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Analysis of complications and proposal of measures to prevent adverse events during drilling activities

Zuzana SÁGOVÁ[1]**, *Tatiana Nikolaevna IVANOVA*[2,3], *Aleksander Ivanovich KORSHUNOV*[3], *Pavol BOŽEK*[1] and *Vladimir Pavlovich KORETCKIY*[4]

Authors' affiliations and addresses:
[1]Department of Automation and Production Systems, Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak Republic
e-mail: zuzana.sagova@fstroj.uniza.sk

[2]Tchaikovsky branch of Perm National Research Polytechnic Institute, Lenin Str 73, Tchaikovsky, 617764, Udmurt Republic, ~~Russia~~
e-mail: tatnic2013@yandex.ru

[3]Federal State Budgetary Institution of Science Udmurt Federal Research Center of the Ural Branch of the RAS Institute of Mechanics, T. Baramzinoy Str., 34, Izhevsk, 426000, Udmurt Republic
e-mail: kai@udman.ru

[4]Kalashnikov Izhevsk State Technical University, Studentcheskaya Str. 7, Izhevsk, 426069, Udmurt Republic
e-mail: vpk1973@yandex.ru

***Correspondence:**
Department of Automation and Production Systems, Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak Republic
e -mail: zuzana.sagova@fstroj.uniza.sk

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Abstract
While drilling slant holes, flat holes, or designer wells, drilling operators are faced with extra work in preparing the borehole for the landing. For example, during the trip, it is difficult to move drilling tools along the borehole. As a rule, the technology selection measures carried out at drilling enterprises enable the landing of a casing column in a single run or reduce the time required for preparing the borehole, as well as decrease the construction time of wells during the casing landing. Nevertheless, the reduction of extra work in the process of preparing the borehole for the landing is an urgent problem.
The completion of wells includes their fastening, landing, and casing cementing jobs. However, not in all cases does landing the casing strings go without complications. The main complication during the landing of the casing strings is their inability to extend along the borehole, resulting in their non-admission.
The primary reasons for the occurrence of slacking off, tight pulls, and seizures are the abundance of clay minerals, the discrepancy between the properties and composition of the drilling and washing fluid, and the flushing mode dictated by the geological and technical conditions of the formation. Seizures are the most common and serious complications during drilling operations.

Keywords
drilling, borehole, casing, hooks, seizure, differential sticking

Introduction

The salvage operations are expensive and include time-consuming measures. The types of seizures and the causes of their occurrence are considered. Measures to reduce the risk of seizures have been presented and described in detail. Adhering to proposed measures, the construction of an oil and gas well and the production of a bore will be of high quality and less costly both financially and in terms of construction time (Tripathi et al., 2021; Kriesky et al., 2013).

Well completion is one of the important operations in the construction of wells, and its quality ultimately determines the long-term, trouble-free operation of a particular well (Basarygin et al., 2000; Mikov et al., 2025). The completion of wells includes fastening, landing, and cementing of casing columns. However, not in all cases does landing the casing strings go without complications. The main complication during casing landing is the lack of permeability along the borehole, resulting in its non-admission (Bakirova et al., 2020). The successful landing of the casing strings into the well is possible with proper preparation of both the casings themselves and the technological equipment, as well as the readiness of the drilling unit, equipment, tools, and the borehole. It is also important to ensure the compliance of the chosen landing technology and the properties of the drilling fluid with the geological conditions of the drilling, particularly with regard to the stability of the rocks composing the borehole.

