

STUDY OF WELLBORE CURVATURE DURING DRILLING IN THE GOGERENDAG FIELD

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ABSTRACT

During the drilling process, the borehole curves for several reasons. Both techno-technological factors and natural factors lead to this. Natural factors include inclined bedding of rocks, alternation of rocks of different hardness, layering, fracturing, presence of caverns and shear planes, and anisotropy of rocks, which means that their properties are not the same both along and across the bedding. The loss of straightness of the bottom of the drill string while creating axial load on the bit, its rotation, use of bent tubing and drill string bottom hole assembly (BHA) layout are technical and technological factors. During the initial drilling period, the well deviates from the vertical due to non-horizontality of the rotor table and non-centredness of the derrick. Two components can determine any wellbore curvature. The first is the azimuth angle or zenith angle, which shows the deviation of the well axis from vertical. The second is the curvature angle. This is the angle between the vertical plane passing through the north end of the magnetic arrow and the vertical plane lying on the axis of the warped borehole. The borehole curves in one plane at constant azimuth, whereas at variable azimuth the borehole curves in space. Investigation of well warp patterns during drilling in the Gogerendag field is the focus of the research study. The focus of the study is to assess the quality of well construction and wellbore verticality assurance. Based on the study, the author offers recommendations and results to prevent wellbore distortion.

Keywords: curvature; wellbore; drilling tool; layout; pendulum; zenith angle; conductor.

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1. Introduction

The Drilling Technology Laboratory conducted a study of well curvature patterns during drilling at the Gogerendag field.

One of the main criteria for assessing the quality of well construction is to ensure verticality of the drilled wellbore, absence of sharp bends in the borehole, formation of the borehole with the required effective diameter, which is facilitated by the correct choice of drill string bottom hole assembly (BHA) [1].

A number of works are devoted to the BHA calculation. However, up to now the problem of correct BHA selection remains actual and not completely solved. This is explained by the fact that the BHA fulfils a number of important functions while drilling wells, the main of which should be considered as follows:

- prevention of borehole curvature when drilling vertical wells;
- Maintaining the direction (trajectory) of the borehole (zenith angle and azimuth) specified by the drilling project;
- creation of optimum bit load for the most efficient

rock destruction at the bottom hole;

- obtaining a certain configuration of the wellbore during drilling that meets the requirements for unobstructed running of intermediate and production casing strings to the intended depth.

2. Brief overview

The analysis of the current state of study of curvature problems shows that, developed innovative technologies (downhole tools) in the field of drilling play a key role in improving efficiency, safety and sustainability in the introduction of drilling operations. However, their successful implementation requires a comprehensive approach and constant adaptation to the specifics of each field. It should also be taken into account that the introduction of innovative technologies requires significant investment in research and development.

Gezberg Y. notes that pendulum-type BHAs are the most widely used to rationalise the main types of layouts used to limit well curvature. These layouts are popular because they are simple and effective in reducing curvature. The author conducted a study of the effectiveness of pendulum layouts for minor wellbore erosion and medium levels of geological influences on wells. The study led to the development of methods and software to determine the traceability charac-

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teristics of layouts for step-out drilling. The author argues that stepped bottom-hole layouts are significantly better than pendulum layouts, especially in the case of hole scour, and they are less susceptible to seizures [2].

According to Ishbaev G. and Vagapov S., the movement of BHA occurs at an uneven speed due to the inequality of the resting and travelling friction coefficients. This leads to non-uniformity of axial load on the bit, which reduces technical and economic indicators of well penetration. Feed correctors, also known as dampers, are designed to maximise the delivery of axial load to the bit. Dampers load the bit evenly and help overcome the friction forces of the BHA against the well wall. Downhole protectors of various sizes are modern high-efficiency BHA elements that can dampen strong single longitudinal, transverse and torsional shocks at the bottom of the drill string [3].

The necessity to combat well curvature, when drilling deep wells is associated with the emergence of difficulties and obstacles, their elimination is associated with the waste of time and material resources. The experience of drilling and issues on prevention of wellbore curvature in the analysis of information published works shows that the main measures to combat curvature is to reduce the axial load on the bit and the use of special BHA. In spite of the great experience in application of special BHA in the world practice, the theoretical basis for calculation of rigid BHA composition has not been fully developed yet.

