewód wiertniczy podczas pracy w odcinku kierunkowym, biorąc pod uwagę jego charakterystykę geometryczną, ograniczoną w stosunku do średnicy otworu bocznego. Obliczono operacyjność przewodu wiertniczego przed wystąpieniem stanu granicznego i określono kryteria szczytowe, po przekroczeniu których mogą potencjalnie wystąpić sytuacje awaryjne. Przeanalizowano wpływ zastosowanej płuczki wiertniczej na właściwości zbiornikowe horyzontu produktywnego formacji Vygoda osadów eocenu Karpat Zewnętrznych (ocena wpływu na współczynnik odzysku przepuszczalności rdzenia). Przedstawiono właściwości strukturalne, reologiczne, tribotechniczne, inhibicyjne i filtracyjne płuczki wiertniczej, które zapewniają stabilność górotworu w strefie przyodwiertowej i bezwypadkowe pogłębienie otworu bocznego. Na podstawie analizy

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systemu i obliczeń zidentyfikowano zagrożenia, które pojawiają się podczas opuszczania filtra linera w otworze bocznym o złożonej architekturze przestrzennej z nieliniowym wskaźnikiem intensywności zmiany kąta zenitalnego. Na podstawie obliczeń wyciągnięto uogólnione wnioski i przedstawiono sposoby rozwiązania problematycznych zagadnień dotyczących możliwości skutecznego opuszczenia linera do otworu. Przedstawiono graficzną interpretację badań nad roztworem uszczelniającym i jego recepturę. Stwierdzono konieczność stosowania ekspandowanych stabilizowanych materiałów uszczelniających oraz specjalistycznych płynów buforowych. Scharakteryzowano główne kryteria praktyczne stosowanych systemów buforowych. Przykład realizacji projektu wiercenia otworu bocznego w odwiercie nr 47 złoża Stynava oraz uzyskana początkowa wydajność wydobycia ropy naftowej potwierdzają konieczność prowadzenia prac związanych z rekonstrukcją odwiertów poprzez wiercenie otworów bocznych w warunkach późnej fazy eksploatacji złóż ukraińskich w celu zwiększenia wydobycia węglowodorów.

Słowa kluczowe: wiercenie, otwór boczny, otwór, rury okładzinowe, cementowanie.

Introduction

In today's realities, there is no basis for a significant improvement in the situation Ukraine's oil and gas industry. Therefore, we should not expect a rapid increase in exploration and development drilling to increase the resource base and hydrocarbon production.

Most of Ukraine's fields are in long-term operation and are at the final stage of development, which is the main reason for the deterioration of technical and economic production indicators. We see a trend towards an increase in the share of hard-to-recover reserves.

According to research, the average oil recovery factor at Ukrnafta's fields is within 0.3 (Doroshenko et al., 2013). In recent years, there has been an active search for effective methods to increase oil recovery at the final stage of field development. Among the ways to increase it is the drilling of directional wells (Agafonov et al., 2022) and horizontal wells (Kozlov et al., 2002; Aldamzharov, 2003; Dovzhok et al., 2003; Stavychnyi et al., 2022), and well sidetracking (Davydenko et al., 2015; Vytyaz et al., 2015).

The rehabilitation of low production wells or wells from the idle well stock by drilling a sidetrack with horizontal completion is one of the most effective methods of stimulating hydrocarbon production and increasing oil recovery.

The efficiency of the workover is due to lower material and time costs compared to drilling a new well. Well rehabilitation also helps to avoid land allocation issues related to changes in ownership structure.

Previous experience in well rehabilitation by drilling sidetracks, including horizontal completions

The beginning of sidetracking, including horizontal completions, dates back to the 1930s. The first wells with an additional sidetrack were drilled in 1930 in Texas (USA).

The first sidetrack drilling in Ukraine was carried out in 1936. However, there was no continuation of such work due to the extremely low efficiency of the available drilling tools, equipment, and technology. Only in the 1950s sidetracking from the main horizontal borehole develop (History of percussion drilling in Ukraine).

In 1957, the first branched-horizontal well No. 1543 was drilled in the Boryslav oil field of the Carpathian region. The additional four sidetracks were drilled from the main borehole in different directions (azimuths). The distances between the bottom holes ranged from 40 m to 120 m. By the end of 1958, three branched-horizontal wells No. 1544, No. 1545, and No. 1546 were drilled in the MEP area (Coastal stratum of the Folded Carpathians). Their production rate was three to four times higher than that of the nearby old wells. In 1959, the well Pomiarky-15 was put into operation, which was drilled as a horizontal-branch well with three boreholes. The depth of the main well was 1697 m (History of percussion drilling in Ukraine; Gilyazov, 2002).

In the 1970s, drilling of complex wells with horizontal sections, including double-borehole wells, was launched by the Dolyna specialized electric drilling firm (Ukraine). Most of the directional wells drilled with electric drills at Ukrnafta's fields reached depths of 2500–3000 m, including the deepest one of 4562 m, with the maximum bottom hole displacement from the wellhead of 1140 m (well 239-Dolyna). Nine branched horizontal wells were drilled at the Dolyna field using electric drills. Well No. 801 at the Dolyna field was completed with five boreholes (Kotskulych et al., 2013).

Active drilling of exploration and production wells in the 1980s and 1990s did not contribute to the development of technologies and engineering solutions for sidetracking. However, most of fields are at the final stage of operation, and the solution of the tasks related to the recovery of wells using the sidetracking method has become relevant and in demand.

A number of foreign and domestic oilfield service companies have emerged on the Ukrainian market, such as Halliburton, Limited Responsibility Company Drilling Company Horizons, Scientific and Technical Company Burova Technika, PJSC Scientific-and-Research Institute Design Bureau Drilling Tools, and many others that specialize in well workovers using the sidetracking.

In detail, the Scientific and Technical Company Burova Technika together with the Pryluky Drilling operations department of PJSC Ukrnafta has developed a complex of technical and technological solutions that allow for successful well recovery at the Hnidyntsi field by drilling sidetracks. The successful side-track with horizontal completion was drilled in well 213. The optimized well profile taking into account the mining and geological conditions of drilling allowed the well to be put into operation with an initial oil flow rate of 30 tons per day.

