NAFTA-GAZ

Nafta-Gaz 2023, no. 10, pp. 651–660, DOI: 10.18668/NG.2023.10.03

Drilling fluids in complicated conditions: a review

Płuczki wiertnicze w skomplikowanych warunkach: przegląd

Yelena Y. Shmoncheva, Gullu V. Jabbarova, Timur E. Abdulmutalibov

Azerbaijan State Oil and Industry University

ABSTRACT: The review in this article focuses on various aspects of drilling extended reach (ERD) wells. Reaching extreme depths and setting world records for deviation illustrates the importance of well design and operating strategies. Studies of articles describing various locations, including Sakhalin Island in Russia and offshore Vietnam, provide insight into ERD operations. Furthermore, the challenges of drilling in specific geological conditions, such as layered sandstones and reactive clay, are considered. Particular attention is paid to issues related to wellbore instability and drilling fluid optimization. The results of technical studies highlight the key role of maintaining wellbore stability in achieving successful ERD results. The articles emphasize the importance of understanding geomechanical factors, employing optimal mud weight, lubrication, and specialized drilling fluids to counteract instability. It demonstrates that maintaining appropriate mud weights and employing specific drilling techniques are crucial for mitigating instability-related issues. The integration of mechanical and chemical approaches is advocated for effectively managing shale-related instability. The utilization of innovative materials and fluid systems is central to the successful resolution of stability-related problems. The incorporation of micronized sealing polymers in conjunction with conventional plugging materials is detailed as an effective approach to counter wellbore instability. The synergistic combination of materials, additives and mud salinity is showcased to achieve effective shale stabilization and optimize drilling time. The authors emphasize the importance of selecting the optimal composition for each well based on experience and laboratory testing and present laboratory-tested solutions that have been successfully applied in field operations. In summary, these articles collectively offer insights into a range of strategies to combat wellbore instability. They cover the use of advanced materials, innovative fluid systems, and chemical approaches to maintain wellbore stability, improve drilling efficiency, and reduce nonproductive time.

Key words: extended reach wells, wellbore instability, drilling fluids, mud loss, shale stabilization, geomechanical factors, mud weight, filter cake, polymer system, optimization.

STRESZCZENIE: Przegląd zawarty w niniejszym artykule skupia się na różnych aspektach wiercenia odwiertów o wydłużonym zasięgu (ERD). Osiąganie ekstremalnych głębokości i ustanawianie rekordów świata w zakresie odchyleń ilustruje znaczenie projektowania odwiertu i strategii eksploatacyjnych. Przegląd artykułów opisujących różne lokalizacje, obejmujące wyspę Sachalin w Rosji oraz szelf w Wietnamie, zapewnia wgląd w operacje ERD. Ponadto rozważane są wyzwania związane z wierceniem w specyficznych warunkach geologicznych, takich jak piaskowce warstwowane oraz reaktywne iły. Szczególną uwagę zwraca się na zagadnienia związane z niestabilnością odwiertów i optymalizacją płuczki wiertniczej. Wyniki badań technicznych podkreślają kluczową rolę utrzymania stabilności odwiertu w osiąganiu udanych wyników ERD. W artykułach podkreślono znaczenie zrozumienia czynników geomechanicznych, stosowania płuczki o optymalnym ciężarze, smarowania oraz specjalistycznych płynów wiertniczych w celu przeciwdziałania niestabilności. Pokazano, że utrzymywanie odpowiedniego ciężaru płuczki oraz stosowanie specjalnych technik wiercenia ma kluczowe znaczenie dla złagodzenia problemów związanych z niestabilnością. Dla skutecznego zarządzania niestabilnością związaną z łupkami zaleca się integrację podejścia mechanicznego i chemicznego. Wykorzystanie innowacyjnych materiałów i systemów płynów ma kluczowe znaczenie dla udanego rozwiązywania problemów związanych ze stabilnością. Włączenie mikronizowanych polimerów uszczelniających w powiązaniu z konwencjonalnymi materiałami uszczelniającymi jest opisywane szczegółowo jako skuteczne podejście w celu przeciwdziałania niestabilności odwiertu. Synergiczne połączenie materiałów, dodatków oraz zasolenia płuczki jest przedstawiane jako sposób osiągnięcia skutecznej stabilizacji łupków i optymalizacji czasu wiercenia. Autorzy podkreślają znaczenie doboru optymalnego składu dla każdego odwiertu na podstawie doświadczenia i badań laboratoryjnych oraz obecne rozwiązania przetestowane laboratoryjnie, które zostały z powodzeniem zastosowane w operacjach terenowych. Podsumowując, artykuły te łącznie oferują wgląd w szereg strategii zwalczania niestabilności odwiertów. Obejmują one zastosowanie zaawansowanych materiałów, innowacyjnych systemów płynów oraz rozwiązania chemiczne w celu utrzymania stabilności odwiertu, poprawy wydajności wiercenia oraz zmniejszenia czasu nieproduktywnego.

