ISSN: 1609-1620 (Print); ISSN: 2674-5224 (Online)
PAHTEI
REFERRED & REVIEWED JOURNAL
56 - 64
VOLUME 27 ISSUE 05 2025

ENHANCING DRILLING PERFORMANCE IN DEPLETED FORMATIONS

Yelena Shmoncheva[1], Elnur Mirzayev[2]
[1,2] Azerbaijan State Oil and Industry University, [1,2] Department of Oil and Gas Engineering
[1]Associate Professor, PhD; [2] Master student
[1]https://orcid.org/0000-0002-3661-7331
E-mail: [1]yelena.shmoncheva@asoiu.edu.az; [2]elnurmirzeyevs24@gmail.com

ABSTRACT

Drilling through depleted formations presents a complex set of geomechanical and operational challenges, including narrowed pressure margins, unpredictable fracture gradients, and heightened risks of fluid losses and borehole instability. Traditional drilling approaches frequently lack the flexibility needed to respond effectively to the dynamic and unpredictable downhole conditions that arise in depleted reservoirs—particularly in high-angle wells or formations characterized by interbedded or naturally fractured lithologies. In response to these limitations, Managed Pressure Drilling (MPD) has emerged as a key enabling technology, offering real-time control of bottom-hole pressure through the application of surface backpressure and automated regulation systems.

This paper provides a comprehensive review of drilling operations in depleted formations, highlighting key geomechanical constraints and real-world case studies from fields such as Brent, South Louisiana, and New Mexico. Comparative analysis of drilling fluid losses with and without MPD demonstrates the significant impact of pressure management on operational efficiency. In addition, the paper explores how MPD integrates with intelligent data systems, including real-time monitoring, automated control algorithms, and digital twin models, to enhance safety and precision during drilling.

The study concludes that MPD is not merely a supplementary technology, but a foundational component of modern drilling strategy in depleted and high-risk environments. Its ability to reduce non-productive time, minimize formation damage, and adapt to complex reservoir conditions makes it essential for maximizing recovery and improving well performance.

Keywords: depleted formation, managed pressure drilling, wellbore stability, drilling fluid losses, real-time monitoring.

Introduction

As global oil and gas production continues to shift towards mature assets and brownfields, drilling operations are increasingly encountering depleted formations [1, 2]. Reservoir depletion, resulting from long-term production or pressure support schemes such as water and gas injection, leads to significant changes in the in-situ stress regime and pore pressure. These changes fundamentally alter the geomechanical behavior of rocks, often resulting in a reduced fracture gradient, loss of wellbore integrity, and a drastically narrowed operational pressure window between pore pressure and fracture pressure. As a result, the margin for safe drilling becomes extremely limited, increasing the risk of both wellbore collapse and formation fracturing [3-6].

Traditional drilling methods, which rely on the static selection of mud weight and casing design based on offset data or conservative estimates, are often insufficient in such conditions. The dynamic nature of pressure changes in depleted zones, particularly in formations with complex

ISSN: 1609-1620 (Print); ISSN: 2674-5224 (Online)
PAHTEI
REFERRED & REVIEWED JOURNAL

VOLUME 27 ISSUE 05 2025

lithologies (e.g., interbedded shales and sands, fractured carbonates), calls for advanced techniques that can adapt in real time to evolving downhole conditions. In many cases, depleted reservoirs also exhibit unpredictable pressure gradients due to uneven depletion, compartmentalization, or nearby producing wells, further complicating the design and execution of safe drilling programs.

One of the most critical challenges in drilling through depleted formations is maintaining wellbore stability while minimizing non-productive time (NPT) and fluid losses. Excessive mud weight may induce fractures in weakened formations, while insufficient weight risks borehole collapse and influxes. Such dual risks necessitate the implementation of real-time monitoring and control systems capable of adjusting annular pressure on-the-fly — a capability uniquely provided by Managed Pressure Drilling (MPD) systems [7].

MPD represents a paradigm shift in well control and drilling operations [8]. Unlike conventional approaches that treat the wellbore as a passive conduit for mud circulation, MPD treats the pressure environment as a dynamic and controllable parameter [9]. Through the use of surface backpressure, closed-loop systems, automated chokes, and high-resolution sensors, MPD enables the operator to precisely manage bottom-hole pressure (BHP) throughout the drilling process [10]. This ability becomes particularly valuable in drilling marginal, depleted, or high-angle wells, where conventional mud windows may not exist.

