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Aspects of effective removal of rock particles from inclined and horizontal boreholes

Aspekty skutecznego usuwania cząstek skalnych z odchylonych i poziomych otworów wiertniczych

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ABSTRACT: Drilling inclined and horizontal wells in offshore conditions presents numerous challenges. One of the main reasons for the large number of complications that can occur when drilling long boreholes, is the removal of cuttings without causing interference at the wellhead. The technical and technological approach discussed in this study constitutes a primary concern in enhancing the efficacy of borehole cleaning from the formation particles in both directional and horizontal wells, particularly in cases of substantial deviations. This technique, which takes geological conditions into account, is compared with traditional well-cleaning methods. It should be noted that the article is of a review nature. One of the most critical aspects of directional well construction is the efficient transportation of drilled rock particles (cuttings) from the well. Ensuring high-quality sludge transport to the surface is essential when drilling horizontal wells. Inadequate borehole cleaning leads to the accumulation of sludge, resulting in severe issues that may require substantial cost to resolve. The efficiency of sludge removal by the upward flow of the drilling mud depends significantly on the borehole's zenith angle. As this angle increases, sludge becomes more challenging. The most significant difficulties typically occur in the 60–90° range, where sludge accumulates on the bottom wall of the well, forming an extended and stable "slurry cushion". Cleaning the borehole in this interval appears to be a challenging task that frequently necessitates a significant investment of time.

Key words: borehole, drilling mud, zenith angle, drill string rotation, sludge particles.

STRESZCZENIE: Wiercenie odchylonych i poziomych odwiertów w warunkach morskich wiąże się z licznymi wyzwaniami. Jednym z głównych problemów w długich otworach wiertniczych jest skuteczne usuwanie zwiercin bez zakłócania pracy na głowicy odwiertu. Podejście techniczne i technologiczne omówione w niniejszym opracowaniu koncentruje się na zwiększeniu efektywności oczyszczania otworów z cząstek skał w odwiertach kierunkowych i poziomych, szczególnie w przypadku znacznych odchyleń. Technika ta, uwzględniająca warunki geologiczne, jest porównywana z tradycyjnymi metodami oczyszczania otworów wiertniczych. Należy podkreślić, że artykuł ma charakter przeglądowy. Jednym z kluczowych aspektów budowy odwiertów kierunkowych jest efektywne usuwanie zwiercin. Zapewnienie odpowiedniego transportu urobku na powierzchnię ma kluczowe znaczenie podczas wiercenia odwiertów poziomych. Niewystarczające oczyszczanie odwiertu prowadzi do gromadzenia się zwiercin, co skutkuje poważnymi problemami wymagającymi znacznych nakładów finansowych na ich rozwiązanie. Skuteczność usuwania zwiercin przez przepływ płuczki wiertniczej w górę zależy w znacznym stopniu od kąta zenitalnego odwiertu. Wraz ze wzrostem tego kąta, usuwanie zwiercin staje się coraz trudniejsze. Największe trudności występują zwykle w zakresie 60–90°, gdzie zwierciny gromadzą się na dolnej ścianie otworu, tworząc wydłużoną i stabilną warstwę osadową. Oczyszczanie odwiertu w tym obszarze jest trudnym zadaniem, które często wymaga znacznych nakładów czasu.

Słowa kluczowe: odwiert, płuczka wiertnicza, kąt zenitalny, obrót kolumny wiertniczej, cząstki zwiercin.

Introduction

The development of offshore oil and gas fields using horizontal and multilateral wells presents significant challenges related to ensuring trouble-free drilling.

The primary cause of complications when drilling directional and horizontal wells with an extensive borehole length is the difficulty of efficient sludge removal to the surface (Shell Exploration and Production Company, 2003).

The technical and technological approach described in the article aims to enhance the effectiveness of borehole cleaning in directional wells under offshore conditions with ultra-large vertical displacements in complex geological and technical environments, compared to conventional well-cleaning methods.

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As global hydrocarbon consumption continues to rise, oil and gas companies must adopt increasingly advanced extraction techniques and methods to enhance well productivity. At present, and in the foreseeable future, the search for and development of new deposits is and will remain a strategic task of the state. Given the peculiarities of constructing directional wells, it is becoming increasingly important to explore new and refine existing approaches, technical and technological solutions for well design and construction, with the aim of reducing capital costs and increasing oil recovery.