The specialists of the PJSC "Scientific-and-Research Institute Design Bureau Drilling Tools" were among the first in Ukraine to develop the technology of well rehabilitation by cutting the opening in production casing with diameters of 140–168 mm and by drilling a side-track oriented in a given direction, including horizontal completion. The experience in carrying out work includes more than a dozen wells in Ukraine and several wells abroad. This company had cut the casing exit and drilled side tracking at 468-Krasnozayarska at a depth of 4,000 m in casing string Ø 139.7 mm to a depth of 4,770 m. Drilling was carried out with bi-centric bits Ø 114×130 mm. The "liner" Ø 120 mm was successfully run down and cemented.

In close cooperation between the specialists of PrJSC "Research and Design Bureau of Drilling Tools" and PJSC Ukrnafta, six wells were rehabilitated at Kachanivka and one well at Pivnichna Dolyna fields.

Specialists of PJSC Ukrnafta also did not stand aside and successfully developed and implemented their own technical and technological solutions based on drilling experience and available material and technical resources. As a result, up to a dozen wells in the Western Oilfield Region (WOR) were restored by sidetracking, including two wells each at Dolyna and Pivnichna Dolyna fields, three wells at Bytkiv-Babchynske field and one well at Oriv-Ulychno field.

In the near future, the company plans to carry out sidetracking workovers at one of the wells at the Anastasivka field in the Eastern Oilfield Region.

However, it is not enough compared to the volume of work on the rehabilitation of the wells by sidetracking at JSC "Ukrgasvydobuvannya". In 2019, JSC "Ukrgasvydobuvannya" and "Halliburton" signed a framework agreement to provide integrated turnkey services for sidetracking in 26 wells. JSC "Ukrgasvydobuvannya" experts predicted that such works would allow to return the wells from the idle stock and obtain more than 2 billion m^3 of additional gas production over the next 10 years.

At the end of 2021, JSC "Ukrgasvydobuvannya" announced a tender for the rehabilitation workover of 17 wells at nine fields in the Eastern Oilfield Region using the workover by sidetracking. The terms of reference for the sidetracking included the use of a drilling rig with a lifting capacity of 180 tons to 225 tons and with a top drive. The sidetracking of the wells was planned from a depth of 2,100 m to 4,700 m. However, military operations on the territory of Ukraine have become an obstacle to the implementation of these works.

Coverage of previously unsolved parts of the overall problem

A large number of oil and gas fields in Ukraine are classified as hard-to-recover, which is more than 72 % of oil reserves and 10–15 % of natural gas reserves (Karpenko et al., 2015). However, they are a significant reserve for increasing domestic hydrocarbon production.

One of the methods to increase hydrocarbon production, particularly in fields with hard-to-recover reserves, is to drill sidetracks with horizontal/sub-horizontal completions.

One of the conditions for successful sidetrack construction and avoidance of potential complications and accidents is compliance with the design profile parameters. The problem of bit motion control in the process of deepening the area of spatial angle gain/loss and the horizontal/subhorizontal part of the borehole remains relevant and has not been fully resolved. The efficiency of oriented bottom hole assembly (BHA) largely depends on its parameters – the length and diameter of individual elements, their weight and stiffness characteristics, installation location, etc. Despite the large number of methods and approaches to designing oriented BHA, the effectiveness of their use currently does not fully satisfy the tasks set. The need to use drill pipes of small diameters (60.3 mm, 73.0 mm, 88.9 mm) imposes additional requirements for the selection process of BHA and recommended operating and technological parameters, especially when designing a combined drilling method (downhole drilling motor + rotary). Improving the design methods of BHA is an important scientific and practical task.

At the final stage of a well rehabilitation, running a casing liner is an extremely important and technically challenging process. 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 of corresponding casing (mostly sleeveless) diameters of 101.6 mm, 114.3 mm, 127.0 mm. Due to the extremely small spacing gaps between the well wall and the casing, in conditions of non-compliance with the design profile of the sidetrack, the success of the work requires, first of all, an assessment of the possibility of the casing reaching the bottom hole by analyzing the results of the geophysical well survey.

The efficiency and success can be significantly increased by combining modern methods of modeling the drill string operation and the process of casing the sidetrack using computer technologies, for example, the Landmark software package by Halliburton.

Engaging highly qualified personnel and implementing modern technological solutions during well rehabilitation by sidetrack is the key to achieving positive results, including the expected hydrocarbon production rate.

Formation of the article's objectives

The article's objectives include showing the advantages of sidetracking for well rehabilitation on the example of well No. 47 of the Stynava field, emphasizing that successful sidetrack construction with horizontal/sub-horizontal completion is possible under conditions of a certain geological and hydrodynamic model of the target object, analysis of geological and technological features of drilling in a particular field, calculation of the optimal architecture and spatial placement of the sidetrack, methods, and means of primary opening and casing, round-the-clock geological and geophysical (geonavigation) and engineering support during drilling.

The purpose of the article

The main purpose of the scientific publication is to highlight the problematic issues that arose in the process of well recovery in order to prevent such events. An example of modern technological approaches to solving the problem and the results of their testing in industrial conditions are provided.

Coverage of the main material of research

The Stynava field was discovered in 1967. The commercially oil-bearing reservoir are productive sandstones of the Lower Menilithic of the Oligocene and Vyhoda formation of the Eocene. In terms of regional tectonics, the Stynava oil field is located in the northwestern part of the Inner Zone of the Precarpathian Trough, partially overlapped by the Carpathian Skyba Unit. The Stynava fold has a typical Carpathian strike and is divided by transverse thrust faults into the Oriv-Ulychno, Dovholuka, Semyhyniv, Morshyn, and Tanyava blocks.

In 1971, initial oil reserves of 14/4.2 million tons of the Vygoda field and 21.6/6.48 million tons of the Lower Menilite reservoir were estimated and confirmed by the State Committee on Reserves of Ukraine.

Since 1974, drilling of new wells at the field has been suspended. This was because the main oil-bearing area coincided with the area of the Stryi groundwater reservoir, within which exploration and drilling operations were prohibited. Only 12 drilled wells were allowed to develop the field. The drilling of exploratory wells (2, 4, 20, 22) in the second structural layer, the first three of which discovered the Semyhyniv oil field that underlies the Stynava oil field, was also suspended.

In 1995, taking into account the significant oil reserves and low rates of oil extraction, the Central Research and Development Laboratory (CRDL) of Ukrnafta prepared a feasibility study for the establishment of the JV (joint venture) "Boryslav Petroleum Company," which is currently developing the field. The purpose of the feasibility study is to attract foreign investment and introduce patented technologies that will ensure efficient use of natural resources and compliance with environmental requirements.

As of 01.01.2024, the field is being developed by 16 wells. Well No. 11 was abandoned during operation due to technical reasons – due to wellhead erosion during the river flooding in 1979 (Geological and economic estimation, 2015).

