ISSN: 2663-8770, E-ISSN: 2733-2055, DOI: 10.36962/ETM

EQUIPMENT TECHNOLOGIES MATERIALS

AVADANLIQLAR, TEXNOLOGİYALAR, MATERİALLAR

VOLUME 33 (08) ISSUE 02 2026

CİLD 33 (08) BURAXILIŞ 02 2026









http://emtasoiu.com/index.php/en/archives

http://bsj.esif.net/index.php/etm

Platform & workflow by OJS/PKP

The beautiful thing about learning is nobody can take it away from you—B. B. King

ISSN: 2663-8770, E-ISSN: 2733-2055, DOI: 10.36962/ETM

EQUİPMENT TECHNOLOGİES MATERİALS

AVADANLIQLAR, TEXNOLOGİYALAR, MATERİALLAR

VOLUME 33 (08) ISSUE 02 2026

CİLD 33 (08) BURAXILIŞ 02 2026

CROSSREF

FREESIA ISDSJ

DISSEMINATION SCORES 2025 – 4.77

QUALITY FACTOR 2025 – 1.3

OAJIF – 1.5 (2023)

AZERBAIJAN BAKU 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

Publisher Management Board Member: Ibrahim Habibov.
Publisher Technical & Reviewer Team Member: Zohra Garayeva.

Nəşriyyatın İdarə Heyətinin Üzvü: İbrahim Həbibov.
Nəşriyyatın Texniki və Resenzent Qrupun Üzvü: Zöhrə Qarayeva.

©Publisher: Azerbaijan State Oil and Industry University. I/C 1400196861 (Azerbaijan).
Rector: Rufat Azizov. Assistant professor.
Registered address: 20, Azadlig pr., Baku, Azerbaijan, AZ1010.
©Editorial office: 20, Azadlig pr., Baku, Azerbaijan, AZ1010.
©Typography: Azerbaijan State Oil and Industry University İ/C 1400196861 (Azerbaijan).
Registered address: 20, Azadlig pr., Baku, Azerbaijan, AZ 1010.

©Nəşriyyat: Azərbaycan Dövlət Neft və Sənaye Universiteti. VÖEN 1400196861 (Azərbaycan).
Rektor: Rüfət Əzizov. Dosent.
Qeydiyyat ünvanı: Azadliq prospekti, 20. Bakı Azərbaycan, AZ1010.
©Redaksiya: Azadliq prospekti, 20. Bakı Azərbaycan, AZ1010.
©Mətbəə: Azərbaycan Dövlət Neft və Sənaye Universiteti VÖEN 1400196861 (Azərbaycan).
Qeydiyyat Ünvanı: Azadliq prospekti, 20. Bakı Azərbaycan, AZ1010.

©Publisher: ICRET. MTÜ (Estonia, Tallinn), R/C 80550594.
Director and Founder: Seyfulla İsayev (Azerbaijan).
Deputy and Founder: Namig Isazade. PhD in Business Administration. (Azerbaijan).
©Editorial office / Redaksiya: Harju maakond, Tallinn, Kesklinna linnaosa, Narva mnt 5, 10117
Telephones / Telefonlar:; +994 55 241 70 12 (Whatsapp); +994 55 280 70 12 +994 51 864 88 94.
Website/Veb səhifə: https://bsj.fisdd.org/; https://bsj.fisdd.org/index.php/etm
E-mail: sc.mediagroup2017@gmail.com
©Nəşriyyat: MTÜ Beynəlxalq Tədqiqat, Təhsil & Təlim Mərkəzi. Q/N 80550594.
Direktor və Təsisçi: Seyfulla İsayev (Azərbaycan).
Direktorun müavini və Təsisçi: Namiq Isazadə. PhD. Biznesin İdarə Olunması. (Azərbaycan).

ISSN: 2663-8770, E-ISSN: 2733-2055, UDC: 62 (051) (0.034)
EQUIPMENT TECHNOLOGIES MATERIALS

Accepted for publication in this edition 10.03.2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

TABLE OF CONTENTS

Shukurali Kazimov, Aliheydar Dayyanov
CORROSION IN DOWNHOLE EQUIPMENT DUE TO THE INFLUENCE OF AGGRESSIVE FORMATION WATERS AND METHODS OF COMBATING IT 06-14
Zaming Ismayilov, Guloysha Tagiyeva
Determination Of Oil And Gas Prospects Of The Productive Zone Based On Modern Geophysical Surveys In Wells 15-25
Gulbala Alasgarov, Elshan Kazimov
EXPERIMENTAL STUDIES OF REINFORCED CONCRETE STRUCTURES OF HYDRAULIC ENGINEERING FACILITIES STRENGTHENED WITH COMPOSITE MATERIALS 26-33
Gulara Imanova, Eldar Hashimov
MODERN METHODS OF ANALYZING THE ECOLOGICAL SITUATION IN THE AREAS OF OPERATION OF UNDERGROUND GAS STORAGE FACILITIES 34-42
Anar Jomardov, Amid Maliyev
FACTORS AFFECTING THE DURABILITY OF CONCRETE IN AGGRESSIVE MARINE ENVIRONMENTS 43-51
Javida Damirova, Rugayya Ashurlu
DEVELOPMENT OF A CONTROL SYSTEM FOR THE EPICHLOROHYDRIN PRODUCTION UNIT 52-63
Rena Zulfugarova
APPLICATION OF ARTIFICIAL INTELLIGENCE FOR TIME SERIES FORECASTING 64-70
Natig Javadov, Ali Amirov, Vugar Ismayilov
DESIGN OF SCALABLE ARCHITECTURE FOR MONITORING AND PREDICTIVE MAINTENANCE OF METAL-CUTTING EQUIPMENT 71-79
Rafiqa Shahmarova, Nargiz Gurbanli
STUDY OF MICROSTRUCTURAL CHARACTERISTICS OF GRINDING BALLS MADE FROM HIGH-QUALITY CAST IRON IN DIFFERENT ZONES 80-90
Elmir Garagozov, Sadig Hasanli
WELL COMPLETION 91-95
Abdulagha Gurbanov, Ismail Valiyev
RESEARCH ON THE TECHNOLOGY OF OPERATING PUMP-COMPRESSOR STATIONS IN THE OPERATION OF THE "GARADAGH" AND "GALMAZ" UNDERGROUND GAS STORAGE FACILITIES 96-105
Khasay Feyzullayev, Sanan Abdulkarimov
ENHANCING RESIDUAL OIL RECOVERY EFFICIENCY THROUGH THE APPLICATION OF WATER FLOW RESTRICTION TECHNOLOGIES IN OIL WELLS 106-113
Ali Hikmat Ahmadov, Shahin Hasanov
RELIABILITY STUDY OF PISTON PUMPS IN MOBILE PUMPING UNITS 114-122
Samira Mansurova, Javid Rahimov
IMPROVEMENT OF PREVENTION AND CONTROL METHODS FOR WATER INFLUX IN PRODUCING OIL WELLS 123-131
Arif Suleymanov, Sureyya Isayeva
ANALYSIS OF PRODUCTIVITY CHANGES IN PRODUCTION WELLS DURING OPERATION ... 132-137

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

Nazim Huseynov, Humay Zahmati
IMPROVING THE CYBERSECURITY OF SCADA SYSTEMS …………………………………………….. 138-149
Alakbar Hasanov, Yunis Guliyev
INVESTIGATION OF THE OLEFIN CONVERSION PROCESS OVER HCBM AND HCBM + 3% ZN CATALYSTS ………………………………………………………………………………………. 150-157
Shukurali Kazimov, Yusif Aslanli
COMBATING SEVERE LOST CIRCULATION USING LOW-DENSITY LCM 158-166
Khasay Feyzullayev, Vusal Heydarov
FORECASTING OF GEOLOGICAL AND TECHNOLOGICAL INDICATORS OF OIL RESERVOIR DEVELOPMENT CONSIDERING THE DYNAMIC INTERACTION OF THE LAYER–WELL SYSTEM ………………………………………………………………………………………. 167-173
Samira Abbasova, Farid Karimov
ANALYSIS OF THE EFFECTIVENESS OF OIL PRODUCTION INTENSIFICATION METHODS APPLIED AT THE X OIL FIELD ………………………………………………………………………. 174-182
Azad Bagirov, Alexey Lobko
ENSURING STABLE OPERATION OF A POSITIVE DISPLACEMENT DOWNHOLE MOTOR BY REGULATING DRILLING PARAMETERS IN DEVIATED WELLS ………………………………... 183-189
Amir Mustafaev, Aqil Murtuzov
DESIGN ANALYSIS OF FISHING TOOLS USED IN WELL WORKOVERS ………………………… 190-198
Amir Mustafayev, Jahid Guliyev
IMPROVING THE EFFICIENCY OF A MILLING REAMER USED FOR CUTTING A “WINDOW” IN A SIDETRACK WELLBORE ……………………………………………………………………... 199-208
Amir Mustafayev, Islam Mahammadov
OPTIMIZATION OF WELL REMEDIATION OPERATIONS USING MILLING TOOLS ……………... 209-216
Javida Damirova, Vagif Salmanov
CONTROL OF COMPRESSOR AND PUMPING SYSTEMS IN THE OIL AND GAS INDUSTRY USING SCADA ……………………………………………………………………………………….. 217-227
Malik Abdullayev, Samira Mansurova, Fahmin Azizli
COMPOSITION AND TECHNOLOGY FOR SELECTIVE ISOLATION OF WATER FLOW IN PRODUCTION WELLS ………………………………………………………………………. 228-235
Javida Damirova, Narmin Aliyeva
AUTOMATION OF QUALITY CONTROL AND DIAGNOSTICS IN THE METAL INDUSTRY …..…. 236-247
Tahir Süleymanov, Tamerlan Mursalli
IMPROVEMENT OF THE METHODOLOGY FOR CALCULATING SPRINGS USED IN PUMP CIRCULATION SYSTEM EQUIPMENT ………………………………………………………... 248-265
Abdulagha Gurbanov, Elparast Hasanov
IMPROVING THE OPERATION OF DEVICES USED IN PREPARING GASES FOR TRANSPORTATION ……………………………………………………………………………... 266-273
Sardar Bayramov, Nihad Aliyev
OIL AND ANNULAR GAS GATHERING AND TRANSPORTATION IN WELLS OPERATED BY SUCKER ROD PUMPING SYSTEMS ……………………………………………………………... 274-281
Fahmin Azizli
POLYMER TECHNOLOGIES FOR ENHANCING OIL RECOVERY: APPLICATION OF WATER INJECTION TECHNOLOGIES BASED ON PRE-CROSSLINKED POLYACRYLAMIDE PARTICLES TO ENHANCE OIL RECOVERY ……………………………………………………………... 282-286

Elvira Huseynova, Eljan Najafli
CHARACTERISTICS OF COMBUSTION PROCESSES IN GASOLINE ENGINES ………………….. 287-296
Gulbahar Mammadova, Nəzir Fərzəliyev
CONDITIONS FOR THE ACCUMULATION OF WATER AND CONDENSATE AT THE BUTTONHOLE OF GAS AND GAS-CONDENSATE WELLS AND ITS IMPACT ON THE OPERATING REGIME 297-305
Gulbahar Mammadova, Faiq Qurbanov
DETERMINATION OF HYDROCARBON LOSSES IN THE GAS-LIQUID MIXTURE COLLECTION AND TRANSPORTATION SYSTEM 306-314
Kanan Guliyev, Zamig Mirzadzhanov
ANALYSIS OF THE DEVELOPMENT PROCESS IN MULTILAYER OIL FIELDS …………………..… 315-321
Vali Fataliyev, Bilal Gulmammadov
CREATION OF AN INNOVATIVE MODEL BY APPLYING A DOUBLE-ROW PLANETARY GEARBOX TO THE OUTPUT SHAFT OF THE PUMPJACK ………………………………...………..……..… 322-330
Veli Fataliyev, Murad Aliyev
DEVELOPMENT OF A RAM-TYPE BLOWOUT PREVENTER USED FOR SEALING THE WELLHEAD ………………………………………………………………………………………………. 331-338
Tahir Suleymanov, Aybeniz Amirova, Elnara Salimova
MATHEMATICAL MODEL OF VIBRATING SIEVE TECHNOLOGICAL PROCESSES ……………. 339-345
Veli Fataliyev, Shahin Garayev
CALCULATION OF TRIBOLOGICAL WEAR OF MANIFOLD GATE VALVES 346-356
Tahir Jabbbarov, Nərmin Najafzade
OPTIMIZATION OF THICKNESS AND STRUCTURAL–MECHANICAL PROPERTIES OF PLASMA-SPRAYED COATINGS BY LASER REMELTING …………………………………………...……..… 357-367
Bunyad Kazymov, Ilham Hasanli
METHODS AND APPROACHES FOR EXTRACTION OF RESIDUAL RESERVES FROM HETEROGENEOUS OIL FIELDS ……………………………………………………..…………..…. 368-375
Kamala Aliyeva, Fidan Akhundova
THE ROLE OF AUTOMATIC CONTROL SYSTEMS IN COKE PRODUCTION …………………….. 376-382
Nazim Mamedov, Ali Gasimov
MAIN CHARACTERISTICS OF WASTEWATER, ITS TREATMENT AND RETURN TO THE ECOSYSTEM …………………………………………………………………………..……...…. 383-391
Veli Fataliyev, Toghrul Alakbarli
SINGLE-FLOW REDUCER WITH AN INNOVATIVE PLANETARY GEAR ……………………..…… 392-402

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
06-14
Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-01
VOLUME 33 (08) ISSUE 02 2026

CORROSION IN DOWNHOLE EQUIPMENT DUE TO THE INFLUENCE OF AGGRESSIVE FORMATION WATERS AND METHODS OF COMBATING IT

Shukurali Kazimov[1], Aliheydar Dayyanov[2]
[1]Associate Professor, Department of Petroleum Engineering, Azerbaijan State Oil and Industry University. E-mail: shukurali.kazimov@asoiu.edu.az
[2]Master's student, Department of Petroleum Engineering, Azerbaijan State Oil and Industry University. E-mail: lidyyanov31@gmail.com

ABSTRACT

The article examines the influence of aggressive environments on the formation of corrosion processes in downhole equipment, and analyzes the main factors causing corrosion in these environments (highly mineralized produced water, CO_2, H_2S, low pH, sulfide-forming bacteria, and temperature changes). In particular, the intensity and kinetics of breakdowns on the surface of equipment as a result of the synergistic effect of these factors in the oil and gas production industry are studied. Special attention was paid to how factors that increase the aggressiveness of the environment behave against the background of sharp changes in pressure and temperature in the well bottom zone.

