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# ABSTRACT

of the dissertation for the degree of Doctor of Science

# ADVANCEMENT OF THE SCIENTIFIC AND TECHNOLOGICAL PRINCIPLES OF CLUSTER DRILLING FOR INCLINED AND HORIZONTAL WELLS

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## GENERAL CHARACTERISTICS OF THE WORK

**Relevance of the Topic and Degree of Study.**

The construction of a cluster well represents a complex system that includes not only drilling, but also casing, cementing, and subsequent stimulation of inflow. The absence of a systematic approach to the design of cluster well sites, trajectory selection, and drilling sequence leads to suboptimal technical and economic performance. The integration of modern digital tools, in particular machine learning methods, for solving planning and operational management tasks is a highly relevant direction.

One of the key tasks is the rational placement of wells on a cluster pad, which allows for reducing capital and operating costs, minimizing environmental impact, and increasing recoverable reserves. Traditional methods of cluster pad and well trajectory design do not always ensure maximum efficiency, since they are based on empirical approaches and fail to account for all factors affecting the drilling process.

The use of machine learning and mathematical modeling algorithms makes it possible to significantly improve design accuracy, predict potential drilling complications, and minimize inter-well interference. This is particularly important under complex geological conditions and when developing fields with dense cluster placement. Optimization of drilling sequence, well trajectories, and cluster pad structure using intelligent technologies ensures more efficient use of drilling equipment, reduces well construction time, and decreases accident risks.

The development of expandable tubular technology in well drilling is an important trend in the oil and gas industry, driven by the need to increase efficiency and reduce costs in well construction and operation. Traditional casing methods significantly reduce the internal diameter, which limits drilling depth and increases costs. In modern deepwater drilling, extended-reach wells, and the operation of aging wells with corroded casings, expandable tubulars are becoming increasingly demanded. They minimize the telescoping effect, preserve wellbore diameter, reduce material needs and drilling time, improve circulation conditions, and allow the repair of old wells without significant diameter reduction — which is vital for extending the service life of oil and gas assets. In the context of deeper reservoirs and more complex development regimes, expandable tubulars are becoming a critical tool for sustainable and cost-effective drilling.

Modern methods of well construction and operation also require reliable solutions for sealing and isolating borehole zones. Swelling packers made of elastomeric materials can change size under the influence of surrounding fluids, making them an effective tool for preventing unwanted fluid and gas migration. Their use is especially relevant for limiting water inflow, preventing gas migration, sealing casing shoe zones to improve cementing quality, and in multistage hydraulic fracturing, where they ensure reliable zonal isolation and enhance stimulation efficiency. They adapt well to different geological conditions, including wells with highly mineralized formation fluids. In mature Azerbaijani fields, where many wells are characterized by high water cut, studying the behavior of swelling packers in contact with fluids of various salinities becomes particularly important for optimizing their use and minimizing operational problems.

Special significance is attached to studying the mechanisms of changes in carbonate rock properties under the influence of chemical reagents. Rock consolidation due to changes in mineralogical composition can stabilize wellbore walls, reduce permeability, minimize circulation losses, and increase wellbore stability during drilling and operation.

Existing research in the field of blowout preventers focuses on improving control systems, monitoring, and sealing materials. However, the scientific literature does not mention the creation of a universal BOP with active abrasive wear reduction, which highlights the novelty of the solution proposed in this dissertation.

These research directions, in various forms, are reflected in the works of Ghulizade M.P., Mamedbekova O.K., Mamedtagizadeh A.M., Efendiyev G.M., Mirzajanzade A.Kh., Kyazimov E.A., Kaufman L.Ya., Sushon L.Ya., Kazymov Sh.P., as well as foreign researchers such as Kalinin A.G., Griguletsky V.G., Abdrakhmanov G.S., Galyamov A.Z., Nicholson T., Wang H., Jeong J., Barati R., Aljawad A., Shukla S.M., Green C.M., Hardman R.A., Zhang J., Gray

K.E., Elkatatny S., and others, confirming their relevance and the necessity of further development.

Thus, despite the availability of numerous studies on individual aspects of complex well drilling, there is no integrated approach combining intelligent planning, advanced casing technologies, and innovative methods of rock property management. This dissertation aims to fill this gap by developing and scientifically substantiating a unified technological platform to improve the efficiency and reliability of cluster inclined and horizontal well construction.

**Object and Subject of the Research.**

The object of the research is the complex technological process of constructing cluster deviated and horizontal wells under challenging geological conditions, which includes the stages of design, drilling, casing, cementing, and operation. The study encompasses the entire range of operations — from intelligent trajectory planning and cluster pad design to the implementation and evaluation of the efficiency of innovative materials and technical devices aimed at increasing well reliability and safety at oil and gas fields, including those in Azerbaijan.

The subject of the research is the physico-chemical, geomechanical, and technological regularities that determine the efficiency and safety of the construction of complex-profile wells.

In particular, the subject of detailed investigation includes:

Principles and methods of intelligent optimization of design solutions based on machine learning algorithms for planning cluster pad structures, well grouping, and the construction of optimal trajectories.

Regularities of wellbore stability through the management of interactions in the "rock – drilling fluid" system, including mechanisms of chemical strengthening of carbonate formations and inhibition of clay deposits.

Hydrodynamic and rheological processes of cuttings transport in horizontal and deviated sections of the wellbore, as well as the influence of polymer additives, particularly hydroxyethylcellulose.

Mechanisms of deformation and sealing of the wellbore using innovative technologies, including expandable tubular technology and the behavior of swelling elastomer packers in fluids of various salinities.

Principles of improving blowout preventer equipment aimed at increasing its operational reliability, including the development of a universal BOP with an active function for reducing wear of sealing elements.

**The aim of the dissertation** is the development and scientific justification of comprehensive scientific and technological foundations for improving the efficiency, reliability, and safety of constructing cluster deviated and horizontal wells.

**Main Research Objectives.**

To achieve the stated aim, the following key scientific and technical objectives were defined and solved:

1. To develop and test intelligent methods and algorithms based on machine learning for comprehensive optimization of the structure of cluster pads, well grouping, and trajectory design in order to minimize technical and economic costs as well as the risks of wellbore intersection.

2. To experimentally investigate and substantiate the use of improved drilling fluid compositions and specialized chemical reagents for the directed modification of the mechanical properties of carbonate rocks, enhancing wellbore stability and improving the efficiency of cuttings removal.

3. To scientifically and experimentally justify the application of innovative technologies for wellbore strengthening and reservoir isolation, including the development of a new double-action reamer design for the implementation of monodiameter technology, as well as the study of the behavior of swelling elastomer packers in formation waters with different salinity levels.

4. To design a new universal blowout preventer with an integrated system for active reduction of seal element wear and, based on laboratory tests, to prove its increased operational reliability and economic efficiency compared to traditional counterparts.

**Methods for Solving the Research Objectives.**

The methods used to address the objectives of the dissertation were based on the comprehensive application of theoretical, computational, and experimental studies, which ensured the completeness and reliability of the scientific results.

The theoretical block included an in-depth analysis and systematization of data from domestic and foreign scientific and technical literature, which made it possible to form the methodological basis of the research and identify key directions for improving drilling and well completion technologies.

Modeling of cluster pad placement and well grouping processes was carried out using machine learning algorithms, including reinforcement learning methods, for well trajectory optimization tasks. To assess the stress–strain state of elastomer seals, the finite element method in the ABAQUS software package was applied, using the Ogden-2 hyperelastic model, which provided an adequate description of seal behavior under large deformations.

The experimental studies included physical modeling of horizontal wellbore cleaning processes, cuttings transport, and drilling fluid–rock interactions. In addition, tests were conducted to study the effects of chemical reagents on the mechanical and filtration-capacity properties of carbonate reservoirs, as well as experiments to evaluate the swelling kinetics of elastomeric materials in media with different salinity levels.

The reliability of the obtained results was ensured by rigorous statistical data processing, and their practical efficiency was confirmed by a techno-economic analysis, which demonstrated the feasibility of implementing the developed technologies in field practice.

**Main Provisions Submitted for Defense:**

1. **Intellectual methodology for cluster pad optimization.** The developed methodology, based on iterative analysis algorithms and machine learning methods, makes it possible to determine the optimal number and placement of stationary platforms and well groupings. Unlike existing approaches, it comprehensively minimizes combined capital and operating costs while accounting for technological constraints, thereby reducing expenditures at the design stage.

2. **Method of real-time well trajectory control based on reinforcement learning.** A new method of dynamic trajectory control using reinforcement learning algorithms has been proposed. Unlike

the traditional approach of reverting to a static design profile, the developed method ensures real-time course adjustment, minimizing a composite functional (costs, time, curvature intensity) and directing the wellbore directly into the target tolerance zone, which increases drilling accuracy and economic efficiency.

3. **New drilling fluid compositions modified with chemical reagents to enhance wellbore geomechanical stability.** The application of drilling fluids modified with chemical reagents (in particular, zinc sulfate) has been substantiated for active control of geomechanical stability. Experimental studies have proven that the proposed compositions initiate phase transformations in carbonate rock, leading to a significant (up to 19%) increase in its strength properties and a reduction in permeability.

4. **Experimentally validated kinetic model of swelling packers accounting for fluid salinity.** Quantitative relationships of swelling rate and the time required to achieve contact with the wellbore wall have been obtained, which made it possible to develop recommendations for the rational use of packers in isolating problematic zones and improving cementing quality.

5. **Double-action reamer design for implementing monodiameter technology.** A new design of a reamer has been developed and scientifically substantiated, allowing two-stage sequential expansion of casing to different diameters in a single run. This design solution is a key element for the practical implementation of monodiameter well construction, eliminating the telescoping effect and reducing material consumption.

6. **Universal blowout preventer design with an active wear reduction system.** A new design of a universal blowout preventer equipped with a hydraulic turbine and grinding mechanism has been proposed and experimentally tested. This creates a new direction in the design of highly reliable blowout prevention equipment.

**The scientific novelty of the research lies in the following:** an integrated methodology for multicriteria optimization of well distribution by platform slots has been developed; a new method of real-time wellbore curvature control based on reinforcement learning has been proposed, which, unlike existing approaches, minimizes a composite functional of costs and risks, directing the wellbore directly into the target tolerance zone rather than to a predefined design line; the possibility of targeted strengthening of carbonate rocks through drilling fluid modification has been experimentally proven and quantitatively evaluated; kinetic patterns of swelling of elastomeric packers in highly mineralized media have been established and characterized, and the process has been described by a two-phase model; a nonlinear dependence of swelling rate on salt concentration has been revealed, which provides a scientific basis for material selection and prediction of wellbore sealing time under specific conditions of Azerbaijani fields; a new design of a double-action casing reamer has been developed, which, unlike existing analogues, enables two-step expansion of the casing to different diameters in a single run. This represents a key technological solution for the practical implementation of monodiameter well construction; a new design of a universal blowout preventer with an integrated mechanism for active reduction of seal element wear has been proposed, which has no analogues in the scientific literature. Its novelty lies in the integration of a hydraulic turbine and a grinding unit, which prevents abrasive wear at the stage of its initiation rather than combating its consequences as in existing approaches.

**The theoretical and practical significance of the research results.** The theoretical value of the dissertation lies in advancing scientific understanding of the regularities of ensuring wellbore stability and managing drilling complications through the integration of geomechanical analysis, physico-chemical properties of drilling fluids, and machine learning methods. The role of a comprehensive approach has been substantiated, including prediction of rock stress–strain state, diagnostics and modeling of elastomer swelling processes, and the application of hyperelastic models in numerical calculations to predict seal durability and design new packer structures. The theoretical significance is also expressed in the development of new principles for casing design using expandable tubulars and double expansion, which extend the possibilities of monodiameter technology. In addition, scientific foundations for integrating machine learning into prediction and optimization systems for drilling parameters have been developed.