One of the main criteria for selecting and justifying the drilling of a horizontal/sub-horizontal section is the result of hydrodynamic modeling, which allows assessing the following factors:

- justification of geological and recoverable oil reserves in the drainage zone;
- results of adaptation of the hydrodynamic model and forecasting of technological indicators of well operation;
- justification of the location and length of the horizontal/sub-horizontal section.

The model of the geological structure of the Stynava gas-condensate-and-oil field is based on geophysical surveys, geological mapping data, and drilling results using spatial correlation of all tectonic elements and units.

According to the survey (Processing and interpretation, 2011), the wave seismic field indicates complex seismic and geological conditions due to the mountainous topography of the study area and the multi-tiered geological structure with a complex system of longitudinal and transverse faults. At the same time, the resulting model obtained from the 3D seismic plate surveys does not fundamentally change the previous existing ideas about the general structural and tectonic structure of the field. Thus, in general terms, the presence of transverse tectonic faults that enclose the Dovholuka block from the northwest and southeast, as well as longitudinal faults that divide the Stynava structure into four sections (central part) of the Semyhyniv block and three sections of the Dovholuka block have been confirmed. However, it should be noted that taking into account the general geological principles of tracing

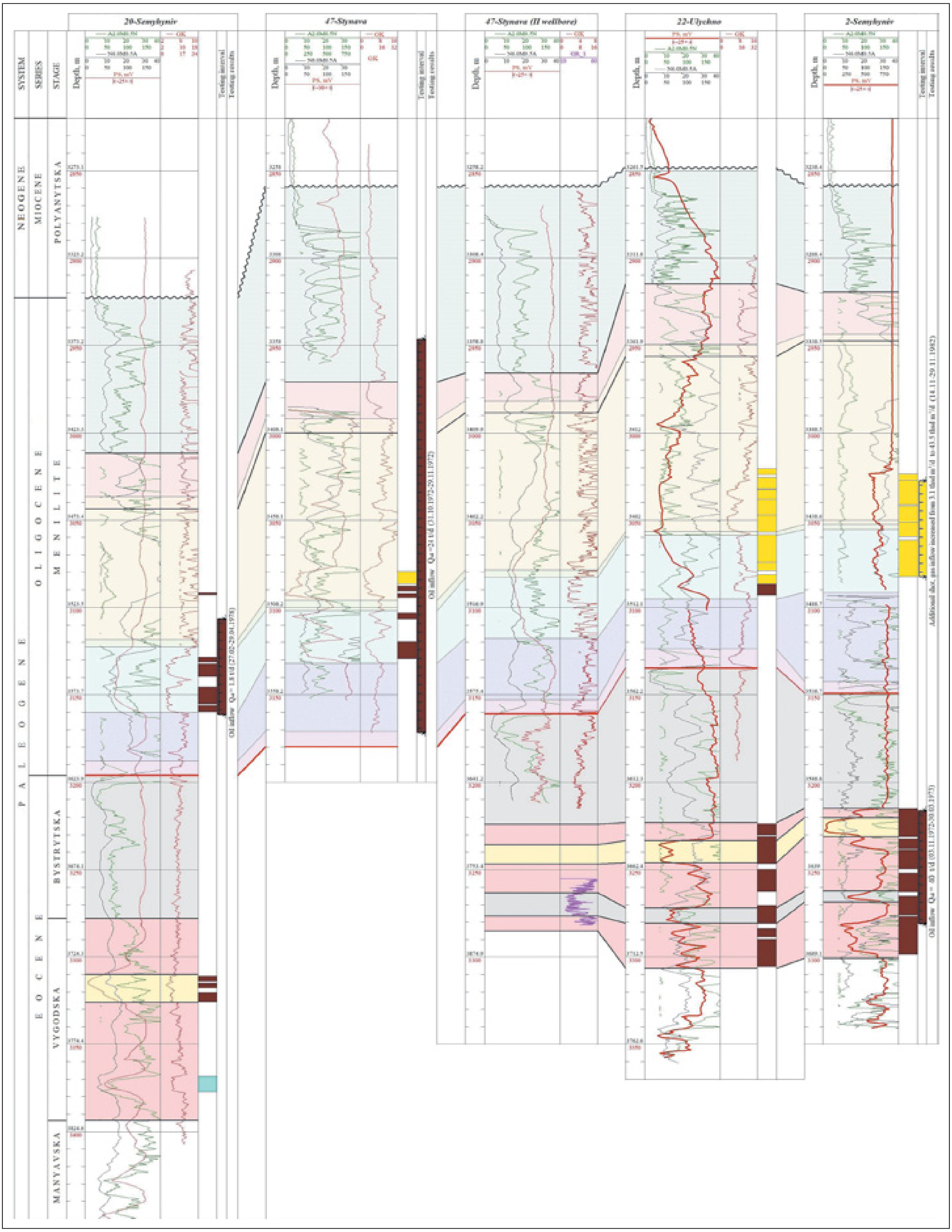

Figure 1. Correlation scheme of well sections at the Stynava field

Rysunek 1. Korelacja międzyotworowa na złożu Stynava transverse faults within the entire Inner Zone and this object in particular, the field model was built using non-arcuate, straight lines of transverse faults.

The geological structure of the field remains poorly understood due to the small number of drilled wells.

In order to assess changes in the characteristics of the Lower Oligocene Menilite reservoir and Eocene Vygoda reservoir, a detailed correlation and reinterpretation of the well logging data was carried out for the Stynava field (see Figure 1). The values of the filtration and capacitance properties determined from the well logging data were used to predict their area and the optimal location of the sub-horizontal sidetrack.

To identify reservoirs and assess their saturation, all methods of geophysical logging of wells, data of core material, conclusions based on the interpretation of well logs data, testing results, and hydrodynamic studies of wells were used.

The basis for reservoir delineation is a complex of geophysical logs at a depth scale of 1:200 and testing data. The well logging diagrams identified promising reservoir formations in productive deposits based on qualitative and quantitative characteristics.

Based on a detailed comprehensive analysis of the materials and the reservoir hydrodynamic model, sidetracking with sub-horizontal completion is planned for well No. 47 of the Stynava field. The main objective of the well rehabilitation by sidetracking is to extract oil from the productive horizon Ꝑvg of the Vygoda formation.