The electrochemical mechanism of corrosion in metal equipment, as well as general and local forms of damage, were evaluated based on scientific literature and industrial data.

The effectiveness of the use of inhibitors, material selection, chemical regulation, cathodic protection and complex preventive measures as methods of combating corrosion was comparatively shown. The technical and economic efficiency of each of these methods was analyzed, and optimal protection strategies were proposed for various operating conditions. It was noted that the use of chemical reagents alone is not enough, but the application of regular monitoring systems is also necessary. Studies have shown that the correct selection of corrosion control methods increases the operational reliability of wells and significantly extends the service life of equipment. As a result, this approach helps prevent accidents, reduce repair costs, ensure the continuity of the production process, and minimize environmental risks.

Keywords: The effect of produced water on metal equipment, corrosion, CO_2, H_2S, downhole equipment, inhibitor, electrochemical processes, corrosion monitoring, operational reliability.

Relevance of the Topic

During the production process in high-water-cut oil and gas wells, the operating environment for downhole equipment is aggressive in nature. Depending on the origin, depth, and geochemical characteristics of the formations, the produced water reaching the surface possesses a high degree of mineralization. In such aggressive environments, formation waters contain components such as sulfides, carbonate ions, CO_2, H_2S, chloride salts, ammonium, and organic acids. These aggressive components interact with the metal surfaces, intensifying electrochemical corrosion processes and significantly reducing the service life of the equipment. Consequently, the operational lifespan of wells decreases, metal equipment fails prematurely, unplanned repair and replacement costs increase, and economic losses occur due to production downtime and increased accident risks. Therefore, studying the mechanism of action of aggressive formation waters and managing corrosion processes is one of the primary research directions in the oil and gas industry.

Thus, the scientific investigation of the causes of corrosion in downhole equipment under constantly changing conditions, the assessment of the aggressiveness of formation waters, and the improvement of protection measures are of significant practical and theoretical importance in terms of increasing the safety, sustainability, and economic efficiency of production processes.

Purpose of the study

The aim of the research is to study the mechanism of the impact of aggressive formation waters on corrosion processes in downhole equipment and to evaluate effective technological and chemical control methods for corrosion prevention.

Discussion of the Research

The continuous operation of downhole equipment (pipes, pumps, valves, gas-oil lifting systems, etc.) in the oil field is a fundamental requirement for production safety, economic efficiency, and productivity. During the well operation process, downhole equipment comes into contact with formation water, harmful gases, and oil mixtures—representing physically, chemically, and thermodynamically aggressive environments [1]. Interaction with metals in these aggressive media leads to corrosion processes. Corrosion is one of the most complex technological challenges in the oil and gas sector. As a result of corrosion, the mechanical stability of equipment decreases, material wall thickness is reduced, and cracks of various sizes form on surfaces. This leads to serious consequences such as accidents, leaks, and production shutdowns [2]. Aggressive environments create significant complications because conditions are characterized by very high temperature, high salinity, and high partial pressure of CO_2 [3]. Under high temperature and pressure in saline environments, the presence of CO_2 can create a low-pH environment with a high degree of aggressiveness, which increases the risk of pipe leakage and catastrophic failure, leading to substantial economic losses [4]. Therefore, evaluating the risk of CO_2 corrosion in well tubing during gas production is essential. In fact, the influence of CO_2 in tubing (production tubing) is a highly complex process involving numerous chemical and electrochemical reactions. The corrosion mechanism and corrosion rate depend on many factors, such as CO_2 partial pressure, temperature, pH, and flow velocity [5].

Metodology

Corrosion control and mitigation in oil and gas engineering is not only a technical-technological issue but also a matter of economics, environment, and safety. The purpose of this research is to present the composition of aggressive formation waters, corrosion mechanisms, types of corrosion, equipment selection and protection, and control and monitoring methods within a unified system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

The aqueous phase existing in the pores of the rock where oil and gas are formed is called formation water. Formation waters depend on the geological structure of the reservoir, temperature, depth, water-oil-gas ratio, and pressure. High salinity, high concentration, and the presence of gases lead to the water becoming aggressive. Aggressive formation water refers to water containing chloride salts (NaCl, $CaCl_2$, $MgCl_2$, etc.), CO_2, H_2S, O_2, organic acids, and other components.
Chloride salts (NaCl, $CaCl_2$, $MgCl_2$, etc.) create high salinity in water. The formation of salinity leads to the breakdown of metal passivation.
Carbon dioxide (CO_2) dissolves in formation water forming carbonic acid (H_2CO_3), which decreases pH, creates an acidic environment, and may cause carbonic acid corrosion on metal surfaces.
The presence of hydrogen sulfide (H_2S) gas creates "sour service" conditions and causes hydrogen diffusion. Sour service in the oil and gas industry can cause cracking in metals. Hydrogen sulfide present in wells, pipelines, reservoirs, and production environments poses a threat to equipment. It leads to problems such as sulfide stress cracking (SSC) and hydrogen embrittlement.
Dissolved oxygen (O_2) in water increases the corrosion rate. In oxygen-containing environments, especially in flow areas, the risk of corrosion increases.
Formation waters contain organic acids, carbonic acid, acids formed as a result of bacterial activity, and organic substances. The presence of these substances increases both the rate and degree of corrosion on metal surfaces.
Consider the role of physical conditions in the corrosion process: In deep wells, temperature and pressure are high. As temperature increases, the rate of corrosion increases. As pressure increases, the solubility of certain gases (H_2S, CO_2) in water increases. As pH and acidity decrease (pH 3–5), passivation of the metal surface becomes more difficult and corrosion rate increases. As flow velocity and turbulence increase, the probability of erosion-corrosion processes rises.
Unlike onshore fields, deep offshore reservoirs have water with high salinity (200–250 g/L). Carbonate reservoirs are characterized by high CO_2 concentration. In onshore fields, the influence of H_2S predominates.
The corrosion rate depends on several factors:

$$v = f(C_{H_2S}, C_{CO_2}, T, pH, C_{Cl^-}, \text{flow rate}, v_q, O_2)$$

From the formula, it can be concluded that when the concentrations of H_2S and CO_2 and the temperature of the environment are high, pH is low, and chloride concentration is high, depending on flow conditions, that is, under severe conditions, corrosion occurs more rapidly. Figure 1 shows the dependence of corrosion rate on gas concentration.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

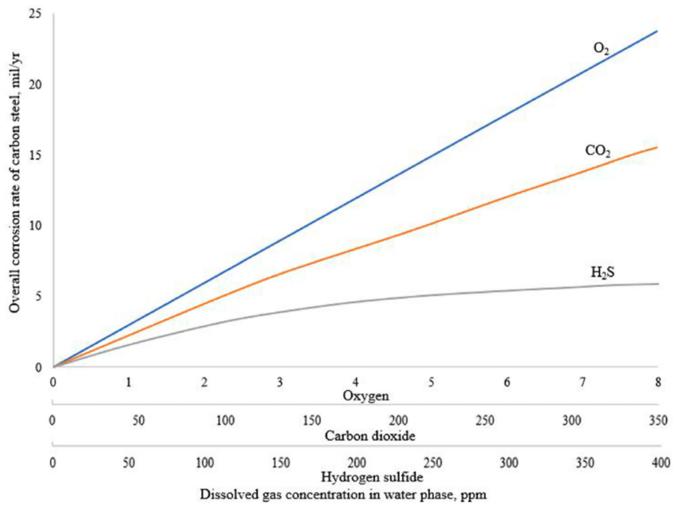


Figure 1: Dependence of corrosion rate on gas concentration.

Interaction Between Formation Water and Equipment:
Pumping systems and downhole pipes are in contact with formation waters. Over time, the pipe wall thickness decreases, which reduces the mechanical stability of the equipment. The composition of the medium-chlorides, salts, and acids-disrupts the passive layer, intensifying the corrosion process. Components of pumps and valves operate under flow, high pressure, and temperature conditions. Corrosion leads to leaks, mechanical failure, and accident risks in valves and pumping systems. The occurrence of corrosion is high in cables, joints, and metal connection parts because the stress is high in these areas and the passive layer is not fully formed. Additionally, the concentration of acid and gas in the flow area is high. On offshore platforms, salinity, high oxygen levels, acidity, and heat intensity work together to increase the corrosion rate. To prevent this, material selection and protection methods for strings require special attention. The CO_2 and H_2S environment in the oil and gas sector is shown in Figure 2. Furthermore, the combined effect of high fluid velocity and the presence of solid particles exacerbates erosion-corrosion, specifically at bends and restrictions within the tubing string. This mechanical removal of protective films continuously exposes fresh metal to the aggressive formation water, accelerating localized attack. Consequently, long-term integrity management requires not only chemical inhibition but also precise metallurgical selection based on the specific downhole conditions. This synergistic interaction ultimately necessitates a comprehensive monitoring strategy to predict and mitigate potential failures before they occur. The CO_2 and H_2S environment in the oil and gas industry is shown in Figure 2.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

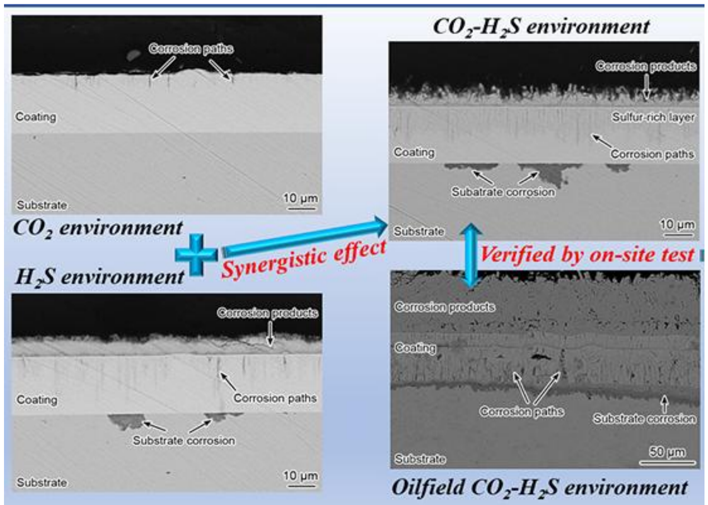


Figure 2: CO_2 and H_2S environment.

Corrosion Control Methods:

To prevent corrosion in oilfield equipment, several measures are implemented:

1. Chemical methods.
2. Physical and technological methods.
3. Operation and monitoring methods.

Chemical methods: These include the application of inhibitors, pH adjustment, oxygen removal, and bacterial control. The inhibitors used (organic amines, ammonium salts, phosphates, etc.) form a protective layer on the metal surface. The protective layer reduces the rate of cathodic and anodic reactions. Inhibitor selection is based mainly on formation water composition, temperature, pressure, and pH. Increasing the pH of formation water neutralizes acidic conditions. Reagents such as $NaOH$, NH_4OH, and $Ca(OH)_2$ are used for pH regulation. As pH increases, corrosion rate decreases. Since dissolved oxygen acts as a catalyst in corrosion processes, oxygen scavengers such as sodium sulfite (Na_2SO_3), hydrazine (N_2H_4), and diethylene glycol are used. Degassing processes are also applied to reduce oxygen. In the method of combating microbiological corrosion, biocides (glutaraldehyde, bronopol, etc.) are used. Additionally, treating formation water and removing bacteria are among the applied anti-corrosion methods. Research shows that inhibitors based on phosphate compounds are more effective. Beyond merely selecting the right inhibitor, the method of application is critical for establishing an efficient corrosion control strategy. Continuous injection via capillary strings is often preferred over batch treatment to maintain a consistent concentration of the chemical downhole, particularly in high-flow wells. Moreover, the synergy between different chemical agents must be considered; for instance, the combination of corrosion inhibitors with scale inhibitors can prevent the formation of solid deposits that otherwise promote localized corrosion cells. Regular analysis of the produced water for iron and residual inhibitor concentration is essential to assess the real-time effectiveness of the treatment program. Ultimately, balancing chemical dosage with operational costs is necessary to achieve an economically optimized protection solution. The effectiveness of an inhibitor depending on its type is shown in Figure 3. Research shows that inhibitors based on phosphate compounds are more effective.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

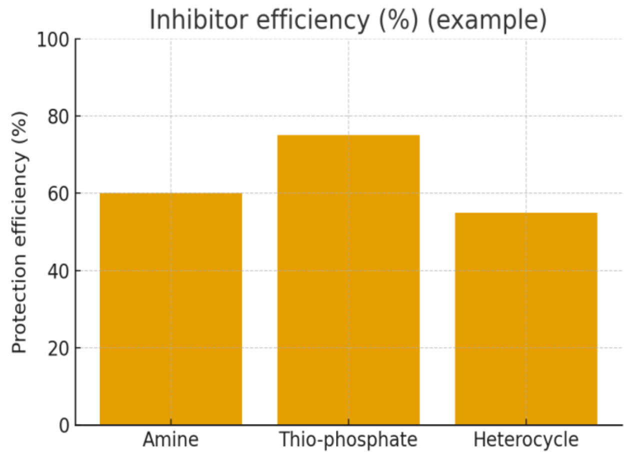


Figure 3: Effectiveness of inhibitors.