The growing demand for MPD is also driven by industry-wide goals to improve efficiency, safety, and environmental performance. By reducing losses, preventing kicks, and limiting the number of sidetracks or well abandonments, MPD contributes to overall cost reduction and improved sustainability of operations. Additionally, the integration of MPD with digital technologies – such as predictive analytics, machine learning, and digital twins – opens new opportunities for adaptive, automated well control systems.

This paper aims to provide a comprehensive overview of the challenges associated with drilling in depleted reservoirs, and to evaluate the role of MPD in mitigating these challenges. It includes a review of geomechanical constraints, real-world case studies from diverse geological environments, analysis of fluid loss data, and a breakdown of how real-time data and intelligent systems are transforming well construction in complex formations. Special attention is given to the integration of MPD with downhole diagnostics, automated control systems, and operational workflows that support successful drilling campaigns in depleted and pressure-sensitive reservoirs.

In summary, as drilling moves deeper and into more geologically complex and depleted environments, the need for adaptive pressure management is greater than ever. MPD is emerging not merely as a useful tool, but as a foundational component of next-generation drilling strategy — one that aligns with the industry's increasing focus on efficiency, risk reduction, and operational intelligence.

Geomechanical Challenges in Depleted Reservoirs. Depleted reservoirs pose a unique set of geomechanical and operational challenges that complicate conventional drilling practices. One of the primary issues is the reduction of horizontal stresses as a result of long-term production or fluid withdrawal, which often leads to a lowered fracture gradient. In classical geomechanical models, fracture pressure is a function of Poisson’s ratio and overburden stress. However, field experience has demonstrated that fracture gradients do not always decrease uniformly. In some

cases, lithological heterogeneity, natural fractures, and structural characteristics maintain higher-than-expected stress levels, prompting a reassessment of conventional predictive approaches.
This uncertainty increases risk during well construction, particularly in formations with a narrow operational window between pore pressure and fracture pressure. Sandstones, commonly found in hydrocarbon-bearing formations and typically characterized by low Poisson's ratio, are especially vulnerable. In these depleted sand formations, even slight overbalances in equivalent circulating density (ECD) can lead to catastrophic outcomes such as massive fluid loss or complete borehole collapse. These conditions necessitate the use of adaptive, real-time control systems like Managed Pressure Drilling (MPD), which offer more precise and responsive pressure management compared to conventional methods.
The severity of these risks has been confirmed by numerous field experiences. At the Brent Field in the North Sea, reservoir pressure declined from 6000 psi to 2500 psi after decades of production. When high-angle infill wells were drilled, severe borehole instability and extensive mud losses occurred due to the convergence of minimum mud weight and fracture pressure. The application of MPD stabilized operations by enabling dynamic annular pressure control, allowing operators to drill within the narrow window safely.
In South Louisiana, BP Amoco successfully drilled through a high-pressure differential interval of over 13,000 psi. While MPD was not explicitly used, precise engineering of the bottom-hole assembly (BHA) and fluid program simulated many MPD benefits. The operation was completed without requiring additional casing strings, reducing complexity and cost.
Another illustrative case occurred in New Mexico, where a dolomite reservoir containing high levels of H_2S (up to 10,000 ppm) and low formation pressure (~500 psi) presented significant drilling hazards. Three different fluid systems were tested, with the aphron-based system—comprising microbubbles—delivering the best results. This approach reduced drilling fluid losses to 800–1000 barrels per well, showcasing how alternative fluid strategies can complement or simulate MPD under the right conditions.
These case studies collectively highlight the growing necessity of MPD, especially when dealing with depleted and geologically complex formations. MPD systems allow operators to maintain bottom-hole pressure precisely within the safe operating window. The technology has demonstrated broad success across different geological environments, including high-pressure high-temperature (HPHT) wells, fractured carbonates, and deepwater offshore projects.
Notable applications of MPD include Chevron's Jack/St. Malo project in the Gulf of Mexico, where mud weight was controlled within a tight 0.1 ppg window to avoid exceeding fracture gradients. In Malaysia, Shell utilized MPD to significantly reduce non-productive time (NPT) by 30–50% and to improve the reliability of well delivery in depleted offshore fields (Shell Technical Report, 2018). In Saudi Arabia, Aramco deployed MPD to enhance borehole stability during the drilling of deviated wells in fractured carbonate reservoirs, achieving higher hole quality and improved cleaning efficiency.
Modern MPD systems rely on automated pressure control (APC), smart choke manifolds, and real-time monitoring platforms, enabling continuous adjustment of surface backpressure and annular pressure based on downhole feedback. These systems are increasingly integrated with digital infrastructure — including predictive models, machine learning, and digital twins — that allow for proactive management of drilling risks and optimization of wellbore construction in pressure-sensitive zones.