**The practical significance of the dissertation results** lies in the development of ready-to-implement engineering solutions, technologies, and methodologies aimed at improving the technical and economic performance and safety of well construction: an algorithm and software have been created for automated optimization of cluster pad placement and well grouping, the use of which makes it possible at the design stage to reduce capital costs by minimizing the number of offshore stationary platforms; practical recommendations have been developed on drilling fluid composition for drilling in salt-bearing formations and unstable carbonate rocks, showing that the chemical composition of reagents and fluid parameters affect salt erosion to a greater extent than temperature changes, which allows optimization of formulations to minimize cavitation; a new design of a double-action reamer has been developed, enabling two-step casing expansion in a single trip, which is a key solution for the practical implementation of resource-saving monodiameter well construction technology; specific engineering recommendations have been obtained for the selection of elastomeric materials for swelling packers depending on the salinity of formation fluids in Azerbaijani fields, which improves formation isolation reliability; a new universal blowout preventer design has been proposed, which, based on laboratory tests, demonstrated an increase in the service life of sealing elements by 35%, an increase in mean time between failures (MTBF) by 15%, and a reduction in overall operating costs by approximately 18%, directly enhancing drilling safety and economic efficiency.

The practical significance and novelty of the key technical solutions developed in the framework of the dissertation are confirmed by patents obtained, including a patent for a reamer for pipes (Patent CN 205605117 U, China) and a universal blowout preventer (Eurasian Patent No. 045267B1), as well as a patent of the Republic of Azerbaijan (No. 20160085).

**The personal contribution of the applicant.** The personal contribution of the applicant to the research consists in formulating the aims and objectives of the study, developing theoretical and methodological foundations, directly conducting key experiments, and analyzing the results obtained. All the main scientific provisions submitted for defense were formulated and substantiated personally by the author. In particular, the applicant contributed to the development of intelligent methods and algorithms for optimizing cluster pads and real-time well trajectory control, including the creation of software. The applicant carried out the full range of experimental studies on the influence of chemical reagents on the mechanical properties of carbonate rocks and on the hydrodynamics of horizontal wellbore cleaning. Laboratory tests to determine the swelling kinetics of elastomeric packers, followed by modeling in the ABAQUS software, were also performed by the applicant. With the direct participation of the applicant and in co-authorship, new patented designs of a double-action reamer and a universal blowout preventer were developed. The personal contribution also includes the systematization of results, formulation of conclusions and practical recommendations, as well as the writing and publication of key scientific works on the dissertation topic.

**Approbation and Implementation of the Results.**

The main scientific results and provisions of the dissertation were consistently presented and discussed at meetings of specialized scientific departments and also received wide coverage at national and international conferences, symposia, and seminars. Among them:

- International Scientific Conference "Non-Newtonian Systems in the Oil and Gas Industry" dedicated to the 85th anniversary of Academician A.Kh. Mirzajanzade (Baku, 2013);
- 10th Jubilee International Scientific and Practical Conference "Ashirow Readings" (Samara, 2013);
- XƏZƏRNEFTQAZYATAQ-2014 (Baku, 2013);
- 11th International Scientific and Practical Conference "Ashirow Readings" (Samara, 2014);
- 12th International Scientific and Practical Conference "Ashirow Readings" (Samara, 2015);
- XƏZƏRNEFTQAZYATAQ-2016 (Baku, 2016);
- 1st International Scientific and Practical Conference "Bulatov Readings" (Krasnodar, 2017);

- 5th International Scientific and Practical Conference "Bulatov Readings" (Krasnodar, 2021);

- International Scientific and Technical Conference "Modern Technologies in the Oil and Gas Industry" dedicated to the 75th anniversary of USPTU (Ufa, 2023);

- 7th International Scientific and Practical Conference "Bulatov Readings" (Krasnodar, 2023);

- Scientific and Practical Conference "Heydar Aliyev and the Oil Strategy of Azerbaijan: Achievements in Petroleum Geology and Geotechnologies" (Baku, 2023);

- International Conference "Field Development Technologies and Process Modeling in Oil and Gas Production" dedicated to the memory of Academician A.Kh. Mirzajanzade (Ufa, 2023);

- SPE Caspian Technical Conference and Exhibition (Baku, Azerbaijan, 2023).

Alongside publication activity, the main results of the research have also been reflected in patent developments, which confirms their applied significance and demand in the oil and gas industry. These include: 油气井用可膨胀套管扩眼工具 (Oil and gas well casing with the expandable reaming tool), Patent CN 205605117 U (China); Patent No. 20160085 dated 11.05.2019 (Azerbaijan); Eurasian Patent No. 045267B1, published in the official bulletin of the EAPO (E21B033/06).

**Reliability of the Results.**

The reliability of the obtained results is confirmed by the use of modern methods of mathematical modeling and machine learning, the correctness of the initial assumptions, and the adequacy of problem formulation for the trajectory control of deviated wells. The reliability of the conclusions is ensured by comparing modeling results with actual field data, testing reinforcement learning algorithms on real drilling data, as well as by the reproducibility of experimental studies on the swelling kinetics of packers in media of different salinity. Additional confirmation of reliability is provided by the consistency of the obtained quantitative dependencies with the data presented in scientific literature and industrial practice, which collectively guarantees the robustness of the scientific provisions submitted for defense.

**The main provisions of the dissertation** are reflected in 20 articles published in national and international scientific journals, 10 of which appeared in journals indexed in both Scopus and Web of Science. In addition, 12 theses were published on this subject, 8 of them in proceedings of international conferences abroad, as well as 1 monograph and 3 patents.

**Organization of the Dissertation Research.**

The dissertation research was carried out at the Department of "Oil and Gas Engineering" of the Azerbaijan State Oil and Industry University with the support of the Problem Laboratory "Well Drilling Technologies" of the Geotechnological Problems of Oil, Gas and Chemistry Research Institute.

**Volume and Structure of the Work.**

The dissertation consists of the introduction, 5 chapters, conclusions and recommendations, a list of references, and appendices. The total volume of the dissertation is 343142 characters.

**Acknowledgments.**

The author expresses deep gratitude and bright memory to the scientific advisor, Doctor of Technical Sciences, Professor A.M. Mamedtagizadeh, whose guidance and comprehensive support laid the foundation for this research. The author also expresses special gratitude to Doctor of Technical Sciences, Professor O.K. Mamedbekov, for his ideas, valuable recommendations, fruitful scientific discussions, and assistance, which contributed to the formation of the key provisions of the dissertation and the successful completion of the study.

## CONTENT OF THE WORK

**The introduction** substantiates the relevance of the dissertation both from scientific and practical perspectives. Complex geological and technical conditions of drilling—high rock anisotropy, narrow safe pressure windows, propensity for circulation losses, and wellbore instability at large deviation angles—predetermine the need for new solutions aimed at ensuring reliability and safety of well construction. It is noted that existing technologies for well design and drilling support do not fully take into account the integrated interaction of geomechanical, hydraulic, and technological factors, which leads to complications, accidents, and increased non-productive costs. In this regard, the development of scientific foundations for integrating modern computational methods, including machine learning and numerical modeling, with experimental studies to improve drilling efficiency is of particular relevance.

It is shown that significant progress has been achieved in the development of adaptive drilling fluids, complication forecasting, and the application of digital technologies in drilling support. However, unresolved remain the issues of integrated modeling of wellbore stability processes, effective control of well trajectory deviation, reliable annular sealing, and extending the service life of blowout prevention equipment. The absence of a unified approach to the selection of drilling fluids considering rock geomechanics, insufficient study of elastomer swelling processes, and the limitations of existing blowout preventer designs confirm the necessity of the research tasks posed in this dissertation.

The aim of the research, directed at improving the efficiency and reliability of well construction in complicated conditions, as well as the main objectives, has been formulated. These include: developing methods for predicting wellbore stability and optimizing well trajectory; studying drilling fluid compositions for active control of geomechanical stability; experimental and numerical modeling of elastomer seal behavior; and substantiating design solutions for a double-action reamer and a universal blowout preventer with an active wear reduction function.

The scientific novelty of the research is presented, which lies in the development of new methodological and technical solutions for wellbore stability management, improvement of drilling fluid compositions, and the creation of innovative technical tools. The practical significance of the results is determined by their potential implementation in drilling deviated and horizontal wells, including in conditions of high formation fluid salinity, which reduces complication risks, extends equipment service life, and increases the economic efficiency of well construction.

The main provisions submitted for defense, the results of approbation including presentations at international conferences and publications in leading national and international journals, as well as patent developments confirming the applied nature of the research, are highlighted.

**The first chapter** presents a comprehensive review of modern approaches to ensuring wellbore stability and optimizing the construction of cluster wells, with a focus on horizontal and extended-reach wells. It is shown that wellbore stability determines the technological reliability and economic efficiency of operations under high deviation angles and complex anisotropic geomechanics. The main mechanisms of instability (mechanical and chemical-mineralogical), their relation to pressure windows, torque and drag dynamics, as well as circulation regimes, are summarized.

The role of drilling fluids as a key stabilizing tool is detailed. Functions of pressure and filtration control, clay inhibition, microfracture sealing, and friction management are considered. Solutions based on water and non-aqueous systems, including KCl-polymer systems, invert-emulsion fluids, and hybrid formulations, are systematized. It is shown that adaptive adjustment of density, rheological parameters, and additive packages simultaneously reduces collapse risks and ensures efficient cuttings transport in extended horizontal intervals.

The section on complications in extended-reach drilling generalizes international experience in the use of weighted and high-density systems, lubricating additives, and wellbore cleaning programs. The most typical challenges remain instability at 80–90°

inclinations, difficulties in cuttings transport in long laterals, increased torque, and differential sticking. Successful practices are linked to equivalent circulating density (ECD) management, quality of hole cleaning (including fibrous LCM sweeps), lithology-based strategies, and real-time geomechanical calibration. For the Azerbaijani shelf, additional risk factors are identified—narrow pressure windows and the probability of gas–oil–water influxes. Promising directions include integrated hydraulic-geomechanical models and high-speed telemetry.

A significant section of the chapter is devoted to the application of machine learning methods in the oil and gas industry. It is shown that for predicting rate of penetration, the best results are provided by neural networks and ensemble methods, while hybrid models improve interpretability and forecast robustness. For drillstring vibration diagnosis and prediction, ensembles and deep learning architectures (CNN/LSTM) are effective, particularly when accounting for time dynamics and combined sensors. In comprehensive optimization of drilling parameters, the rationale for multicriteria formulations (rate of penetration, specific mechanical energy, vibrations, torque) and evolutionary optimizers operating over ML surrogates in closed-loop control has been substantiated.

Predictive solutions for circulation losses are separately considered: pre-drilling risk screening by geomechanics and lithology, online detection of "loss/influx/normal" via WITSML channels, and classification of loss intensity for LCM strategy selection. The importance of class balancing, noise filtering, and material balance accounting in narrow pressure windows is emphasized. Approaches to predicting and managing drilling fluid rheology are presented: from the "digital rheometer" and GPR/ANN models of viscosity curves to hybrid hydraulic calculations with ML-based corrections, as well as inverse problems for designing formulations under specified parameters.

The analysis of publications (see Fig. 1) has shown that current drilling technology development is focused primarily on optimization of operating parameters (about 60%) and control of drilling fluid and rock properties (22%), reflecting the high practical significance of these directions.

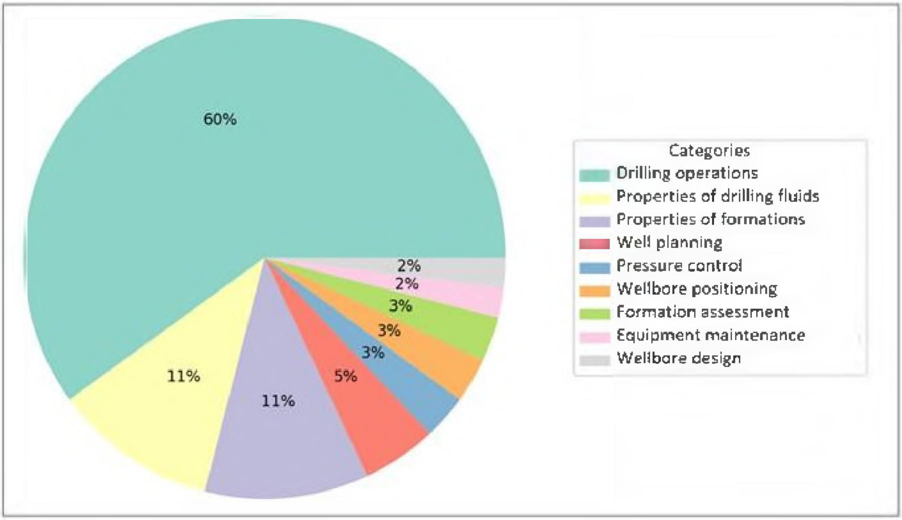


**Fig. 1. Distribution of publications by thematic research categories**

At the same time, the problems of wellbore design and positioning, which determine trajectory stability, controllability of the drilling process, and successful penetration of productive intervals, remain less studied (in total less than 10%). This imbalance indicates the need for active development of research in the integration of machine learning methods and geomechanical modeling into the processes of planning and supporting well construction. Solving this problem will improve the reliability and efficiency of drilling in complex geological and technical conditions and ensure the creation of comprehensive digital tools to support engineering decisions.