Problem analysis

A general technological measure to prevent accidents during the landing of the casing column is to study the sites of tight holes (Atlasov et al., 2015) (according to the borehole caliper) at a speed of 20-50 m/h. At this stage, oil or other lubricating (anti-stick) additives are usually added to the drilling fluid to reduce the stickiness of the mud cake (Bai, Y. Y. and Okullo, S.J., 2018). When cleaning before lowering the casing column, the parameters of the cleaning liquid are carefully monitored and adapted to the values regulated for this particular well. After cleaning and working out the well, its borehole is gaging with a run gage ring of three or four case pipes, which are set in the wall on a drill string. Failing to reach the total depth of the gage ring and tightening or sticking of more than 10% of its own weight, the intervals are revised. There was observed tightening when lowering was made, or tightening if there was pulling out. Having finished gage ring running, the well is cleaning out; that takes one or two circulation cycles.

Potential geological complications of oil wells are the following:

- Instability of the wellbore;
- Loss of circulation and disastrous loss of circulation;
- Caving and collapse of the borehole walls (unstable intervals);
- Tight hole within salt-bearing intervals or in sections with the presence of clays (expansive clay).

The main technological technique for maintaining the stability of the borehole walls and ensuring the tightness of the annular space is the descent of the casing. The success of this operation is determined by the borehole's profile (zenith and azimuth angles), the drilling fluid's parameters (filtration rate and lubricating properties), the casing hardware, and the running speed and stability (Polyakov et al., 1999; Marey, 2019).

The primary causes of slacking-offs, tight pulls, and side well sticking are the abundance of clay minerals, the discrepancy between the properties and composition of the drilling and washing fluids, and the flushing mode dictated by the geological and technical conditions of the formation penetration (Ivanova et al., 2020).

By the term "side well sticking," we ought to understand the loss of mobility of the column of pipe and casing, borehole tools, and equipment, which is not restored even in the position of the maximum allowable loads (within the proportional limit of the pipe material). Sidewall sticking is the most common and serious type of complication when borehole drilling has been carried out. In some instances, the salvage operation involves considerable time and cost.

The existing types of sidewall sticking can be categorized into the following types (Polyakov et al., 1999; Ismayilzade, 2022).

1. Side well sticking under pressure drop (differential pressure sticking);
2. Side well sticking due to swelling;
3. Side well sticking due to packing and balling;
4. Side well sticking due to seizure by foreign objects;
5. Side well sticking due to the flow of plastic rocks;
6. Side well sticking due to jamming of the drill string, casing column in the narrowest part of the borehole;
7. Side well sticking due to a violation of the shape of the borehole;
8. Side well sticking due to jamming the drill pipe in the mud return and solids removal system;
9. Side well sticking due to the cutting bed formation.

The causes of differential pressure sticking are the following (Tretyak et al., 2016):

- The presence of permeable beds;
- Sandstone, fractured limestone;
- Abnormal formation pressure;
- Filer cake;
- Column contact with the borehole wall;
- Stationary state of the column; time without column movement;
- Side force.

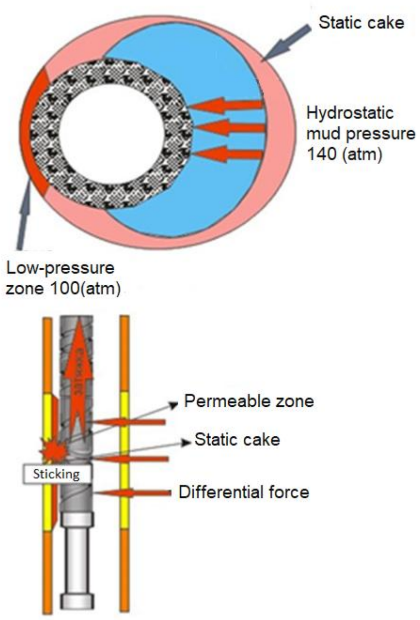

Fig. 1. Differential pressure sticking

Material and Methods

Differential pressure sticking includes the drilling string seizures that occur in permeable (porous or fractured) rocks under excess hydrostatic pressure, which causes fluid filtration into the reservoir and the formation of a mud cake on the walls of the well (Fig. 1). The sticking force depends on some factors, including the following:

- The permeability of the rock;
- The level of excess pressure;
- The properties of the drilling fluid;
- The physical and mechanical properties of the mud cake (thickness, permeability, friction factor, etc.) (Costa et al., 2023);
- The borehole crookedness;
- The cross-sectional configuration of the borehole (the presence of mud launder, etc.);
- The size and configuration of the drill string;
- The duration of stationary contact between the drill string and the mud cake on the borehole wall surface.