Drilling directional wells is almost always accompanied by challenges in cleaning horizontal and inclined sections. Traditional approaches, such as using high-viscous drilling mud, increasing the rotational speed of the drilling tool, high pump efficiency, and performing frequent injection operations, can mitigate these challenges if the well reaches the design depth quickly enough.

However, when drilling long open borehole sections, well cleaning must be more effective; otherwise, numerous complications may arise.

Causes of complications in directional and horizontal wells

Improper well cleaning can lead to costly problems and complications during drilling, such as:

- mechanical sticking of the drill pipe;
- premature wear of the drill bit;
- relatively slow drilling speed;
- hydraulic fracturing;
- excessive torque;
- difficulties in logging and cementing;
- difficulties with the descent of the casing.

The most common problem is increased torque, which often makes it impossible to achieve the project objectives when drilling.

Factors affecting borehole cleaning include:

- shape and size of rock particles;
- drilling speed;
- zenith angle;
- borehole and drill string diameters;
- fluid flow velocity and mode;
- rheology of drilling mud;
- drill string eccentricity;
- drill string rotation.

One of the main reasons for the large number of complications that can occur when drilling inclined and horizontal wells with a very long borehole is the difficulty of removing rock particles without interference to the wellhead.

Therefore, during the construction of directional and horizontal wells, efficient transportation of drilled cuttings from the well in challenging geological conditions is a critical task.

In this regard, considering the peculiarities of constructing extended directional wells, solving this problem is a key factor in confirming the effectiveness of the use of horizontal wells (HW) and multilateral wells (MLW) with a large deviation from the vertical (Akbulatov et al., 2005).

Inefficient well cleaning leads to the accumulation of sludge in the well, causing serious problems that may require high costs to resolve, often exceeding the cost of preventive measures to improve the cleaning of the wellbore (Matytsyn et al., 2002).

One of the most common problems caused by sludge accumulation is the mechanical sticking of the drill string (approximately 30% of such incidents in vertical wells are associated with inadequate borehole cleaning, while in wells with a large zenith angle – more than 80%). Drilling with incomplete sludge removal leads to the formation of so-called sludge cushions, which, upon lifting the drill string, move along with the wider part of the bottom-hole assembly.

As a result, the annular space becomes clogged, leading to pressure surges, which can cause sticking and complete circulation loss (Gorpinchenko and Dilmiev, 2010).

The efficiency of sludge removal by the upward flow of the drilling mud significantly depends on the borehole's zenith angle. As the zenith angle increases, sludge removal becomes more difficult (Kulikov, 2008).

The most difficult-to-solve cleaning problems typically occur in the 60–90° range, where sludge accumulates on the bottom wall of the well, forming extended and stable "slurry cushion". This sludge remains on the well wall due to frictional forces. Cleaning the borehole in this interval appears to be a challenging task that frequently necessitates a significant investment of time (Mitchell, 2001; Khabibullin, 2007).

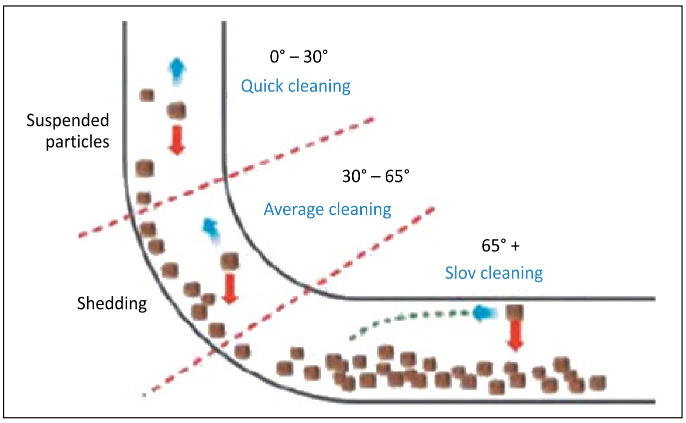

Figure 1. The relationship between borehole inclination angle and drill cuttings removal

Rysunek 1. Zależność między kątem nachylenia otworu wiertniczego a usuwaniem zwiercin

In an inclined well, three separate sections can be distinguished.

The first zone is from 0° to 30° (vertical).

In the space behind the pipe, a uniform distribution of rock particles can be observed, regardless of the velocity profile of the upward fluid flow.

The second zone is from 30° to 65° (transitional).

The distribution of rock particles in the well space begins to be disrupted, and the concentration of rock particles begins to increase in the lower part of the well space compared to the upper part. In this zone, almost all rock particles tend to settle or collapse due to the low velocity of the liquid flow in the space behind the pipe. At the same time, it is noticeable that the flow moves downstream toward the nozzle.