**In the second chapter** of the dissertation, intellectual methods for optimizing cluster pads and well trajectories are examined in detail, being one of the central elements of the modern concept of digital well design and drilling. The main goal of this stage of the research was to develop a scientifically substantiated approach, based on mathematical methods, optimization algorithms, and machine learning technologies, to the selection of the number of stationary platforms, rational grouping of wells, and management of their trajectories.

At the beginning of the chapter, it is shown that a cluster pad represents a complex of wellheads located within a limited area, which makes it possible to minimize capital and operating costs and reduce environmental impact on the surrounding environment[1]. Optimization of the structure of cluster pads is directly related to the geological conditions of the field, hydrodynamic characteristics of the reservoirs, technical capabilities of the equipment, and environmental requirements. To increase the reliability of design decisions, geological and geophysical modeling, hydrodynamic calculations, spatial data analysis, as well as machine learning algorithms are applied.

Special attention is given to the problem of determining the minimum number of offshore stationary platforms for a given well stock. Using the example of a hypothetical field including 27 production wells, a step-by-step study was carried out. The initial data on the coordinates of the well bottoms were presented in the form of a matrix ordered by abscissas, which made it possible to formalize the problem as a geometric coverage problem. At the first stage, the entire development area was covered with squares of side $L\sqrt{2}$, where $L$ corresponds to the maximum allowable deviation (Fig. 2).

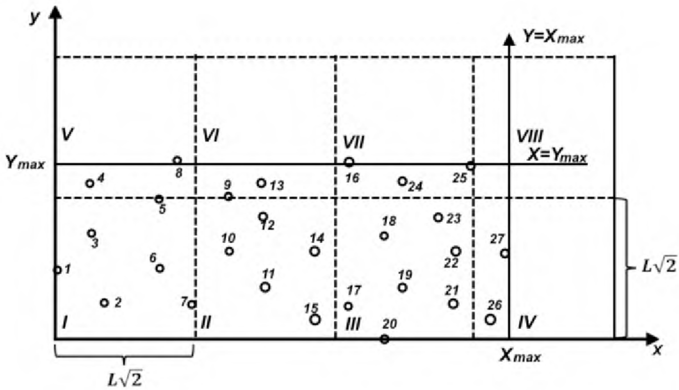


**Fig. 2. Field scheme covered with squares**

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[1] Karsakov, V.A., Tretyakov, S.V., Devyatyarov, S.S., Pasynkov, A.G. Well Construction Capital Investment Optimization during Field Development Conceptual Engineering. Oil Industry Journal. 2013. – Issue 12. – pp. 33–35.

The number of squares along the $X$ and $Y$ axes was calculated using the formulas

$$\left|\frac{X_{max}}{L \cdot \sqrt{2}}\right| + 1 = S_x$$

$$\left|\frac{Y_{max}}{L \cdot \sqrt{2}}\right| + 1 = S_y$$

were

$S_x$ – number of squares along the $X$-axis,

$S_y$ – Number of squares along the $Y$-axis.

In our case, $S_x = 4$, $S_y = 2$, were obtained, which gave the initial upper estimate of the number of platforms

$$N = S_x \cdot S_y = 8$$

At the second stage, empty subsets were excluded, i.e., squares that did not contain a single well. After analysis, it turned out that one square was empty, and the number of platforms was reduced to seven. Then, by applying a discrete shift of the squares by Δh (greater than the base size of the platform), it was possible to merge the coverage and exclude two more squares, which reduced the number of platforms to five. Further shifting of individual squares, in particular shifting square III to the right by Δh, ensured coverage of well No. 26, and as a result, four squares remained with one uncovered well, No. 27.

For final optimization, the coordinates of the centers of the squares were calculated, after which the possibility of merging well No. 27 with other wells was examined. The result was a scheme with four platforms, as shown in Fig. 3. This result demonstrates almost a twofold reduction in the number of platforms compared with the initial estimate (from 8 to 4), which means a significant decrease in capital expenditures.

The mathematical formulation of the problem was expressed through the cost objective function (formula 1), which includes the cost of drilling individual wells considering deviation and the cost of platform construction.

$$C = \sum_{r=1}^{M} \sum_{s=1}^{N} C_{rs} + \sum_{r=1}^{M} C_r \qquad (1)$$

where

$C_{rs}$ – the cost of drilling wells depending on their deviation;

$M$ – the number of offshore stationary platforms (OSP);

$N$ - the total number of wells in the field;

$C_r$ – the total cost of OSP depending on sea depth and the wells assigned to it.

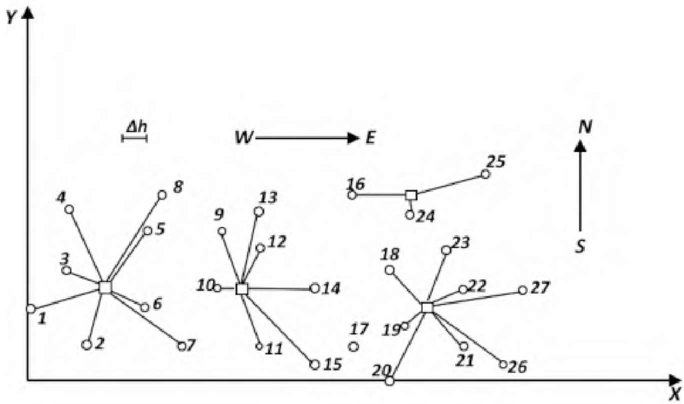


**Fig. 3. Solution of the well grouping problem**

To refine the solutions, a non-stationary coordinate system was used, tied to the centers of the offshore stationary platforms, whose coordinates were calculated as the average values of the coordinates of the wells assigned to them (formula 2).

$$x_r^{\theta} = \frac{\sum_{s=1}^{n_{ri}} X_s}{n_i} \; u \; y_r^{\theta} = \frac{\sum_{s=1}^{n_{ri}} Y_s}{n_i} \qquad (2)$$

$n_{ri}$ – the number of wells assigned to each platform.

Geometric constraints included the requirement that all wells be located within circles of radius R, the condition of intersection or tangency of circles, the prohibition of drilling wells in the same azimuth, as well as full coverage of the well stock. The algorithm assumed step-by-step movement of platforms and verification of conditions. If the conditions were met, the new solution was accepted; if not, new iterations were performed. Thus, in section 2.1, a detailed algorithm was developed that makes it possible to solve the problem of optimizing the number of platforms and their placement based on matrix analysis of coordinates, discrete geometric discretization, and optimization procedures.

In section 2.2, a brief description of the system of criteria for grouping cluster wells is provided. Four criteria were introduced: by profile (inclined and horizontal wells depending on zenith angle), by sidetracking technology (using deflected casing strings or steerable BHA), by drilling sequence (distribution by angular sectors), and by kick-off depth. Schemes demonstrating the operation of these criteria are presented in Figs. 4 and 5. These criteria make it possible to unify the design process and reduce the probability of wellbore intersections[2].

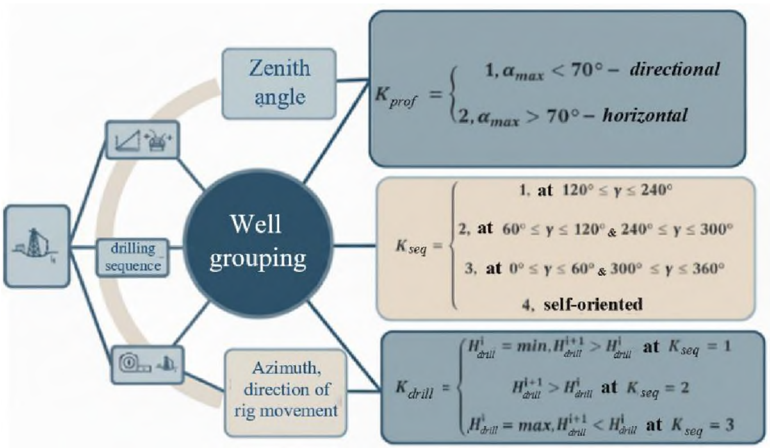


**Fig. 4. Scheme of general well cluster grouping**

In section 2.3, a description is given of the developed software that implements the proposed algorithms. The system automatically performs profile classification, calculates the drilling sequence and kick-off depth, and generates reports and tables. This ensures automation of engineering design and minimization of the human factor.

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[2] Шмончева, Е. Е. Компьютерные программы для расчетов при бурении наклонных скважин. Германия: LAP LAMBERT Academic Publishing, 2015. ISBN 978-3-659-77390-7.

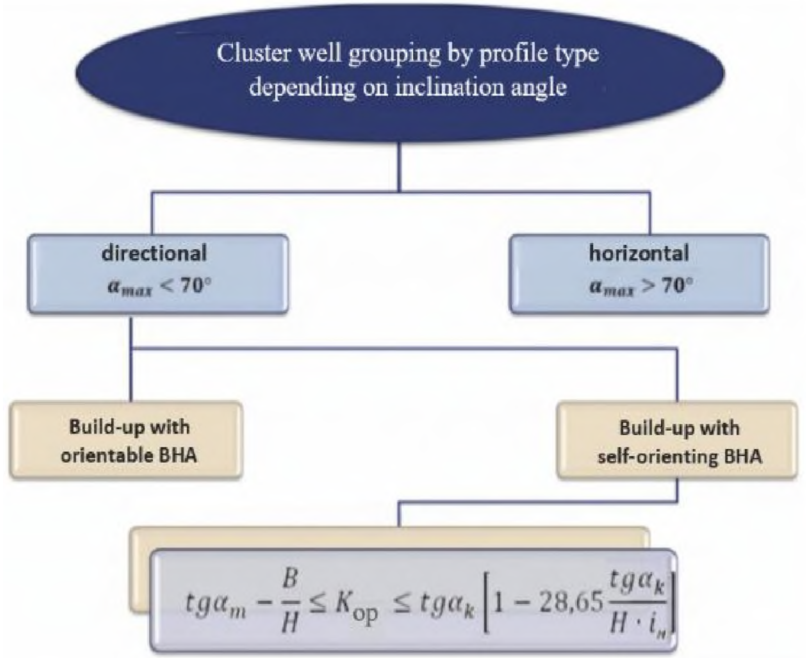


**Fig. 5. Scheme of well cluster grouping by profile**

In section 2.4, the application of machine learning[3] for optimizing the trajectories of deviated and horizontal wells is described in detail. To solve this problem, the use of machine learning is proposed, which makes it possible to account for uncertainty and stochasticity of the drilling process.

The control of a deviated well is usually carried out along a trajectory determined by the well design profile. For machine learning models, the optimization criteria were taken as drilling time and costs associated with drilling and cementing the wellbore.

The mathematical models used in the design process can be represented either by general regularities of wellbore curvature in various profile sections characteristic for the given field (in this case

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[3] Gola, G., Nybo. R., Sui, D. et al. 2012. Improving Management and Control of Drilling Operations with Artificial Intelligence. Paper presented at the SPE Intelligent Energy International, Utrecht, The Netherlands, 27-29 March. SPE-150201-MS. https://doi.org/10.2118/150201-MS.

the optimization parameters are the model coefficients), or by functions describing the curvature intervals of the well. These models can be used in machine learning by employing drilling data to predict the optimal well trajectory and minimize operating costs and time.

Three optimization criteria are introduced. The first criterion, $Kr$, minimizes the deviation of the actual trajectory from the design trajectory. In the case of wellbore deviation from the given direction, it might seem logical to control curvature so as to return the well to the path defined by the design profile, since the design profile, chosen from among the permissible ones according to some optimization criterion, should obviously define the optimal path. In this case, the control criterion $Kr$ for $\overline{U}$ can be written as:

$$Kr(\overline{U}) = \int_{x_0}^{x} |\overline{y}(x) - \overline{y}^*(\overline{U}, x)| dx \qquad (3)$$

In this equation:

$x_0$ – the coordinate (depth) of the initial control point;

$x$ – the design depth;

$\overline{y}(x)$ – the equation of the design profile ($\overline{y}$ – is the radius vector of the design profile point at depth $x$);

$\overline{y}^*(\overline{U}, x)$ – the equation of the actual well path ($\overline{y}^*$- is the radius vector of the trajectory point at the current depth).