Based on the analysis of the latest published sources shows that at the present time on the nature of wellbore curvature there is no common unified opinion. Based on the analysis of different opinions, in order to successfully solve the problems of wellbore curvature control it is necessary to solve the stability on the elasticity and nature of the drill string curvature.

2. Materials and methods

In analysing the causes of wellbore curvature in the Gogerehdag field, the drilling history of more than 60 wells drilled from the 1970s to the present day was used. For the analysis we used the well inclinometry data and collected the data available to date on the drilling tool bottoms, well designs, stratigraphy and lithology of the field [4-8].

The mining and geological conditions for drilling oil and gas wells in the Gogerehdag area are notable for the complexity of construction. Abnormally high formation pressures in the red-coloured strata reach values of 2.10-2.20. In the intervals of 570 m to 3550 m, if the repression is higher than the permissible one, there is a possibility of drilling absorption with the maximum loss rate of up to 10 m³/hour. At creation of repression lower than permissible and increase of water yield of drilling mud from the design value from the depth of 570 m to 3200 m due to high-debit aquifers with free flow rate of 1700 m³/hour water penetration is planned. Due to the presence of thick clays in the section from the depth of 570 m to 3550 m is a tacking zone associated with pressure drop, wedging, packing.

At the Gogerehdag field, the elements of bedding (dip) of strata along the bottom are as follows: 0-570 m 1-2 degrees, 570-1500 m 5-10 degrees, 1500-3550 m 10-15 degrees. The coefficient of cavernousness in the intervals 0-570 m – 1.05, 570-1500 m – 1.20, 1500-2500 m – 1.25, 2500-3550 m – 1.17.

The deposit has the following frequent alternation of

rocks by depth: 0-570 m – soft, 570-1285 m – medium, hard, medium rocks, 1285-1480 m – soft, hard, medium rocks, 1480-2920 m – hard, soft, medium, 2920-3550 m – hard, medium, soft, hard and medium rocks.

The main complicating factor is the presence of thick clay layers in the red-coloured strata, which are the cause of wellbore alteration by cavern formation and the presence of the angle of occurrence (dip) of the layers, as well as the frequent change of rocks of different hardness leading to borehole curvature.

In the analysis we used the data of drilling wells: block I – 9 wells; II – 12; IIa – 7; III – 6; IV – 15; V – 5; VI – 4; block VII – 4 wells.

At a number of wells drilled in the Gogerehdag field, the inclinometry data revealed the lack of centring of drilling equipment when drilling the wells, which led to an increase in the zenith angle of the wellbore directly from the wellhead from the direction [9].

The analysis has shown that in blocks I, II, IIa, III and IV there is a stable characteristic tendency of wells curvature in the general direction north-east, east (fig.1). To construct a summary diagram of horizontal displacement of the bottomhole (plan) of the wells, the initial data including actual values of inclinometric measurements were used. These data represent the values of zenith and azimuth angles taken at specified intervals along the wellbore, as well as the coordinates of the starting point. For more visual perception of information, all wells in figure 1 are brought to a common conventional wellhead. Based on the results obtained from the diagram, it can be seen that the curvature of all wells is observed depending on the azimuthal angle, from north-south to west-east direction. From this it can be concluded that the curvature of these wells is due to high dip angle and excessive alternation of hardness of formations.

In addition, it was found that the clearly pronounced curvature of wells in a certain direction cannot be explained only by violations of drilling technology, because the wells involved in the analysis were drilled at different times, using different designs with different levels of technology and with the use of different layouts of the bottom of the drilling tools. Well curvature in a certain direction is noted only in blocks I, II, IIa, III and IV, in blocks V, VI and VII this pattern is no longer traceable, which confirms the geological reasons causing spontaneous curvature of wells in the above-mentioned blocks. Probably, the reason for this phenomenon lies in the conditions and character of ancient sedimentation during