As the well angle increases from zero to approximately 65° from the vertical, well cleaning becomes more difficult, and the need for drilling fluid consumption increases (Cameron, 2001).

The third zone is 65° + (horizontal).

In this zone, there is significant deposition of rock particles in the lower part of the annulus. This settled suspension does not slide against the liquid flow.

The Boycott effect describes how particles in the inclined part of the well begin to settle faster than in the vertical part.

In some solutions under static conditions, sludge settles out of the solution, forming a layer of purified liquid closer to the upper wall. The forces of hydrodynamic resistance cease to act on the deposited sludge particles, and the resulting force vector is directed tangentially to the wall, leading to an avalanche-like deposition of sludge particles on the well wall. The resulting density gradient causes the lighter liquid to move up while the heavier liquid moves downward. It should be noted that this effect is enhanced at angles of 30–60°, causing the most severe complications.

This is due to the fact that in the inclined section of the well, the drill string tends to rest on the lower borehole wall due to gravity. This creates a very narrow gap in the annular space beneath the drill string, leading to extremely low fluid velocity and making it impossible to transport the sludge to the surface (Pilehvari et al., 1999).

As the eccentricity of the drill string's position in the borehole increases, the velocity of drilling mud particles in the narrow gap decreases, especially for highly viscous fluids, thereby creating unfavorable conditions for sludge transport to the surface (Erge and van Oort, 2020).

If the circulation rate, yield point, and viscosity are increased, complications can be reduced; however the Boycott effect cannot be completely eliminated (Krylov and Kretsul, 2005).

Sludge accumulation in the well significantly obstructs the passage of logging devices, often necessitating additional well drilling and causing problems during casing string installation (Gorpinchenko and Dilmiev, 2010).

The efficiency of sludge removal with an increase in the length of the wellbore is determined by multiple factors, primarily the overall effect of the technological parameters of the equipment used and on the hydraulic parameters of flushing (rheology of the drilling mud, pressure losses in various sections of the circulation system, flow type, etc.) (Bolchover, 2007).

Currently, the industry produces numerous devices designed to improve and accelerate borehole cleaning. One method for effective sludge removal involves inserting a special ball into the drill pipes, pumping it along with the drilling fluid, and installing it in the landing socket. When the pressure reaches the threshold value, the circulation ports open, allowing the ball to slip further into a ball trap device. From this point onward, a portion of the low-pressure flow begins to flow out of the ports, while the remainder continues to flow through the bit nozzles. This device has been successfully tested in drilling wells in various fields, resulting in increased annular velocities and more efficient sludge removal to the surface.

The range of manufactured devices can be categorized into several types:

- circulation converters, powered by drop balls and constructed using thick-walled drill pipes (hereinafter TDP);
- blade elements, which interact with the slurry cushion and lift accumulated sludge into regions of increased flow rates.

For example, the drilling valve "Well Commander", manufactured by Mi-Swaco, is a ball-operated circulation exchanger that enables partial discharge of the passing flow. The device is installed above the "sensitive" components of the bottom-hole assembly, such as MWD and LWD (devices for measuring parameters for monitoring drilling and logging processes), and screw downhole motors.

This valve is used to create additional peripheral drilling fluid circulation zones to mitigate associated drilling risks.

The operation of this process consists of following stages:

1. Touching the ball;
2. Valve activation;
3. Opening of circulation ports;
4. Complete sealing of the bottom-hole assembly;
5. Valve closure;
6. Removal of the ball that seals the bottom-hole assembly;
7. Passage of the ball through the trapping device;
8. Insertion of an activated ball;
9. Ball passage through the trapping device.

Paradigm Oilfield Services, Vam Drilling, and Halliburton supply specialized drill pipes with improved hydraulic characteristics (Figure 2). Practical experience with these pipes has demonstrated their effectiveness, particularly in well sections with large zenith angles (35°–65°) and sig-

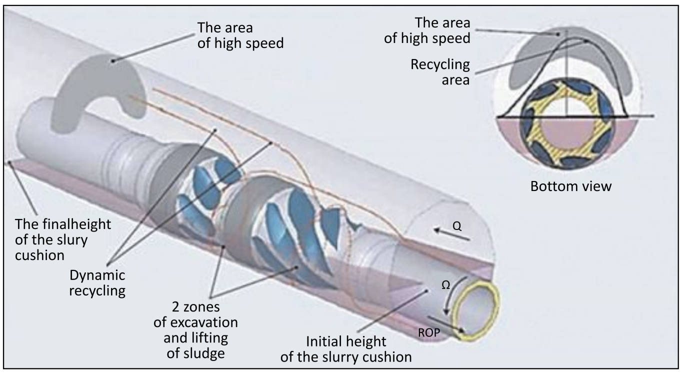

Figure 2. Principle of operation of the improved drill pipe by Vam Drilling

Rysunek 2. Zasada działania ulepszonej rury wiertniczej firmy Vam Drilling

nificant "sludge cushion" formation. These drill pipes replace conventional thick-walled drill pipes, reducing torque and tangential stresses.