With optimal contro $\overline{U}_{opt}$ the control criterion $Kr$ should take the minimum value:

$$\int_{x_0}^{x} \left|\overline{y}(x) - \overline{y}^*\left(\overline{U}_{opt}, x\right)\right| dx = minKr(\overline{U}) \qquad (4)$$

The second criterion $C$ accounts for drilling costs and time:

$$C(\overline{U}) = \int_{x_0}^{x} c[\overline{y}(\overline{U}, x), \overline{U}] \left|\frac{d}{dx} \cdot \overline{y}^*(\overline{U}, x)\right| dx \qquad (5)$$

In this equation:

$c[\overline{y}(\overline{U}, x), \overline{U}]$ – a value reduced to one unit of well length representing drilling efficiency (cost per meter of penetration, drilling time per meter, etc.).

The third criterion $Kr_{build\ up}$ is introduced for the build-up section of the inclination angle and controls the direction of the well relative to the allowable circle.

The criterion for the inclination angle build-up interval has the following form:

$$Kr_{build\ up}(\overline{U}) = \begin{cases} |\Delta\varphi(\overline{U})|, if\ |\Delta\varphi(\overline{U})| > arctg\left(\frac{R}{H}\right) \\ 0,\ if\ \ |\Delta\varphi(\overline{U})| \leq arctg\left(\frac{R}{H}\right) \end{cases}$$

$\Delta\varphi(\overline{U})$ – the angle between the horizontal projection of the tangent to the well axis and the line connecting the well bottom at the end of the correction interval with the design point, $R$ – radius of the tolerance circle, $H$ – residual deviation.

The control sought is the one that ensures the minimum of the criterion. By formulating the constraints in different ways, different variants of control can be obtained. Artificial intelligence may choose the option in which the length of the correction interval equals the distance from the point where the correction begins to the point where drilling must be stopped due to the need to replace the bit. In this case, the control parameters will be considered as the deflector setting angle and the skew angle of its axes, the values of which are determined by minimizing the criterion.

If, however, the deflector setting angle and the skew angle of its axes are chosen, then the control parameter will be the length of the run.

It is also possible to select the final zenith angle in the correction interval. This angle may be taken as either the zenith angle at the stabilization interval (when drilling with a four-interval profile) or as the initial angle of the low build-up interval (when drilling with a five-interval profile). Other approaches to setting this angle are also possible. In this case, the control parameters are the deflector skew angle and its setting angle, while the length of the correction interval is determined.

Each of the listed options has its own advantages and disadvantages. The advantage of the first option is that it is aimed at performing corrections without interrupting drilling. The advantage of the second option lies in the high probability that the general direction of the actual wellbore curvature during correction will coincide with the predicted one. Such coincidence of curvature direction with the assigned one is ensured by maximizing the difference between the chosen setting angle values and those values at which the general direction of curvature changes. In addition, the higher control accuracy in the second option is ensured by the fact that the control parameter—the run length—can vary continuously.

The most significant advantage of the third formulation is the invariability of control aimed at achieving the final design result of drilling with steerable BHA. Consequently, the entire subsequent trajectory, starting from the moment of correction, in the build-up interval must be drilled without changing the action plane of the deflector. This simplifies its installation at the well bottom after bit replacement or measurements, as well as increases the reliability of maintaining the chosen drilling trajectory.

In addition to the above-mentioned constraints that determine the formulation of the problem, each option also includes restrictions reflecting technical, technological, and geological conditions of drilling (for example, the need to complete the build-up interval before setting casing, or to a given depth, the prohibition of exceeding the specified zenith angle values or its build-up rate, etc.).

Machine learning is applied only to the zenith angle build-up interval. The idea of control based on the criterion introduced is to curve the wellbore so that by the end of the correction its horizontal projection is directed into the tolerance circle, and the zenith angle equals the design zenith angle at the stabilization interval. At the same time, the continuation of the well trajectory in the stabilization interval of the zenith angle and in the subsequent drop interval, starting at the final correction point, should intersect the horizontal plane passing through the design bottomhole no closer than that bottomhole. Otherwise, the zenith angle at the end of correction is selected so as to ensure that after the subsequent natural drop interval, starting from that point, the wellbore enters the tolerance circle. The criterion should ignore the design profile if drilling according to it in the low build-up and stabilization intervals of the zenith angle is associated with additional costs. It is assumed that the training algorithm will not require achieving any predetermined zenith angle value by the end of the correction (the design profile may be ignored).

The only requirement that must be fulfilled is that the azimuth change during correction ensures that by its end the wellbore exits into the direction of the tolerance circle, and the acquired zenith angle allows hitting the design bottomhole without using a steerable deflector. All variants of the problem statement also include constraints that account for drilling conditions, wellbore construction technology requirements, and subsequent well operation.

To verify the approach, the software was trained on actual trajectory data and compared with traditional trajectory calculation methods—tangential, balanced, average angle method, curvature radius method, and minimum curvature method.

In Fig. 6, the initial vertical projection is shown, and in Figs. 7 and 8 — the results of machine learning.

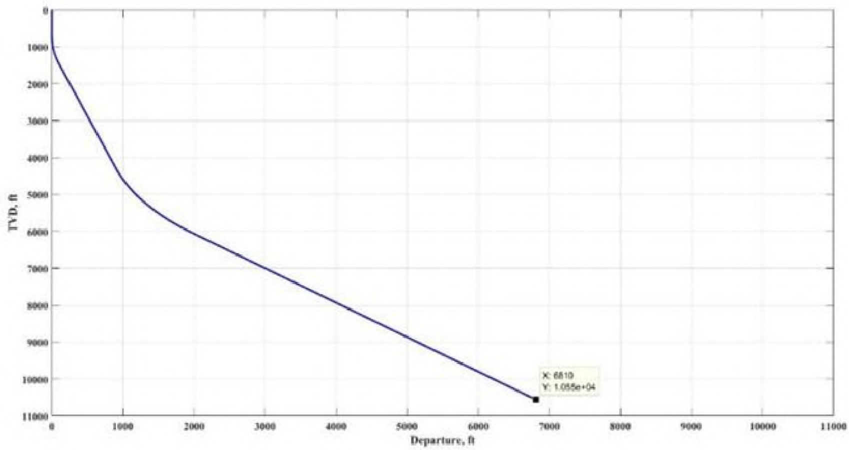


**Fig. 6. Actual well trajectory**

The comparison showed a high degree of coincidence between the predicted trajectory and the actual one. This confirms the effectiveness of applying machine learning algorithms to trajectory optimization problems.

In the synthesis of Chapter Two, it is emphasized that the proposed intelligent methods make it possible to substantially reduce the number of stationary platforms, to establish a system of criteria for well grouping, to automate the design process by means of software, and to optimize well trajectories using machine learning.

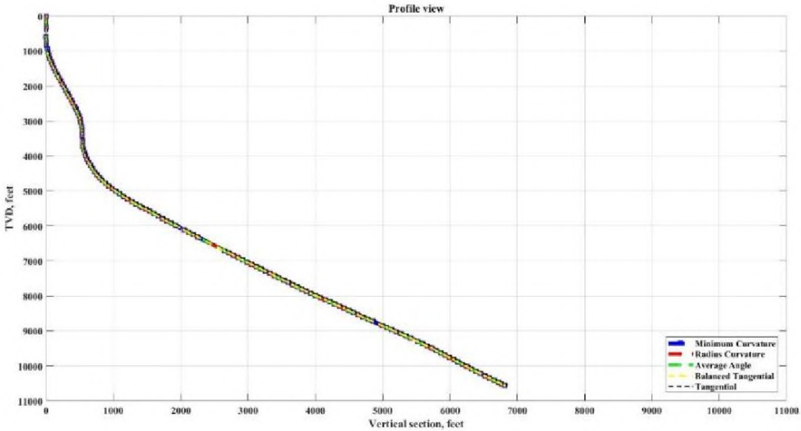


**Fig. 7. Vertical projections of the well calculated by five methods using machine learning**

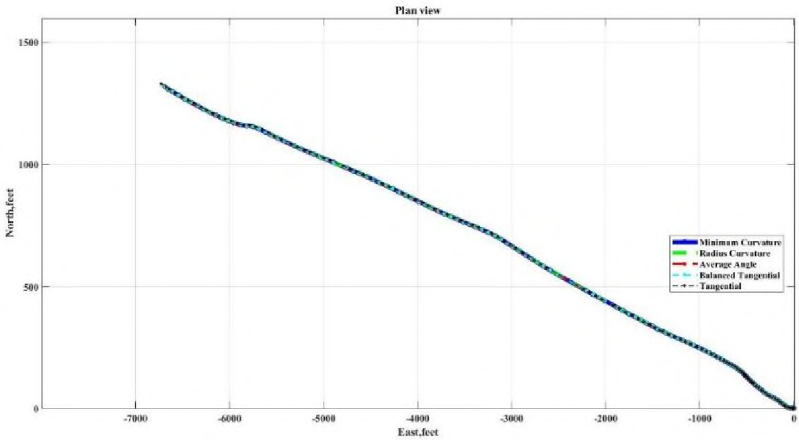


**Fig. 8. Horizontal projections of the well calculated by five methods using machine learning**

The scientific value of the chapter lies in the development of formalized algorithms that combine geometric discretization, optimization functions, and trajectory control. The methodological value consists in creating a unified system of criteria and a software implementation that enables standardization of cluster pad design and trajectory management. The practical value is expressed in reducing capital expenditures by decreasing the number of platforms, preventing wellbore intersections, enhancing the safety of drilling operations, and enabling the use of machine learning technologies for real-time trajectory control.

**In the third chapter** of the dissertation, the results of experimental studies aimed at quantitatively assessing the influence of drilling fluids and chemical additives on wellbore cleaning processes and interaction with rocks are consistently presented. The chapter combines four interrelated directions: (1) study of the effect of hydroxyethyl cellulose (HEC) on the formation and stability of the cuttings "bed" in horizontal sections; (2) determination of cuttings transport patterns under targeted modification of HEC fluid rheology; (3) laboratory evaluation of cavitation and dissolution of salt rocks by different circulating systems, including under elevated temperature and salt-saturated solutions; (4) investigation of changes in the mechanical properties of carbonate rocks under the action of zinc sulfate and sodium fluoride solutions.

In section 3.1, a methodology was developed and verified for quantitative observation of the height of the cutting's "bed" in horizontal pipes with adjustable inclination. A laboratory setup was created, including a transparent working section adjustable by angle, a measuring line, a flowmeter with computer registration, as well as fluid preparation and rheology control units. The test section, 6 m long, was assembled from a transparent PVC tube (1.0 m) connected with steel inserts (1.75 m and 3.25 m) and removable joints, ensuring both visualization and stability of hydraulic conditions. The main task was to record the time to reach steady-state and measure the stable cuttings bed height at given flow parameters.

The fluid was prepared with HEC concentrations of 0; 0.5; 1.0; 2.0 g/L. The pump rotation frequency was varied from 5 to 30 Hz (discrete values: 5; 10; 15; 20; 25; 30 Hz), which corresponded to a wide range of flow rates. Additionally, the inclination was set at 80′ (minutes), the average bulk density of the particles was 2.4 g/cm$^3$, and the average size was 2 mm. Mandatory pump calibration for volumetric delivery was performed for each HEC concentration. Table

1 presents the experimental "frequency–flow rate" dependencies for all concentrations; they demonstrate a consistent decrease in flow rate as the HEC concentration increases, which is associated with an increase in effective viscosity and flow resistance.

**Table 1**

**Pump calibration results**

| Flow frequency (Hz) | HEC concentration (g/L) | | | |
|---|---|---|---|---|
| | 0,0 | 0,5 | 1,0 | 2,0 |
| | Flow rate (L/min) | | | |
| 5 | 28,6 | 26,0 | 23,5 | 13,0 |
| 10 | 33,3 | 29,6 | 26,3 | 15,0 |
| 15 | 38,9 | 34,5 | 35,9 | 20,1 |
| 20 | 44,8 | 41,6 | 37,5 | 35,2 |
| 25 | 49,0 | 42,9 | 38,7 | 35,3 |
| 30 | 51,3 | 50,0 | 41,7 | 37,7 |

After calibration, the fluid with a given solid phase fraction was supplied into the horizontal section, varying the pump frequency and observing the formation of the cutting's "bed" along the lower generating line of the pipe. The time to reach the steady-state height of the layer and the height itself were measured. For verification, the experimental values were compared with calculated estimates obtained using the adopted theoretical model of solid phase transport in the channel.