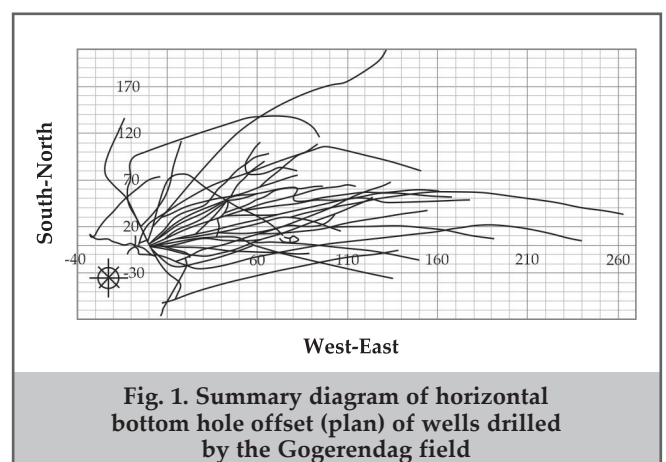


Fig. 1. Summary diagram of horizontal bottom hole offset (plan) of wells drilled by the Gogerehdag field

the formation of this interval in the middle reddish-coloured time, as well as in the character of sand interlacing and the direction of sediment drift.

It has been established that intensive change of zenith angles of the wellbore starts after the wells penetrate the thick sandy horizon under the clays of benchmark 14 and starts spontaneously decreasing after the roof of benchmark 16 is penetrated [10, 11].

It was also found that in the majority of wells the curvature growth with a slow rate of angle acquisition starts already at a depth of about 1500 m. At the same time, it was noted that the BHAs used in practice do not significantly affect the behaviour of the wellbore trajectory. Angle acquisition occurs even when pendulum arrangements are used [12, 13]. The pendulum arrangements used in practice, as a rule, which include one centraliser installed at a distance of 36 m from the bottomhole, do not influence the intensity of angle acquisition and start to work on its reduction only after opening the roof of reference 16.

It is also necessary to note a significant increase of mechanical drilling speed in the above mentioned sandy interval, and it is provided that drilling in this interval is carried out, as a rule, with limited (up to 4 tonnes) bit load because of the danger of increasing the angle rate (fig.2). The diagram is plotted as a function of zenith angle and well depth. Each point shows the maximum value of zenith angle depending on depth. According to the obtained results of the mentioned diagram it can be concluded that from the well-head to 1500 m natural curvature of the well, which occurred due to the lack of centring of drilling equipment, and from the depth of 1500 m to 3550 m the use of inappropriate pendulum arrangements of the drill string to prevent minimisation of the curvature angle.

3. Results

According to the results of the comparative analysis of actually used BHAs in previously drilled wells, it was found that during drilling of practically all wells the designed drill-string bottom arrangements were not complied with, both in terms of the composition of weighted drill pipes and in terms of the number and location of support-centre elements in the arrangement.

Pendulum BHAs are often used to reduce vibration during well drilling. However, their effectiveness depends on specific terrain conditions, including geological features. The subsurface of the Gogerendag field is characterised

by highly heterogeneous geological layers, including soft, medium and hard rocks, as well as significant amounts of shale. These differences affect the performance of pendulum BHAs as the tool uses mechanical motion in the well to correct inaccuracies.

Pendulum BHAs often include one or more centralisers installed along the drill string. The centralisers are used to position the fittings at the centre of the well and minimise the possibility of misalignment. The effectiveness of this tool can be reduced in areas such as the Gogerendag, which are characterised by high-pressure zones and water reservoirs of varying hardness. When drilling in hard rock, the BHA can experience increased friction, which can lead to uneven movement and less effective trajectory control. In Gogerendag, there are significant differences in the hardness of geological formations, resulting in uneven wear of the central element, particularly at intersections of shale or ridge formations. Uneven wear reduces the tool's ability to accurately correct deviation. The presence of high-pressure zones and potential holes complicates the operation of pendulum BHAs. In areas with significant pressure fluctuations, BHA bending strength may be insufficient, resulting in an inability to effectively steer the wellbore trajectory. In addition, if the tool loses fluid or pressure increases during drilling, the ability to maintain a stable trajectory is reduced, which can lead to further deviations in the wellbore.