The chance of being absorbed for drilling mud and differential sticking can be reduced by the planned addition of bridging agents with a suitable particle size, which reduces filtration and penetration of drilling mud. The issue of mechanical properties is dealt with in detail by the authors' collective types (Kopas et al., 2017). Processing and maintaining the concentration of bridging agents in the drill fluid is the most important factor for trouble-free drilling of highly permeable formations. When processing layers with chalk ($CaCO_3$, marble chips), the probability of differential sticking decreases sharply.

To reduce the risk of seizure from a pressure drop, the following measures must be taken:

- The density of the drilling fluid should be chosen so that the excess pressure on the reservoir keeps the established norm specified in the drilling program;
- Special attention should be paid to the layout of the bottom of the drill string;
- Drill collars with rifling are the least hazardous when drilling in permeable rocks;

- The layout elements of the bottom of the drill string, installed above the calibrator, should not have sharp edges and other details that contribute to the disruption of the mud cake on the borehole walls;
- When lowering the tool before entering the hazardous area, in an intermediate casing shoe or in the safe area, the reserve engine under load, the rotor circuitry, pumps, etc., should be checked. All pumps must be reliable and functional (Qazizada and Pivarciová 2018). Never should they enter the safe zone in the event of electrical or other equipment failure.

The most hazardous part of the borehole in terms of sticking is the freshly opened-up area, where there is intense clogging of the borehole walls and the formation of a mud cake; therefore, all measures should be taken to reduce the time of stationary contact of the column with the borehole walls adding in this area. The adding of drill pipe length must be built up on slips in order to create rotation of the layout of the bottom of the drill string by the rotor if the duration of the operation is extended.

During idle time in a hazardous zone, it is necessary to reciprocate the drilling tool constantly for the entire length of the zone (or, if there is a top drive system (TDS), for the length of the pipe stand) with its rotor turning as it is lowered. At the same time, it is necessary to make sure that the drill string has fixed its weight.

If there are seizures or suspensions of the bottom-hole assembly during drilling, the driller is required to secure the well-bottom band. If the sticking does not disappear after that, lift the tool 15 m above the drilling trouble zones without stopping the intensive pacing of the drill string, inform the drilling foreman or field supervisor, and continue to act based on their instructions.

In the event of a tightening, immediate measures should be taken to restore the normal mobility of the drill string through intensive flushing and the addition of lubricating additives to the drilling fluid.

The causes of seizures due to the formation of ledges are the following (Fig. 2):

1. Interbedding of hard rocks: hard rocks have a nominal diameter, are weakly cemented, and have cavities, respectively.
2. During lowering or lifting, tightening or landing occurs while the stabilizer blades and tool couplings are sticking under or above the ledge as a result of friction against the walls of the well opposite to the sticking;
3. Sharp hole crookedness of any type;
4. High spatial intensity of the borehole (Lipanov, 2016).