Physical and technological methods: application of coatings, cathodic protection, material selection, and treatment of formation water. Epoxy, polyurethane, zinc coatings, and composite or ceramic layers are used to protect metal equipment—pumps, valves, and pipes—from corrosion. The coatings used protect the surfaces of metals in contact with formation water from both chemical and physical impacts. Cathodic protection refers to applying an external negative potential to the metal to stop the anode reaction on the surface. This method is widely used in protecting pipelines and reservoirs. Based on the composition of the formation water, corrosion-resistant materials such as stainless steel, chrome-nickel alloys, and titanium are used for aggressive environments. For sour service environments containing H_2S, alloys complying with NACE MR0103/ISO 17945 standards are recommended. Separating carbon dioxide (CO_2) and hydrogen sulfide (H_2S) from formation waters and reducing salt content decreases aggressiveness. For this purpose, degassers are used for gas separation, and filtration systems are used for water purification. Optimizing the flow rate reduces the probability of corrosion in the pump-tubing system.

Operation and monitoring methods include measuring the corrosion rate, adjusting inhibitor dosages, and control systems. Sensors are placed to regulate the corrosion rate on the metal surface, and wall thickness is measured using ultrasonic methods. Monitoring of formation water and oil-gas flow parameters and analysis of the corrosion process are conducted to regulate inhibitor consumption, which helps in optimizing inhibitor use. Furthermore, inhibitor consumption is regulated using PLC and SCADA systems.

Conclusion

Corrosion resulting from the influence of aggressive formation waters leads to several problems: equipment failure, accidents and leaks within the well and pump-tubing systems, increased operating costs, and other issues. High amounts of CO_2 and H_2S in aggressive formation waters, low pH values, and high temperatures increase the corrosion rate. The summarized results of the analysis are as follows:

1.Corrosion rate depends on formation water composition and environmental aggressiveness. High CO_2 and H_2S concentrations significantly increase corrosion rate.

2.Low pH (acidic environment) and high temperature accelerate the corrosion process. Increasing temperature enhances ion exchange, electrode processes, and the aggressiveness of the medium. Increased aggressiveness reduces the effectiveness of the protective layer on the metal surface.
3.The complex application of methods for preventing or mitigating corrosion is more effective. The simultaneous application of protective layer selection, inhibitor use, reduction of salinity in formation water, degassing, water treatment, and cathodic protection will yield more effective results.
4.The correct selection of inhibitors used against corrosion plays a special role. Inhibitors containing amines, phosphates, and ammonium compounds show effective results against carbon dioxide and hydrogen sulfide corrosion.
5. Optimizing the material of downhole metal equipment by manufacturing them from corrosion-resistant chrome and nickel alloys increases the efficiency of downhole equipment usage and reduces operating costs.

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Corrosion Control in the Oil and Gas İndustry, Ben Cotton, Maarten Griffiths, Elsevier, 2012.
2. Oil and Gas Corrosion Prevention, James G.Speight, Elsevier, 2014.
3. X.D.Lan, X.X.Lü, Y.M.Zhu, H.F.Yu,J.Nat.Gas.Sci.Eng:22,633, 2015.
4. D.Sandana, M.Hadden, J.Race, E.Charles,J.Pipeline Eng.11,229, 2012.
5. Y.Liu, L.N. Xu, M.X.Lu, Y.Meng, J.Y.Zhu, L.Zhang, Appl.Surf.Sci.314,768, 2014.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

6. Corrosion Protection for the Oil and Gas Industry: Pipelines, Subsea Equipment and Structures, Mavis Sika Okyere, CRC Press,2019.
7. Trends in oil and Gas Corrosion Research and Technologies, Elsevier,2018.
8. Metallurgy and Corrosion Control in Oil and Gas Production, D.J.Klein, Wiley,2010.
9. Ali Emadi, D.H. Jeong. Corrosion in Oil and gas production. Mechanisms and Prevention.Springer,2020.
10. Mammadov, R. A., Lay sularinin kimyevi terkibi ve korroziya proseslerine tesiri, ADNSU Elmi Xeberler, 2023.
11. Huseynov F.E., Kazimov Sh.P. Karbohidrogen yataqlarinin lay sulari ve islenmenin texniki-iqtisadi gostericileri: NQETLI-nin nesriyyati. Baki 2010. 212 seh.

AQRESSİV LAY SULARININ TƏSİRİNDƏN QUYUDAXİLİ AVADANLIQDA KORROZİYANIN BAŞ VERMƏSİ VƏ ONUNLA MÜBARİZƏ ÜSULLARI

Şükürəli Kazımov[1], Əliheydər Dəyyanov[2]
[1]Azərbaycan Dövlət Neft və Sənaye Universiteti,”Neft-qaz mühəndisliyi”kafedrasının dosenti.
E-mail: shukurali.kazimov@asoiu.edu.az
[2]Azərbaycan Dövlət Neft və Sənaye Universiteti,”Neft-qaz mühəndisliyi”kafedrasının magistrantı.
E-mail: lidyyanov31@gmail.com

XÜLASƏ

Məqalədə aqressiv mühitin quyudaxili avadanlıqlarda korroziya proseslərinin formalaşmasına təsiri araşdırılmış, bu mühitlərdə korroziyaya səbəb olan əsas amillər (yüksək dərəcədə minerallaşmış lay suyu, CO_2, H_2S, aşağı pH, sulfid əmələ gətirən bakteriyalar və temperatur dəyişmələri) təhlil edilmişdir. Xüsusilə, neft və qaz hasilatı sənayesində bu amillərin sinergetik təsiri nəticəsində avadanlıqların səthində yaranan dağılmaların intensivliyi və kinetikası öyrənilmişdir. Mühitin aqressivliyini artıran faktorların quyu dibi zonada təzyiq və temperaturun kəskin dəyişməsi fonunda necə davrandığına xüsusi diqqət yetirilmişdir.
Metal avadanlıqda baş verən korroziyanın elektrokimyəvi mexanizmi, həmçinin ümumi və lokal zədələnmə formaları elmi ədəbiyyat və sənaye məlumatları əsasında qiymətləndirilmişdir.
Korroziyaya qarşı mübarizə üsulları kimi inhibitorların tətbiqi, material seçimi, kimyəvi tənzimləmə, katod mühafizəsi və kompleks profilaktik tədbirlərin effektivliyi müqayisəli şəkildə göstərilmişdir. Bu metodların hər birinin texniki-iqtisadi səmərəliliyi təhlil edilərək, müxtəlif istismar şəraiti üçün optimal mühafizə strategiyaları təklif olunmuşdur. Qeyd olunmuşdur ki, sadəcə kimyəvi reagentlərin istifadəsi kifayət etməyib, həm də mütəmadi monitorinq sistemlərinin tətbiqi zəruridir.
Aparılan tədqiqatlar göstərir ki, korroziya nəzarət metodlarının düzgün seçilməsi quyuların istismar etibarlılığını artırır və avadanlığın xidmət müddətini əhəmiyyətli dərəcədə uzadır. Nəticə etibarilə, bu yanaşma qəzaların qarşısının alınmasına, təmir xərclərinin azaldılmasına, hasilat prosesinin fasiləsizliyinin təmin olunmasına və ekoloji risklərin minimuma endirilməsinə xidmət edir.

Açar sözlər: lay sularının metal avadanlığa təsiri, korroziya, CO_2, H_2S, quyudaxili avadanlıq, inhibitor, elektrokimyəvi proseslər, korroziya monitorinqi, istismar etibarlılığı.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

КОРРОЗИЯ СКВАЖИННОГО ОБОРУДОВАНИЯ, ВЫЗВАННАЯ ВОЗДЕЙСТВИЕМ АГРЕССИВНЫХ ПЛАСТОВЫХ ВОД, И МЕТОДЫ БОРЬБЫ С НЕЙ

Шукюрали Кязимов[1], Алигейдар Дайянов[2]
[1]Доцент кафедры «Нефтегазовое дело», Азербайджанский Государственный Университет Нефти и Промышленности. E-mail: shukurali.kazimov@asoiu.edu.az
[2]Магистратура кафедры «Нефтегазовое дело», Азербайджанский Государственный Университет Нефти и Промышленности. E-mail: lidyyanov31@gmail.com

РЕЗЮМЕ

В статье рассматривается влияние агрессивных сред на формирование коррозионных процессов в скважинном оборудовании и анализируются основные факторы, вызывающие коррозию в этих средах (высокоминерализованная попутная вода, CO_2, H_2S, низкий pH, сульфидообразующие бактерии и изменения температуры). В частности, изучаются интенсивность и кинетика разрушений на поверхности оборудования в результате синергетического воздействия этих факторов в нефтегазодобывающей промышленности. Особое внимание было уделено поведению факторов, повышающих агрессивность окружающей среды, на фоне резких изменений давления и температуры в призабойной зоне скважины. На основе научной литературы и промышленных данных была проведена оценка электрохимического механизма коррозии металлического оборудования, а также общих и локальных форм повреждений.

Была сравнительно показана эффективность применения ингибиторов, подбора материалов, химического регулирования, катодной защиты и комплексных профилактических мер как методов борьбы с коррозией. Проанализирована технико-экономическая эффективность каждого из этих методов, предложены оптимальные стратегии защиты для различных условий эксплуатации. Отмечено, что использования одних только химических реагентов недостаточно, необходимо также применение систем регулярного мониторинга. Исследования показали, что правильный выбор методов борьбы с коррозией повышает эксплуатационную надежность скважин и значительно продлевает срок службы оборудования. В результате такой подход помогает предотвращать аварии, снижать затраты на ремонт, обеспечивать непрерывность производственного процесса и минимизировать экологические риски.

Ключевые слова: Влияние сточных вод на металлическое оборудование, коррозия, CO_2, H_2S, скважинное оборудование, ингибиторы, электрохимические процессы, мониторинг коррозии, эксплуатационная надежность.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

15-25

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-02

DETERMINATION OF OIL AND GAS PROSPECTS OF THE PRODUCTIVE ZONE BASED ON MODERN GEOPHYSICAL SURVEYS IN WELLS

Zaming Ismayilov[1], Guloysha Tagiyeva[2]
[1]Lecturer at the Department of Petroleum Engineering, Azerbaijan State Oil and Industry University.
E-mail: zaminq.ismayilov@socar.az
[2]Master's student, Department of Petroleum Engineering, Azerbaijan State Oil and Industry University.
E-mail: tagiyevaguloys@gmail.com

ABSTRACT

Advanced geophysical well logging is an essential tool for identifying, evaluating, and planning the development of oil and gas reservoirs. Data collected from boreholes allow for accurate determination of critical petrophysical properties, such as porosity, lithology, bulk density, and hydrocarbon saturation, which are crucial for both resource assessment and production optimization.

This paper presents a comprehensive review of state-of-the-art downhole geophysical methods, including Nuclear Magnetic Resonance (NMR), gamma–gamma density, neutron, acoustic, and electromagnetic induction logging. For each technique, the underlying principles, measurable geological and engineering parameters, applications in hydrocarbon prospectivity, and practical interpretation examples are thoroughly examined.

NMR logging, in particular, provides reliable insights into the distribution of water, oil, and gas by analyzing the relaxation characteristics of fluids within the pore network, thereby complementing conventional methods in evaluating pore structure and hydrocarbon saturation. The integrated interpretation of density, neutron, acoustic, and electromagnetic induction logs enhances reservoir modeling accuracy and enables dependable assessment of hydrocarbon potential, even in low-porosity and geologically complex systems. The efficacy of these techniques is demonstrated through statistical evaluations, interpretative plots, and case studies from real well data, supporting the development of precise petrophysical models across structural, lithological, and dynamic parameters and facilitating optimized hydrocarbon exploration.

Keywords: geophysical well logging, hydrocarbon prospectivity, Nuclear Magnetic Resonance (NMR), gamma–gamma density, neutron logging, acoustic logging, electromagnetic induction logging.

Introduction

Geophysical investigations play a pivotal role in the detection, evaluation, and development of oil and gas reservoirs. In modern petroleum engineering, the increasing geological complexity of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

reservoirs, heterogeneity of rock formations, and heightened production risks have necessitated a shift from conventional geophysical techniques to advanced, high-resolution downhole measurement methods. While traditional geophysical approaches have long served as primary sources of reservoir information, they sometimes fail to fully capture key characteristics such as true reservoir porosity, the presence of microfractures, dynamic processes affecting production, and the distribution of fluid phases.

Over the past decades, advanced logging methods—including Nuclear Magnetic Resonance (NMR), pulsed neutron, and sigma logging—have been increasingly adopted to address these limitations. The main advantage of modern downhole geophysical methods lies in their ability to evaluate not only the static properties of reservoir layers but also their dynamic behavior. For instance, NMR logs can differentiate between bound and free fluid volumes and provide detailed micro- and macroporosity analysis. Integrating these data enables a more reliable and scientifically robust assessment of hydrocarbon potential.

The primary objective of this paper is to systematically analyze contemporary geophysical techniques applied in wells, elucidate their physical principles and areas of application, and demonstrate their role in hydrocarbon prospectivity evaluation. Drawing upon international scientific literature, technical reports from global oil and gas companies, and modern interpretation approaches, this study comprehensively examines the significance of well logging within the context of petroleum engineering.