Słowa kluczowe: odwierty o wydłużonym zasięgu, niestabilność odwiertu, płyny wiertnicze, ucieczki płuczki, stabilizacja łupków, parametry geomechaniczne, ciężar właściwy płuczki, placek filtracyjny, system polimerowy, optymalizacja.

Corresponding author: Y.Y. Shmoncheva, e-mail: *yelena.shmoncheva@asoiu.edu.az*

Article contributed to the Editor: 10.04.2023. Approved for publication: 13.10.2023.

Introduction

Wellbore stability is a critical factor in the successful drilling of horizontal and extended reach drilling (ERD) wells (Agbaji, 2011; Kaushik et al., 2016). Horizontal and ERD wells have gained prominence in the oil and gas industry due to their ability to access larger reservoir areas and improve overall production rates (Judzis et al., 1999; Szymczak, 2021). However, drilling these types of wells presents unique challenges, and maintaining wellbore stability is crucial for their successful execution (Gradishar et al., 2014; Hakim et al., 2022).

In the context of drilling, wellbore stability refers to the ability of the wellbore walls to maintain their integrity and prevent any detrimental failures or collapses during drilling operations (Dahab et al., 2020). Horizontal and ERD wells pose specific challenges to wellbore stability due to their extended length and complex geologic formations (Kaushik et al., 2016). The horizontal section of these wells can extend over long distances, exposing the wellbore to various geological formations with varying rock properties, stresses and pressures (Wilson, 2018). The horizontal trajectory also creates additional mechanical forces on the wellbore, such as the drag and torque caused by the drill string (Aarrestad, 1994; Wilson, 2018). These factors increase the risk of wellbore instability, including issues such as borehole collapse, differential sticking, and mud losses (Shakhova et al., 2021). The consequences of poor wellbore stability can be significant. Wellbore collapses or formation damage can lead to non-productive time, costly repairs, and even the abandonment of the well. Moreover, instability issues can hinder efficient drilling operations, reducing drilling rates and increasing operational costs (McLellan, 1996; Krygier et al., 2020). To ensure the successful drilling of horizontal and ERD wells, drilling professionals employ various techniques to assess and maintain wellbore stability. This includes comprehensive geomechanical analysis to understand the stress distribution and rock properties, as well as the selection of appropriate drilling practices and technologies (Russell et al., 2006; Agbaji, 2011; Khan et al., 2021).

The role of drilling fluids in wellbore stability is vital to ensure the success and safety of drilling operations (AlBahrani et al., 2022). Drilling muds serve multiple functions, with one of the primary objectives being to maintain wellbore stability throughout the drilling process (Ge et al., 2022). The properties and characteristics of the drilling fluid, such as its viscosity, density, and lubricity, are carefully chosen to exert pressure on the wellbore walls and prevent collapses (Yadav et al., 2016; Kuru, 2022). The drilling fluid acts as a support medium, creating a hydraulic barrier that stabilizes the wellbore and reduces the risks of instability (Ramirez et al., 2006; Pavlenko and Glukhareva, 2007; Al-Bazali et al., 2008).

Drilling fluids exert hydrostatic pressure on the wellbore walls, counterbalancing the formation pressure to prevent collapses or caving-in of the wellbore. By maintaining adequate pressure, drilling fluids help to stabilize the wellbore, preventing formation damage and minimizing the risk of wellbore instability (Spagnolo et al., 2022). Drilling fluids act as a protective barrier between the wellbore and the formation. They help to minimize the invasion of fluids into the formation and control the interaction between the drilling fluid and the formation rock (Cameron et al., 2003). This prevents the destabilization of the formation, avoiding wellbore instability issues such as swelling, sloughing, or heaving. Drilling fluids lubricate the drill string and the wellbore, reducing friction and drag forces during drilling operations. By minimizing friction, they facilitate smooth and efficient drilling, reducing the likelihood of differential sticking and minimizing the risks of wellbore instability associated with excessive torque or drag (Cameron et al., 2003). Drilling fluids aid in the efficient removal of drilled cuttings from the wellbore. They suspend and transport the cuttings to the surface, preventing them from accumulating and potentially bridging or blocking the wellbore. Efficient cuttings transport helps to maintain a clear and stable wellbore, reducing the risks of instability caused by debris or blockages (Pandya et al., 2020). Some drilling fluids formulations, such as weighted or high-density fluids, can enhance wellbore stability by strengthening the wellbore walls. These fluids provide additional support and prevent wellbore collapse in mechanically weak or unstable formations (Reid and Santos, 2006; Tan et al., 2021). To optimize wellbore stability, drilling engineers carefully design drilling fluid systems tailored to the specific wellbore conditions, formation properties, and drilling objectives. They consider factors such as fluid properties (density, viscosity, filtration control, etc.), drilling fluid additives (Cameron et al., 2003; Vryzas and Kelessidis, 2017), and the selection of appropriate drilling fluid types (water-based, oil-based, or synthetic-based muds) (Kuru, 2022). It is important to note that maintaining wellbore stability is a continuous process throughout drilling operations. Monitoring the performance of drilling fluids, assessing wellbore conditions, and making adjustments as necessary are crucial to effectively manage wellbore stability and mitigate potential risks (Carpenter, 2021; Ge et al., 2022).