Comparison series for all HEC concentrations show satisfactory agreement between theory and experiment across the entire flow rate range. The summary comparative diagram (Fig. 9) illustrates two stable effects: (1) with increasing HEC concentration, the height of the cuttings "bed" decreases under otherwise equal conditions, which is explained by the increase in the carrying capacity of the fluid and the development of shear stresses in the contact zone; (2) at insufficient flow rates, the height of the "bed" is higher than at increased flow rates; the optimal flow rate range for minimizing the "bed" consistently lies between 30–40 L/min, except in the case of zero HEC concentration (0.0 g/L), where a slightly higher flow rate is required to destroy the "bed."

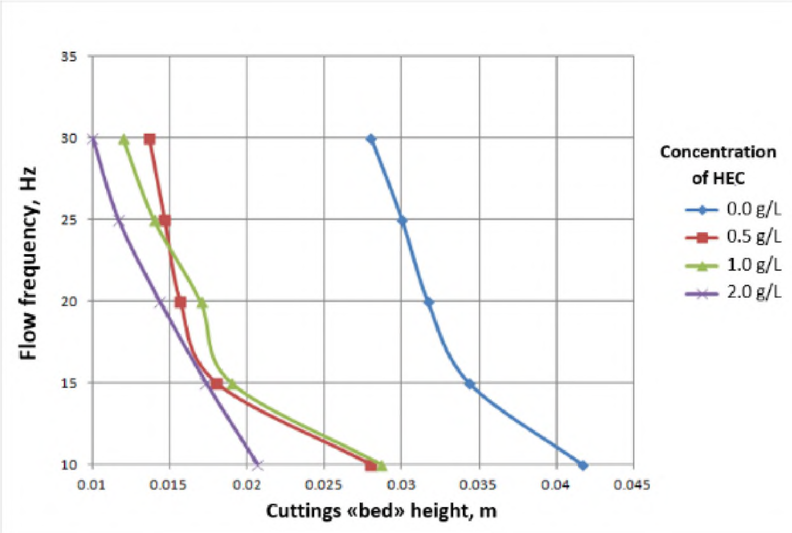


**Fig. 9. Comparative diagram for different HEC concentrations**

The practical result of section 3.1 is the parameterization of cleaning regimes: with an increase in HEC concentration, it is permissible to reduce flow rate without deteriorating cuttings transport efficiency; however, for each combination of "concentration – cuttings dispersion – inclination," there exists a lower flow rate limit below which the "bed" stabilizes and grows.

In section 3.2, an extended experimental study of cuttings transport was carried out through the analysis of the dependence of the particle drag coefficient on the Reynolds number for a Newtonian fluid (water) and for power-law fluids obtained by introducing HEC at several mass fractions. Four particle fractions were investigated (by sieve analysis): 0.6–0.7; 0.4–0.5; 0.2–0.3; 0.05–0.06 cm. The rheology of the power-law fluids was determined using a Fann viscometer, which allowed for the reconstruction of the flow law parameters for each composition and the transition to averaged Reynolds numbers of the particles. The experiment with a fixed vertical channel (a graduated glass tube of 1 m) was based on repeated measurements of settling velocity (by measuring the time of passage through one meter), followed by the calculation of the drag coefficient and Reynolds number.

A consistent pattern was obtained: for all fractions, the drag coefficient decreases with increasing Reynolds number; for power-law fluids, at the same particle sizes, the Reynolds numbers are lower and the drag coefficients higher than for water, which corresponds to increased viscosity and, consequently, more pronounced particle retardation. In Fig. 10, a direct comparative dependence for the coarse fraction (0.6–0.7 cm) is given: the difference between the curves for Newtonian and non-Newtonian media appears already in the laminar flow region.

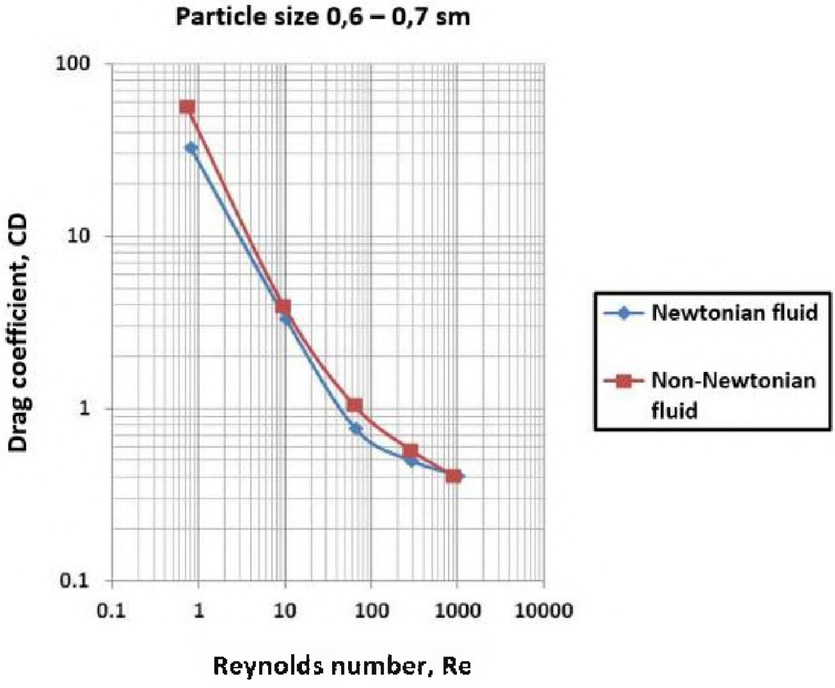


**Fig. 10. Dependence of the drag coefficient on the Reynolds number for 0.6–0.7 cm particles in Newtonian and non-Newtonian fluids**

As a result, the possibility of purposefully controlling solid phase transport through the regulation of HEC fluid rheology has been confirmed; the optimal choice of HEC concentration and flow rate makes it possible to keep particles in a suspended state and reduce the likelihood of forming a stable cutting "bed," even when pulling through long horizontal intervals.

In section 3.3, a laboratory study was carried out on the interaction of drilling fluids with salt-bearing rocks, and the tendency to cavitation was evaluated depending on the composition, pump performance, and temperature. The initial solubility tests were performed on standard rock salt samples (mass 30 g, diameter 25 mm, height 30 mm) in filtrates of drilling systems treated with various reagents: chromium-containing lignosulfonate compositions, nitrolignin, carboxymethylcellulose, sulfite-alcohol stillage, oxyl, as well as oxyl with 40% salt content and oil components. The mass loss of the sample over time was measured. A distinct induction period of impregnation (2–3 minutes) before the onset of noticeable dissolution was observed, as well as a significant dependence of the dissolution rate on the chemical composition of the fluid.

Further, a model scheme of cavitation was implemented by pumping through samples of four types of drilling mud (Table 2): a clay-based water fluid; a "basic" fluid with additives of carboxymethylcellulose, bentonite, and starch; a starch-based fluid with oxyl, aluminum nanopowder, and oil component; as well as a "basic" fluid with sulfite-alcohol stillage, chromium-containing reagent, coal-alkaline reagent, starch, and bentonite. For salt-free systems at pump capacities of 5 and 15 L/min, dependencies of the change in internal washout volume over time were obtained. As expected, an increase in pump capacity leads to higher washout rates (for example, for the water–clay fluid at 15 L/min over 12 minutes, the volume change was ~35 $cm^3$). Measurements at elevated temperature (60 °C, capacity 15 L/min) showed a moderate increase in washout relative to room temperature (multiplicative factor ~1.02–1.04 for different fluids), indicating a secondary role of heating compared to chemical composition and hydrodynamic parameters. When the fluids were saturated with salt (60–100%), the washout values predictably decreased; moreover, fluids of composition No. 3 (with oxyl and aluminum nanopowder) demonstrated lower cavitation tendencies in both unsaturated and saturated states. Visual inspection revealed a more uniform distribution of caverns across the cross-section when using salt-saturated systems—an important feature in terms of borehole geometry and wall stability.

**Table 2**

**Types of drilling mud**

| Drilling mud title | Quantity of additives |
|---|---|
| Drilling mud №1 | |
| Water-based clay drilling mud | - |
| Drilling mud №2 | |
| Initial solution<br>CMC<br>Bentonite clay<br>Starch reagent | 100<br>8<br>2<br>2 |
| Drilling mud №3 | |
| Starch solution<br>Oxil<br>Aluminum nanopowder<br>Oil | 100<br>5<br>0.6<br>2 |
| Drilling mud № 4 | |
| Initial solution<br>CSAS<br>Chrompeak<br>Coal-alkali Reagent<br>Starch reagent<br>Bentonite clay | 100<br>6<br>2<br>2<br>1.5<br>2 |

The final conclusion of section 3.3: when drilling extensive salt formations, the key factor is not the increase in flushing temperature, but rather the optimization of chemical composition and maintaining pump performance at a level that prevents localized washout; the use of salt-saturated fluids significantly reduces cavitation, while functional additives (oxyl, aluminum nanodopants) additionally stabilize the wellbore walls.

In section 3.4, the change in the mechanical properties of carbonate rocks (limestone, chalk) upon contact with drilling fluids containing soluble salts with zinc and fluoride ions is considered. The aim is to increase hardness and reduce permeability through targeted chemical transformations of matrix minerals. The strengthening mechanism used is precipitation reactions in pores and at grain contacts. For the "zinc sulfate – calcium carbonate" system, a transformation was realized with the formation of smithsonite and gypsum:

$$Zn^{2+} + SO_4^{2-} + CaCO_3 \xrightarrow{2H_2O} ZnCO_3 \downarrow + CaSO_4 \cdot 2H_2O \downarrow \quad (1)$$

For the "sodium fluoride – calcium carbonate" system — the formation of calcium fluoride:

$$CaCO_3\,(s) + 2NaF\,(aq) \rightarrow CaF_2\,(s) + 2Na^{+}\,(aq) + CO_3^{2-}\,(aq) \quad (2)$$

Hardness was evaluated by the Brinell method (ball diameter: 5 mm; load: 600 N for chalk, 1200 N for limestone; exposure time: 10 s). To assess porosity, a rock density and porosity analyzer AP-2 was used, designed to determine open porosity, bulk and mineralogical density, moisture, mass, and sample volume. The samples were kept in solutions at room temperature: $ZnSO_4$ 0.1 M — 48 hours; NaF 0.1 M — 120 hours; after which they were rinsed and dried under regulated conditions. Control measurements of ion concentrations in the solutions over time showed intensive interaction of limestone with $ZnSO_4$ solution: $Zn^{2+}$ concentration decreased by ~1000 mg/L (Fig. 11), while $Ca^{2+}$ concentration increased (Fig. 12).

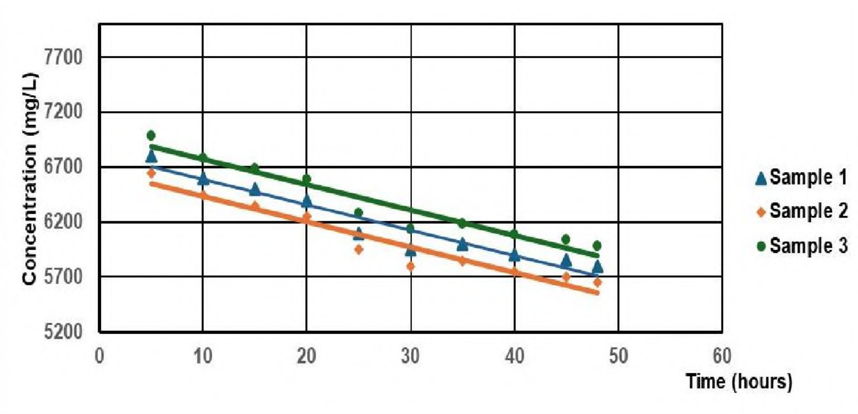


**Fig. 11. Change in $Zn^{2+}$ ion concentration over time**

The result is a 19% increase in limestone hardness and a 76% reduction in permeability relative to the initial level, indicating effective formation of a dense mineral phase in the pores and at the contacts.