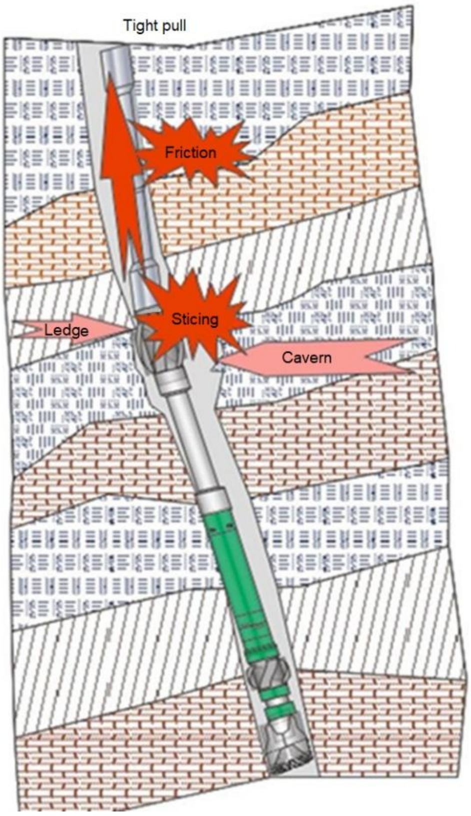

Fig. 2. Sticking and seizures due to ledges

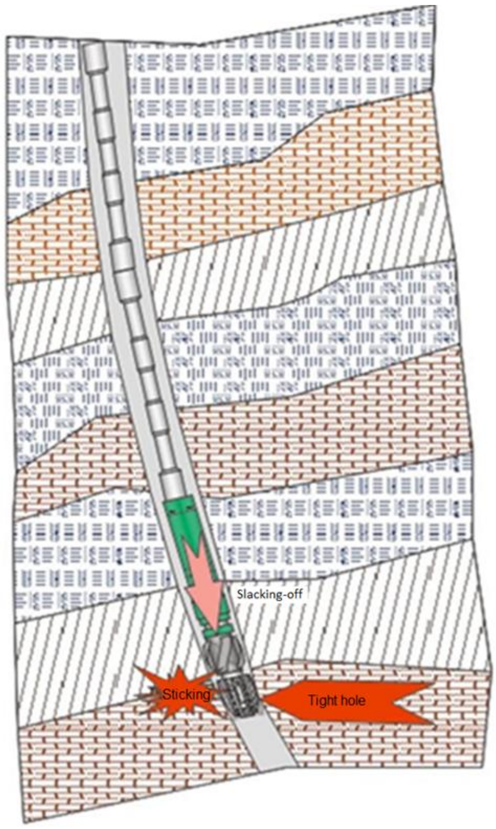

Fig. 3. Sticking due to a tight hole

Causes of seizures and sticking due to tight holes (Figure 3):

1. Loss of the diameter of the drill bits and the calibration elements of the drill string. Drilling of hard abrasive rocks with drill bits with dull diameters;
2. Drill heads of smaller diameter are used in the core sampling intervals;
3. Jamming of a drill bit or stabilizers with a diameter greater than the nominal diameter of the borehole. This sometimes happens with fused drill bits and restored stabilizers;
4. Leakage of plastic rock into the borehole of nominal diameter during flow rock drilling. Sandstones experiencing tectonic stresses may exhibit creep (fluidity) along one axis, decreasing the effective diameter (Adolfsson et al. 2020);
5. Plastic rocks such as salt, coal, and gumbo clay can exhibit fluidity along two axes;
6. Rapid increase in the thickness of the filter cake. The parameters of the washing liquid do not match the design ones;
7. Swelling of the near-wellbore layer of rocks (Ivanova, 2021).

A tight hole can occur in both permeable rocks and mud shale, as well as in impervious strata. The tight hole in permeable, stable rocks is always associated with the buildup of a mud cake. The causes of tight hole occurrence in impermeable mud shale are related to the plastic flow of shale due to its natural moisture. A tight hole has the following indicators:

- Landings when lowering the tool after being away from the well for a while;
- Tight pulls when lifting the drill bit after a relatively long stay at the face of the well;
- Removal of a small amount of drilling sludge or clumps of curdled drilling fluid mixed with particles of drilled rock during processing.

To prevent complications associated with the tight hole, it is necessary to reduce the water loss of drilling mud with known reagents in permeable rocks. It is essential to keep the lowest possible drilling fluid density.