In summary, wellbore stability is of paramount importance when drilling horizontal and extended reach wells. Addressing stability challenges through comprehensive analysis, appropriate drilling practices, and the use of suitable drilling fluids is crucial for the successful execution of these wells, ensuring safe and efficient drilling operations. By effectively managing wellbore stability in horizontal and ERD wells, drilling operations can be carried out safely, efficiently, and with minimal downtime. It allows for optimal reservoir access, maximized production rates, and overall improved well performance.

This manuscript has two interrelated goals: to describe the problems of drilling ERD wells in specific geological conditions such as layered sandstones and reactive clays, and to show that the use of advanced materials, innovative drilling fluid systems, and chemistry approaches is effective in maintaining wellbore stability and improve drilling efficiency.

Drilling problems in extended reach wells

The technical examinations presented by Dowson et al. (1999) and Judzis et al. (1999) yield the following primary findings. The wellbore instability experienced in wells NK-11 and NK-41 can be attributed to both compressive and tensile failures of the shale formations. These wells were drilled using mud with static weight lower than those recommended by the wellbore stability analysis. To maintain stability, mud weights range from 1260 kg/m^3 to 1320 kg/m^3 and no less than 1295 kg/m^3. To mitigate the effects of radial tension, it was proposed that Equivalent Circulating Densities (ECDs) should not exceed 1560 kg/m^3. The re-entry of NK-11 was effectively drilled using a mud with a static mud weight of 1260 kg/m^3. The study's outcomes underscore the importance of incorporating knowledge about subsurface conditions and wellbore stability into both well design and operational approaches for successful extended reach drilling.

The article written by Walker et al. (2009) describes the experience of drilling extended reach (ERD) wells and completions in the Chayvo field on Sakhalin Island (more than 10.5 kilometres, Russia). The drilling and completion of the Z-12 well were accomplished within 88 days, with a NPT of 9%, and all well objectives were successfully achieved. The augmentation in mud weight appears to have led to a notable enhancement in borehole quality. The hydraulic models designed for utilizing the finely ground barite mud system overestimated the reduction in Equivalent Circulating Density (ECD) that was anticipated from employing the system. Despite this, the thinner viscosity did contribute to minimal swab pressures during the retrieval of the drill string, likely aiding in hole stability. Furthermore, engineering oversight and the application of lubricants have contributed to improved hole cleaning and decreased ECD values.

The paper presented by Walker (2012) describes the completion of drilling operations at the Odoptu Field, offshore Sakhalin Island, Russia, operated by ExxonMobil, operator of the Sakhalin-1 project.

A total of nine extended reach wells were drilled offshore as part of the development of the Odoptu field, culminating in the outstanding achievement of the OP-11 well, which set the world record for vertical reach. Well OP-11 achieved an exceptional total depth of 12,345 meters measured depth (MD), with a true vertical depth (TVD) of 1,784 meters and 11,479 meters vertical section, all completed in just 60 days (NPT less than 1%). This document is a comprehensive chronicle of the drilling and completion of well OP-11.

The introduction of extended reach drilling (ERD) techniques has become a common approach to economically use existing infrastructure, access previously inaccessible reserves, and mitigate the environmental impact of drilling and production facilities. This, of course, forces operators to expand the boundaries of the ERD area, not only in terms of drilling, but also in terms of completion. The design of such wells typically involves complex modelling, but a deep understanding of the operational complexities associated with ERD is also required. Throughout the Odoptu drilling campaign, well design and operational strategies have been refined to optimize drilling efficiency while minimizing potential hazards. The article written by Walker (2012) describes successful solutions to various problems, including wellbore instability, vibration, shock, and high torque. The use of mud with higher weight helped to prevent wellbore instability. At a wellbore depth of 9,900 meters, drilling torque reached approximately 81.4 kNm, requiring the introduction of lubricants into the system. The conclusions presented in this paper (Walker, 2012), including design considerations and methodologies, provide an invaluable guide to drilling future ERD wells. Lessons learned from extreme ERD operations should be intelligently applied to future well planning that pushes the boundaries of what is possible.