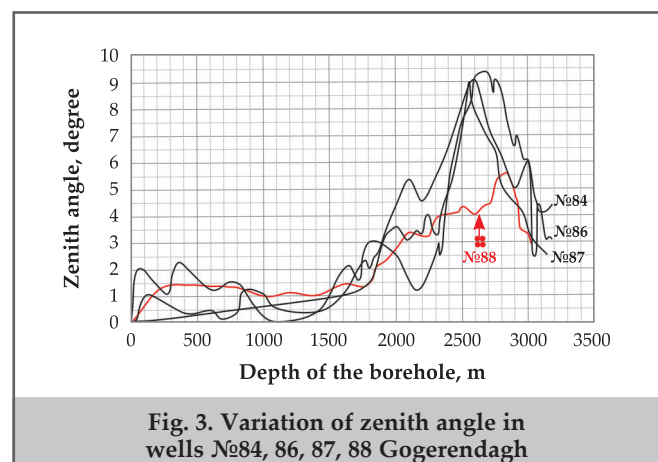
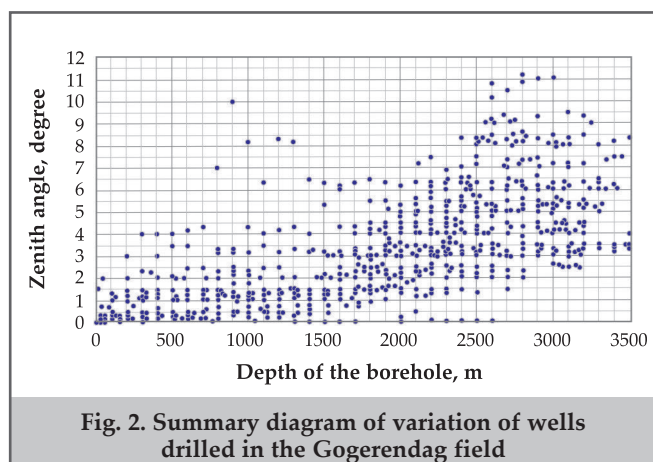
The performance of rotary BHA tools in the Gogerendag field is dependent on the complex geological environment, which requires careful consideration of tool design and operating parameters to ensure optimal performance.

For a more detailed analysis, boreholes drilled in recent years in Blocks IIa and IV, where drilling operations are currently underway – specifically boreholes No. 82, 83, 84, 86, and 87 – have been selected. Based on the analysis, the following BHAs (bottom hole assemblies) are recommended for drilling borehole No. 88 Gogerendag [14, 15]:

1. When drilling the surface casing and intermediate casing sections – the planned BHAs with strict adherence to both the diameters of the HWDP (heavy weight drill pipe) and stabilisers used, as well as the planned lengths of the BHA components and the placement of the centralisers.

2. Drilling the production casing section from a depth of 1800 m should be carried out with the following assembly:

a) in the case of a vertical borehole (inclination angle – no more than 1.5 degrees) – bit 215.5 mm + near-bit stabiliser 215.9 mm + HWDP-178 mm – 3 m + stabiliser 214 mm +



+HWDP-178 mm – 5 m + stabiliser 214 mm + HWDP-178 mm – 9 m + stabiliser 213 mm + HWDP-178 mm – 74 m + drill pipe 146 mm – 37 m;

b) in the case of a deviated borehole (inclination angle greater than 1.5 degrees) – bit 215.5 mm + HWDP-178 mm – 14 ... 15 m + stabiliser 214 mm + HWDP-178 mm – 9 m + stabiliser 214 mm + HWDP-178 mm – 74 m + drill pipe 146 mm – 37 m.

The results obtained when using the recommended BHA while drilling well #88 in the Gogerendag field are presented in figure 3, where the well profile is plotted based on actual inclinometric data of zenith angles as a function of depth. This diagram is made for the purpose of comparative analysis of well curvature of previously drilled No. 84, 86, 87 wells and well No. 88 with the new recommended investigated pendulum arrangement. Based on this profile, it can be concluded that the recommended new pendulum-type BHA in this field has shown its effectiveness in reducing wellbore curvature [16].