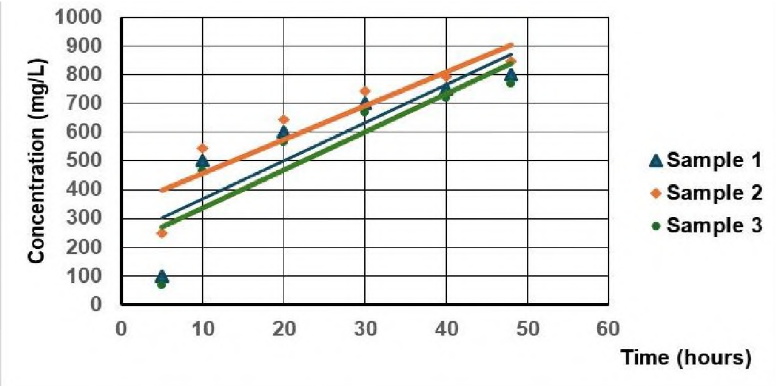


**Fig. 12. Change in $Ca^{2+}$ ion concentration over time**

When exposed to 0.1 M NaF solution, no noticeable increase in hardness was recorded, and the reduction in permeability amounted to ~12%. Increasing the NaF concentration to 0.9 M led only to a moderate increase in hardness (~3.8%) with significant consumption of fluoride ions (from ~18,000 to ~11,000 mg/L; Fig. 13).

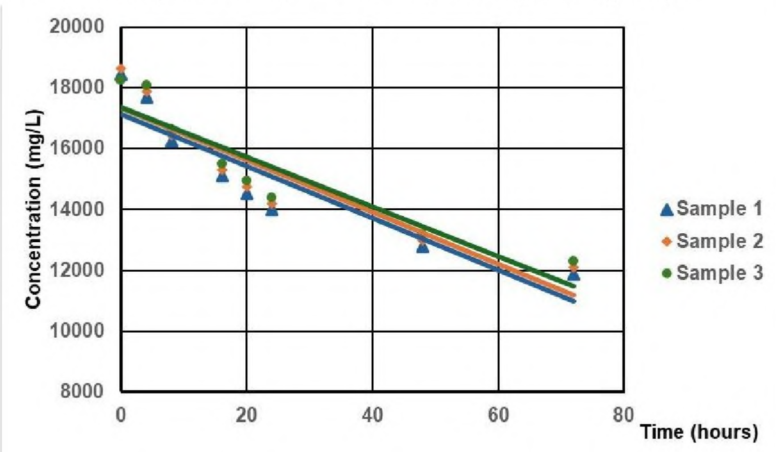


**Fig. 13. Change in $F^{-}$ ion concentration over time (NaF 0.9M)**

Comparison of the results shows the incomparably higher effectiveness of the zinc-containing system for limestone strengthening. At the same time, attention is drawn to the need for strict environmental protection measures when using solutions containing zinc ions and fluoride ions: well casing integrity, high-quality cementing, controlled fluid disposal, and monitoring of groundwater and surface water quality are required. This note is due to the high solubility and toxicity of these components in the event of unauthorized entry into aquifers.

In conclusion, Chapter 3 provides a coherent picture of "composition – regime – effect." The results of sections 3.1–3.2 show that the addition of HEC purposefully alters the hydrodynamics of solid-phase transport: at concentrations of 0.5–2.0 g/L it is possible to keep particles suspended at lower flow rates than in the base case, while the stability of the cuttings "bed" decreases; however, for each concentration there is a lower flow rate threshold below which the "bed" stabilizes and cleaning worsens. In section 3.2, the correlation of drag coefficient decreasing with increasing Reynolds number is quantitatively confirmed, which makes it possible to proceed to practical calculations of critical lifting velocities for "fluid–cuttings" mixtures taking into account rheology. In section 3.3, it is established that the chemical composition of the fluid and the degree of salt saturation are dominant factors in managing cavern formation in salts; increasing the temperature to 60 °C without chemical modification has a moderate effect, whereas salt saturation and functional additives allow for a significantly more uniform washout profile. In section 3.4, it is experimentally shown that treatment of limestone with zinc sulfate solution at room temperature under laboratory conditions leads to the formation of slightly soluble precipitates in the pore space, increases hardness, and sharply reduces permeability; sodium fluoride at the investigated concentrations provides a limited strengthening effect, which should be taken into account when designing compositions for carbonate wall stabilization.

The final results of Chapter 3 can be summarized as follows. First, a laboratory methodology for direct measurements of the cuttings "bed" height and solid-phase transport parameters in horizontal sections has been developed and tested; it is shown that the use of HEC in the range of 0.5–2.0 g/L at properly chosen flow rates (reference corridor 30–40 L/min for the studied conditions) significantly reduces cuttings bed height and improves wellbore cleaning reliability. Second, experimental "drag coefficient – Reynolds number" dependencies were constructed for Newtonian and power-law fluids, which allowed proposing approximations for engineering calculations of critical lifting velocities and circulation regimes considering fluid rheology. Third, it has been established that in salt formations, the chemical composition of the drilling fluid and its degree of salt saturation have the greatest effect on the rate and nature of cavern formation; the temperature factor up to 60 °C plays a secondary role. Fourth, the principal possibility of carbonate rock strengthening through the introduction of components into the drilling fluid that form slightly soluble precipitates in the pores has been proven: for zinc sulfate solution, a 19% increase in limestone hardness and a 76% reduction in permeability were recorded, while sodium fluoride solutions at 0.1–0.9 M showed limited effect.

The practical conclusion is that for carbonate wall stabilization, zinc-containing compositions are more promising, provided that strict environmental requirements are observed; for cleaning horizontal intervals, it is advisable to use HEC-modified fluids with flow rates maintained in the range that ensures destruction of the "bed." The collected data provide an experimental basis for the subsequent development of guidelines for selecting drilling fluid compositions and operating regimes in complex geological and technical conditions, as well as for calibrating models of solid-phase transport and borehole wall stability.

**Chapter 4** of the dissertation addresses the technological and experimental foundations for improving well casing and cementing, which are of fundamental importance for enhancing the reliability of isolating productive and aquifer horizons, as well as for extending well service life. Section 4.1 examines the development of expandable tubular[4] technology and substantiates the necessity of using a dual-

[4] Stringer, J. A., and D. B. Farley. "The Evolution of Expandables: A New Era of Monobore Expandable Well-Construction Systems." Paper presented at the SPE

action reamer for the construction of monodiameter wells under complex geological and technical conditions.

It is shown that traditional methods of localizing drilling complications—such as loss of circulation, wellbore instability, differential sticking, and excessive reservoir damage—lead to the sequential installation of casing strings and the inevitable telescopic reduction of diameter, which is critical for deepwater and highly deviated wells. The technology of solid expandable tubulars allows problematic intervals to be isolated without losing the design diameter of the production casing, thereby eliminating the telescopic effect. Its industrial development, from Chevron's first application in the Gulf of Mexico (1999) to widespread adoption onshore and offshore, confirms the maturity of the solutions and the diversity of their applications: local isolation of perforations and water inflows, repair of corroded sections, installation of expandable liners and hangers, sand control, and more.At the same time, the basic mechanics of expansion in industrial systems (Halliburton, Schlumberger, Enventure, Weatherford, Baker Oil Tools, READ Well Services) rely on irreversible plastic deformation of the pipe with the reamer moving upward under hydraulic pressure differential and the tension of the inner string. To implement the concept of a constant internal diameter well, it is shown that reamers are required that are capable of forming a bell at the lower end of the pipe and then performing secondary expansion of the string to a smaller diameter, ensuring a technological transition between expansion modes when moving both from bottom to top and from top to bottom—an operation fundamentally more complex than classical single-stage expansion.Analysis of known local reinforcement tools with profiled packers and swagers (roller/cone)[5] as well as devices for straightening deformed pipes with multiple balls and grooves revealed their key limitations: the inability to efficiently expand round steel strings made of expandable material

Middle East Oil and Gas Show and Conference, Manama, Bahrain, March 2013. doi: https://doi.org/10.2118/164171-MS

[5] Abdrakhmanov G.S. Well Casing with Expandable Tubulars. 2nd edition. — M.: VNIIOENG, 2015. — 236 p. — ISBN: 978-5-905999-69-7

to two target diameters and, consequently, the inability to build a fully functional monodiameter well.To overcome these limitations, a new dual-action expander assembly for round casing pipes was proposed and engineered: a cylindrical body with circular windows in the middle section, connected to the drill string by a hollow mandrel; a piston and a hydraulic chamber are placed in the upper part of the body and linked to the mandrel through check valves; a shaped (variable-diameter) cone with three transverse grooves is mounted on bearings to the lower surface of the piston and can rotate about its axis; steel balls located in the body windows are supported by the cone grooves and are pushed outward from the body by a preset amount (Fig. 14). Operating principle: in the initial state, the balls are aligned with the cone's smallest diameter; after dropping a ball into the mandrel seat and applying hydraulic pressure, the piston moves the cone downward, shifting the balls into the maximum-diameter groove so that they extend outward—this provides the primary expansion of the pipe over one pipe interval while the body rotates and the tool is pulled up (first stage). Further pumping moves the cone again, transferring the balls into a groove of smaller diameter and setting the second projection—repeating the "rotation + pull-up" kinematics forms the second, smaller-radius expansion over the remaining designed length of the string (second stage) (Fig. 15).

Such kinematics ensures the formation of a bell (flared end) at the lower end and the subsequent bringing of the string to the target "smaller" diameter, which is required for sequential assembly of a monodiameter well without loss of drift when changing stages. The technological cycle is integrated into the standard construction scheme: preparation and expansion of the section for the liner, running the expandable string with the tool, cementing, primary and secondary expansion of the liner body, hanging and sealing via an elastomer element, and shoe drill-out. The economic effect from implementing the monodiameter technology with a dual-action expander is estimated at 30–50% in drilling time and cost due to reduced volumes of cement, steel, and drilling fluid, reduced cuttings removal, and the use of lower-power equipment at comparable performance, as well as fewer casing stages and lower energy consumption.

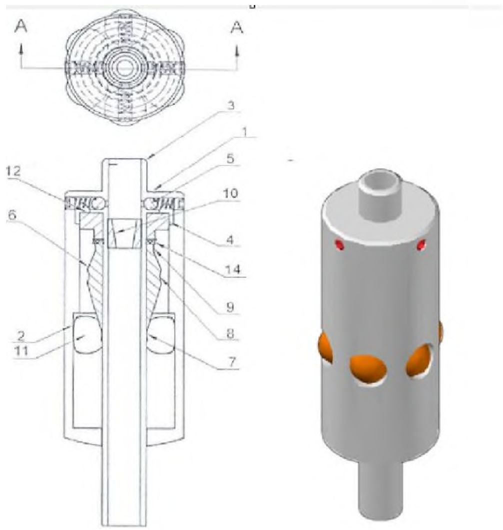


**Fig. 14. Pipe expander in the initial position**

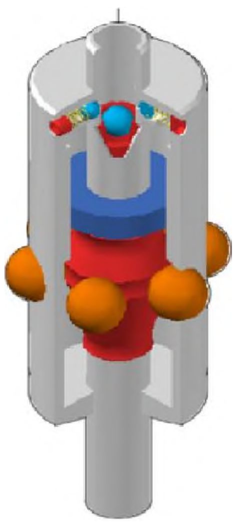

**Fig. 15. Pipe expander in the operating position**

Thus, a technological basis is formed for the serial design and industrial implementation of monodiameter wells with predictable hydrodynamics, simplified subsea and surface tie-ins, and improved environmental and energy efficiency.

It is shown that the proposed design provides the required functionality of dual expansion of round steel casing strings, extending the applicability of expandable tubulars to the construction of constant-diameter wells in deepwater projects, as well as to repair and isolation of problematic intervals.

Section 4.2 presents the results of laboratory studies on the swelling kinetics of packers in drilling fluids of various salinities and the assessment of the time required to achieve contact with the wellbore wall. The study is motivated by the practical need to match elastomer properties to real reservoir and technological conditions, since the swelling rate and ultimate swelling degree determine the effectiveness of zone isolation, crossflow control, and multi-stage operation scenarios. The experiment was performed on cylindrical elastomer samples at 28 °C in three media: fresh water (0% NaCl), 1% NaCl, and 5% NaCl solutions. Geometric parameters (mean diameter and height) were determined by six repeated caliper measurements to minimize the influence of surface micro-roughness; volume was calculated as that of a cylinder, and volume change was expressed as a percentage of the initial value. A continuous series of measurements was carried out during the first five days, after which the samples were kept at rest with control points on days 10, 15, and 20–25. For each regime, "volume–time" and "ΔV, %–time" curves were plotted.