The article written by Gui et al. (2012) presents an example from an offshore field in Vietnam, where stability problems were historically not significant for vertical and directional wells. The initial plan was to develop the field by drilling highly deviated and ERD wells from a single platform. However, during the drilling of one of the planned wells, instability issues emerged, leading to frequent sticking of liners and considerable non-productive time. The well had to be cut three times and eventually drilled at a lower angle than originally intended. To understand the geomechanical factors contributing to the instability, the authors used core samples, well logs, and drilling data to construct a field-scale geomechanical model. This model characterized the reservoir stress, pore pressure, and rock mechanical properties. By analysing offset well logs and collapse failure mechanisms recovered from the problematic well, they gained insights into the nature of the instability issues in the extended reach well. The problems were associated with failure of weak bedding planes and anisotropic rock strength in shale interbedded sandstones. As a result, mud with higher weight were needed to control sag and anisotropic failure, requiring a revision of the original ERD plan. New optimal well trajectories were developed to accommodate drilling problems, completion, and production requirements (Gui et al., 2012).

This article written by Al-Ajmi et al. (2013) presents compositions of drilling and completion fluids for drilling long lateral and horizontal wells in the North Kuwait field and their application in wells RA-492, RA-493 and RA-499. The offset wells were tested to identify problems associated with complex trajectory drilling through problem formations that showed severe wellbore stability problems. An individual system of drilling and completion fluids was developed for various intervals, considering the following tasks: increasing the stability of the wellbore through stressed formations, increasing the efficiency of cleaning the wellbore at critical angles, minimal damage to the formation section during the drilling stage, elimination of bottom hole damage. Al-Ajmi et al. (2013) describes individual characteristics of drilling and completion fluids. Well RA-492 was successfully drilled, setting the longest lateral section record at 1.610 m without any major problems such as hole blockage during tripping, shale sloughing, stuck pipe, or lost circulation events. In wells RA-493 and RA-499, after a series of failures, the traditional oil-based fluid system was replaced with a fluid system with improved plugging technology. The well's production exceeded expectations compared to offset wells. Lessons learned from these wells have been incorporated into subsequent wells to further improve productivity.

ERD wells, in addition to wellbore instability, can have serious wellbore cleanout, torque and drag problems (Cameron et al., 2003). Cleaning a well without creating excessive equivalent circulation density (ECD) leading to well losses can be a major problem when drilling extended reach wells. The reduced mud weight/fracture gradient window can limit the injection rate, making it difficult to achieve solids transport, especially in long tangential sections. World record long-reach drilling (ERD) experience led to the discovery that certain lost circulation fibrous materials (LCMs) have the ability to improve hole cleaning and significantly reduce torque and drag in highly deviated and horizontal wellbores. Cameron et al. (2003) focuses on the successful application of fibrous LCM in the first extended reach well drilled in Abu Dhabi by Abu Dhabi Company for Onshore Oil Operations (ADCO). By optimizing drilling techniques and incorporating a specially designed wellbore cleanout program, the need for cleanout operations can be minimized. Significant value in the drilling operation has been achieved by reducing the total time required to drill a well and the time required to prepare a wellbore.

The article presented by Elsborg et al. (2005) describes the problems and their solutions that have arisen during the drilling and completion of an extended reach oil well (ERD). The Hibernia development project is located in a water depth of 80 m, 322 km off the coast of Newfoundland and Labrador, Canada's easternmost province, in the Grand Banks region of the Atlantic Ocean. The reservoir consists of a series of thick layered sandstones separated by intermediate shales. It is subdivided into large compartments or 'blocks' by a series of faults that run through the reservoir in two directions. The well was successfully drilled, and an advanced chemical treatment system was implemented to expedite the transition from synthetic-based drilling fluid to water-based completion fluid.

Horizontal and ERD well drilling has become more routine with advancing technology (Zhang et al., 2006). However, wellbore instability remains a significant challenge hindering the reduction of drilling costs. Dealing with instability can be difficult and costly, resulting in non-productive time and increased drilling fluid expenses. Nevertheless, proper well design, including trajectory optimization and drilling fluid formulation, can mitigate these problems and avoid complications such as stuck pipe and lost circulation caused by collapse and wellbore failure. Shale's unique properties, like low permeability, layering, and reactive clay, necessitate an integrated approach involving both mechanical and chemical actions (Zhang et al., 2006).

Table 1 shows ERD well data and well problems.