Sidetracking was planned from a depth of 3280 m to a vertical depth of 3700 m (3950 m along the borehole) with the tapping of the promising productive horizon Ꝑ$_2$vg by a sub-horizontal wellbore at an angle of 71° with a length of 204 m in azimuth of 80° with a total displacement of the bottom hole from the vertical of 437 m.

The well profile was selected based on complex tasks, taking into account both the technological features of the well operation and its construction. The design profile of the sidetrack of well No. 47 at the Stynava field is shown in Figure 2.

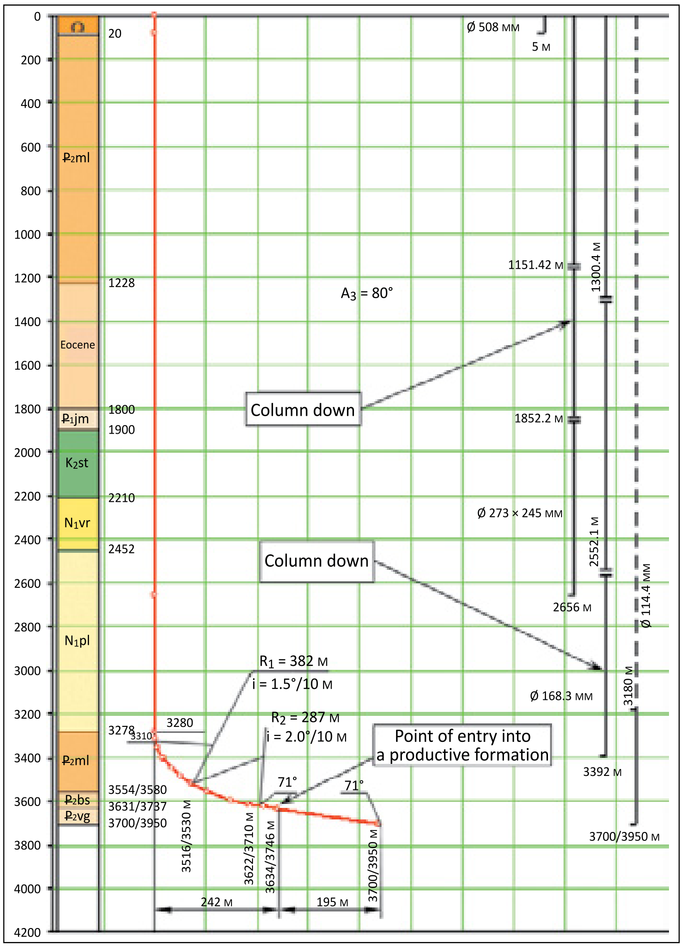

Figure 2. Design profile of the well sidetrack No. 47 at the Stynava field

Rysunek 2. Profil projektowy odwiertu bocznego nr 47 na złożu Stynava

A machine-trailer unit VARCO K 225 was used to drill the well.

The work technology included:

- installation of a whipstock and cutting opening in the casing Ø 168 mm in a given azimuth;
- opening of the design horizon Ꝑ$_2$vg with a sub-horizontal borehole;
- running and casing of the production casing “liner” Ø 101.6 mm;
- well development.

To carry out the planned works, JV “Boryslav Petroleum Company” engaged company “Integral-4” LLC, a contractor, which engaged a number of subcontractors: “Wellspring Energy” LLC (sidetracking and directional drilling services), “DI-PI Service” LLC (bit service), “NK Gazinvestproekt” LLC (drilling fluids service), “Ukrspetsgeologiya” LLC (geophysical survey of the well). Scientific-Researches and Design Institute (SRDI) supervised the implementation of the design solutions.

The assembly, installation of the hydraulic whipstock KLEN and milling of the casing exit were carried out under the supervision of engineers of “Wellspring Energy” LLC. The rig up of the assembly for cutting the casing exit (see Figure 3), its lowering, installation, and orientation of the whipstock in the desired direction, guided by the drilling tool measure according to the well logging data (casing collar log of the drilling tool according to the gamma-ray log), using geophysical equipment, which was lowered into the middle of the drill pipes and equipment for determining the position of the whipstock chute, was successfully carried out.

The opening was cut in the casing Ø 168 mm in the interval 3282–3286 m. The work directly related to the mechanical destruction of the casing took a little more time than specified