Results for the freshwater medium show a rapid initial volume increase: by day 5 the growth was ~163%, by day 10 ~221%, and by day 25 ~274% (Fig. 16). In the 1% NaCl solution, the curve has a similar shape but is shifted in magnitude: ~150% on day 5, ~193% on day 10, and ~258% on day 25 (Fig. 16). For the most saline medium (5% NaCl), pronounced swelling retardation is observed: ~95% on day 5, ~149% on day 10, and ~195% on day 20 (Fig. 16).

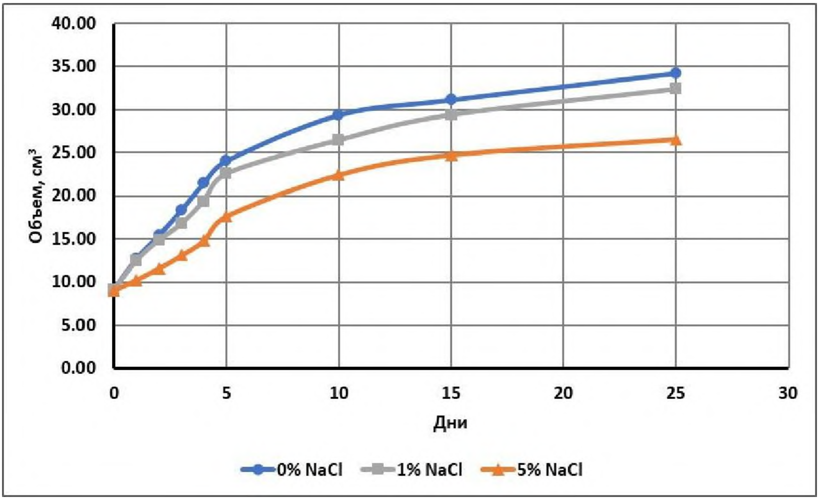


**Fig. 16. Time dependence of the cylindrical sample's volume change during swelling**

Thus, the experiment confirms the typical effect for anionic brines of suppressing osmotically driven swelling: the higher the fluid salinity, the lower the swelling rate and extent. At the same time, all three media exhibit a "fast" phase in the first 3–5 days followed by a slowdown, indicating a transition from a diffusion-kinetic regime to quasi-steady saturation. The experimental studies were carried out on a small cylindrical sample. To calculate the time for a real packer to contact the wellbore wall after swelling, special calculations are required. First, the volume of the real packer before swelling is computed.

Then the packer volume during swelling is calculated. For this, the initial packer volume, the percentage volume change of the sample from the experiment, and a special correction factor are used. After obtaining the packer volume as a function of time, the packer diameter ($OD_P$) is determined (Table 3).

After determining the diameter, we plot the graph. In Fig. 17, the straight line represents the wellbore's internal diameter. The intersection points of the other lines with this line indicate the moments when the swelling packer makes contact with the wellbore wall.

**Table 3**

**Results of calculating the volume and outer diameter of the real packer during swelling**

| **Days** | 0 | 1 | 2 | 3 | 4 | 5 | 10 | 15 | 25 |
|---|---|---|---|---|---|---|---|---|---|
| **Well diameter, cm** | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 |
| Water solution (0% NaCl) | | | | | | | | | |
| **Volume change, %** | 0 | 39.43 | 68.68 | 100.83 | 134.79 | 163.14 | 221.40 | 240.60 | 274.30 |
| **$OD_P$, cm** | 14.35 | 14.70 | 14.95 | 15.23 | 15.51 | 15.74 | 16.21 | 16.36 | 16.62 |
| 1% NaCl | | | | | | | | | |
| **Volume change, %** | 0 | 38.67 | 64.90 | 85.94 | 114.92 | 150.18 | 193.13 | 225.39 | 258.49 |
| **$OD_P$, cm** | 14.35 | 14.69 | 14.92 | 15.10 | 15.34 | 15.64 | 15.99 | 16.24 | 16.50 |
| 5% NaCl | | | | | | | | | |
| **Volume change, %** | 0 | 13.75 | 28.46 | 45.21 | 63.90 | 95.52 | 148.89 | 174.55 | 194.74 |
| **$OD_P$, cm** | 14.35 | 14.47 | 14.60 | 14.75 | 14.91 | 15.18 | 15.63 | 15.84 | 16.00 |

As seen from the graph (Fig. 17), a packer placed in a drilling fluid prepared with fresh water will, upon swelling, touch the wellbore wall after 3 days. A packer that, under real conditions, will be in formation water with 1% NaCl by mass will touch the wall after 3.5 days. As the salt concentration in the drilling fluid or formation water increases, the period for the packer to swell and touch the wellbore wall increases from 3 to about 5.5–6 days.

The obtained results have direct practical significance for planning isolation works: (1) the studies allow setting a time window for deployment and pressure testing, taking into account the actual salinity of the drilling/formation fluid; (2) the calculations provide an estimate of the time to achieve sealing contact; (3) the critical importance of preliminary compatibility tests of the “elastomer–fluid” pair is confirmed.

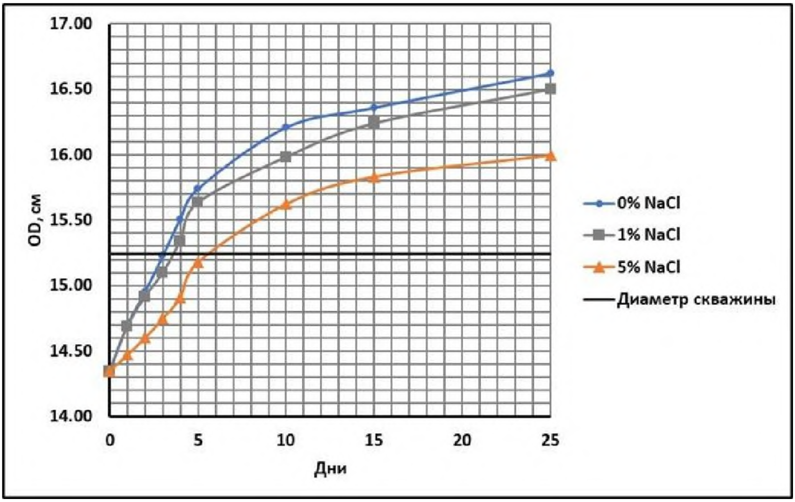


**Fig. 17. Time for the swelling packer to contact the wellbore wall**

The study's limitations are related to the laboratory scale of the samples and isothermal conditions at 28 °C; additional tests are required under pressure, with cyclic loads, and under real temperature and ionic gradients (including divalent cations and anions affecting osmotic balance and diffusion). Overall, the data of section 4.2 experimentally confirm the operability of swelling packers over a wide range of salinities and quantitatively show that increasing salinity slows both the rate and extent of swelling; thus, for emergency scenarios requiring rapid commissioning, fresh-water media or low-salinity brines are preferable, whereas at high salinity increased waiting times should be planned and/or elastomers with enhanced osmotic activity should be selected.

Section 4.3 justifies the choice of a hyperelastic model for the computational description of the sealing elements of swelling packers and their associated contact interaction under large deformations and a nearly incompressible material response. Based on analysis of experimental data (tension/compression, shear, hardness, patterns of volumetric swelling and density change) and comparative modeling, it is shown that Hooke's linear elasticity law is applicable only within small strains and fundamentally fails to capture the characteristic nonlinear "stiffening" of elastomers at large stretches.

Classical low-parameter hyperelastic models (Neo-Hookean) provide correct descriptions over a narrow strain range; multi-parameter Mooney–Rivlin and Yeoh improve the fit of tension/shear curves, but show sensitivity when extrapolated beyond the calibration window and insufficient flexibility under triaxial loading typical for packers. Limited-chain-extensibility models (Gent, Arruda–Boyce) have physical interpretability but require specialized tests to reliably identify limiting chain parameters, complicating routine engineering use[6].

Hooke's law is applicable only at small strains and cannot describe the behavior of real sealing elastomers. The Ogden-1 model provides an approximate solution but underestimates the stress growth at large deformations. The Ogden-2 model offers a more reliable reproduction of experimental data and is therefore optimal for modeling a swelling packer, where operating strains significantly exceed the limits of linear elasticity.

Given these limitations, the Ogden class of models was chosen in this work, in which the strain-energy density is specified via the principal stretches $\lambda_i$ and parameter pairs ($\mu_i$, $\alpha_i$): The Ogden model is based on the strain-energy density function:

$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right)$$

where $W$ – is the strain energy density,

$\lambda_1, \lambda_2, \lambda_3$– are the principal stretch ratios,

$\mu_i$, $\alpha_i$ – are material parameters determined from experimental data.

ABAQUS finite element software is most commonly used for modeling. The system geometry is set as axisymmetric: the elastomer seal is vulcanized onto the inner steel pipe and contacts either the outer

[6] Арсентьев М. Ю., Сысоев Е. И., Балабанов С. В. Исследование механических свойств материалов с топологией ТППМЭ методом компьютерного моделирования // Физика и химия стекла. – 2021. – Т. 47, № 5. – С. 582–589. – DOI: 10.31857/S0132665121050048.

casing string or the formation walls. All components are treated as deformable, and contact interactions are described by a Coulomb friction model. For a rough rock surface, the friction coefficient is taken to be about 0.4, whereas for the smooth casing surface it is about 0.1.

ABAQUS analysis shows that the contact pressure is distributed non-uniformly along the seal. It is minimal at the ends of the element and reaches a maximum in the central zone, which agrees with experimental observations. Varying the seal thickness and length, as well as the mechanical properties of the rock, makes it possible to predict the sealing capacity of the packer and to select optimal design parameters.

Thus, for modeling the sealing elements of swelling packers, the choice of the Ogden-2 hyperelastic model combined with axisymmetric hybrid elements CAX4RH is justified. The resulting computational toolkit, verified against experimental data, is then used for parametric studies of how seal geometry, friction coefficient, and swelling conditions affect the sealing capability of packers under real thermobaric and rheological conditions.

Section 4.4 presents the results of modeling the behavior of a swelling elastomer seal in various media (low-salinity and medium-salinity brines, oil) and under different wellbore conditions (open hole and cased). In all cases, the pressure distribution along the seal has a characteristic "bell-shaped" profile with a maximum at the center and zeros at the ends (Fig. 18).

It is shown that material B provides significantly higher contact pressure compared to material A—by a factor of 2–5 depending on the medium. Swelling proceeds fastest in low-salinity water, forming the highest pressures, whereas in oil the kinetics slow down and the ultimate values are minimal. In open hole, the pressure is 20–40% higher than in casing, which is associated with the higher friction coefficient at the "elastomer–rock" interface. A comparison of materials showed that material B has better sealing capability and reaches operating mode faster ($t_{50}$ and $t_{90}$ times). Material A behaves softer and generates lower pressures, which limits its use at high differential pressures.

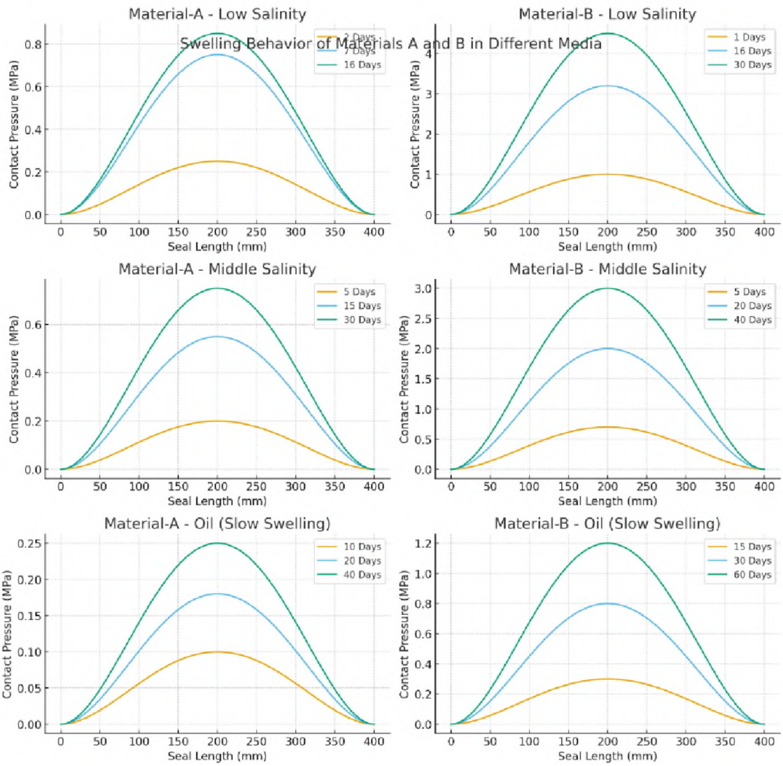


**Fig. 18. Time evolution of contact pressure during swelling of materials A and B in media of different salinity and in oil**

Practically, this means that for aggressive conditions and high sealing requirements, material B is preferable—especially in low-salinity media and in open hole. In oil intervals, to ensure reliability, it is necessary to increase seal length, raise the initial interference (pre-compression), or use a pre-swelling technique.