Discussion of the study

Nuclear Magnetic Resonance (NMR)

Nuclear Magnetic Resonance (NMR) logging enables precise characterization of fluid distributions—water, oil, and gas—within the reservoir by measuring the relaxation behavior of the pore system (Figure 1).

Figure 1: NMR Logging.

NMR logging provides the capability to directly measure both porosity and the composition of fluid phases within a formation. The tools record the resonance relaxation times (T_2 and T_1) of hydrogen nuclei in the pore fluids under the influence of a magnetic field generated in the borehole. Based on these measurements, information regarding pore size and fluid type can be obtained: short T_2 relaxation times are associated with microporosity and heavy oil phases,

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

whereas long T_1 relaxation times correspond to larger pores, light oil, and gas. Consequently, NMR logging allows for the calculation of total porosity, free fluid volume, and bound fluid fraction [1,2,8].

In practice, the shape of the NMR T_2 distribution curve provides insights into the hydrophobicity and hydrodynamic behavior of the reservoir [3,4,9]. For example, T_2 distributions derived from NMR measurements, as shown in Figure 2, clearly illustrate the resolvable relaxation times of oil in various pore-size windows (RÖPS) [5]. In low-resistivity zones, NMR data can be used to identify production-specific intervals and the distribution of free fluids [1,2]. An example of an NMR log is presented in Figure 3.

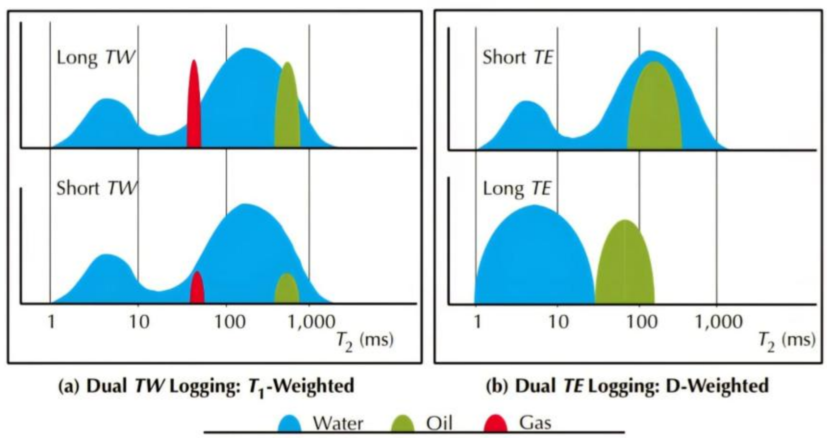


Figure 2: T_2 relaxation time distribution in NMR measurements.

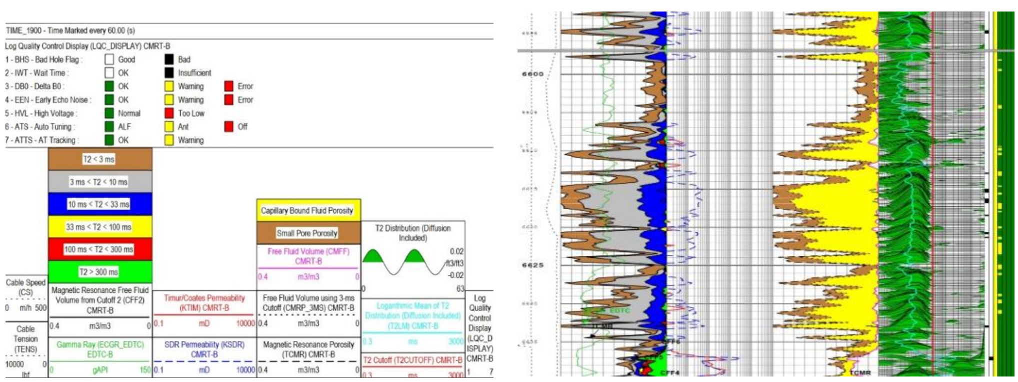


Figure 3: Example of NMR logging.

NMR technology, particularly the analysis of T_1 and T_2 relaxation times, is distinguished by its ability to directly reflect the physical properties of fluids (water, oil, and gas) within the pore space of the reservoir [3,4]. Variations in T_2 distributions across different measurement windows (TW, TE, and RÖPS) provide valuable information on fluid viscosity, diffusion behavior, and fluid–pore interactions [2,5]. This enables reliable discrimination of dispersed gas or mobile oil phases even in low-porosity formations [5].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

NMR interpretation based on Dual TW logging (T_1-weighted) and Dual TE logging (diffusion-weighted, D-weighted) measurement mechanisms allows clear differentiation between water and oil, viscous and mobile oil, and gas and liquid phases [2,7]. Since these methods are independent of formation water salinity, they deliver more robust results than conventional resistivity-based analyses under conditions of mixed or unknown salinity [5].

In particular, modern logging-while-drilling technologies such as MagniSphere™ LWD NMR provide real-time T_2 distributions, facilitating prompt geosteering and operational decision-making. These data contribute significantly to the timely identification of productive zones, exclusion of non-prospective intervals, and optimization of wellbore trajectory [7].

Overall, interpretation of NMR logs based on T_1 and T_2 relaxation mechanisms reduces uncertainty in hydrocarbon prospectivity assessment, enables more accurate reserve estimation, minimizes production risks, and serves as a key scientific and technical tool in modern petroleum engineering [3,4].

Electromagnetic Induction Well Logging

Electromagnetic induction (EMI)–based well logging is a wireline geophysical measurement technique used to detect variations in the integrated electrical conductivity of formations adjacent to the borehole. Unlike resistivity logging and other direct current (DC) methods, EMI measurements do not require direct electrical contact with the formation through conductive drilling mud or borehole fluids. Owing to the non-invasive nature of the electromagnetic induction mechanism, EMI logging can be safely applied in almost all well constructions, except in steel-cased wells.

The electrical conductivity of a rock, and its inverse property—resistivity—depend on lithology, mineral composition, porosity, permeability, fluid saturation, and the concentration of dissolved ions in formation waters. EMI logging evaluates the apparent bulk electrical conductivity (σ_a) of the rock–fluid system, which is used to analyze relative changes in lithology and pore-fluid electrical properties. By employing multiple induction coils of different spacings, EMI measurements are performed at various radial distances from the borehole, yielding depth-continuous logs that reflect the vertical distribution of apparent conductivity.

In the EMI system, an alternating current (AC) applied to the transmitter coil generates a time-varying magnetic field around the wellbore. According to Faraday's law of electromagnetic induction, this field induces an electromotive force in nearby conductive formations, producing eddy currents. These currents generate a secondary magnetic field, which in turn induces a voltage in the receiver coil. The measured voltage is proportional to the electrical conductivity of the formation.

Because a basic EMI tool with one transmitter and one receiver coil senses the combined response of all materials within the radius of investigation (ROI), the recorded values may differ from the true formation conductivity. Coil spacing strongly affects both vertical resolution and depth of investigation. Focused systems, such as normal-EMI and dual-EMI tools, reduce the influence of the invaded zone. Dual-induction EMI instruments measure apparent conductivity in both "medium" and "deep" ROIs, optimizing resolution and investigation depth, and therefore represent the most widely used EMI logging systems in practice [10].

Gamma-Gamma Density (GGD) Well Logging

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Gamma–gamma density (GGD) well logging is an active nuclear geophysical method used to determine the bulk density of rock formations intersected by a borehole. The technique is based on measuring the interaction between gamma rays emitted from a controlled radioactive source within the tool and the surrounding subsurface materials. Unlike passive gamma-ray methods, which record only natural radioactivity, GGD logging involves active irradiation and detection of the scattered gamma photons.

GGD probes are sensitive to variations in electron density, which in most subsurface media is directly proportional to bulk formation density. The measured bulk density, combined with grain and fluid densities, enables the calculation of formation porosity. Consequently, GGD logs are widely applied to assess vertical variations in porosity and to interpret lithology and pore-fluid composition.

Gamma radiation is one of the three types of radiation produced during radioactive decay and is characterized by a поток of high-energy photons that exhibit both wave- and particle-like behavior. In gamma–gamma density tools, focused sources such as Cobalt-60 or Cesium-137 emit high-energy gamma photons into the formation. As these photons propagate through the subsurface, they undergo several interaction processes, including photoelectric absorption, pair production, and Compton scattering. Among these, Compton scattering is the dominant mechanism in density logging, causing photons to lose energy and be redirected back toward the tool, where they can be detected.

GGD instruments employ scintillation detectors, typically made of sodium iodide (NaI) or cesium iodide (CsI) crystals. When gamma photons strike the crystal, they produce ionization and generate light pulses. The number and rate of these pulses are recorded and used to determine formation density. The detector is shielded to preferentially register scattered photons and to minimize the influence of direct photons from the source.

In free space, gamma photons traveling directly from the source to the detector produce the highest count rate. As electron concentration in the formation increases, the number of scattered photons also increases. Therefore, the gamma count rate is inversely related to electron density, while electron density is directly proportional to the bulk mass density of the rock. As a result, gamma counts can be calibrated to obtain bulk density (ρ_b), which forms the basis of data

interpretation.

For porous formations, bulk density is expressed as:

$$\rho_b = \phi \rho_f + (1-\phi)\, \rho_{ma}$$

where ρ_b is bulk density, φ is porosity, ρ_f is fluid density, and ρ_{ma} is matrix density.

If certain material properties are known, porosity can be calculated directly. In near-surface studies, fluid density is often assumed to be 1 g/cm³ (freshwater). If fluid density is unknown, matrix density can be determined using GGD data in combination with neutron or sonic logs. In practice, laboratory-measured standard matrix density values for sandstone, limestone, and dolomite are frequently applied.

The GGD method has been widely used in geophysical investigations and finds application in the following areas:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

•Calculation of porosity as a function of depth
•Differentiation and correlation of lithology and stratigraphy
•Evaluation of gravel pack and drilling-mud distribution
•Interpretation of surface gravity and seismic data
• Assessment of matrix conditions [11]

Neutron Well Logging

Neutron logging is an active-source geophysical method that measures the response of subsurface formations to neutron radiation emitted from a radioactive source. Fast neutrons (approximately 4 MeV) generated by americium–beryllium or plutonium–beryllium sources within the tool penetrate the formation and undergo elastic and inelastic collisions with atomic nuclei. Through these interactions, the neutrons lose energy and pass through epithermal (0.1–100 eV) and thermal (~0.025 eV) energy ranges.

In elastic collisions, neutron energy loss depends on the mass of the target nucleus and is greatest in collisions with hydrogen nuclei. Therefore, the rate of neutron slowing is directly related to the hydrogen content of the formation, making neutron logging primarily a porosity-evaluation technique.

Thermal neutrons are captured by heavier nuclei, producing capture gamma photons. Although these photons can be recorded in neutron–gamma logging, additional absorption effects from elements such as chlorine and boron prevent a direct one-to-one relationship between gamma counts and hydrogen content. For this reason, neutron–gamma methods are considered outdated in modern practice and have largely been replaced by neutron–neutron tools that measure thermal and/or epithermal neutrons. Epithermal neutron measurements, in particular, are less sensitive to external effects and more directly reflect hydrogen concentration.

In formations with high hydrogen and chlorine content, neutrons slow down more rapidly and travel shorter distances from the source. Consequently, high neutron count rates correspond to low hydrogen content. Assuming that all hydrogen resides in pore fluids, neutron logs are used to estimate porosity in saturated zones and volumetric water content in unsaturated zones.

Neutron logging adds substantial value to geophysical investigations and is applied in the following areas:

• Determination of oil–water contact
• Identification of gas contacts
• Structural interpretation
• Horizon identification
• Delineation of porous formation intervals
• Definition of geological layer boundaries [12].

Acoustic Well Logging

Acoustic well logging is a primary geophysical method employed to investigate the seismic and physical properties of formations surrounding the borehole. This technique allows for the analysis of seismic wave propagation within rock layers, enabling the evaluation of reservoir characteristics based on the measured data. An example of an acoustic well log is presented in Figure 4.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

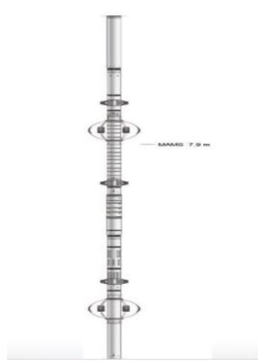


Figure 4: Acoustic well logging.

Acoustic well logging measurements are typically conducted in three primary directions:

1. Analysis of seismic wave propagation characteristics (based on compressional, acoustic, waveform, and full-waveform data)
2. Evaluation of cementing quality and cement–casing bonding in the borehole
3. Recording of acoustic reflections within the formation using acoustic televiewer logging

The method relies on the propagation behavior of seismic waves in geological media, providing information to determine porosity, fluid saturation, and the presence of fluid-filled or potentially conductive fractures. Acoustic logging is essential for the comprehensive assessment of reservoir petrophysical and geotechnical properties.

Acoustic logging tools utilize the energy of acoustic waves propagating through the subsurface formations. First-generation tools measured compressional (P-wave) velocity by recording the first arrival time of an acoustic pulse generated by a transducer. Modern systems are equipped with two or more receivers and additional transmitters. The placement of the transmitter in front of the receivers compensates for variations in borehole diameter. These tools record the full waveform train, enabling analysis of compressional (P), shear (S), borehole (Stoneley), and mud-wave velocities.