In summary, the convergence of geomechanical risks, operational complexity, and technological advancement makes MPD an indispensable tool for drilling in depleted formations. By enabling safe, efficient, and controlled drilling, MPD transforms previously marginal or hazardous reservoirs into economically viable opportunities.

Managed Pressure Drilling. Managed Pressure Drilling (MPD) has become a cornerstone technology in modern drilling operations, particularly in depleted, complex, or high-risk formations. Its key strength lies in enabling dynamic control of annular pressure, allowing the operator to precisely manage bottom-hole pressure (BHP) within narrow drilling margins. MPD systems are highly adaptive, offering a real-time response to changing downhole conditions—an essential feature when drilling in environments with tight pore pressure and fracture pressure windows.

The technology has been successfully implemented in a variety of challenging scenarios, including high-pressure high-temperature (HPHT) wells, fractured carbonate reservoirs, and offshore operations. Among the most illustrative examples:

- Chevron’s Jack/St. Malo project (Gulf of Mexico) achieved exceptional control by managing mud weight within a tight ±0.1 ppg window.
- Shell (Malaysia) reported a 30–50% reduction in non-productive time (NPT) by using MPD, improving drilling reliability and operational continuity.
- Aramco (Saudi Arabia) improved borehole stability in fractured carbonates by integrating MPD with real-time data analysis and advanced borehole cleaning strategies.

The core components of MPD systems include automated pressure control (APC) units, intelligent choke manifolds, and real-time monitoring tools. These systems rely on data gathered from surface and downhole sensors, which measure key parameters such as:

- surface backpressure;
- standpipe and annular pressure;
- mud weight and flow rate;
- equivalent circulating density (ECD);
- mud and formation temperature.

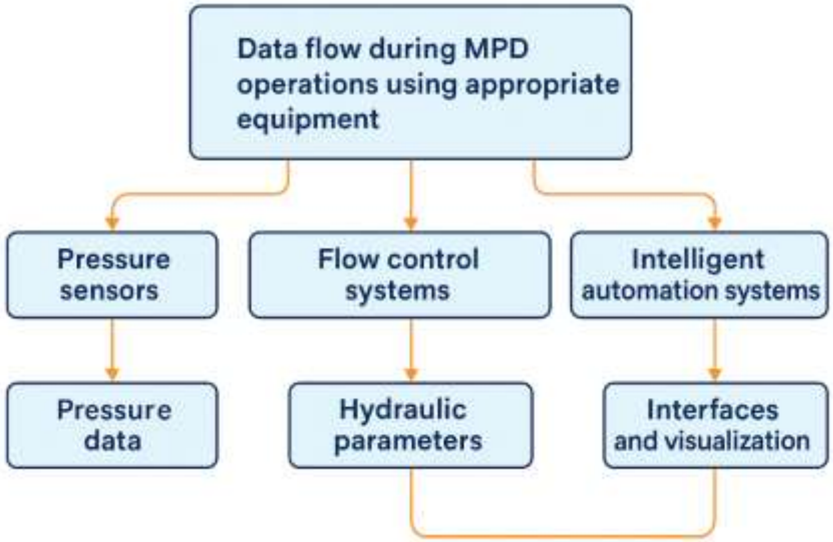
These data streams are processed and visualized via Human-Machine Interfaces (HMI), allowing the driller to monitor pressure behavior dynamically. Advanced MPD control platforms—such as Weatherford’s Microflux™ provide a continuous feed of measured and derived parameters, including flow-in/flow-out, BHP, ECD, standpipe pressure (SPP), and choke actuation status. This high-resolution data environment enables early detection of operational hazards, including formation influxes, fracture propagation, and loss circulation.

Figure 1 presents a schematic overview of the MPD data flow process, outlining the main measurement sources, feedback loops, and control modules that contribute to automated well pressure management.