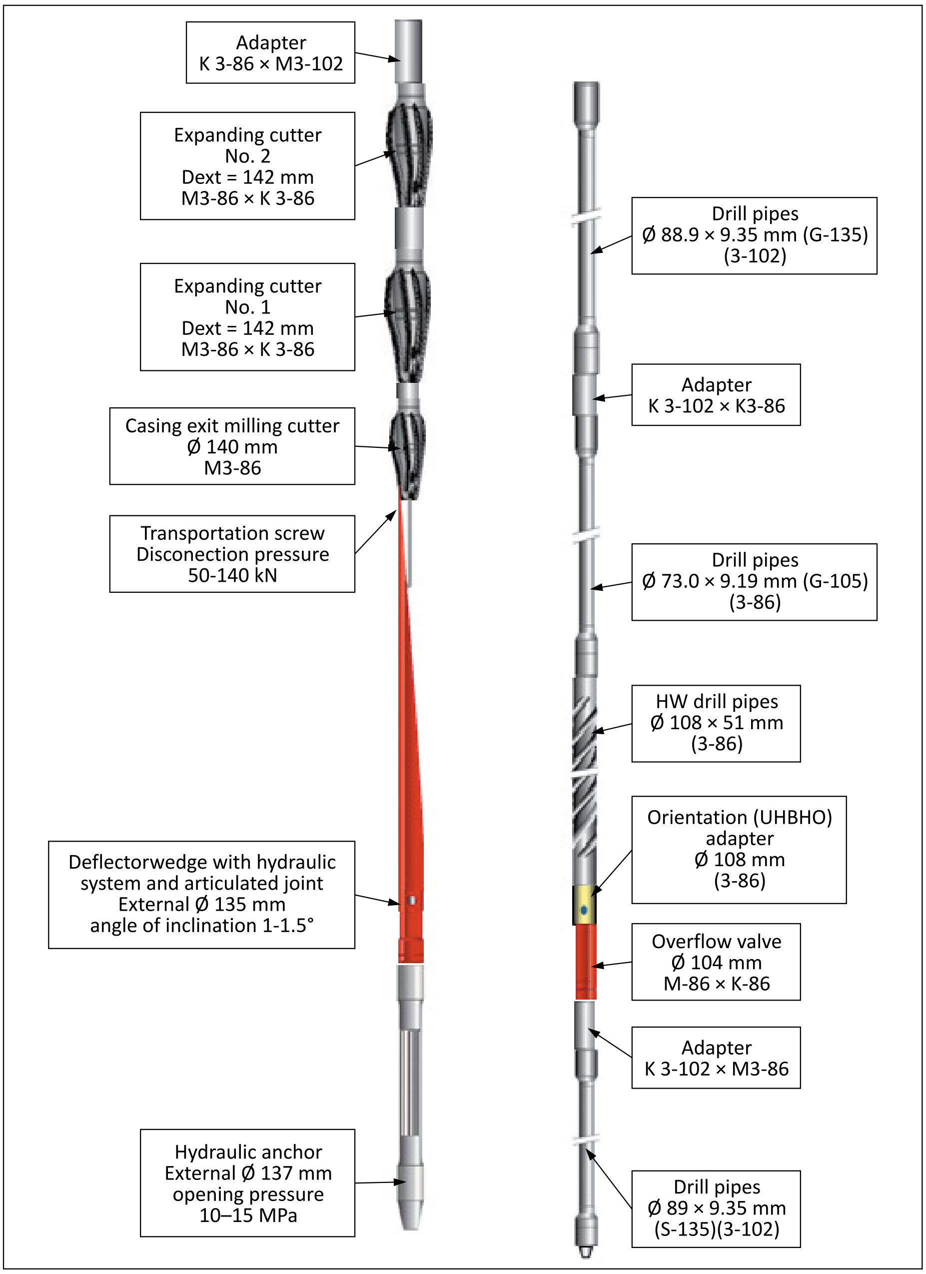

Figure 3. Scheme of assembly for cutting the opening in the casing string Ø 168.3 × 12 mm (D)

Rysunek 3. Schemat zestawu do wycinania otworu w przewodzie osłonowym Ø 168,3 × 12 mm (D)

by the equipment manufacturer – 7.8 hours (calculated based on the results of casing exit cutting operations in 72 wells), which may indicate the selection of operating and technological parameters that did not quite contribute to the optimal process of casing exit cutting (Catalog "Slips-whipstock…").

The process of implementing the design profile provided that after leaving the casing exit of column Ø 168 mm, drilling of the zenith angle section up to 33° with an intensity of 1.5° per 10 m (from the depth of MD 3310 m to MD 3530 m (TVD 3516 m), at an azimuth of 80°. At the drilling section up to the depth of MD 3710 m (TVD 3622 m), the zenith angle shall be increased to 71° with an intensity of 2.0° per 10 m at 80° azimuth with further deepening and stabilization.

Drilling for the production filter-liner Ø114.3 mm, in the interval 3286–3909 m, was carried out with the zenith angle reaching a maximum value of 81.2° at a depth of 3734.6 m with a further drop to 58.9° at a depth of 3895 m. The intensities of the zenith angle set fluctuated in wide ranges and reached peak values at depths of 3390 m, 3686.3 m, 3705.5 m, and 3720.1 m and amounted to 6.1°, 4.89°, 7.04° and 5.0° per 10 m, respectively. In general, there was a lag in the acquisition of the zenith angle. The values of the zenith angle intensity in the intervals 3363.9–3380.5 m, 3380.5–3408.4 m, 3408.4–3579.7 m were 1.3°/10 m, 1.07°/10 m, and 1.41°/10 m, respectively (the project was 1.5°/10 m), and the previous values were even lower. Increasing the skew angle on the downhole drilling motor to 1.5° from a depth of 3455.3 m did not provide the expected results.

The design and actual vertical projections of the sidetrack trajectory of well No. 47 of the Stynava field are shown in Figure 4.

The adopted technological solutions – the use of roller cutter bits Ø 139.7 mm (code of IADC 547X) instead of PDC bits and an increase in the skew angle on the downhole drilling motor to 1.83° – the intensity of the zenith angle gain to 3.76° per 10 m of penetration (in the range of 3659–3691.2 m) was significantly increased. However, it was not possible to reach the design profile and open the productive horizon at a distance of 242 m from the borehole, at a vertical depth of 3634 m. Thus, the sidetrack was brought closer to the OWC (oil water contact), which may lead to faster watering down of products in the process of oil production.

It would have been possible to achieve the required zenith angle intensity by changing the drilling mode parameters, in particular, the bit load. However, the complex architecture of the borehole did not contribute to the optimal operation of the drill string and BHA elements, or to the rational distribution of the energy expended.

The drill string used in new well or sidetrack drilling projects performs most of the functions regardless of depth, drilling method, operational and technological parameters. In the process of deepening a well, the drill string is subjected to complex loads resulting from the simultaneous action of axial tension and compression, torsion and bending stresses. Some of these loads are constant, while others are constantly changing. The stresses that occur in the drill string depend on the drilling technology and the drill string design. The design and selection of the drill string structure is described in the methods proposed by Bulatov, Sultanov, Kalinin and Saroyan, which are based on the compliance of the selected structures with the conditions of static strength and endurance (Daili et al., 1968; Sultanov et al., 1973; Alexandrov, 1978; Chudyk, 2008).

A drill string is a complex mechanical system with a large number of similar elements connected in series. Its main difference from other structures is that when the length-to-diameter ratio of the drill string is large, it rotates in the well due to loss of stability, losing its straightforward balance form (Yunin and Khehai, 2004; Chudyk et al., 2017). Stresses arising in the drill string can lead to premature failure of column elements. To prevent premature failures associated with the appearance of destructive stresses, their change must be within acceptable limits, and the choice of BHA and operating parameters is based on dynamic rather than static calculations.

For this purpose, the modeling of the well drilling process was carried out using the Landmark software package by