When drilling through dirt and clay prone to plastic flow, the drill bit should be processed over time, during which no tight hole is observed. If there are landings (overpulls) of more than 5 tons from the transport weight when drilling a slant hole, it is recommended to suspend the running drilling tool and then raise (or lower) it to a length of 15-20 meters and process the dangerous zone for free movement of the layout to be achieved. Having achieved the free movement, it is recommended to continue running the drilling tool.

While the restoration of circulation and working out go on, it is necessary to control the level of pressure. An increase in pressure may be an indicator of the start of clogging the annular space. In these cases, the drilling pumps should be turned off, and the drill string should be lifted by at least the length of the drilled pipe stand (lead pipe). Then it is necessary to restore circulation and, in the absence of any tight pull, to continue working. If, during lifting, a tightening of more than 5 tons in excess of the weight of the drill string occurs, the driller should not attempt to restore circulation in the tightening interval.

In this case, the drill string should be lowered below the tightening point by 1-2 pipe stands, circulation should be restored with minimal productivity, and the flow rate should gradually increase to normal (after normalization of pressure). After flushing the well, the drill string rises to the tightening point.

If, during run-in-hole operation, there is no normal increase in the weight of the drill string, the operation should be stopped and the drill string should be lifted by a drill pipe stand above the point from where the weight increase stopped. Having restored circulation in the absence of a tight pull, the well should be cleaned with controlled and conditioned mud throughout the entire work cycle. Further run-in-hole operation should comprise cleaning. If it turns out that the lack of filling of the drill string is the cause of the weight shortage, it is necessary to fill it with drilling fluid by controlling air escape and then screwing up the lead pipe, restoring circulation, and cleaning the well.

High values of the drilling tool torque factor are usually associated with its contact with the wall of the open hole and casing column. A cutting bed on the lower side of a hole also increases the torque factor; these cuttings can be detected when a tight pull occurs while the trip out of the hole goes on. High torque factor and tightening can also occur when insufficient inhibition of mud shale is present, particularly if the latter is prone to dilatation and bridging. Thorough cleaning of the well by flushing will contribute to keeping the torque at a low level and preventing the occurrence of tight pulls. For large intervals of slant drilling, treatment with a lubricating additive in an amount of at least 2-4% by volume is necessary to improve sliding.

The causes of sticking due to jamming of the drill string or casing column are a violation of the shape of a borehole (Figure 4):

1. Frequent changes in direction or angles when drilling a slant hole. If the angle between the end of the drill bit and the line of formation dip is less than 45°, then the drill bit tends to go updip;
2. The natural deviation of the drill bit when drilling alternating hard and soft formations. When moving from a soft formation to a hard one, the drill bit tends to change its direction. One side of the bit hits the hard formation, and the other continues to drill into the soft formation. Therefore, there is an uneven resistance of the formation to destruction, and the drill bit deviates up dip or slides down bed dip;

3. An insufficiently rigid or unstable bottom-hole assembly is used for high axial weight on the drilling bit;
4. Unstable or small compared to the size of the heavyweight drill pipe bit used. If the natural tendency to cross-range of the bit is not limited, then the minimum effective bit diameter will be smaller.

Jamming of the drill string can be the result of the following reasons:

- Getting it into the ditch system;
- Careless running-in of the stiff assembly of the drill string and whipstocks into wells with bends, difficulties, or those drilled with less stiff assembly;
- Running in full-size bits and tools into the interval of a well drilled with less than full-size or diameter-adjusted drill bits;
- Falling out of the chunk of solid rock or the entry of foreign objects into the well.
- The formation of keyseats is a result of the mainly translational movement of the drill string along the borehole wall (Fateev, 2026). Keyseats occur throughout the borehole; however, jamming occurs mainly in hard formations (sandstones, limestones, marls, etc.), so here the keyseats are the most dangerous.