Figure 1. Data Flow Diagram

ISSN: 1609-1620 (Print); ISSN: 2674-5224 (Online)
PAHTEI
REFERRED & REVIEWED JOURNAL

VOLUME 27 ISSUE 05 2025



Beyond pressure regulation, MPD systems support Formation Integrity Tests (FIT) and Leak-Off Tests (LOT) with minimal interruption to operations. This capability reduces drilling uncertainties and enhances decision-making in real time, particularly in zones with high pressure variability—such as virgin and depleted reservoirs.

The operational value of MPD is further highlighted by quantitative comparisons. Data from multiple field operations show that MPD drastically reduces drilling fluid losses when compared to conventional methods.

Table 1. Comparison of drilling fluid losses during operations with and without MPD

Field	Losses without MPD (bbl)	Losses with MPD (bbl)
Brent	8000	1000
South Louisiana	5000	1200
New Mexico	15000	800
Malaysia (Shell)	6000	2500
Saudi Arabia (Aramco)	7000	1300

As illustrated in Figure 2, the most dramatic reduction occurred in New Mexico, where MPD helped cut fluid losses from 15,000 to just 800 barrels – a compelling demonstration of its utility in high-risk environments.

ISSN: 1609-1620 (Print); ISSN: 2674-5224 (Online)
PAHTEI
REFERRED & REVIEWED JOURNAL
VOLUME 27 ISSUE 05 2025

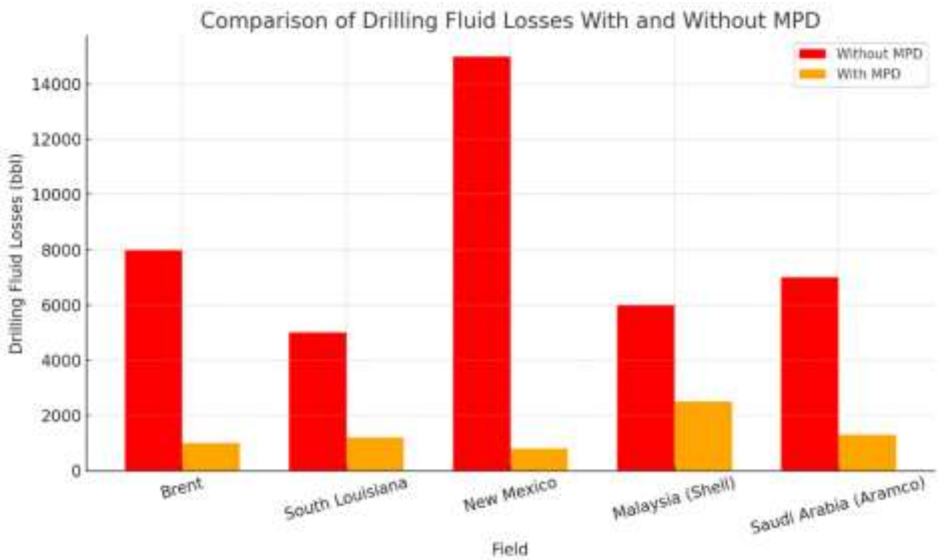


Figure 2. Comparison of drilling fluid losses with and without MPD across selected fields

The integration of MPD with intelligent automation, predictive models, and digital twins creates a closed-loop ecosystem capable of not only reacting to, but also anticipating downhole changes. By transforming the wellbore into a controllable pressure system, MPD redefines the approach to drilling in depleted and uncertain geological settings.

Drawing a conclusion from all of the above, we can write the following conclusion. Drilling in depleted formations requires a holistic approach that incorporates geomechanical analysis, adaptive well design, and advanced pressure control systems. The experience gained from various fields confirms that MPD technology significantly enhances wellbore stability and reduces drilling fluid losses, particularly in formations with narrow pressure margins. MPD enables precise pressure management, transforming previously risky or economically unviable drilling scenarios into achievable operations. Its integration with real-time data analytics and intelligent automation positions MPD as a key enabler of future drilling efficiency, safety, and optimization. As the industry continues to prioritize complex and mature reservoirs, MPD is expected to play an increasingly central role in drilling strategies worldwide.