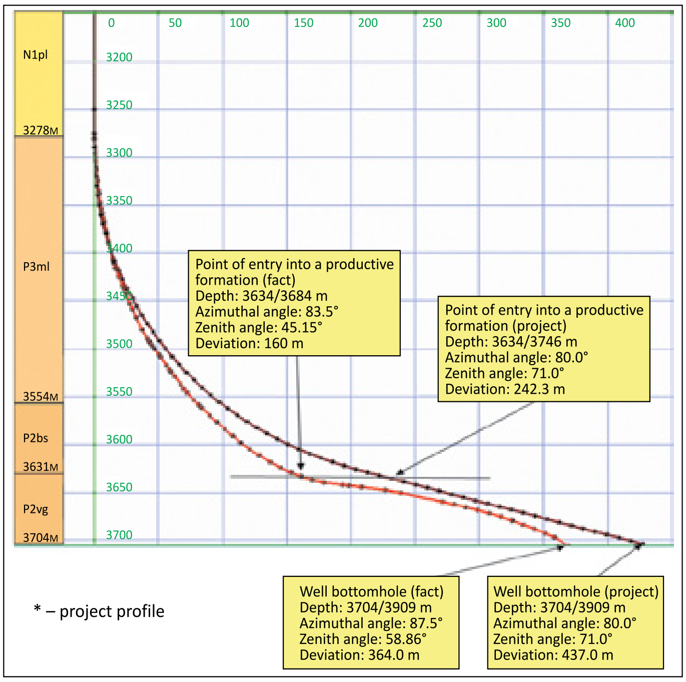

Figure 4. Design and actual vertical projections of the sidetrack trajectory

Rysunek 4. Projekt i rzeczywiste rzuty pionowe trajektorii odwiertu bocznego

Halliburton. The calculation model was based on the BHA, which did not achieve the required values of the intensity of the curvature gain, and which included:

- bit Ø 139.7 mm – 0.35 m,
- adapter Ø 108 × 32 mm – 0.21 m,
- downhole drilling motor Ø 95 mm (skew angle 1°15") – 4.89 m,
- adapter Ø 108 × 32 mm – 0.25 m,
- orientation adapter Ø 105 × 61.8/55 mm – 0.86 m,
- non-magnetic drill collar Ø 105 × 51 mm (telecommunication system) – 18.98 m,
- adapter Ø 119 × 50 mm – 0.31 m,
- HW drill pipes Ø 89 × 57 mm – 93.59 m,
- drill pipes Ø 89 × 9.35 mm S135 – 96.99 m,
- adapter Ø 119 × 57 mm – 0.34 m,
- drill collar Ø 108 × 51.5 mm – 8.94 m,
- jars Ø108 × 54 mm – 2.73 m,
- drill collar Ø 108 × 51.5 – 27.25 m,
- adapter Ø 117 × 51 mm – 0.25 m,
- drill pipes Ø 89 × 9.35 mm S135 – 96.69 m,
- adapter Ø 119 × 57 – 0.34 m,
- drill pipes Ø 73 × 9.19 mm G105 – 2839.63 m,
- adapter Ø 118 × 52 mm – 0.25 m,
- drill pipes Ø 89 × 9.35 mm S135 – 262.45 m.

The calculations were carried out at constant bit rotation speed, drilling pump productivity, and drilling fluid parameters, taking into account the spatial curvature of the borehole. The axial load on the bit was operated as a variable, as one of the factors affecting the curvature set when other drilling parameters and geometric characteristics of the drill string are fixed. It should be noted that the deterministic approach to solving the problem of determining dynamic stresses in drill string elements and their reliability is approximate and requires the selection of extreme conditions.

The calculation algorithm is based on the principle of optimality, which can be formulated as follows. If the control is optimal, then whatever the initial state of the system and the control of the system at the initial time, the subsequent control is optimal relative to the state in which the system will be as a result of the initial control. In other words, the optimal control at any given time does not depend on the previous control (prehistory) and is determined only by the state of the system at that moment and the control goal.

The calculations were carried out in the range of two extreme conditions of axial weight on the bit (Gd). The condition Gd_1 = 2 tons is the minimum value that the driller can record on the hydraulic weight indicator control panel. The condition $Gd_{(1+n)}$ = 8 tons is the maximum axial load, above which the zero section rises above the jars, which would lead to its spontaneous charging and subsequent triggering.

According to the results of calculations and graphical interpretation, it was found that this BHA is not able to carry out the planned set of curvature. Thus, with axial loads on the bit from 2 tons to 5 tons, all the strength conditions of the drill string are met, but according to the actual results of deepening, the required intensity of curvature gain is not achieved.

When the axial load is increased to 6 tons, 7 tons, and 8 tons, the torsional strength conditions are not met and in the latter case, the compressive strength conditions are not met either. Therefore, it is not possible to achieve the required intensity of the zenith angle gain by increasing the load on the bit, as this is a prerequisite for an accident associated with a drill string breakdown.

The average mechanical drilling speed of the sidetrack of well No. 47 of the Stynava field was 0.85 m/h, which correlates with the average values obtained when drilling sidetracks in similar mining and geological conditions with Ø 139.7 mm bits.

During the deepening of the well, based on the results of measuring the trajectory every 4–4.5 m and the curve of gamma ray log (when conducting in the productive formation) in real time, geological monitoring, engineering, and technological support were carried out to make the necessary adjustments to the drill string profile. As a result, the structural and tectonic model of the field was confirmed and the length of the sub-horizontal section in the productive horizon was increased to 225 m, which is almost 111% of its design length, despite the failure to meet the design profile (see Figure 4).

Successful implementation of the sidetrack drilling project requires the use of special drilling fluids. Typical problems during directional and sub-horizontal drilling of well section are the reduced stability of the near-stem rock mass (landslides and cave-ins), differential seizures in permeable intervals and chute formation, which can complicate the movement of the drill string (up to complete loss of mobility), sufficient sludge removal in areas with a zenith angle of more than 30º, and minimal negative impact on the reservoir properties of productive horizons (Azyukovskyi et al., 2022; Koroviaka et al., 2023). Among other things, an important factor is ensuring environmental safety during drilling operations. The above criteria formed the basis for selecting the mud formulation for sidetracking well No. 47 of the Stynava field, which was carried out under the potential risks of the above complications, in compliance with environmental norms and standards to prevent water contamination of the Stryi groundwater field. The well was drilled using the drilling fluid "BR-PRODGOR-GIP" type, the parameters of which are shown in Table 1.