The intensity of key seating depends on the following factors:

- Rock conditions in the borehole zone;
- The borehole crookedness and the rate of its change;
- The number of longitudinal motions of the drill string during cleaning, processing, and stops in the open hole;
- The number of roundtrips;
- Design of drill string elements, especially joints;
- Caverns, especially in areas of hard fractions.

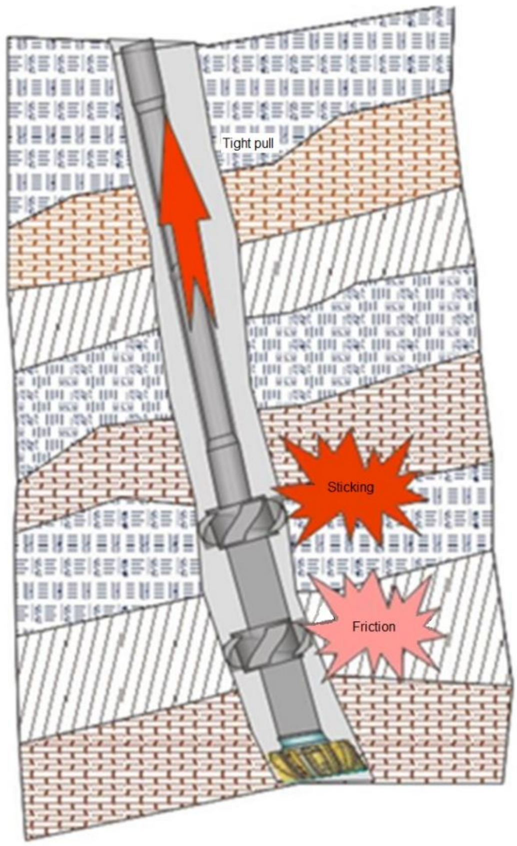

Fig. 4. Tight pull due to drill string or casing column sticking caused by violation of the borehole shape

The size of the key-seats is proportional to the duration of exposure to the above factors. The key seats not only create a risk of jamming elements of the drill and casing strings in them but also aggravate other troubles, like reducing the upward flow rate, creating stagnant zones, and increasing the contact area of the columns with the borehole wall. A characteristic feature of tightening in the keyseats is that they are confined to certain depths with each round trip. During drill-string running, in these intervals, the drill string, as a rule, passes without jamming.

To reduce key seating, the following measures are effective:

- While drilling intervals where because of geological conditions, the slope or azimuthal angles of borehole deviation are naturally changing, the layout of the drill string and drilling mode must be such as to restrict the rate of angles altering and keep their absolute value within limits; likewise, deter the formation of ledges and sharp bends of the borehole and enable drilling the borehole as close to vertical as possible;
- The drilling location of the new borehole should be chosen above the area of intense deviation, taking into account all geophysical information. An important measure against keyseating is to reduce the duration of drilling hours. When drilling in intervals favorable for key seating, unproductive time should be minimized, the most productive drill bits should be utilized, and unproductive runs of the drill string should be avoided. Each new interval of key-seat tight pull needs to be logged and shared with the staff when changing shifts. In the key-seat zone, the drill string should be pulled out at a low speed.

Discussion

When the drill string enters the keyseat, the driller should not intensify pulling beyond the current one. It is necessary to release the drill string by offloading. Having released the drill string, one should lower it, turn the rotor at a certain angle, and attempt to lift it above the key seat, thereby preventing a tight pull of more than 5 tons over its weight. If this method does not work, the drill string should be passed lower into the safe zone. The drill string should be released from the key seat by unscrewing, with slight pulling in excess of its own weight (0.5-2 tons).

Work to eliminate drill string locking should be initiated immediately to reduce risks associated with cuttings sliding and the string sticking to the borehole wall.

In the event of jamming in the keyseat during operation, the drill string is released by reciprocation at a maximum permissible pulling force in excess of its own weight and offloaded to a load less than one during jamming. The safety factor against stretch at all points of the drill string during drill string reciprocation should not be less than 1.2, while the load on the wall hook should not exceed the permissible load on the drilling derrick, drilling line system, lifting bails, etc.