Conclusion

1. Drilling in depleted formations demands a comprehensive approach that integrates geomechanical analysis, adaptable well design, and precise pressure control technologies such as MPD.
2. Managed Pressure Drilling (MPD) has demonstrated its effectiveness in enhancing wellbore stability and minimizing fluid losses, particularly in formations with narrow pressure margins and complex stress regimes.
3. Field case studies from Brent, South Louisiana, New Mexico, Malaysia, and Saudi Arabia clearly confirm the value of MPD in mitigating common drilling complications and improving well performance.
4. Quantitative data analysis highlights MPD’s operational impact, showing substantial reductions in drilling fluid losses and overall improvements in efficiency and safety.

5. MPD systems leverage real-time data from pressure sensors and automated control modules to enable adaptive and responsive pressure management in high-risk environments. Visual tools such as flow diagrams and performance charts further support decision-making and technology adoption.
6. Far beyond being a supplemental tool, MPD has become a core component of modern drilling strategy. Its integration with digital solutions – including predictive analytics, automated control, and digital twin models – positions it as a key enabler of intelligent, efficient, and future-ready drilling operations.

Declarations
The manuscript has not been submitted to any other journal or conference.

Study Limitations
There are no limitations that could affect the results of the study.

Acknowledgment
The author would like to express gratitude to the care support workers and elderly individuals who participated in this study, sharing their invaluable insights and experiences. Their cooperation and openness have significantly contributed to the depth and richness of the research findings.

Funding source
None.

Competing Interests
No potential conflict of interest was reported by the authors.

REFERENCES

1. Addagalla Ajay, Maley Iain, Lawal Ishaq and eth. Minimum Stress, Maximum Pressure: A New High Performance Bridging System Facilitates Drilling Depleted Formations at High Overbalance in Middle East. // Paper presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition, Brisbane, Australia, October 2018. doi: https://doi.org/10.2118/192051-MS
2. Omer Mohammed, Duarte Miguel, Fragachan Francisco E., and Alfredo Alvarez. Using an Advanced Geomechanics-Based Workflow to Prevent Wellbore Shear Failure When Drilling Across Depleted Formations.// Paper presented at the International Petroleum Technology Conference, Dhahran, Saudi Arabia, February 2024. doi: https://doi.org/10.2523/IPTC-23395-EA.
3. Gupta M., Ramli A., and F. Sedaralit. Technologies to Mitigate Geomechanical Challenges of Deepwater Resource Development. // Paper presented at the International Geomechanics Conference, Kuala Lumpur, Malaysia, November 2024. doi: https://doi.org/10.56952/IGS-2024-0875.
4. Kongsumrit W., Adisornsupawat, K., Chansawad, P., and P. Santadgarn. Unleashing the Potential: Geomechanics and Fracture Gradient Modelling Reshape the HPHT Landscape

in SA Gas Field, Gulf of Thailand. // Paper presented at the International Petroleum Technology Conference, Kuala Lumpur, Malaysia, February 2025. doi: https://doi.org/10.2523/IPTC-24823-MS.
5. Alawami Mohammed, Al-Yami Abdullah, Gharbi Salem and Mohammed Al-Rubaii. A Real Time Geomechanics Drilling Mud Window to Enhance Drilling Efficiency. // Paper presented at the SPE Conference at Oman Petroleum & Energy Show, Muscat, Oman, March 2022. https://doi.org/10. 2118/200033-MS.
6. Montoya O., Sandra J., and Javier Sanchez O. Expect the unexpected: Geomechanics challenges in the Colombian Caribbean Offshore.// Paper presented at the ISRM 8th International Symposium Geomechanics, Bucaramanga, Colombia, May 2019.
7. Onifade James, Patel Bhavin, Ertas Engin and eth. Managed Pressure Drilling System Provided Value To Offshore Drilling Operation. // Paper presented at the Offshore Mediterranean Conference and Exhibition, Ravenna, Italy, March 2015.
8. Hannegan Don and Azfar Mahmood. Offshore Well Integrity Management with MPD Tools and Technology.// Paper presented at the Offshore Technology Conference, Houston, Texas, USA, May 2015. doi: https://doi.org/10.4043/25723-MS.
9. Zhou L., Liu Y., Anfinsen B. and eth. Automating Influx Management Envelope (IME) Generation Through Cloud-Based Solutions. // Paper presented at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition, Rio de Janeiro, Brazil, September 2024. doi: https://doi.org/10.2118/221442-MS.
10. Ta Quoc Bao, Dalgit Singh, Harpreet Kaur and eth. Successful Wellbore Pressure Management Using Intelligent MPD and Continuous Circulation System on an HPHT Well in Vietnam. // Paper presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Virtual, October 2021. doi: https://doi.org/10.2118/205600-MS