The role of drilling fluids in wellbore stability and their composition

The article written by Al-enezi et al. (2018) presents 2 successful applications of a deformable sealing polymer to solve drilling problems. Drilling a highly deviated or horizontal wellbore in highly permeable formations is a challenging task. Drilling these wells is becoming difficult as an increasing number of directional wells are being drilled in formations with a high potential for wellbore instability. High differential pressure can lead to wellbore instability, differential sticking, and lost circulation. The average cost of stability problems is 5–10% of the total cost of exploration and operation of a well due to loss of time and sometimes equipment. It has always been preferred to drill these wells with oil-based drilling fluids and casing isolation of problem areas. Another solution is to redesign the drilling fluid system. The fluid system will primarily provide effective plugging, minimizing pore pressure transfer, and strengthening the wellbore. It has been found that conventional bridging materials, including calcium carbonates and graphite material, are not sufficient to solve the problem of pore pressure transmission. It was important to include a micronized sealing deformable polymer along with a conventional plugging material that effectively plugged the

Table 1. Overview of problems in ERD wells
Tabela 1. Przegląd problemów w odwiertach ERD

Source	Well	Field	Location	Mud Type	TVD / MD [m]	Degree inclination	Problem	Solution
Dowson et al., 1999, Judzis et al., 1999	NK-41/41A	Niakuk	Alaska	Oil-based mud	–/6000–7000	>80	Wellbore instability	Mud weight change
	NK-11							
Walker et al., 2009	Z-12	Chayvo	Sakhalin, Russia	Non-aqueous fluid (NAF)	2600/11.680	90	Wellbore instability	Drilling fluid with lubricants, increase drilling fluid weight
Walker, 2012	OP-11	Odoptu	Sakhalin, Russia	Non-aqueous fluid (NAF)	1784/12.345	90	Wellbore instability	Drilling mud with fluid lubricants
Gui et al., 2012	W-3	Nam Con Son Basin	Vietnam	–	>5000	82	Stability incidents	Mud weight change
Al-Ajmi et al., 2013	RA-492	Raudhatain	North Kuwait	Oil-based mud (OBM) and proprietary synthetic organic polymer	–	90	Wellbore stability, hole cleaning	Drilling mud + calcium carbonate and graphite
	RA-493					90		Fluid system with a bridging technique
	RA-499					90		
Cameron et al., 2003	–	–	Abu Dhabi	Oil-based mud	–	–	Hole cleaning and torque and drag issues	Application of fibrous LCMD sweeps
Elsborg et al., 2005	Hibernia B-16 36 (OPA1)	Hibernia	Canada	An advanced chemical cleaning system	3960.27/9356.75	–	Hole cleaning, directional and torque and drag issues	Mud weight change, bridging additives
Dosunmu et al., 2015	OGG 78	–	Niger delta	Oil-based mud	4572	–	Hole cleaning issues	Cuttings monitoring model

pore channels and minimized fluid intrusion. The deformable polymer component can change its shape to fit a wide range of pore channel sizes, which was previously unattainable using conventional technology. The addition of a micronized sealing polymer allows the additive to plug and seal microcracks. Laboratory testing using API test procedures has demonstrated improved filtration control and confirmed that the addition of micronized sealing polymer does not adversely affect rheology or other drilling fluid properties. The optimized bridging and sealing system (OBSS) consist of a combination of highly resilient carbon-based additives with a deformable, micronized sealing polymer. This combination of materials has been shown to be effective in bridging and sealing drilling fractures.

The results obtained during laboratory tests have been effectively applied in the field. The results attained in laboratory testing were effectively conveyed to the field. The optimized shut-off and sealing system has been successfully applied to a number of wells in North Kuwait (Al-enezi et al., 2018). Drilling was successfully performed with no recordable differential sticking or losses incidents. There were no wellbore stability incidents. By reducing the risk of wellbore instability, non-productive time (NPT) was negligible compared to similar wells.

The paper presented by Shaver et al. (2015) outlines the geologic framework and log based characterization of formations, drilling problems are explained as well as a potential solution to drilling at high angles. Causes of wellbore instability include chemical factors. This article (Shaver et al., 2015) focuses on chemical instability and how to reduce it. Chemical reactions between drilling fluids and lithologies, which include clays, evaporites and various carbonates, catalyse wellbore damage. Shaver et al. (2015) highlights the benefits of KCl drilling fluid. The decision was made to create a KCl polymer system and test its effect on preventing well hole expansion. The KCl Polymer/PHPA/Glycol system contained three shale inhibitors. The article (Shaver et al., 2015) presents additives, their concentration levels in the proposed drilling fluid and their functions.

1. KCl when used in proper concentration is a powerful shale inhibitor. It interacts with clays such as illite or montmorillonite and reduces their swelling.
2. Partially hydrolysed polyacrylamide (PHPA) as functional additive is used to control wellbore shale.

As a shale control drilling fluid, PHPA is believed to seal microfractures. The particulate removal efficiency is improved.
3. Glycol, which not only acts as a good shale inhibitor, but also provides wellbore stability, fluid loss control and lubricity.