Acoustic logging instruments typically generate pulsed sound waves in the 10–20 kHz frequency range using piezoelectric, electrostrictive, or magnetostrictive transducers. The wave initially propagates through the borehole fluid, then travels along the formation at a critical incidence angle as head waves, and finally re-enters the borehole fluid to reach the receivers. At the receivers, piezoelectric crystals convert the pressure waves into electromagnetic signals, which are analyzed in terms of wave velocity, amplitude, and attenuation.

Wave velocity is calculated as the ratio of the distance between receivers to the difference in arrival times; in some cases, the reciprocal of velocity, known as slowness, is used to better characterize formation transmission properties. Measurements require the borehole to be fully fluid-filled, and the transmitter and receivers must be acoustically isolated. Frequencies are optimized according to borehole diameter, rock type, and investigation objectives.

Acoustic measurements can be negatively affected by variations in borehole diameter, mud pressure, and borehole wall damage. However, compensated tools and centralizers mitigate these effects. Consequently, modern acoustic logging systems enable high-precision evaluation of lithological, petrophysical, and geotechnical reservoir properties.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Prior to initiating acoustic logging, it is essential to have a clear understanding of the study objectives and the types of data required. When tool selection is aligned with the investigation goals and logging parameters are optimized for the borehole environment, noisy borehole acoustic logs can effectively support the following analyses and evaluations:

- Determination of compressional (Vp) and shear (Vs) wave velocities
- Estimation of formation porosity
- Analysis of lithology and stratigraphic features
- Assessment of geomechanical parameters and material properties
- Detection of fracture zones
- Evaluation of fracture permeability and fluid transmissivity
- Assessment of cemented interval bonding quality
- Evaluation of cement and/or formation integrity
- Correlation of borehole data with surface studies and other geophysical logs [13]

Table 1. Multiple sonic measurements of transmitted waves and applications.

Wave Components (Velocity and Amplitude)	Application
Full waveform	Determination of velocity profiles, lithology characterization, and fracture detection
	Evaluation of cement bonding
	Calibration of surface seismic data
Compressional wave velocity (Vp)	Porosity and lithology
	Evaluation of hydrocarbon reserves
	Assessment of cemented formation
Shear wave velocity (Vs)	Mechanical properties
	Detection and evaluation of fractures and faults
	Permeability Vs/Vp ratio for lithology identification and gas detection
Borehole (Stoneley) waves	Evaluation of fractures and permeability

Conclusion

Based on industrial practice, the role of modern geophysical investigation methods in evaluating hydrocarbon prospectivity has been extensively analyzed. It has been established that, although geophysical techniques can determine the physical and petrophysical properties of formations with high precision, the use of Nuclear Magnetic Resonance (NMR) logging is particularly advantageous for more accurate reservoir modeling and reliable identification of prospective zones. The ability of NMR to measure the relaxation behavior of fluid phases within the formation enables precise determination of water, oil, and gas distributions.

The application of NMR in both laboratory and field measurements provides one of the most reliable methods for assessing porosity and hydrocarbon saturation, complementing conventional logging techniques and, in some cases, overcoming their limitations. This contributes to a deeper understanding of the topological and petrophysical characteristics of hydrocarbon-bearing zones and enhances the reliability of formation parameter modeling.

While density, neutron, acoustic, and electromagnetic induction logs can be applied individually, their integrated interpretation significantly improves the accuracy of petrophysical parameters. The combined use of modern geophysical methods represents the most reliable approach for evaluating hydrocarbon prospectivity. By strategically combining these techniques, a detailed petrophysical characterization can be achieved across structural, lithological, and dynamic parameters, enabling reliable identification of hydrocarbon-bearing zones even in low-porosity and geologically complex formations.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Allen, D., Kenyon, W. E., & Kleinberg, R. L. (2000). Nuclear magnetic resonance logging. Oilfield Review, 12(1), 4–19. Schlumberger.
2. Coates, G. R., Xiao, L., & Prammer, M. G. (1999). NMR logging: Principles and applications. Houston, TX: Halliburton Energy Services.
3. Dunn, K. J., Bergman, D. J., & Latorraca, G. A. (2002). Nuclear magnetic resonance: Petrophysical and logging applications. Oxford, UK: Pergamon Press.
4. Kenyon, W. E. (1997). Petrophysical principles of applications of NMR logging. The Log Analyst, 38(2), 21–43.
5. Freedman, R., Heaton, N., Flaum, M., Hirasaki, G. J., Flaum, C., & Chen, S. (2006). In situ fluid typing and quantification with 1D and 2D NMR logging. Journal of Petroleum Science and Engineering, 53(1–2), 42–57.
6. Kleinberg, R. L., Flaum, C., Griffin, D. D., Brewer, P. G., Malby, G. E., Peltzer, E. T., & Yesinowski, J. P. (2003). Deep-sea NMR: Methane hydrate growth habit in porous media

and its relationship to hydraulic permeability. Journal of Geophysical Research, 108(B10), 2508.
7. Schlumberger. (2022). MagniSphere™ high-definition NMR logging-while-drilling service. Schlumberger Technical Brochure.
8. Schlumberger. (2021). NMR logging fundamentals. Schlumberger Oilfield Glossary & Technical Papers.
9. Vista Clara Inc. (2019). NMR logging principles and applications. Vista Clara Technical White Paper.
10. US Environmental Protection Agency (EPA). (n.d.). Borehole Electromagnetic Induction. Environmental Geophysics.
11. US Environmental Protection Agency (EPA). (n.d.). Gamma-Gamma Density Logging. Environmental Geophysics.
12. US Environmental Protection Agency (EPA). (n.d.). Neutron Borehole Logging. Environmental Geophysics.
13. US Environmental Protection Agency (EPA). (n.d.). Sonic Borehole Logging. Environmental Geophysics.

QUYULARDA MÜASİR GEOFİZİKİ TƏDQİQATLARA ƏSASƏN MƏHSULDAR ZONANIN NEFT-QAZ PRESPEKTİVLİYİNİN TƏYİNİ

Zaminq İsmayılov[1], Gülöyşə Tağıyeva [2]
[1]Azərbaycan Dövlət Neft və Sənaye Universiteti,"Neft-qaz mühəndisliyi"kafedrasının müəllimi.
E-mail: zaminq.ismayilov@socar.az
[2]Azərbaycan Dövlət Neft və Sənaye Universiteti,"Neft-qaz mühəndisliyi"kafedrasının magistrantı.
E-mail: tagiyevaguloys@gmail.com

XÜLASƏ

Müasir geofiziki quyu ölçmələri neft-qaz yataqlarının aşkar edilməsi, qiymətləndirilməsi və hasilat strategiyalarının müəyyənləşdirilməsində mühüm və əvəzolunmaz rol oynayır. Quyulardan əldə olunan məlumatlar süxurların əsas petrofiziki xassələrini – məsaməlilik, litologiya, sıxlıq və hidrokarbon doymuşluğu – yüksək dəqiqliklə təyin etməyə imkan verir. Bu məlumatlar, həmçinin neft və qaz ehtiyatlarının kəşfiyyatı və hasilat planlarının optimallaşdırılması üçün vacibdir. Məqalədə quyudaxili tətbiq olunan müasir geofiziki üsullar, o cümlədən nüvə maqnit rezonansı (NMR), qamma-qamma sıxlıq, neytron, akustik və quyu elektromaqnit induksiyası karotajları sistemli şəkildə təhlil edilir. Hər bir metodun prinsipləri, ölçdüyü geoloji və mühəndislik parametrləri, neft-qaz perspektivliyinin müəyyənləşdirilməsində tətbiqi və praktik interpretasiya nümunələri detallı şəkildə araşdırılır.
Xüsusilə NMR karotajı lay daxilində maye fazalarının relaksasiya xüsusiyyətlərini ölçməklə su, neft və qazın paylanmasını dəqiq müəyyən etməyə imkan verir və məsamə quruluşu ilə hidrokarbon doymasının qiymətləndirilməsində ənənəvi üsulları tamamlayır. Sıxlıq, neytron, akustik və elektromaqnit induksiya karotajlarının inteqrativ interpretasiyası lay parametrlərinin modelləşdirilməsinin dəqiqliyini artırır və hətta aşağı məsaməlikli, mürəkkəb çöküntü sistemlərində belə hidrokarbon perspektivlərinin etibarlı qiymətləndirilməsini təmin edir. Metodların effektivliyi statistik analizlər, izah qrafikləri və real quyu verilənlərinə əsaslanan

şəkillərlə vurğulanır. Bu yanaşma həm struktur, həm litoloji, həm də dinamik parametrlər üzrə dəqiq petrofiziki modelin yaradılmasına və hidrokarbon ehtiyatlarının optimal kəşfiyyatına imkan verir.

Açar sözlər: müasir geofiziki tədqiqatlar, neft-qaz prespektivliyi, nüvə maqnit rezonansı (NMR), qamma-qamma sıxlığı, neytron, akustik, quyu elektromaqnit induksiyası.

ОПРЕДЕЛЕНИЕ НЕФТЕГАЗОВЫХ ПЕРСПЕКТИВ ПРОДУКТИВНОЙ ЗОНЫ НА ОСНОВЕ СОВРЕМЕННЫХ ГЕОФИЗИЧЕСКИХ ИССЛЕДОВАНИЙ В СКВАЖИНАХ

Заминг Исмаилов[1], Гулойша Тагиева[2]

[1]Преподаватель кафедры нефтетехники Азербайджанского государственного нефтегазового университета E-mail: zaminq.ismayilov@socar.az

[2]Магистратура кафедры «Нефтегазовое дело», Азербайджанский государственный университет нефти и промышленности E-mail: tagiyevaguloys@gmail.com

РЕЗЮМЕ

Современные геофизические исследования скважин являются ключевым инструментом для обнаружения, оценки и планирования разработки нефтегазовых месторождений. Данные, получаемые из скважин, позволяют с высокой точностью определять фундаментальные петрофизические параметры пород — пористость, литологию, плотность и насыщенность углеводородами — что критически важно как для оценки ресурсов, так и для оптимизации добычи.

В статье систематически рассматриваются современные методы скважинной геофизики, включая ядерно-магнитный резонанс (ЯМР), гамма-гамма каротаж, нейтронное, акустическое и электромагнитное индукционное каротажирование. Для каждого метода анализируются базовые принципы, измеряемые геологические и инженерные параметры, возможности применения при оценке нефтегазового потенциала, а также практические примеры интерпретации.

Особое внимание уделено ЯМР-каротажу, позволяющему количественно оценивать распределение воды, нефти и газа в пласте на основе релаксационных характеристик жидких фаз, что дополняет традиционные методы при оценке структуры пор и насыщенности углеводородами. Интегративная интерпретация данных плотности, нейтронного, акустического и электромагнитного индукционного каротажа повышает точность моделирования пластовых параметров и обеспечивает надежную оценку нефтегазового потенциала даже в системах с низкой пористостью и сложной осадочной структурой. Эффективность методов подтверждается статистическими анализами, графическими интерпретациями и кейс-стади на основе реальных скважинных данных. Такой подход способствует созданию точных петрофизических моделей по структурным, литологическим и динамическим параметрам и оптимизации разведки углеводородных ресурсов.

Ключевые слова: скважинная геофизика, нефтегазовый потенциал, ядерно-магнитный резонанс (ЯМР), гамма-гамма каротаж, нейтронное каротажирование, акустическое каротажирование, электромагнитная индукция.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
26-33

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-03

VOLUME 33 (08) ISSUE 02 2026

EXPERIMENTAL STUDIES OF REINFORCED CONCRETE STRUCTURES OF HYDRAULIC ENGINEERING FACILITIES STRENGTHENED WITH COMPOSITE MATERIALS

Gulbala Alasgarov[1], Elshan Kazimov[2]
[1]Associate Professor, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: gulbala.alasgarov@asoiu.edu
[2]Master's Degree Student, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: elsen_kazimov_96@mail.ru

ABSTRACT

During operation (especially in long-term service), the necessity arises to strengthen the reinforced concrete structures of hydraulic engineering facilities. In recent years, in industrial and civil construction, the strengthening of reinforced concrete structures using externally bonded reinforcement systems made of composite materials (for example, carbon-based) has been applied. However, in hydraulic engineering construction, such strengthening solutions are encountered only in isolated cases. The experimental studies of reinforced concrete structures of hydraulic engineering facilities strengthened with an external reinforcement system made of carbon materials, presented in the article, were carried out to substantiate the application of external reinforcement systems made of carbon-based materials (strips and laminates) for the purpose of strengthening reinforced concrete structures of this type of facilities.
Keywords: composite materials, reinforced concrete models, carbon fiber strips, bending moment, external reinforcement system, carbon-based materials, strength, strengthening of structures.

Introduction
At present, the strengthening of industrial and civil reinforced concrete structures using external reinforcement made of composite materials is widely applied. However, in domestic practice of hydraulic engineering construction and the operation of hydraulic structures, the application of such strengthening is observed only in isolated cases. Therefore, there is a need to substantiate the application of external reinforcement systems made of carbon-based materials (strips and laminates) for the purpose of strengthening reinforced concrete structures of hydraulic engineering facilities. The reinforced concrete structures of hydraulic engineering facilities differ fundamentally from the reinforced concrete structures of industrial and civil buildings.

Methodology
Experiments on strengthening hydraulic engineering facilities using external reinforcement made of carbon materials were carried out on specially prepared beam-type hydraulic reinforced

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

concrete models. During modeling, characteristics typical of hydraulic structures—low concrete strength classes and a low reinforcement ratio (less than 1%)—were taken into account. The reinforced concrete models were strengthened using carbon fiber strips and laminates. Experimental studies were conducted under the action of bending moments in accordance with standard methodologies. As a result of the studies, the increase in strength of reinforced concrete structures due to strengthening with carbon fiber strips and laminates was determined.