The use of the recommended BHAs reduced the intensity of well curvature almost twice – from 8-9.5 to 4-5.5 degrees, but did not completely solve the problem of well curvature. Also, the expected decrease in the zenith angle after opening of the roof of the 16 rep 16 did not occur. Apparently, the reason for this is the excessive rigidity of the pendulum arrangement [17-19].

Two main methods of BHA were considered in the study: pendulum and stepped methods. Each method has its advantages and disadvantages, which need to be quantified under the conditions of the Gogerendag field. As mentioned above, pendulum BHAs are often used because of their cost effectiveness and simplicity. However, their efficiency can be unstable, especially in complex geological conditions such as in the Gogerendag field. Pendulum systems are less effective in preventing well deviation in areas with thick geological formations. This is supported by the results of a study in which zenith angle measurements showed that the pendulum BHA could not significantly reduce deviation when drilling more complex formations, such as sand and shale, at depths between 1500 and 2500 metres. The overall performance of the system is limited by the lack of centralised control and potential wear caused by increased friction in these formations. Unlike pendulum BHAs, stepped BHAs have multiple centring stages and are designed to better control wellbore deformation. The stepped design provides more reliable trajectory control by using multiple centring elements along the entire length of the device. Stepped BHAs provide better tool load distribution and minimise friction, making them more suitable for use in fields with uneven geological layers and in high-pressure zones such as Gogerendag. The study showed that the use of the stepped BHA significantly reduced the inclination angle, especially in areas where the pendulum BHA did not work. The stepped system reduced bending by 50% compared to the swing system.

In order to quantitatively compare the swing and stepped BHA drilling systems, it is necessary to focus on metrics such as overall trajectory stability during drilling, rate of wellbore curvature development, and wellbore inclination angle reduction. Based on the results, the pendulum BHA reduced the zenith angle by about 30 per cent of the initial deviation, with a maximum deviation of 8-9 degrees. The stepped system reduced the zenith angle by 50%, but at

the same drilling depth (1500-2500 m) the maximum deviation was only 4-5 degrees. This significant difference in performance shows that the stepped BHAs do a better job of controlling wellbore bends. The change in zenith angle per unit depth was used to determine the rate of warp development. During the first 1500 metres of drilling, the rate of deviation for the pendulum BHA was 0.003 degrees per metre. At greater depths this rate increases to 0.006 degrees per metre. The deviation of the BHA stage from vertical was between 0.001 and 0.002 degrees per metre regardless of depth. This shows that the staged system provides more reliable well trajectory control and reduces the risk of excessive wellbore deviation. The staggered BHA showed greater stability in maintaining the planned drilling trajectory. However, the pendulum BHA showed greater oscillation. This was particularly noticeable in the depth range from 1500 to 2500 m, where anomalies were observed frequently. It can be said that the reason for these oscillations is the limitations of the pendulum structure under the complex geological conditions of Gogerendag.

4. Discussion

In turn, D. Gao highlights that the application of appropriate BHA taking into account geological, technical and technological factors of well curvature significantly increases the efficiency of drilling operations. It is noted that the development of new types of BHA elements and geological and technical support can increase the productivity of drilling wells, reduce the costs of their operation and ensure optimal utilisation of oil fields [20].

The results presented by researchers [21] are another confirmation of the negative significance in the field of oil and gas drilling of the consequences of natural well curvature. They highlight important aspects of optimising processes in the fields through the use of new drilling and control methods. By comparing both studies, it can be emphasised that the use of innovative drilling methods and technologies, combined with effective control strategies, represents the most promising direction for increasing the overall efficiency of oil and gas production. Both approaches emphasise the importance of integrated approach and management, which demonstrates the promising potential of such strategies in the development of the oil industry.

As U. Zalluhoglu notes, the downhole orientation fixation controller is an important technological component that has revolutionised the well drilling process. Its ability to provide automatic control and correction of well orientation is of great importance to the oil and gas industry. Initially, well drilling required significant effort and multiple corrections to achieve the desired trajectory. The downhole orientation fix controller greatly simplifies this process by providing high accuracy and predictability in the direction of the well. This reduces path tortuosity and significantly reduces drilling time, which is critical for efficient hydrocarbon production [22].