Thus, a simple potassium/polymer drilling fluid system, providing excellent rheological and filtration properties, was designed to minimize expected wellbore expansion due to shale. Potassium-polymer drilling fluid significantly reduced hole expansion, reduced drilling time, reduced the risk of not reaching the target depth with casing, improved cementing operations (Shaver et al., 2015).

Predein and Klykov (2015) describe the main problems in the construction of horizontal wells in the deposits of the Devonian system, associated with the loss of stability of clay rocks. The destruction of clay rocks occurs because of the loss of rock stability because of wedging of microcracks under the influence of drilling fluid. Experience in the construction of horizontal wells in Devonian rocks shows that the use of invert emulsion drilling fluid does not always eliminate the complications associated with the loss of stability of the well walls. Therefore, for the construction of horizontal wells, it is necessary to optimize the formulation of invert-emulsion drilling fluid. The authors (Predein and Klykov, 2015) recommend the use of non-aqueous solutions based on thickened mineral oils and invert emulsions. To increase the time of the stationary state of rocks in the invert solution, it is necessary to choose the optimal composition and concentration of the aqueous phase and select a complex of micro colmatants. Studies have shown that the maximum saturation of the aqueous phase with calcium ions allows the maximum preservation of the initial strength of rock samples. The ratio of water and oil in the drilling fluid does not significantly affect the strength properties. The combined effect of three components on the filtration characteristics of invert-emulsion drilling fluids: ultrafine clay particles (organ bentonite), drops of the aqueous phase and a partially soluble reagent that reduces fluid loss. Using different solid and liquid bridging agents with different molecular weights and structures, it is possible to ensure the formation of a blocking impermeable screen to prevent further penetration of the liquid phase of the drilling fluid deep into the fracture. In this case, the effect of 'plastering' occurs, and the stability of the wellbore is maintained. Based on the results of the study of the filtration properties of the invert-emulsion drilling fluid, a complex of micro colmatants can be selected, which makes it possible to reduce the filtration rate of the drilling fluid to almost zero (Predein and Klykov, 2015).

According to Giri (2010), the success in achieving extra-stability of the wellbore in highly reactive shales is due, among other things, to the use of K+Cl-polymer mud chemistry.

The use of the water-based KCl-K Lignite Polymer drilling fluid system for drilling deeper shale has demonstrated excellent shale stability for more than 60% of the non-drilling period due to downtime due to surface equipment failures and longer tripping cycles. Lignosulfonates mixed with KCl polymer at concentrations greater than 4% by weight effectively reduce shale permeability by 50–70% in pore fluid formulations. This confirms the claim that drilling fluids with a high concentration of lignosulfonates provide shale stabilization.

A few years ago, an article published by Simpson et al. (1998) provided information that showed the ability to control the activity of the aqueous phase of the drilling fluid, both on a water basis and on a hydrocarbon emulsion. This regulation can create an osmotic pressure capable of controlling the influx of water or the extraction of water from tight, low permeability shales. The paper (Simpson et al., 1998) also highlights that the hydraulic differential between well pressure and shale pore pressure plays a key role in water movement. Analysis of the results of these tests provides recommendations for more efficient use of modern drilling fluids. The findings may also help develop new environmentally friendly water-based systems to address shale problems, especially when the use of hydrocarbon fluids is prohibited.

In the article written by Ramirez et al. (2006), the authors believe that inhibited potassium drilling mud do not bring the desired result for South American fields. Wells drilled in the Andean region of South America are particularly challenging due to unstable micro fractured shales. Operators have encountered difficulties drilling wells using both water-based (WBM) and oil-based drilling muds (OBM). In many of these areas, environmental legislation discourages the use of OBM due to the potential environmental impact and costs associated with waste disposal, and in many cases OBM has not prevented wellbore instability problems. This article (Ramirez et al., 2006) explains how a lack of practice in using a good mud design has led to wellbore problems. As is known the salinity of the OBM water phase and the use of appropriate inhibitors in the drilling fluid play a key role in minimizing wellbore problems. However, for non-expanding kaolinite clays, the presence of shale inhibitors such as potassium and the high salinity of the water phase in OBM exacerbate the problems. The authors of the article (Ramirez et al., 2006) believe that an aluminium-chemical approach to stabilizing problematic shale is an alternative to salt-inhibited fluids with a reduced environmental impact. Aluminium hydroxide complex (AHC) is a source of chemicals capable of settling into shale pores and shale microfractures, providing long-term wellbore stability. Laboratory tests have shown that AHC is suitable for South American kaolinite shale formations. The article (Ramirez et al., 2006) describes two mechanisms of deposition of soluble and insoluble aluminates, which provide the process of slowing down the transfer of pore pressure to the bottomhole zone of the well. Reducing the pore pressure transfer rate provides increased wellbore stability. The chemistry has been further improved to be the main part of the new High-Performance Water Based Drilling Fluid (HPWBM). Successful application of this drilling fluid in several wells has demonstrated its effectiveness.