The following features are characteristic of reinforced concrete structures of hydraulic engineering facilities:

– large dimensions, including cross-sectional heights exceeding 1 m;
– low concrete strength classes (B10–B25);
– low-strength classes of working reinforcement (A-II, A-III; in recent years, reinforcement of class A500 has also been applied);
– low reinforcement ratio (less than 1%);
– large diameters of reinforcing bars (up to 70 mm for A-II and up to 40 mm for A-III);
– presence of construction joints between blocks;
– specific characteristics of load effects (including hydrostatic counterpressure of water in opened joints and cracks).

Domestic and international experience in strengthening reinforced concrete structures using external reinforcement systems made of carbon-based materials [1–7] was analyzed, and it was established that the most appropriate method for strengthening reinforced concrete structures is the application of external reinforcement systems consisting of carbon fiber strips and laminates.

1. Purpose of the study

In order to experimentally substantiate the application of external reinforcement systems made of composite materials for strengthening hydraulic engineering facilities, experimental studies were carried out on the strength of reinforced concrete structures of hydraulic engineering facilities strengthened with carbon fiber strips and laminates under the action of bending moments.

2. Materials and methods of the study

To investigate the effect of bending moments, beam-type reinforced concrete models with a length of 215 cm, a height of 30 cm, and a width of 15 cm were prepared (Figure 1). In this process, two series of models with different reinforcement and concrete classes characteristic of hydraulic engineering structures were created. Models of the first series were reinforced with two reinforcing bars of 10 mm diameter, class A500C (reinforcement ratio 0.39%), and made of concrete of class B15 (Figure 1a). Models of the second series were reinforced with three reinforcing bars of 12 mm diameter, class A500C (reinforcement ratio 0.83%), and made of concrete of class B25 (Figure 1b).

Each series included the following models:

– two unstrengthened “reference” beams;
– two “reference” beams strengthened with carbon fiber strips;
– two “reference” beams strengthened with carbon fiber laminates.

Thus, a total of twelve beam-type reinforced concrete models were prepared.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

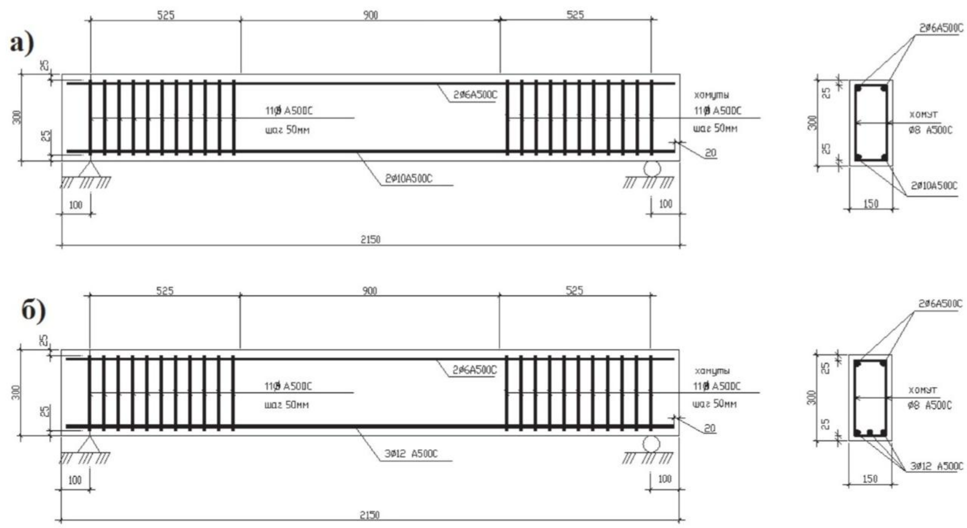


Figure 1: Structural configuration of the reinforced concrete models.

For strengthening the reinforced concrete models, carbon fiber strips of the FibArm Tape 230/300 type with a thickness of 0.128 mm and carbon fiber laminates of the FibArm Lamel 12/50 type were used. The width of the strips was taken equal to the width of the models—150 mm, while the laminates had a thickness of 1.2 mm and a width of 50 mm. The strips were bonded in two layers to the bottom tensile surface of the models. The laminates were also bonded to the bottom tensile surface of the models. In the support regions, the longitudinally arranged carbon fiber strips and laminates were additionally strengthened with anchoring wraps of the FibArm Tape 230/300 type, 300 mm in width (Figures 2 and 3).

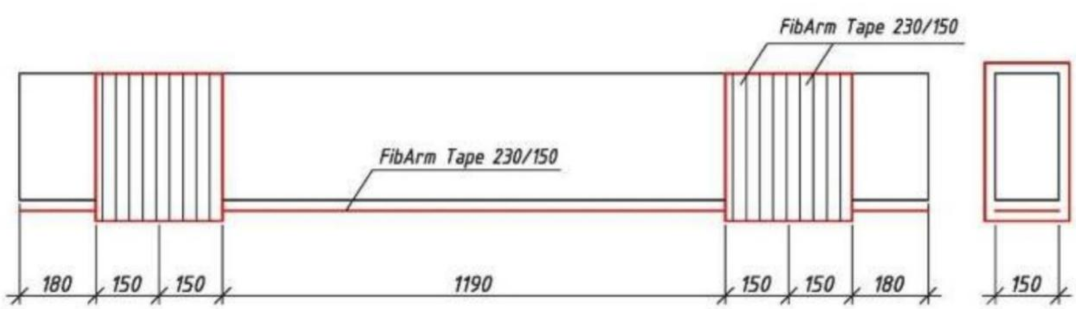


Figure 2: Scheme of strengthening reinforced concrete models with carbon fiber strips.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

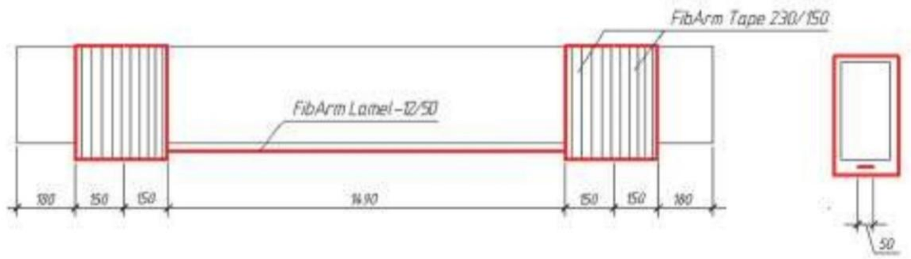


Figure 3: Scheme of strengthening reinforced concrete models with carbon fiber laminates.

In order to determine the actual compressive and tensile strength of the model concretes, as well as the modulus of deformation, standard control specimens were cast simultaneously with the models: cubes with dimensions of 100×100×100 mm; prisms with dimensions of 100×100×400 mm; and cylinders with a diameter of 150 mm and a height of 150 mm. To conduct tests under the action of bending moments, reinforced concrete models with a length of 2.15 m were placed on two supports on a special test frame. The distance between the supports was 1.95 m. One support was fixed, while the other was roller-type (movable). For the application of vertical loading, a hydraulic jack positioned at the center of the test frame was used. The load was applied symmetrically to the structure at two points via a distributing traverse, located 45 cm from the center of the frame and 52.5 cm from the supports (Figure 3). During testing of the reinforced concrete models, the test load was applied in stages, each stage amounting to 10% of the ultimate load. Upon reaching 80% of the ultimate load, loading was continued in smaller increments (5% of the ultimate load). At each stage, after applying the corresponding load, it was maintained for 15 minutes, after which the instrument readings were recorded. The experimental studies were carried out taking into account the research experience related to hydraulic concrete structures [8–13]. The results of experimental studies of reinforced concrete hydraulic structures with interblock construction joints, conducted with the participation of the author, are presented in [14].

As a result of the conducted tests, including the behavior of reinforced concrete models strengthened with carbon fiber strips and laminates under bending moments, the following results were obtained. Unstrengthened twin reinforced concrete models made of B15 concrete with a reinforcement ratio of 0.39% failed under loads of 83.0 and 88.0 kN. Twin models made of B15 concrete with a reinforcement ratio of 0.39% and strengthened with carbon fiber strips failed under loads of 159.2 and 191.0 kN. Twin models made of B15 concrete with a reinforcement ratio of 0.39% and strengthened with carbon fiber laminates failed under loads of 161.1 and 160.0 kN. Unstrengthened twin models made of B25 concrete with a reinforcement ratio of 0.83% failed under a load of 165.8 kN. Twin reinforced concrete models made of B25 concrete with a reinforcement ratio of 0.83% and strengthened with carbon fiber strips failed under loads of 232.0 and 257.0 kN. Twin models made of B25 concrete with a reinforcement ratio of 0.83% and strengthened with carbon fiber laminates failed under loads of 250.6 and 238.7 kN. The results of the conducted experimental studies are presented in the table. Results of experimental studies of reinforced concrete models strengthened with carbon fiber strips and laminates under bending moments.

Table 1. Comparison of the strengthening results of concrete specimens.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

№	Model	Strengthening, Installation of elements	Compressive strength of concrete, MPa	Ultimate load, kN	$R_e$ks, $R_h$es
	Concrete B15, reinforcement 2Ø10A500C				
1	B-İ15-1	Without strengthening	25,8	88,00	1,14
2	B-İ15-2	Without strengthening	15,9	83,00	1,09
3	B-İ15-3	Strengthening with carbon fiber strips	24,4	191,00	2,50
4	B-İ15-4	Strengthening with carbon fiber strips	24,4	159,20	2,10
5	B-İ15-5	Strengthening with carbon fiber strips	20,5	161,10	2,15
6	B-İ15-6	Strengthening with carbon fiber strips	20,5	160,00	2,13
	Concrete B25, reinforcement 3Ø12A500C				
7	B-İ25-1	Without strengthening	29,5	165,80	1,03
8	B-İ25-6	Without strengthening	36,5	165,80	1,03
9	B-İ25-4	Strengthening with carbon fiber strips	39,7	257,00	1,57
10	B-İ25-5	Strengthening with carbon fiber strips	24,3	232,00	1,42
11	B-İ25-2	Strengthening with carbon fiber strips	37,4	250,60	1,53
12	B-İ25-3	Strengthening with carbon fiber strips	37,4	238,70	1,46

Thus, as a result of strengthening with carbon fiber strips, the strength of reinforced concrete structures made of B15 concrete and reinforced with 0.39% reinforcement increased on average by 2.3 times, while the strength of structures made of B25 concrete and reinforced with 0.83% reinforcement increased by 1.5 times. As a result of strengthening with carbon fiber laminates, the strength of reinforced concrete structures made of B15 concrete and reinforced with 0.39% reinforcement increased on average by 2.14 times, and the strength of structures made of B25 concrete and reinforced with 0.83% reinforcement increased by 1.5 times. Consequently, even with a lower reinforcement ratio and a lower concrete strength class, the strengthening of reinforced concrete structures proves to be more effective, which confirms the relevance of applying this strengthening method in hydraulic engineering facilities.

Conclusions

1. Data on the strength of reinforced concrete structures of hydraulic engineering facilities, both unstrengthened and strengthened with carbon fiber strips and laminates, under the action of bending moments were obtained.
2. Based on the conducted comparison, an increase in the strength of reinforced concrete structures due to strengthening with carbon fiber strips and laminates was identified.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

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

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

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Richardson, M.G. Fundamentals of Durable Reinforced Concrete; Spon Press: London, UK, 2002.
2. Melchers, R.E.; Li, C.Q. Reinforcement corrosion initiation and activation times in concrete structures exposed to severe marine environments. Cem. Concr. Res. 2009, 39, 1068–1076.
3. Melchers, R.E.; Chaves, I.A. A comparative study of chlorides and longer-term reinforcement corrosion. Mater. Corros. 2017, 68, 613–621.
4. Wakeman, C.M.; Dockweiler, E.V.; Stover, H.E.; Whiteneck, L.L. Use of concrete in marine environments. Proc. ACI 1958, 54, 841–856.
5. Wood, C.R.J. Phoenix. In The Civil Engineer at War. Docks and Harbours: A Symposium of Papers on War-Time Engineering Problems; The Institution of Civil Engineers: London, UK, 1948; Volume 2, pp. 336–368.
6. Melchers, R.E. Long-term durability of marine reinforced concrete structures. J. Mar. Sci. Eng. 2020, 8, 290.
7. Melchers, R.E.; Howlett, C.M. Reinforcement corrosion of the Phoenix caissons after 75 years of marine exposure. Proc. Inst. Civil Eng. Marit. Eng. 2020, 174, 19–30.
8. Tuuti, K. Service life of structures with regard to corrosion of embedded steel. In Performance of Concrete in Marine Environment; ACI SP-65; American Concrete Institute: Detroit, MI, USA, 1984; pp. 223–236.