**Chapter Five** addresses current issues in applying Managed Pressure Drilling (MPD) technology and the role of blowout preventer (BOP) equipment in ensuring the reliability and safety of this process.

Under modern conditions, MPD has become particularly relevant due to the need to minimize risks when developing complex and depleted fields. This technology provides precise control of circulating pressure, allowing effective management of the wellbore pressure gradient, prevention of drilling fluid losses, and reduction of the likelihood of influxes and kicks.

A key element for MPD reliability is the BOP, which must operate strictly in accordance with design parameters and international standards (API Spec 16A, API Spec 53, ISO 13533). Any malfunction or emergency shutdown of the BOP can lead to serious consequences, including uncontrolled fluid releases, equipment damage, and threats to personnel safety.

Beyond industrial safety, the environmental component is crucial. Blowout incidents risk contaminating the environment with oil and gas, potentially causing major damage to marine and terrestrial ecosystems as well as social and economic losses. In this regard, improving BOP designs and operating algorithms, and introducing intelligent monitoring and diagnostics systems, is essential to enhance both the technological and environmental resilience of drilling operations.

Subsea preventers used in deepwater drilling continue to face serious reliability challenges, significantly increasing equipment failure frequency and nonproductive time costs.

Thus, the development and fail-safe operation of BOP equipment is a necessary condition for the successful implementation of MPD, for elevating industrial safety, and for minimizing environmental risks in hydrocarbon development.

This chapter focuses special attention on innovative BOP design solutions aimed at improving reliability, adaptability, and integration into digital drilling control systems.

In practical reports and the scientific literature, there are no references to a universal preventer that incorporates a hydraulic turbine system capable of grinding the surface of drill pipes to reduce wear of elastomer seals. None of the reviewed studies describes or evaluates a device with such a function. Existing works focus mainly on control systems, monitoring technologies, seal materials, or external configurations, but do not address internal abrasive mechanisms that can actively extend seal life. This gap underscores the novelty and originality of the present research.

One of the main problems encountered with rotating preventers is the wear of rubber sealing elements. When these seals fail, they must be replaced. However, replacement requires disassembling the preventer or rotating head, which takes considerable time and lowers productivity. This problem is especially acute on offshore platforms—such as semi-submersible rigs and drillships—where access to equipment is difficult and downtime entails extremely high costs.

The primary source of rubber component wear is the drill pipe passing through the rotating preventer during drilling. The situation is further aggravated by tong-mark scars left on pipe surfaces after repeated make-up and break-out. Such damage is particularly common when operating older drill strings subjected to intensive use.

A new direction in the design of universal BOPs is presented, aimed at increasing seal durability and reducing nonproductive time by integrating a hydraulic turbine with a grinding mechanism into the assembly.

The main objective of the invention is to create an improved universal preventer design intended to seal the wellhead. Implementation of this concept will significantly increase preventer reliability, extend mean time between repairs, improve longevity, and simplify maintenance.

The design is based on the hydraulic system of a universal preventer.

The proposed universal preventer (Fig. 19) consists of several main elements. Its design includes a hollow body (1) and a cover consisting of an upper (2) and a lower hollow part (3) with central openings. A gasket (4) is placed between these parts to ensure tightness during assembly. The components are joined using a dowel-pin connection (5).

In the cavity of the lower cover part (3), a grinding element with lugs (7) is installed on bearings (6) and inserted into the slots of a turbine (8), which is also mounted on bearings (9). The turbine (8) is connected to a channel (10) passing through the lower cover part (3) and the body (1), which provides its connection to a hydraulic pressure source.

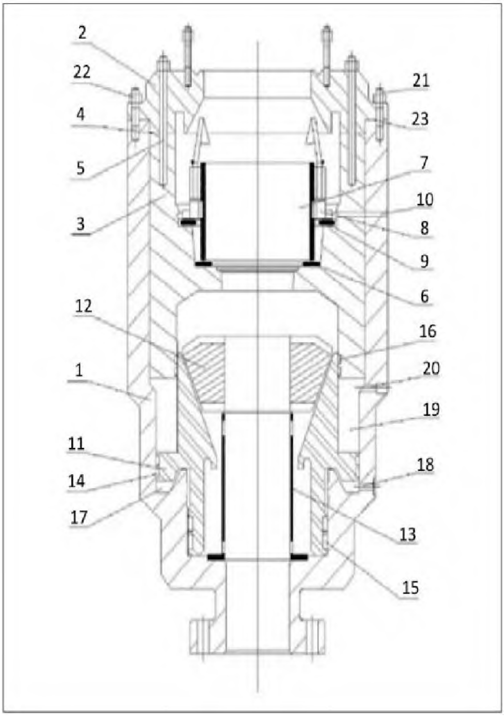


**Fig. 19. Schematic of a universal preventer with grinding elements**

Inside the body (1), in contact with the base of the cover (3), there is a plunger (11) with an internal conical surface. A seal (12) with an external conical surface, reinforced with metal inserts and having a central inner opening, is placed inside the plunger (11).

To protect the internal assemblies from damage, the preventer is equipped with a sleeve (13). The body (1), the lower part of the cover (3), and the plunger (11) form two hydraulic chambers in the preventer using sealing cuffs (14, 15, 16): the working chamber (17) is connected to a pressure source through a channel (18) in the body (1), and the return chamber (19) is connected to a pressure source through a channel (20) in the body (1).

The upper part of the cover (2) is fastened to the body (1) with a stud (21) and a nut (22), with a gasket (23) installed between them to ensure tightness.

When hoisting operations are performed with the pipe string, working fluid is supplied from the preventer control station through the channel (18) in the body (1) into the working chamber (17), creating hydraulic pressure. Under this pressure, the plunger (11) rises, compressing the seal (12) along its external conical surface. As a result, the seal (12) tightly embraces the pipe string or completely closes the central opening in emergency situations, sealing the wellhead.

When pipes pass through the closed sealing element (12), wear primarily occurs on the narrow edge of the elastomer material near its inner upper rim. As wear increases, the width of this zone gradually grows until it covers the entire height of the compressed seal.

To reduce wear of the sealing element (12), pressure from the pump is supplied to the hydraulic channel (10) passing through the body (1) and the lower part of the cover (3) and directed at a right angle onto the turbine (8). This drives the turbine, transmitting torque to the grinding element (7), which begins to rotate and grind the pipe surface.

To unseal the wellhead, working fluid pressure is supplied to the channel (20) leading to the return chamber (19). This causes the plunger (11) to move downward and release the seal (12). Thanks to the material's elasticity, the seal (12) returns to its original state, opening the central opening to its initial size.

The grinding element and its components are shown in Fig. 20.

Main tool components: outer sleeve (1); inner sleeve (2); lugs with a grinding surface (3) and balls on the reverse side to reduce friction; a spring mechanism (5) that connects the two parts of the grinding lugs and ensures their compression and expansion depending on pipe diameter.

Under standardized experiments simulating real drilling operations, the effectiveness of the proposed universal preventer was rigorously evaluated. The methodology included comprehensive laboratory tests reproducing repeated passage of drill pipes through the preventer's sealing element, closely approximating real operating scenarios.

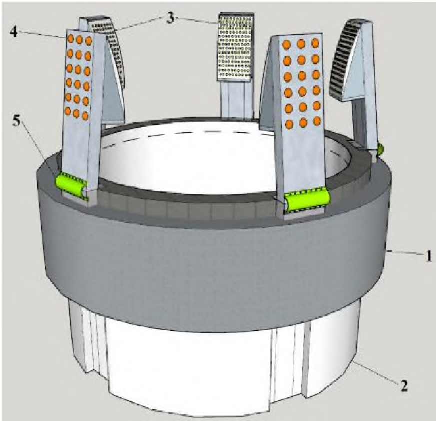


**Fig. 20. Grinding element**

The experiments were performed in the following sequence:

1. Standard elastomer sealing elements were prepared, identical to those used in conventional preventers and in the proposed design with the grinding mechanism, ensuring comparability of results.
2. Multiple cycles of drill pipe passage through the sealing elements were conducted until critical wear requiring replacement was reached. Tests were carried out separately for conventional models and for the new design with the grinding mechanism.
3. The test bench was equipped with high-precision load and torque sensors, enabling objective measurement of axial forces and rotational resistance and recording the seal degradation process.
4. During the tests, mean time between failures (MTBF) and maintenance intervals (seal replacements) were systematically recorded, allowing assessment of reliability improvements.

In standardized laboratory simulations of drilling processes, the proposed universal preventer design demonstrated significantly higher performance across all evaluated criteria compared to conventional models. As shown in Table 4, the new preventer with a grinding mechanism increased the number of full pipe-pass cycles by 35% before the elastomer seal reached critical wear—from 1,000 cycles for the standard model to 1,350 cycles for the upgraded version.

Thus, for the first time, a design solution for a universal preventer with an active function to reduce abrasive impact on sealing elements—through the use of a built-in hydraulic turbine and grinding block—is proposed. Unlike existing approaches focused mainly on improving control systems, monitoring, or using new sealing materials, the proposed concept aims to prevent wear at its earliest stage. This expands the equipment's functional capabilities and opens a new direction in the design of blowout-prevention devices.

**Table 4**

**Comparative analysis of operating characteristics of the conventional preventer and the proposed design with a grinding element**

| **Performance indicator** | **Conventional preventer** | **Proposed preventer with grinding element** | **Improvement (%)** |
|---|---|---|---|
| Seal wear (number of cycles to critical wear) | 1,000 | 1,350 | +35% |
| Mean time between failures (hours) | 80 | 92 | +15% |
| Seal replacement interval (days) | 50 | 61 | +22% |

## CONCLUSIONS AND RECOMMENDATIONS

1. Intelligent methods have been developed to optimize the placement of cluster well pads and well trajectories, enabling a reduction in the number of offshore platforms without loss of performance [35].

2. A methodology has been proposed for grouping and spacing wells that accounts for differences in profiles, BHA configuration type, and spud sequence, ensuring safe and rational drilling operations [3].

3. It has been shown that applying machine learning algorithms provides more accurate prediction of optimal trajectories compared to traditional geometric approaches [1, 34].

4. Experimental studies established that modifying drilling fluids with hydroxyethyl cellulose improves wellbore cleaning efficiency by enhancing cuttings transport, and revealed the dominant influence of fluid composition and salinity on salt-formation washout (cavernization)—crucial for selecting optimal circulation systems and preventing drilling complications [17, 28].

5. Targeted chemical treatment achieved strengthening of carbonate rocks, increasing hardness and reducing permeability, thereby providing a basis for improving wellbore stability in complex geotechnical conditions.

6. The technology for constructing constant-diameter wells using a dual-action expander has been substantiated, delivering significant reductions in drilling time and cost [12, 18, 33].

7. The operability of swelling packers in media of various salinities has been experimentally confirmed, and the laws governing salinity effects on swelling rate and extent have been established [26, 32].

8. The choice of the Ogden-2 hyperelastic model has been justified for the computational description of packer sealing elements, ensuring reliable predictions of their sealing capacity.

9. Modeling and analysis confirmed differences in seal contact pressures depending on material and operating conditions, enabling rational selection of their design [32].

10. A new design of a universal preventer with a hydroturbine grinding unit has been developed, increasing seal durability and reducing nonproductive downtime [31, 36].

Collectively, the results form a scientifically grounded system of solutions aimed at improving the efficiency, reliability, and environmental safety of drilling and operating cluster deviated and horizontal wells.

**The main content of the dissertation is reflected in the following works:**

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