The article presented by Monasterio et al. (2023) describes a successful drilling practice using a high-performance water-based drilling fluid system for drilling complex 3D trajectory wells in the South Sub-Andean Basin of Bolivia in the Aguarague National Park. The use of oil-based drilling fluids is also prohibited in this zone due to their high environmental sensitivity.

The well was drilled through highly reactive shales without any wellbore stability issues due to precise density control and appropriate concentrations of drilling fluid additives such as biopolymers or synthetic polymers. The synergy of the key components of the drilling fluid ensured stable rheology and low fluid loss.

In the article presented by Kazakov et al. (2020), the authors developed an approach to reduce wellbore stability issues. It includes geomechanical modelling and physico-chemical studies of the impact of oil-based drilling fluids. This approach was successfully applied when drilling a well with a horizontal ending at one of the fields in the Perm region. In unstable rocks, when inclination angle was of more than 70 degrees (Kazakov et al., 2020), a special composition of the drilling fluid was developed and control over compliance with the specified requirements was carried out. This made it possible to eliminate the problems associated with the instability of the wellbore (Kazakov et al., 2020). To eliminate the risks associated with the stability and cleanup of the well, an invert emulsion fluid based on mineral oil has been proposed. The first fluid composition was proposed based on past well data analysis and laboratory confirmation. The fluid composition of each subsequent well was selected based on the experience of drilling the first well and risk reduction. Numerous laboratory tests have been carried out to select the best drilling fluid composition. Solutions have been developed to ensure proper wellbore stability. The mud parameters given in the manuscript (Kazakov et al., 2020) were recommended for the intermediate and remaining intervals based on previous experience in the area.

In the study written by Subbiah et al. (2018), the authors emphasize that the instability in the reservoirs is associated with an increase in pore pressure in the reservoirs due to the chemical potential mechanism. An increase in pore pressure will lead to possible formation swelling and a less stable wellbore. Therefore, the activity of water in the drilling fluid must be sufficiently low (i.e., have a sufficiently high concentration of salts).

The proposed drilling fluid system relies on the following unique components (Subbiah et al., 2018):

1. Shale Inhibitor. This component is a liquid additive. This reduces the hydration of clay and the migration and absorption of water by the clay mineral. The component works with fresh water and environments with a high salt content.
2. Enhanced Sealant. This is a unique co-polymeric additive. The component seals shale layers and microcracks. This limits the transmission of pressure to shale formations.
3. Encapsulates. It is a moderately cationic copolymer. The component stabilizes shales and cuttings. The encapsulate provides a protective coating to the wellbore and prevents cuttings from accumulating in the annulus and on the surface. The component is not toxic to the marine environment.
4. Anticrete. This is a special blend of surfactants. It protects the bit and bottom hole assembly (BHA) from sticking solids.

The required mud salinity was calculated based on field criteria for various shale. The established range of mineralization of drilling fluids was 6.5–16% NaCl.

In the article presented by Wenquan et al. (2019), the authors also recommend optimizing the drilling fluid by increasing plugging and inhibition. As is known, plugging and anti-sludge materials contain 50% insoluble substances. They are easy to remove, which is why the authors chose SMA (surface modifying agents) type products. These SMAs have been described as non-hardening resins, insoluble in water and oil (Lehman et al., 2003; Weaver et al., 2007). The effect of this material on the reduction of filter cake permeability has been verified by experimental studies. The authors (Wenquan et al., 2019) use SMA and organic salt as the primary anti-sloughing inhibitor in combination with field proven SRIPE-inhibitor1 and SRIPE-inhibitor2. The optimized drilling fluid exhibits a better expansion inhibition effect than the existing drilling fluid. The experiment shows that after 40 hours the expansion of the core sample is 65%. Over time, the core sample will continue to absorb water and swell. After 100 hours, its expansion reaches 105% and continues to increase, which leads to a decrease in the strength of the rock. With an optimized drilling fluid system, core sample expansion is only 40% after 40 hours. The expansion value remains at 43% after 100 hours, indicating that the shale no longer absorbs water and swells. By increasing the plugging capacity and inhibition the drilling fluid can quickly form a tight sealing barrier (mud cake), provide pressure isolation, and slow down the further expansion of fractures. This helps to prevent wellbore collapse and leaks, improve drilling efficiency, and reduce nonproductive time (Wenquan et al., 2019).

Based on the review, Table 2 presents drilling fluid compositions to prevent wellbore instability problems.