Turning to V. Mansouri's definition that optimising the well path separation factor plays an important role in preventing the risk of natural well curvature and ensuring safe drilling operations. This factor determines before there is a risk of the wells deviating from their intended trajectory. Minimising the risk of natural wellbore deviation from the designed path is important to prevent potential accidents and environmental damage. One method of optimising the sep-

aration factor is careful well trajectory planning. Engineers and geologists must consider the geological characteristics of the field to design optimal paths for the wells, minimising their mutual influence [23].

It is worth adding that it is important to utilise modern technology and navigation systems such as GPS systems and downhole telemetry systems to accurately monitor well position and orientation in real time. This allows operators to react quickly to any deviations from the planned trajectory. All these efforts are aimed at ensuring the safety and efficiency of drilling operations, as well as minimising the risk of natural well curvature, which is a key aspect in the successful production of hydrocarbon resources.

Based on the research conducted, taking into account geological, technical and technological factors, the main causes of well curvature are follows:

1. Presence of formations with large angles of occurrence (dip) in the well section.
2. Frequent change of rocks of different strength,
3. high coefficient of cavernosity in the rocks through which the wells are being driven,
4. Presence of thick clay layers in the section, which cause cavernous formation in the wellbore.
5. The zenith angle acquisition in all wells starts directly from the wellhead due to non-centred drilling equipment.

The following measures are recommended to prevent warping of wells drilled in the Gogerendag field:

1. Before drilling a well, 3D modelling of geological formations using seismic and magnetic data should be performed to accurately assess the strength and cavernosity of rocks prone to curvature. These data should be used in designing the trajectory and selecting the type of BHA.
2. Perform a thorough inspection and alignment of drilling equipment, including inspection of drill pumps, vibratory screens and guide systems, with data synchronised with real-time sensors that record pressure, temperature and vibration in the borehole.
3. Integrate machine learning and artificial intelligence algorithms into the drilling system to analyse inclinometer data, predict trajectory changes and automatically adjust drilling parameters (load, rotations, drilling fluid composition).

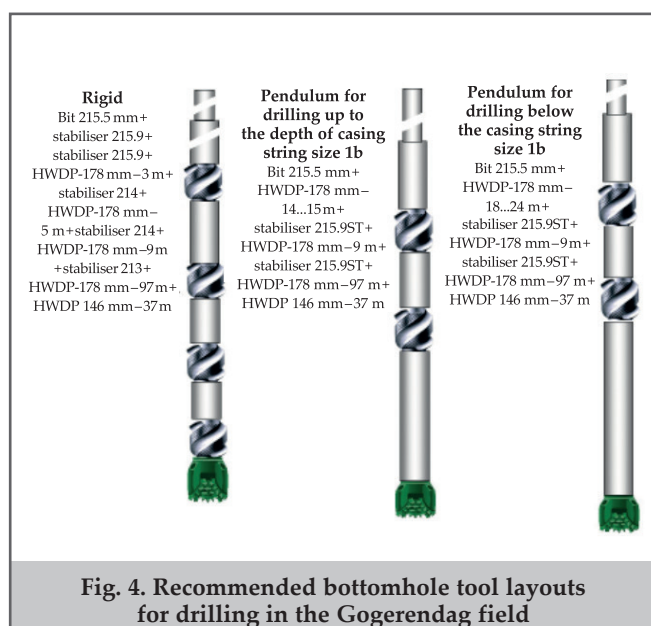


Fig. 4. Recommended bottomhole tool layouts for drilling in the Gogerendag field

4. use adaptive BHAs with automatic adjustment of stiffness and geometry, as well as multifunctional components with damping elements to reduce friction and vibrations when driving through alternating rocks of different strength.