9. Clear, K.C. Performance after 830 daily salt applications, FHWA-RD-76-70. In Time-to-Corrosion for Reinforcing Steel in Concrete Slabs; Federal Highway Administration: Washington, DC, USA, 1976; Volume 3, p. 64.
10. Angst, U.M.; Elsener, B.; Larsen, C.K.; Vennesland, O. Critical chloride content in reinforced concrete—A review. Cem. Concr. Res. 2009, 39, 1122–1138.
11. Melchers, R.E.; Li, C.Q. Phenomenological modelling of corrosion loss of steel reinforcement in marine environments. ACI Mater. J. 2006, 103, 25–32.
12. Melchers, R.E. Experienced-based physico-chemical models for long-term reinforcement corrosion. Corros. Mater. Degrad. 2021, 2, 100–119.
13. Hadley, H.M. Concrete in seawater: A revised viewpoint needed. Proc. ASCE 1941, 107, 345–358.
14. Foley, T.R. The role of the chloride ion in iron corrosion. Corrosion 1970, 26, 58–70.
15. Butler, G.; Stretton, P.; Beynon, J. Initiation and growth of pits on high-purity iron and its alloys with chromium and copper in neutral chloride solutions. Br. Corros. J. 1972, 7, 168–173.
16. Serdyuk A.I., Chernyavskiy V.L. Opyt usileniya stroitel'nykh konstruktsiy kompozitsionnymi materialami pri rekonstruktsii Baksanskoy GES // Gidrotekhnika. 2013. № 3 (32). S. 115–117.
17. Kozyrev D.V., Simokhin A.S., Chernyavskiy V.L., Os'mak P.P. Remont uchastkov napornogo kollektora kompozitnymi materialami // Montazhnye i spetsial'nye raboty v stroitel'stve. 2009. № 9. S. 2–5.
18. Rubin O.D., Lisichkin S.E., Balagurov V.B., Aleksandrov A.V. Novaya tekhnologiya remonta GTS posredstvom armirovaniya kompozitnymi materialami // Izvestiya VNIIG. 2016. T. 280. S. 3–10.
19. Lisichkin S.E., Rubin O.D., Lyapin O.B., Nefedov A.V. Issledovaniya betonnykh i zhelezobetonnykh energeticheskikh sooruzheniy // Gidrotekhnicheskoe stroitel'stvo. 1999. № 8/9. S. 22–28.
20. Rubin O.D., Lyapin O.B., Ni V.E. Usilenie ekspluatiruemykh podpornykh sooruzheniy // Gidrotekhnicheskoe stroitel'stvo. 1989. № 12. S. 42–45.

KOMPOZİT MATERİALLARLA MÖHKƏMLƏNDİRİLMİŞ HİDROTEXNİKİ QURĞULARIN DƏMİR-BETON KONSTRUKSİYALARININ EKSPERİMENTAL TƏDQİQATLARI

Gülbala Ələsgərov[1], Elşan Kazımov[2]
[1]Dosent, "Neftin-Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: gulbala.alasgarov@asoiu.edu
[2]Magistr, "Neftin Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: elsen_kazimov_96@mail.ru

XÜLASƏ

İstismar prosesində (xüsusilə uzunmüddətli istismar zamanı) hidrotexniki qurğuların dəmir-beton konstruksiyalarının möhkəmləndirilməsi zərurəti yaranır. Son illərdə sənaye və mülki tikintidə dəmir-beton konstruksiyaların kompozit materiallardan (məsələn, karbon əsaslı) hazırlanmış

xarici bərkitmə sistemləri ilə möhkəmləndirilməsi tətbiq olunur. Lakin hidrotexniki tikintidə bu cür möhkəmləndirmə hallarına yalnız ayrı-ayrı nümunələrdə rast gəlinir.Məqalədə təqdim olunan karbon materiallardan hazırlanmış xarici armatura sistemi ilə möhkəmləndirilmiş hidrotexniki qurğuların dəmir-beton konstruksiyalarının eksperimental tədqiqatları, bu tip qurğuların dəmir-beton konstruksiyalarını möhkəmləndirmək məqsədilə karbon əsaslı materiallardan (lentlər və lamellərdən) hazırlanmış xarici armatur sistemlərinin tətbiqinin əsaslandırılması üçün aparılmışdır.
Açar sözlər: kompozit materiallar, dəmir-beton modelləri, karbon lentləri, əyilmə momenti, xarici armatur sistemi, karbon əsaslı materiallar, möhkəmlik, konstruksiyaların möhkəmləndirilməsi.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ГИДРОТЕХНИЧЕСКИХ СООРУЖЕНИЙ, УСИЛЕННЫХ КОМПОЗИТНЫМИ МАТЕРИАЛАМИ

Гюльбала Алескеров[1], Эльшан Казымов[2]
[1]Доцент, “Кафедра транспорта и хранения нефти и газа”, “Азербайджанский Государственный Университет Нефти и Промышленности”, Азербайджан. E-mail: gulbala.alasgarov@asoiu.edu
[2]Магистрант, “Кафедра транспорта и хранения нефти и газа”, “Азербайджанский Государственный Университет Нефти и Промышленности”, Азербайджан. E-mail: elsen_kazimov_96@mail.ru

РЕЗЮМЕ

В процессе эксплуатации (особенно при длительной эксплуатации) возникает необходимость усиления железобетонных конструкций гидротехнических сооружений. В последние годы в промышленном и гражданском строительстве применяется усиление железобетонных конструкций с использованием внешних систем усиления, выполненных из композиционных материалов (например, на углеродной основе). Однако в гидротехническом строительстве такие способы усиления встречаются лишь в отдельных случаях. Представленные в статье экспериментальные исследования железобетонных конструкций гидротехнических сооружений, усиленных внешней арматурной системой из углеродных материалов, проведены с целью обоснования применения внешних арматурных систем, изготовленных из углеродных материалов (лент и ламелей), для усиления железобетонных конструкций данного типа сооружений.
Ключевые слова: композитные материалы, железобетонные модели, углеродные ленты, изгибающий момент, система внешней арматуры, материалы на углеродной основе, прочность, усиление конструкций.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

34-42

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-04

MODERN METHODS OF ANALYZING THE ECOLOGICAL SITUATION IN THE AREAS OF OPERATION OF UNDERGROUND GAS STORAGE FACILITIES

Gulara Imanova[1], Eldar Hashimov[2]
[1]Associate professor, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: gulara.imanova.is@asoiu.edu.az
[2] Master's Degree Student, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: hsimoveldar8@gmail.com

ABSTRACT

Underground gas storage facilities are strategically important complex engineering facilities used for seasonal storage of natural gas resources, ensuring energy security and increasing the reliability of gas supply systems. During the injection of gas under high pressure into the deep layers of the earth's crust and its subsequent extraction for production purposes, a significant anthropogenic impact is exerted on environmental components - soil cover, groundwater and surface water horizons, atmospheric composition, as well as local biocenoses. These processes are accompanied by the risks of deformation of the earth's surface, disruption of the groundwater balance, emission of greenhouse gases and damage to ecosystems.
The presented article systematically studies and classifies modern analytical methods applied for a comprehensive assessment of the ecological situation in the areas of operation of underground gas storage facilities. The research covers geophysical monitoring technologies - recording microseisms using seismoacoustic stations, measuring variations in the gravity field with high-precision gravimeters and mapping the electrical conductivity of soil layers using electromagnetic methods.
Various systems allow for early detection of environmental changes, ensuring compliance of the operation of underground gas storage facilities with national and international safety standards, and proactive minimization of potential environmental risks. The article also discusses the principles of integration of various analysis methods, their synergistic mechanisms, advantages, and practical application areas in a scientifically and technically justified manner.
Keywords: underground gas storage, environmental monitoring, geophysical methods, satellite data, geochemical analysis, hydrogeological parameters, environmental risk, safety, environment, mathematical modeling.

Introduction

Underground gas storage facilities are strategic facilities created to meet seasonal demand for gas supply, increase the reliability of energy systems and ensure gas supply in emergency situations. The main part of underground gas storage facilities used in the world is located in depleted oil and

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

gas fields, salt structures or natural reservoirs. In Azerbaijan, the development of underground gas storage infrastructure is an important priority within the framework of the strategy for strengthening energy security.
A number of environmental risks arise in the process of operating underground gas storage facilities. During the injection of gas into soil layers under high pressure and subsequent extraction, deformations on the surface of the earth, changes in the chemical composition of groundwater horizons and methane emissions may be observed. In the event of a gas leak, there is a risk of greenhouse gases being released into the atmosphere and damaging local ecosystems. In this regard, the implementation of continuous environmental monitoring in the areas of underground gas storage facilities arises from the requirements of international standards and national legislation.
Traditional environmental control methods - laboratory analysis of soil and water samples, stationary measurement of air quality - are carried out with limited spatial coverage and low frequency. Modern technologies allow for the establishment of highly accurate, real-time, automated monitoring systems covering large areas. Geophysical sensors, satellite radars, digital modeling tools, and artificial intelligence-based forecasting methods have taken the ecological analysis process to a qualitatively new level.

Purpose
The main objective of the study is to present a systematic description of modern analytical methods for a comprehensive analysis of the ecological situation in the regions of operation of underground gas storage facilities and to formulate practical application recommendations. To achieve this goal, the following tasks have been set:
-Identification and classification of the main environmental impact factors arising during the operation of underground gas storage facilities;
-Analysis of the technical capabilities and areas of application of geophysical monitoring methods - seismoacoustic, gravimetric, electromagnetic surveys;
-Comparative assessment of methods for measuring geochemical and hydrogeological parameters;
-Investigation of methods for monitoring atmospheric emissions and analyzing greenhouse gases;
-Study of the role and effectiveness of mathematical and computer modeling tools in ecological forecasting;
-Development of the concept of a comprehensive environmental monitoring system based on the integration of various methods.

Methods
Modern methods for analyzing the ecological situation in underground gas storage areas can be grouped into several main areas. Each area is focused on measuring and assessing specific ecological parameters.
Geophysical monitoring methods.
Geophysical methods are based on recording physical processes occurring in the earth's crust - mechanical deformations, changes in density and elasticity parameters, variations in electrical conductivity. During the operation of underground gas storage facilities, the injection of gas into the reservoir under high pressure and its subsequent extraction creates dynamic stresses in the soil layers and causes vertical and horizontal displacements of the earth's surface.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Seismic methods: Microseisms - weak vibrations resulting from the propagation of elastic waves in the earth's crust indicate the deformation of rocks at the microlevel during gas storage. These vibrations can be recorded and localized through a network of passive seismic stations. An increase in seismic frequency or a change in energy release allows detecting the risk of mechanical instability of the reservoir structure at an early stage.
Gravity measurements: Measurement of variations in the gravity field reveals density anomalies associated with changes in the mass of gas in the reservoir. High-precision gravimeters - devices that can measure changes in the level of micro-gall - allow you to track seasonal changes in the volume of gas in the reservoir and identify hidden leakage zones. Electromagnetic methods: Measuring the electrical resistivity of soil and rocks allows you to track the movement and chemical composition of groundwater horizons. A decrease in soil moisture or a change in salinity because of a gas leak is reflected in the electrical conductivity.

Analysis of geochemical and hydrogeological parameters

Geochemical methods are aimed at detecting changes in the chemical composition of environmental components. During the operation of underground gas storage facilities, gas leakage, reservoir water displacement, and the introduction of anthropogenic pollutants change the chemical profiles of groundwater and surface waters, soil, and atmosphere.
Laboratory analysis of soil and water samples: Systematic samples are taken from designated points in and around the underground gas storage facilities. The concentrations of heavy metals (lead, mercury, cadmium, chromium), petroleum products, and salts are determined in soil samples. pH, mineral content, organic compounds, and dissolved gases (methane, ethane, and other hydrocarbons) are measured in water samples. Samples are usually taken at monthly or quarterly intervals.
Isotope analysis: The isotope signatures of methane and other hydrocarbon gases allow us to determine the origin of the gas. This method is especially important in identifying the source of the leak. In addition to the analysis of stable isotopes, measurements of radioisotopes determine the movement and age of groundwater flows.
Biological indicators: Changes in the composition and activity of soil microorganisms are an early indicator of contamination processes. An increase in the population of methanotrophic bacteria is considered a biological sign of gas leakage. Monitoring the spectral properties of vegetation allows for the assessment of stress conditions and ecological disturbances through phytoindication. Hydrogeological monitoring: Continuous monitoring of water level, chemical composition and temperature in groundwater horizons is carried out. Automatic water level sensors (piezometers) transmit information in real time. Sudden changes in water level indicate the effect of reservoir pressure on groundwater or leakage zones. Hydrodynamic tests determine the filtration and drainage properties of underground aquifers. Geothermal measurements establish a temperature profile in wells and determine gas movement paths through thermal anomalies.

Atmospheric emissions monitoring and greenhouse gas analysis

The emission of methane and other greenhouse gases from underground gas storage facilities into the atmosphere is a significant problem in the context of environmental and climate change. The global warming potential of methane is 28-36 times higher than that of carbon dioxide, so even

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

small leaks can have a significant environmental impact. Atmospheric monitoring systems are installed to detect, quantify and localize emissions.
Stationary measuring stations: Automatic air quality monitoring stations located in and around the underground gas storage facilities continuously measure the concentration of methane, carbon dioxide, nitrogen oxides and other gases.
When placing the measuring stations, the prevailing wind directions, topography and the location of potential emission sources are taken into account. Usually, a central station and four or more perimeter stations are placed in the main wind directions in the underground gas storage facilities. The measurement height is chosen between 2-10 meters, which reflects the gas concentrations in the surface layer. Data is transmitted to the server every minute or every 5 minutes and automatic quality control algorithms are applied.
Mobile measurement platforms: Mobile measurement systems equipped with vehicles, drones or portable devices allow for rapid scanning of the area and localization of emission sources. Portable analyzers based on Cavity Ring-Down Spectroscopy (CRDS) technology measure methane fluxes with high accuracy and speed. Drone-based systems build a vertical profile of the atmosphere at different altitudes and create a three-dimensional map of emission plumes.
Mobile monitoring campaigns are usually carried out at weekly or monthly intervals. Vehicle-based measurements collect gas concentration data synchronized with GPS coordinates and generate concentration maps on a GIS platform. If high concentration zones are detected, additional detailed studies are carried out. Drone measurements are particularly useful in inaccessible or dangerous areas. Drones fly at an altitude of 50-200 meters and automatically collect atmospheric samples or make real-time measurements.
Eddy Covariance method: This micrometeorological method is based on the direct measurement of methane and carbon dioxide fluxes released into the atmosphere by turbulent flows. The eddy covariance tower is equipped with a high-frequency (10-20 Hz) three-dimensional anemometer and a gas analyzer. The calculation of the covariance of the gas concentration and the vertical wind speed determines the emission flux per unit area (e.g., mg $CH_4/m^2/h$). This method is ideal for measuring the average emission rate over large areas.
Optical remote sensing: Systems based on Differential Absorption LIDAR or Fourier Transform Infrared Spectroscopy (FTIR) technologies allow remote measurement of gas concentrations in the atmosphere. The Differential Absorption LIDAR system sends laser pulses at two different wavelengths - one corresponding to the absorption band of methane, and the other is used as a reference. The difference in the signals reflected from the atmosphere gives the path integral of methane concentration. Open-path FTIR systems measure average gas concentrations at hundreds of meters using natural infrared sources.