Table 2. Drilling fluid compositions
Tabela 2. Składy płuczek wiertniczych

Source	Drilling mud
Ramirez et al., 2006	Aluminium hydroxide complex (AHC), HPWBM
Giri, 2010	The water-based KCl-K Lignite Polymer
Shaver et al., 2015	The KCl Polymer/PHPA/Glycol system + three shale inhibitors
Predein and Klykov, 2015	Non-aqueous solutions based on thickened mineral oils and invert emulsions
Al-enezi et al., 2018	The optimized bridging and sealing system (OBSS) consist of a combination of highly resilient carbon-based additives with a deformable, micronized sealing polymer
Subbiah et al., 2018	Shale Inhibitor + Enhanced Sealant + Encapsulates + Anticrete
Wenquan et al., 2019	SMA and organic salt as the primary anti-sloughing inhibitor in combination with field proven SRIPE-inhibitor1 and SRIPE-inhibitor2
Kazakov et al., 2020	The invert emulsion fluid based on mineral oil
Monasterio et al., 2023	Density control and appropriate concentrations of additives (biopolymers or synthetic polymers)

Conclusion

The compilation of papers provides a comprehensive overview of the complexities and solutions related to drilling extended reach wells. The articles underscore the importance of a holistic approach encompassing well design, drilling fluid optimization, and operational techniques to overcome challenges and maximize the success of ERD endeavours.

As practice has shown, most often change the mud weight and rheological parameters (the viscosity and shear force can be enhanced) of the oil-based muds and applied the appropriate pumping flow rate will help reduce the scouring and maintain wellbore stability.

The impact of hydration on rock stability can be reduced by effectively increasing inhibition and using a combination of different polymers.

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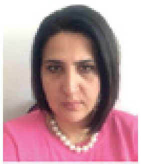

Gullu Valeh JABBAROVA, Ph.D.
Associate Professor at the Azerbaijan State Oil and Industry University
16/21 Azadliq Ave., AZ 1010, Baku, Azerbaijan
E-mail: *gullu.cabbarova@asoiu.edu.az*

Yelena Yevgenyevna SHMONCHEVA, Ph.D.
Associate Professor at the Azerbaijan State Oil and Industry University
16/21 Azadliq Ave., AZ 1010, Baku, Azerbaijan
E-mail: *yelena.shmoncheva@asoiu.edu.az*

Timur Elmanovich ABDULMUTALIBOV, M.Sc.
Junior Researcher at the Azerbaijan State Oil and Industry University
16/21 Azadliq Ave., AZ 1010, Baku, Azerbaijan
E-mail: *abdulmutalibov.tmr@gmail.com*

OFERTA BADAWCZA ZAKŁADU SEJSMIKI

- przetwarzanie danych sejsmicznych 2D Prestack i Poststack;
- przetwarzanie i interpretacja pionowych profilowań sejsmicznych PPS 1C/3C;
- interpretacja strukturalna i litofacjalna danych sejsmicznych 2D i 3D;
- budowa modeli prędkościowych w domenie czasu i głębokości (na podstawie danych sejsmicznych i geofizyki otworowej) na potrzeby konwersji czas-głębokość oraz migracji głębokościowej;
- poprawa rozdzielczości danych sejsmicznych z wykorzystaniem procedury dekompozycji spektralnej;
- konstrukcja map powierzchniowych w domenie czasu i głębokości;
- opracowanie i analiza map atrybutów sejsmicznych, inwersji sejsmicznej, dekompozycji spektralnej;
- obliczanie inwersji symultanicznej oraz stochastycznej na danych sejsmicznych;
- wyznaczanie obszarów perspektywicznych dla formacji łupkowych (*sweet spots*) oraz wskaźników DHI dla złóż konwencjonalnych na danych sejsmicznych;
- prognozowanie ciśnień porowych na podstawie danych sejsmicznych i geofizycznych;
- interpretacja parametrów petrofizycznych w przestrzeni okołootworowej w oparciu o pomiary pionowego profilowania sejsmicznego (PPS);
- kompleksowa interpretacja geologiczno-złożowa w oparciu zintegrowane dane geologiczne i geofizyczne (analiza cech makroskopowych rdzeni wiertniczych, objawy i wyniki prób złożowych, profilowania geofizyki otworowej, interpretacja sejsmiczna);
- szczegółowa interpretacja sejsmostratygraficzna kompleksów skał klastycznych i węglanowych z wykorzystaniem metody stratygrafii sekwencji.

Kierownik: dr Andrzej Urbaniec **Adres:** ul. Bagrowa 1, 30-733 Kraków
Telefon: 12 617 74 86 **Faks:** 12 653 16 65 **E- mail:** andrzej.urbaniec@inig.pl

INSTYTUT NAFTY I GAZU
– Państwowy Instytut Badawczy