FlowMax Circulation Translator

The FlowMax circulation translator, manufactured by Drilling System International, is a new product on the oil market that enhances well cleaning and hydraulics when drilling directional wells (Figure 3) due to the inclusion of self-opening hydraulic monitoring valves in its design. This device is installed as part of a drilling tool in areas prone to slurry cushion formation and is designed to inject fluids that clog drilling mud absorption zones. This increases the circulation rate of drilling mud in highly inclined or horizontal wells and, consequently, reduces drilling costs. The FlowMax operating principle is described below. Based on the practical experience and theoretical analysis of the solution to the problem of removing drilling sludge from the well, and considering the application of the FlowMax circulation translator for this purpose, the following recommendations should be taken into account to optimize the process in highly inclined wells:

1. The choice of drilling fluid is extremely important when drilling wells with a large deviation from the vertical, particularly in active shale and clay-bearing formations. Hydrocarbon- or synthetic petroleum-based drilling fluids should be considered to enhance wellbore stability, thereby minimizing wellbore expansion and reducing the load on drilling sludge in the wellbore.
2. Increasing the flow rate should be the first option to consider if the well cleaning is insufficient. When calculating drilling hydraulics, the maximum flow rate should be taken into account, which requires an accurate hydraulic program that takes into account pump performance, etc.

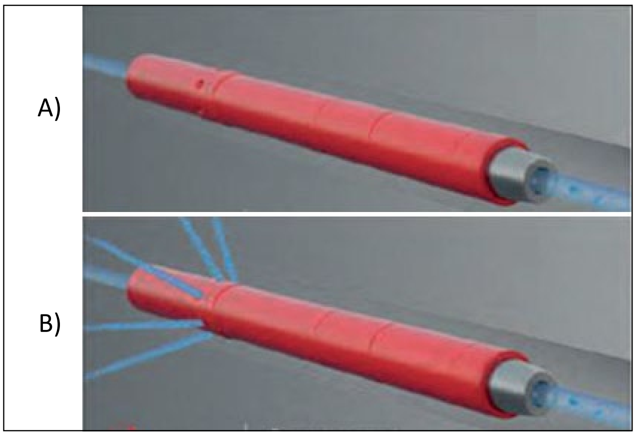

Figure 3. FlowMax circulation translator; A) Closed position: *Flow rate of 600 gal/min (38 l/s) in the bottom-hole assembly; *no turbulent flow in the annular space; B) Open position: *Increase in flow rate up to 800 gal/min (50 l/s : 38 l/s – in the bottom-hole assembly + 12 l/s through Flow Max

*Enhanced well cleaning efficiency, creating a turbulent flow of drilling mud in the annular space with Re > 4000

Rysunek 3. Przełącznik cyrkulacyjny FlowMax; A) pozycja zamknięta: *przepływ na poziomie 600 gal/min (38 l/s) w dolnym zestawie przewodu wiertniczego; *brak przepływu turbulentnego w przestrzeni pierścieniowej; B) Pozycja otwarta: *wzrost przepływu do 800 gal/min (50 l/s : 38 l/s – w zestawie przewodu wiertniczego + 12 l/s przez FlowMax)

*Zwiększona efektywność oczyszczania odwiertu, generowanie turbulentnego przepływu płuczki wiertniczej w przestrzeni pierścieniowej przy Re > 4000

Conclusions

1. Well cleaning efficiency can be improved through mechanical (pulsation) action on the flow.
2. The capacity for sludge removal to the surface is primarily dependent on the design parameters of various technical devices and the hydraulic flushing parameters.
3. Increasing the velocity of the upward flow of drilling mud in the annulus, reducing well flushing time by half, reducing hydrodynamic pressure in the well by 30%, and increasing mechanical drilling speed can be achieved using the FlowMax system in the directional well drilling process.

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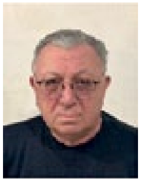

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