Table 1. Parameters of the drilling fluid „BR-PRODGOR-GIP" type
Tabel 1. Parametry płynu wiertniczego typu „BR-PRODGOR-GIP"

Fluid parameters	Design values	Actual values at the bottom hole				
		3412 m	3544 m	3703 m	3773 m	3909 m
Density [kg/m^3]	1200–1240	1200/1200	1220/1220	1240/1240	1260/1260	1220/1230
The conditional viscosity (Marsh's funnel) [sec]	–/35–60	24/40	24/40	40/48	41/53	47/55
GEL through 10 sec/1 min/10 min [dPa] (Ofite 800)	10–40/–/30–70	29/34/34	34/38/43	58/ 62/72	67/ 77/86	72/76/86
Filtration rate API in 30 min [sm^3]	<4	3.1	3.5	3.0	2.5	2.7
Thickness of the filter crust [mm]	<0.5	film of oil	0.5	film of oil	film of oil	film of oil
Crust friction coefficient	–	0.0780	0.0612	0.0690	0.0690	0.0568
Hydrogen content of the fluid [pH]	9.5–11	8.64	8,84	10,35	9,36	9.33
Total mineralization [%]	>15	18.13	19.80	23.07	17.13	17.01

cont. Table 1/cd. Tabela 1

Fluid parameters	Design values	Actual values at the bottom hole				
		3412 m	3544 m	3703 m	3773 m	3909 m
Concentration of calcium ions [mg/l]	–	300.6	651	1303	701	701
Concentration of magnesium ions [mg/l]	–	364.8	365	673	547	304
Colloidal phase content, %/MBT [kg/m^3]	<21	0.1/2.15	0.13/2.8	0.26/5.7	0.33/7.1	0.33/7.1
Concentration of carbonate ions CO_3^{-2} [mg/l]	–	120	60	240	240	0
Concentration of bicarbonate ions HCO_3^- [mg/l]	–	732	793	1352	1220	3172
Lubricant content [%]	1–2	1.7	2.0	4	4	4
Solid phase content by retort [%]	<16	10	12	14	14	14
Sand content [%]	<1.0	<1.0	<1,0	<1,0	<1.0	<1.0
Potassium chloride content [%]	8–10	5.9	10.5	8.7	8.3	8.2
Plastic viscosity (*t* °C 20/70) [mPa · s]	12–25	12/10/2/6	11/11/6/5	15/10/7/6	18/9/10/8	12
Dynamic shear stress, (*t* °C 20/70) [dPa]	70–100	77/62/100/58	91/58/82/82	124/134/124/120	158/178/139/139	211
Stability index [kg/m^3]	–	–	5,0	10	–	10
Sedimentation rate [%]	–	–	0,5	0	–	0
3 RPM / 6 RPM	–	5/6	6/9	11/12	15/16	15/16
LSYP	–	4	3	10	14	14

Control testing of the drilling fluid at PJSC Ukrnafta confirmed that the system had satisfactory filtration, rheological, tribotechnical, structural and mechanical properties. In case of discrepancies in certain parameters, recommendations were promptly provided on the directions of further processing of the drilling fluid.

During the monitoring of the technological parameters of the drilling fluid from well No. 47 of the Stynava field, special attention was paid to the non-model rheological indicator LSYP, which characterizes the recovery capacity. This indicator was not standardized in the drilling fluids program, but given its exceptional importance, this indicator was monitored from the beginning to the end of drilling. During the drilling by bit Ø 139.7 mm with a zenith angle of more than 30º (in our case starting from a depth below 3550 m), the LSYP value should exceed 5.5. The obtained values of 3 RPM/6 RPM and LSYP confirm the high removal rate of the used drilling fluid.

Also, researches were carried out to determine the impact of the drilling fluid BR-PRODGOR-GIP type on the permeability of reservoir rocks for the bottom hole 3909 m. The recovery of core permeability was equal to $\beta = 80\%$ after pumping 15 pore volumes of hydrocarbon fluid for 40 minutes. The filtration velocity was stable in the range of 0.04–0.03 cm/s.

To determine the effective method of decolmatation, the hydrochloric acid formation treatment method was used. The recovery of core permeability then reached 95% after pumping 15 pore volumes of hydrocarbon fluid in 20 minutes. The filtration velocity decreased from 0.1 cm/s to 0.04 cm/s. Thus, it is concluded that this fluid causes the formation of a shielding layer that is almost completely destroyed by hydrochloric acid.

Due to the optimally designed values of structural, rheological and tribotechnical properties, high inhibitory and minimal filtration properties, the use of this drilling fluid system allowed drilling the subhorizontal section of the sidetrack without any complications.

The sidetrack of well No. 47 of the Stynava field in the interval 3137–3908 m was to be cased with a casing liner Ø 114.3 × 7.37 mm, grade P-110, connection thread VAGT, length of the filtered part 146 m.

As a result of the deepening, a sidetrack of a complex spatial configuration was obtained, which was characterized by a nonlinear change in the intensity of the zenith angle set. The peak intensity values significantly exceeded the maximum design value of 2.0º deg per 10 m. In addition, the condition of changing the intensity of the curvature from 2.0º to 2.5º per 10 m of penetration, which meets all the requirements for running the casing into a directional well, was not met (Industry Standard of Ukraine 41-00032626-00-012-2000, 2000).

The sticking of the drilling tool, which occurred at a well depth of 3870.7 m, did not add to the optimism. After drilling in the slide mode to a depth of 3873.0 m, the next time the bit was pulled off the bottom hole, a "drag" of up to 72 tons was obtained with a tool weight of 62.3 tons. The tool runout within the range of 62–72 tons did not yield a positive result. The jar did not work, the tool did not release. The tool was released as a result of the drill string rotation under its own weight (10 rotations, at the 9th rotation the tool rotated and went up without “drag”).

In view of the above, there were concerns about the possibility of successfully running the Ø 114.3 mm casing liner into the nominal Ø 139.7 mm sidetrack. The actual geometric parameters of the borehole were not available, as it was impossible to conduct appropriate geophysical surveys (cavernometry, profiling) in the above conditions.

From a technological point of view, all the necessary operations were performed before running the casing liner. The borehole was wiper tripped without any complications, during which a viscoelastic pack of drilling mud was pumped before lifting. There was no increase in the intensity of cuttings removal. The drilling fluid was treated with EcoLube lubricant. The tool was lifted from the bottom hole “cleanly” – without “drag.”

Based on the results of the gamma-ray logging data interpretation, the depth of the casing liner was adjusted to 3857 m and the interval of the filtered part to 3719–3857 m.

In order to verify the possibility of successful lowering of the filter-liner into the sidetrack of a complex configuration, the modelling of the casing process was carried out using the Landmark software package of Halliburton. Based on the results of calculations and graphical interpretation, it was concluded that the well could be successfully cemented to a depth of 3857 m with a casing of Ø 114.3 mm.

The well casing process is the final and one of the most critical stages of well building. The effectiveness and success of its implementation will mainly depend on the quality of technological equipment and the professionalism of the personnel.

Having assessed all the possible risks, we successfully ran the drill pipe with the use of the liner hanger 114/168 manufactured by private company Mechanic and Bulat LLC, a casing liner Ø 114 mm in the interval 3126–3857 m (filter part of the column in the interval 3706.5–3856.5 m). Taking into account the difficult mining and geological conditions, a hydraulic sleeve packer for cuff cementing Ø 114 mm was installed (by private company Mechanik and Bulat LLC) to reliably separate the filter casing and further cementing the entire casing.