5. When drilling the production string from a depth of 1800 m, use stepped or pendulum layouts depending on inclinometry readings and dynamic deviation prediction. It is also recommended to use multilevel anchor systems to stabilise the drill string in zones with high dip angle. Drilling should be carried out by the following arrangement (fig. 4):

a) If the well is vertical (zenith angle not exceeding 1.5 degrees) – Bit 215.5 mm + stabiliser 215.9 + stabiliser 215.9 + HWDP-178 mm – 3 m + stabiliser 214 + HWDP-178 mm – 5 m + stabiliser 214 + HWDP-178 mm – 9 m + stabiliser 213 + HWDP-178 mm – 97 m + HWDP 146 mm – 37 m;

b) in case of wellbore curvature (zenith angle more than 1.5 degrees):

to a depth of 2500 metres – Bit 215.5 mm + HWDP-178 mm – 14...15 m + stabiliser 215.9ST + HWDP-178 mm – 9 m + stabiliser 215.9ST + HWDP-178 mm – 97 m + HWDP 146 mm – 37 m,

at a depth of 2500 metres – Bit 215.5 mm + HWDP-178 mm – 18...24 m + stabiliser 215.9ST + HWDP-178 mm – 9 m + stabiliser 215.9ST + HWDP-178 mm – 97 m + HWDP 146 mm – 37 m.

7. It is necessary to observe the following modes when drilling under the production string: bit load 6-8 tonnes, drilling fluid flow rate – 19-22 l/s.

8. Number of rotor revolutions before the entire BHA from the 'shoe' of the intermediate string – 90 m⁻¹, then increase the rotor rotational speed up to 110 m⁻¹.

9. Implement a blockchain platform to store and analyse real-time drilling data, providing full transparency and traceability of parameters. Data can be integrated with geological processing stations (GPS) and remote monitoring systems.

10. If the zenith angle of the borehole grows when working with a rigid configuration (a), change the configuration to a pendulum configuration (b). Perform one chiselling and perform wellbore inclinometry. If the zenith angle continues to grow, reduce the bit load to 2-3 tonnes.

11. Perform inclinometry at least every 200 m, as well as after each drilling cycle, especially when leaving the casing, with subsequent correction of the trajectory. If zenith angle growth is detected, it is necessary to promptly switch to an alternative arrangement with reduced bit load.

12. In connection with the increased torque on the rotor due to the use of rigid layouts, all drill pipes, HWDP and BHA elements used should meet the existing requirements for both strength and alignment categories.

13. Provide continuous training of personnel in modern drilling methods, work with AI and automated trajectory control systems [24]. Introduce a multi-level safety system with elements of predictive diagnostics and automatic shut-down at the threat of significant deviation.

14. When designing new wells, provide for energy-efficient drilling rigs with the possibility of partial power supply from renewable energy sources, which will reduce the carbon footprint and increase the sustainability of the project.

15. Encourage the drilling contractor to conduct core sampling in the interval of intense zenith angle acquisition between repairs 14 and 16.

16. Recommend that the drilling contractor carry out a set of geological and technological studies of several wells using GPS stations.

Conclusions

1. The study showed that complex geological and lithological conditions in the Gogerendag field, such as alternation of rocks of different hardness, presence of clays with high cavernosity and high dip angles of formations, are the main causes of wellbore deviation. In addition, the initial deviation of wells is significantly influenced by technical reasons, first of all, the drilling equipment is not centred during drilling.
2. During the analysis, it was found that the pendulum BHAs used in practice do not provide sufficient control over the drilling trajectory in variable geology. On the other hand, stepped layouts appeared to be more effective because they provide better axial load distribution and trajectory stability. This is especially true in the depth intervals between 1500 and 2500 metres, where pendulum layouts cause the most distortion.
3. By using the recommended BHA designs, an average 40-50 % reduction in zenith angle was achieved in Well No. 88 compared to similar well intervals previously drilled. This proves that the updated engineering approach was feasible. In addition, the proposed plan provides state-of-the-art real-time well trajectory control by integrating 3D geomodelling, automated data analysis and adaptive drilling systems.
4. Thus, the study not only confirmed the need for careful consideration of geological and technical factors in the design and execution of drilling operations, but also suggested new ways to improve drilling efficiency. In the future, it is recommended to extend the comparative analysis using telemetry and artificial intelligence systems in other areas of the field to confirm the results obtained and to scale the proposed solutions.

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