Jamming of drilling bits can occur because of the following factors:

- The use of a bit with a larger diameter than the previous ones or a bit with a different shape than the ones that worked before;
- The use of a new drill bit in the work section of the previous one, which has lost its nominal diameter.

Bit jamming can also occur in keyseats or narrow sections of the borehole during pulling and running operations.

Borehole reaming after drilling any section takes a considerable amount of time, as has been found (Basarygin et al., 2000; Ivanova, 2021), and there is a certain risk of the drill string becoming stuck during down-hole operations or during the running of the casing.

Thus, meeting the established requirements for safe operations is mandatory for all contributors, regardless of the importance and the volume of mobilized hardware resources. Compliance with the above-stated measures ensures the high quality of oil and gas well construction and reduces financial and time costs regarding the construction term.

Results

The analysis of cases of upset conditions of sticking during drilling for a sample consisting of 380 wells located in 10 countries allowed us to determine the percentage of total drilling time lost when replacing equipment, including the following:

- Column heads in straight well—1%;
- Blowout preventers—1%;
- Casing columns—2%;
- Preventive maintenance—3%;
- Remedial maintenance of drill string parting—2.5%;
- Tool repair—5.5%;
- Lost circulation treatment—1.5%;
- Casing cementing—1.8%.

For controlled-angle drilling, similar costs increase by 30–40%, and for flat, complicated, and multi-branch wells in complex environments, up to 70% of the total time is lost during drilling (Maikobi et al., 2026; Leonov and Kravtsov, 2024; Altindal et al., 2024).

Existing methods for preventing sticking are based on the improvement of the filtration and lubricating drilling mud properties, further improvement and development of hydrodynamic devices for well flushing, the use of devices and equipment to prevent and eliminate sticking of the drill string during pulling and running, and the use of anti-sticking assemblies for the bottom-hole assembly or replacing the hole profile and design (Sinitskih and Popov, 2025; Ivanova et al., 2024; Ivanova et al., 2018; Duan et al., 2023; Nae et al., 2014). Modern drilling with rotary steerable systems enables the drilling of flat or low-angle wells with lengths exceeding 10,000 m, minimizing stickings due to the constant rotation of the drill string, timely cleaning of the borehole from cuttings, and a higher ability to push the column along the horizontal borehole.

However, if cement is pumped in the annulus along the entire column from the wide side of the annulus, then on the other side, a channel is formed through which gas or drilling mud flows. The recommended optimal type of centralizer will help correctly place a column inside the well, straighten the axis of the wellbore, or deflect the well, which will reduce the likelihood of sticking.

The designs and materials of centralizers are quite diverse and may be specific to certain countries worldwide. They can be casing and roller. Casing centralizers serve as centering and supporting equipment for boreholes, including deep ones, to be calibrated. Such centralizers are a monolithic structure with three special reinforced blades. The blades can be made of chopped reinforced carbon fibers (Majko et al., 2022). They diverge to the sides, touching the drilled formation wall. To increase the stability of the centralizer, the blades are framed with additional cutting structures at the ends, ensuring the long-term preservation of the device's centering capabilities. Casing centralizers with two types of pipe joints, featuring both external and internal threads, are installed at the connection between reinforced drill pipes. For installing the centralizer above the drill bit, both joints are installed inside. The last type of casing centralizer can be equipped with an edge tool for well-site calibration. If it is necessary to change the direction of the well, roller centralizers are used. They consist of a main drive coupling, blades, and a collet. Six reinforced blades are located on the surface of the coupling. Having a standard conical thread, the collet is screwed into the coupling. This is usually necessary to secure the roller centralizer to the engine. When the coupling is turned, the collet begins to close, safely securing the engine body.
The proposed parameters for selecting the type of centralizer are presented in Table 1.