The cementing was carried out using stabilized expandable plugging material with reduced water loss RTM-120PV and spacer fluid BS-AV-5 (manufactured by UKRSKS LLC) to separate the process fluids.

The use of expandable plugging materials ensures the formation of a dense, homogeneous insulating screen with high adhesion and resistance to aggressive fluids, low permeability and brittleness of the stone, reliable overlap of the wellbore space and is widely used in the world practice of well cementing in difficult conditions. The advantages of stabilized systems include the absence of water separation and minimal water loss, high strength and sedimentation resistance, and the avoidance of premature setting of the plugging fluid.

The technological process of cementing (after running the casing liner) involved first of all the activation of the packer clutch Ø 114 mm. The ball was thrown in and, after it was seated by gradually increasing the pressure to 100 atm, unpacking was carried out. The cementing windows were opened at a pressure of 160 atm. Spacer and plugging fluids were prepared and pumped into the well in the following sequence: spacer BS-AV-5 – 3.0 m^3 with a density of 1520 kg/m^3, a portion of the plugging fluid (RTM-120PV) – 5.8 m^3 with a density of 1810 kg/m^3, a plug was thrown in, and then the spacer fluid (2^{nd} spacer – 1 m^3 with a density of 1000 kg/m^3 + drilling mud – 2.0 m^3 + 3^{rd} spacer – 2.0 m^3 with a density of 1000 kg/m^3 + + drilling mud – 6.8 m^3). The “STOP” signal was received – 150 atm. The pressure was monitored for 15 minutes – no drop occurred. According to the results of pressure testing with a pressure of 150 atm – the casing string is hermetically sealed. The liner hanger 114/168 was anchored and unpackered in the production string Ø 168.3 mm by gradually increasing the pressure to 180 atm. The drilling tool was disconnected with a pressure of 250 atm and the plugging fluid was flushed out. Waiting on cement. No process violations were recorded during well cementing.

The assessment of the quality of casing cementing according to the results of geophysical surveys (acoustic logging of cementing) is satisfactory.

From the drilling practice, there are a number of wells, including those at the Stynava field, where the production casing with a diameter of 139.7 mm and a wall thickness of 10.54 mm or 12.7 mm was used. In such cases, wells can be cased with 101.6 mm or even 89 mm diameter pipes with collar cementing or filter-liner installation. For drilling of technological equipment (opening of packer coupling or cutting of filter caps), in particular in column Ø 89 mm, it is advisable to use coiled tubing technologies, which involve the use of couplingless flexible pipes with small-sized bits and downhole drilling motors. As is well known, the use of coiled tubing for workover operations in a well allows for a multiple of times faster workover operations compared to conventional technologies, which is achieved due to:

- prompt installation/dismantling of process equipment;
- the reduction in the number and duration of running and lifting operations;
- the ability to perform operations in oil and gas wells without killing them, which makes it impossible to negatively affect the filtration and capacitive characteristics of productive horizons of technological fluids;
- the ability to work in wells with complex spatial architecture, including horizontal wells;

- gaining potential well production rate as soon as possible after workover.

It should be noted that the main factor in the successful completion of well No. 47 of the Stynava field by means of side tracking is steady monitoring, timely and professional adjustment by the team of drillers, geologists and developers of workover technologies, taking into account changes in mining and geological conditions of drilling. The use of Halliburton's Landmark software system allowed us to assess most of the risks that arise during side tracking with a complex spatial architecture. As a result, the well was completed by drilling and casing without disrupting the technological process (complications, accidents).

The success was confirmed by the development results – the initial well flow rate exceeded the expected figures by several times, which confirmed the thesis that it is advisable to rehabilitate wells by drilling with horizontal/sub-horizontal completion.

The successful results of the work performed on this well demonstrate the further feasibility of the recovery of well No. 35 of this field by means of the sidetrack.

Conclusions

1. Based on the example of well No. 47 of the Stynava field, the possibility of increasing hydrocarbon production in Ukraine by rehabilitating oil and gas wells by sidetracking has been proved.
2. Successful drilling of a sidetrack with horizontal/sub-horizontal completion is possible only under conditions of a defined geological and hydrodynamic model of the target object, the analysis of geological and technological features of drilling in a particular field, which allows to calculate the optimal spatial location of the sidetrack.
3. Based on the results of the sidetracking, the structural and tectonic model of the target formation was confirmed, which will ensure effective decision-making for the further development of the Stynava field, both in terms of hydrocarbon production forecasting and well drilling/rehabilitation planning.
4. The problem of bit motion control in the process of deepening the area of the spatial angle set and the subhorizontal part of the borehole is emphasized. The problems of the consequences arising from the loss of control over the controllability and the reasons for such a loss are outlined.
5. The main risks that could potentially have a negative impact on the process of sidetrack casing (running of the casing liner) in the conditions of a complex spatial architecture of the well are identified.
6. An example of modern technological approaches to solving the problem and the results of their testing in commercial conditions are given.
7. Due to the complex combination of modern methods of modeling the drill string operation and the process of sidetrack casing using the Landmark software package by Halliburton, technical and technological solutions were adopted that allowed avoiding accidents with the drill string and complications during the lowering of the casing liner into the sidetrack.
8. It is emphasized that a positive result (obtaining at least the expected flow rate) is not possible without the use of high-quality drilling fluids that must meet the mining and geological conditions of drilling and minimize the negative impact on productive horizons, and stabilized expandable plugging materials and spacer fluids that ensure successful casing and reliable isolation.
9. The initial flow rate obtained allows us to consider the prospect of drilling both new wells at the Stynava field and sidetracks from the existing wells, confirms the feasibility of horizontal/sub-horizontal wells in general, and highlights the possibility of increasing hydrocarbon production at the existing license areas.
10. Without the involvement of highly qualified personnel, and teamwork of drillers, geologists, and developers, it is extremely difficult to obtain a positive result, especially in the context of the impossibility of timely adjustment of the technological process for various reasons (lack of necessary equipment, materials, changes in mining and geological conditions of drilling, etc.)

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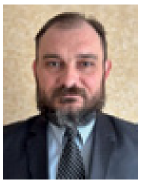

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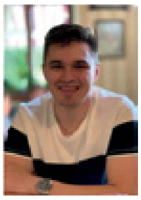

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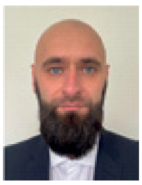

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