TÜKƏNMİŞ LAYLARDA QAZMA SƏMƏRƏLİLİYİNİN ARTIRILMASI

Yelena Şmonçeva[1], Elnur Mirzəyev[2]
[1,2]Azərbaycan Dövlət Neft və Sənaye Universiteti, [1,2] "Neft-qaz mühəndisliyi" kafedrası
[1] Dosent, t.ü.f.d.; [2]Magistr tələbəsi
[1]https://orcid.org/0000-0002-3661-7331
E-mail: [1]yelena.shmoncheva@asoiu.edu.az; [2]elnurmirzeyevs24@gmail.com

XÜLASƏ

Məqalədə istismar olunmuş laylarda qazma əməliyyatlarına dair geniş icmal təqdim olunur. Tədqiqatda Brent, Cənubi Luiziana və Nyu Meksiko kimi sahələrdən real sahə nümunələri və əsas geomekanik məhdudiyyətlər araşdırılır. MPD ilə və onsuz aparılan qazma zamanı məhlul itkilərinin müqayisəli təhlili göstərir ki, təzyiqin effektiv idarə olunması əməliyyat səmərəliliyinə ciddi təsir göstərir. Eyni zamanda, MPD-nin real vaxtda monitorinq, avtomatik idarəetmə alqoritmləri və rəqəmsal əkiz modelləri daxil olmaqla ağıllı məlumat sistemləri ilə inteqrasiyası qazma zamanı təhlükəsizlik və dəqiqliyi artırır. Tədqiqatın nəticələri göstərir ki, MPD yalnız əlavə texnologiya deyil, həm də istismar olunmuş və riskli laylarda müasir qazma strategiyasının əsas elementidir. Onun qeyri-produktiv vaxtı azaltmaq, layın zədələnməsini minimuma endirmək və mürəkkəb yataq şəraitinə uyğunlaşmaq qabiliyyəti hasilatı və quyunun ümumi performansını artırmaq üçün vacibdir..

ISSN: 1609-1620 (Print); ISSN: 2674-5224 (Online)
PAHTEI
REFERRED & REVIEWED JOURNAL

Açar sözlər: tükənmiş lay, idarə olunan təzyiqli qazma, quyu divarının sabitliyi, məhlul itkisi, real vaxt monitorinqi.

ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ БУРЕНИЯ В ИСТОЩЁННЫХ ПЛАСТАХ

Елена Шмончева[1], Эльнур Мирзаев[2]
[1,2]Азербайджанский Государственный Университет Нефти и Промышленности
[1,2]Кафедра «Нефтегазовая Инженерия»
[1]Доцент, к.т.н.; [2]студент-магистр
[1]https://orcid.org/0000-0002-3661-7331
E-mail: [1]yelena.shmoncheva@asoiu.edu.az; [2]elnurmirzeyevs24@gmail.com

РЕЗЮМЕ

В статье представлен всесторонний обзор буровых операций в условиях истощения пластов, с акцентом на основные геомеханические ограничения и реальные примеры из таких месторождений, как Брент, Южная Луизиана и Нью-Мексико. Сравнительный анализ потерь бурового раствора при бурении с применением MPD и без него демонстрирует значительное влияние эффективного управления давлением на производительность. Также в работе рассматривается интеграция MPD с интеллектуальными системами, включая мониторинг в реальном времени, алгоритмы автоматического управления и цифровые двойники, что позволяет повысить безопасность и точность бурения. Исследование показывает, что MPD является не просто вспомогательной, а фундаментальной технологией современной буровой стратегии, особенно в условиях, истощённых и сложных с точки зрения геологии пластов. Её способность снижать непроизводительное время, минимизировать повреждение пласта и адаптироваться к сложным условиям делает её незаменимой для повышения извлекаемости и эффективности разработки.
Ключевые слова: истощённый пласт, управляемое давление, устойчивость ствола, потери бурового раствора, мониторинг в реальном времени.

Publication history

Article received: 01.04.2025;
Article accepted: 14.04.2025
Article published online: 30.04.2025
DOI: https://doi.org/10.32010/TJPX3939