Tab. 1. Types of centralizers and their basic properties

Type of Centralizer / *Properties*	 *1. Casing Centralizer*	 *2.Casing Centralizer*	 *3.Roller Centralizer*	 *4 Casing*
Rotation	+	+	+	+
Reduction	-	+	_	+
Size for Casing Type	±	±	-	+

Sizes of layouts with centralizers (type 4) for stabilizing the deviation angle and the azimuth (Northern Asian) are in Table 2.

Tab. 2. Parameters of centralizers for stabilizing the deviation angle and the azimuth

Diameter, mm			*Centralizer Diameter, mm*		*Distance to Centralizer, mm*	
Bit	*Calibrator*	*Turbodrill*	*First*	*Second*	*To the First*	*To the Second*
215.9	*215.9*	*195*	*212*	*210*	*1500*	*18000*
295.3	*295.3*	*240*	*280*	*270*	*3500*	*24000*

Sizes of layouts with centralizers (type 4) for the deviation of slant holes regulation (Northern Asia) are in Table 3.

Tab. 3. Parameters of centralizers for zenith deviation and azimuth regulation

Diameter, mm			*Increasing the Deviation Angle*		*Reducing the Deviation Angle*	
Bit	*Calibrator*	*Turbodrill*	*Centralizer diameter, mm*	*Distance to centralizer, mm*	*Centralizer diameter, mm*	*Distance to centralizer, mm*
190	*190*	*172*	*188*	*1200*	*184*	*8000*
215.9	*215.9*	*195*	*214*	*1500*	*210*	*12000*
295.3	*295.3*	*240*	*290*	*2000*	*270*	*16000*

Conclusions

Geophysical results, exemplified by the cementing of a horizontal well (highlighted in yellow), demonstrated that the centralizer is installed at the designated location and is serviceable. No difficulties, tightening, or sticking of the casing have been recorded during lowering the casing. There are no cross-flows in the annulus, and there is a low probability of sticking (Figure 5).

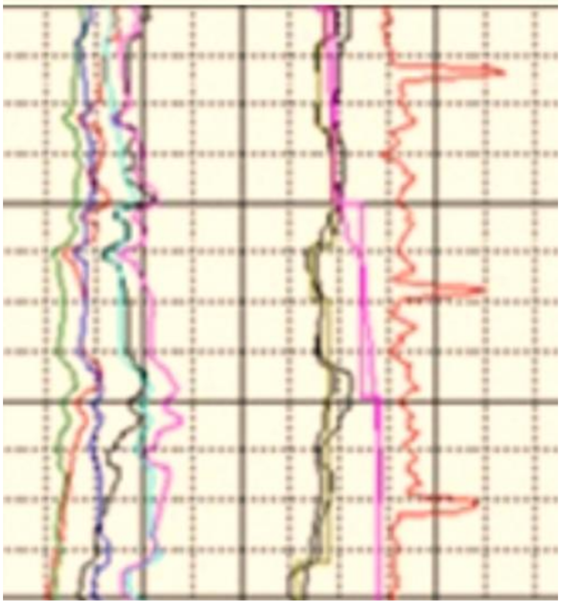

Fig. 5. Geophysical results of the quality of cementing of a horizontal well study

Thus, one of the simplest and most reliable ways to reduce the probability of sticking is the correct installation of a centralizer. In this case, the optimal design of the centralizer is based on the type of casing strings and the conditions of their running. In practice, the use of a centralizer allows for centering the casing string while cementing is in progress, prevents differential sticking of the string by reducing the contact area with the well wall, reduces torque and friction during running, or protects the packer in an open hole.

When troubles occur or in the event of an emergency, drilling operators use their previous experience in eliminating sticking. Investigating the causes of troubles during drilling and identifying the onset of their occurrence enables timely measures to prevent further complications or remediation as soon as possible. One of the simplest and most reliable ways to reduce the chance of sticking is proper installation and an informed choice of the type of centralizer.

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