Mathematical modeling and forecasting

Mathematical and computer modeling methods serve to simulate ecological processes, make predictions for various scenarios, and support the decision-making process.
Hydrodynamic models: Three-dimensional mathematical models are built to simulate the movement of gas and water in the reservoir. Based on Darcy's law and multiphase filtration equations, changes in pressure, saturation, and temperature distribution under reservoir conditions are calculated. Software packages such as ECLIPSE, CMG, and TOUGH allow modeling of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

complex geological structures. Geomechanical coupling simulates the effect of reservoir pressure changes on rock deformation.

Atmospheric dispersion models: Gaussian plume models or Lagrangian particle dispersion models are used to predict the dispersion of methane in the atmosphere in the event of a gas leak. These models take into account wind speed, direction, atmospheric stability, and topography parameters.

Risk assessment models: Probabilities for various ecological risks are calculated based on probability theory and Monte Carlo simulations. The development of accident scenarios, the definition of the impact area and the assessment of damages provide the basis for the development of risk management strategies. Cause-effect networks model the interdependencies between multiple factors.

Data assimilation: Combining observational data with mathematical models increases the accuracy of the model. The Kalman filter and its variants update model parameters and correct predictions based on real-time input data. Data assimilation is the basis for adaptive monitoring systems.

Integration of methods and complex monitoring systems

The modern approach involves the integration of various monitoring methods and their unification into a single information system. A complex ecological monitoring system includes the following components:

1. Sensor networks - automatic measuring stations located in and around the YQA measure gas concentration, methane emissions, meteorological parameters, soil moisture and other indicators in real time.
2. Geophysical and geochemical research complex - periodic and continuous geophysical measurements, sampling and laboratory analyses enrich the database. Data are stored in a single format and time-space relationships are preserved.
3. Database and GIS platform - all monitoring data are stored and visualized in a geospatial information system (GIS). Platforms such as ArcGIS, QGIS provide spatial analysis and mapping functions.
4. Analytical and forecasting modules - statistical analyses, trend analysis and forecasts are built based on the collected data. Machine learning algorithms automatically detect anomalies and generate warning signals. Programming environments such as Python and MATLAB are used for data processing and visualization.
5. Decision support system - operators and managers are provided with real-time information about the environmental situation, risk assessment and recommendations. Visual dashboards and mobile applications allow for remote monitoring. Interactive maps, graphs and an alarm system facilitate operational response.

An integrated approach ensures mutual verification of data obtained from various sources and a multi-faceted assessment of the environmental situation. For example, the deformation of the earth's surface detected by seismoacoustic data is confirmed by gravimetric measurements, and the results of geochemical analysis are confirmed by atmospheric emission data. Integration creates a synergistic effect and the limitations of each method are compensated by the others.

The security and reliability of the monitoring system are critical. Data backups are stored on various servers and cloud infrastructure. Cybersecurity measures - encryption, authentication, firewalls - protect the system from unauthorized access. Maintenance and calibration of sensors

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

are planned. Spare parts for equipment are supplied, and quick replacement is ensured in case of failure.

Conclusıons

Based on the research conducted on the analysis of the ecological situation in the areas of operation of underground gas storage facilities, the following results were obtained:

1. Geophysical monitoring methods - seismoacoustic, gravimetric and electromagnetic methods - allow for the detection of physical changes occurring in the earth's crust in real time during the operation of underground gas storage facilities and play a key role in assessing the mechanical stability of the reservoir structure.
2. Systematic analysis of geochemical and hydrogeological parameters provides the basis for tracking changes in the chemical composition of soil, water and atmosphere, identifying pollution sources and determining the dynamics of groundwater movement.
3. Atmospheric emissions monitoring systems - stationary and mobile measuring devices, Eddy Covariance and optical remote sensing technologies - allow for the quantitative determination of methane and other greenhouse gas emissions, localization of sources and assessment of environmental impact.
4. Mathematical and computer modeling tools - hydrodynamic models, atmospheric dispersion models and risk assessment algorithms - serve to simulate ecological processes, build forecasts for various scenarios and scientifically substantiate the decision-making process.
5. Integration and combination of various monitoring methods into a single information system creates a synergistic effect, allows for mutual verification of data and significantly increases the accuracy of a comprehensive assessment of the ecological situation.
6. Automation of modern ecological monitoring systems, real-time data collection and the application of artificial intelligence-based anomaly detection algorithms facilitate operational decision-making and increase the level of ecological safety.
7. In the context of the development of underground gas storage infrastructure in Azerbaijan, the study of international experience and the formation of national ecological monitoring standards adapted to local geological and hydrogeological conditions are a pressing issue and constitute one of the priority areas of future research.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Aliyev R.M., Huseynov T.N. "Geomechanical monitoring of underground gas storages and modeling of deformation processes". News of the Azerbaijan Academy of Engineering. Baku, 2022, No. 1, pp. 34-42.
2. Mustafayev G.A., Rzayev A.H. "Methods of ensuring environmental safety during the operation of gas storage facilities". Journal of Environmental Monitoring and Safety. Baku, 2023, No. 2, pp. 67-75.
3. Mammadov I.S. "Prospects and environmental aspects of underground gas storage capabilities in Azerbaijan". Scientific Works of ASOIU. Baku, 2021, No. 4, pp. 89-97.
4. Abdullayev N.K., Ismayilov F.Y. "Application of InSAR technology in monitoring oil and gas industry facilities". Space Research and Technologies. Baku, 2023, No. 3, pp. 45-53.
5. Evans DJ, Chadwick RA. "Underground gas storage: an introduction and UK perspective". Geological Society, London, Special Publications, 2020, Vol. 313, pp. 1-10.
6. Teatini P., Ferronato M., Gambolati G. et al. "Geomechanical response to seasonal gas storage in depleted reservoirs: A case study in the Po River basin, Italy". Journal of Geophysical Research, 2021, Vol. 116, F02002.
7. Vasco D.W., Rucci A., Ferretti A. et al. "Satellite-based measurements of surface deformation reveal fluid flow associated with the geological storage of carbon dioxide". Geophysical Research Letters, 2020, Vol. 37, L03303.
8. Schout G., Drijver B., Gutierrez-Neri M. et al. "Analysis of recovery efficiency in high-temperature aquifer thermal energy storage: A Rayleigh-based method". Journal of Hydrogeology, 2022, Vol. 22, pp. 281-291.
9. Furre AK, Eiken O., Alnes H. et al. "20 Years of monitoring CO2-injection at Sleipner". Energy Proceedings, 2019, Vol. 114, pp. 3916-3926.
10. Jacob T., Bayer R., Chery J. et al. "Time-lapse surface to depth gravity measurements on a karst system reveal the dominant role of the epikarst as a water storage entity". Geophysical Journal International, 2021, Vol. 177, pp. 347-360.

YERALTI QAZ ANBARLARININ İSTİSMARI BÖLGƏLƏRİNDƏ EKOLOJİ VƏZİYYƏTİN TƏHLİLİNİN MÜASİR ÜSULLARI

Gülarə İmanova[1], Eldar Həşimov[2]
[1]Dosent, "Neftin-Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: gulara.imanova.is@asoiu.edu.az
[2]Magistr, "Neftin Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: hsimoveldar8@gmail.com

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

XÜLASƏ

Yeraltı qaz anbarları təbii qaz ehtiyatlarının mövsümi saxlanması, enerji təhlükəsizliyinin təmin edilməsi və qaz tədarükü sistemlərinin etibarlılığının artırılması məqsədilə istifadə olunan strateji əhəmiyyətli mürəkkəb mühəndislik obyektlərdir. Qazın yüksək təzyiq altında yer qabığının dərin qatlarına vurulması və sonradan istehsal məqsədi ilə çıxarılması zamanı ətraf mühit komponentlərinə - torpaq örtüyünə, yeraltı və səth su horizontlarına, atmosfer tərkibinə, həmçinin yerli biosenozlara - əhəmiyyətli antropogen təsir göstərilir. Bu proseslər yer səthinin deformasiyası, yeraltı su balansının pozulması, sera qazlarının emissiyası və ekosistemlərə zərər riskləri ilə müşayiət olunur.
Təqdim olunan məqalədə Yeraltı qaz anbarların istismarı bölgələrində ekoloji vəziyyətin kompleks qiymətləndirilməsi üçün tətbiq edilən müasir analitik üsullar sistemli şəkildə araşdırılmış və təsnifləşdirilmişdir. Tədqiqat çərçivəsində geofiziki monitorinq texnologiyaları - seysmoakustik stansiyalar vasitəsilə mikroseysmlərlərin qeydə alınması, yüksək dəqiqlikli gravimetrlərlə cazibə sahəsinin variasiyalarının ölçülməsi və elektromaqnit üsullarla torpaq qatlarının elektrik keçiriciliyinin kartalaşdırılması - əhatə olunmuşdur.
Müxtəlif sistemlər ətraf mühitdə baş verən dəyişikliklərin erkən mərhələdə aşkar edilməsinə, Yeraltı qaz anbarların istismarının milli və beynəlxalq təhlükəsizlik standartlarına uyğunluğunun təmin edilməsinə və potensial ekoloji risklərin proaktiv minimizasiyasına imkan yaradır. Məqalədə həmçinin müxtəlif analiz metodlarının inteqrasiyası prinsipləri, onların sinerjik təsir mexanizmləri, üstünlükləri və praktiki tətbiq sahələri elmi-texniki cəhətdən əsaslandırılmış şəkildə müzakirə edilmişdir.
Açar sözlər: yeraltı qaz anbarı, ekoloji monitorinq, geofiziki üsullar, peyk məlumatları, geokimyəvi analiz, hidrogeoloji parametrlər, ekoloji risk, təhlükəsizlik, ətraf mühit, riyazi modelləşdirmə.

СОВРЕМЕННЫЕ МЕТОДЫ АНАЛИЗА ЭКОЛОГИЧЕСКОЙ СИТУАЦИИ В РАЙОНАХ ЭКСПЛУАТАЦИИ ПОДЗЕМНЫХ ГАЗОХРАНИЛИЩ

Гюлара Иманова[1], Эльдар Гашимов[2]
[1]Доцент, "Кафедра транспорта и хранения нефти и газа", "Азербайджанский Государственный Университет Нефти и Промышленности", Азербайджан. E-mail: gulara.imanova.is@asoiu.edu.az
[2]Магистрант, "Кафедра транспорта и хранения нефти и газа", "Азербайджанский Государственный Университет Нефти и Промышленности", Азербайджан. E-mail: hsimoveldar8@gmail.com

РЕЗЮМЕ

Подземные газохранилища представляют собой стратегически важные комплексные инженерные сооружения, используемые для сезонного хранения запасов природного газа, обеспечения энергетической безопасности и повышения надежности газоснабжения. При закачке газа под высоким давлением в глубокие слои земной коры и его последующей добыче в производственных целях оказывается значительное антропогенное воздействие на компоненты окружающей среды – почвенный покров, горизонты грунтовых и поверхностных вод, состав атмосферы, а также локальные биоценозы. Эти процессы сопровождаются рисками деформации земной поверхности, нарушения водного баланса, выбросов парниковых газов и ущерба экосистемам.

В представленной статье систематически изучаются и классифицируются современные аналитические методы, применяемые для комплексной оценки экологической ситуации в районах эксплуатации подземных газохранилищ. Исследование охватывает геофизические технологии мониторинга – регистрацию микросейсмических событий с использованием сейсмоакустических станций, измерение вариаций гравитационного поля с помощью высокоточных гравиметров и картирование электропроводности слоев грунта электромагнитными методами.

Различные системы позволяют заблаговременно выявлять изменения окружающей среды, обеспечивая соответствие эксплуатации подземных газохранилищ национальным и международным стандартам безопасности, а также заблаговременно минимизировать потенциальные экологические риски. В статье также научно и технически обоснованно рассматриваются принципы интеграции различных методов анализа, механизмы их синергии, преимущества и области практического применения.

Ключевые слова: подземное хранение газа, экологический мониторинг, геофизические методы, спутниковые данные, геохимический анализ, гидрогеологические параметры, экологический риск, безопасность, окружающая среда, математическое моделирование.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

43-51

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-05

VOLUME 33 (08) ISSUE 02 2026

FACTORS AFFECTING THE DURABILITY OF CONCRETE IN AGGRESSIVE MARINE ENVIRONMENTS

Anar Jomardov[1], Amid Maliyev[2]
[1]Docent, Department of Oil and Gas Transportation and Storage, Azerbaijan State Oil and Industry University. Email: anarcomerdov1978@gmail.com
[2]Master's Degree Student, Department of Oil and Gas Transportation and Storage, Azerbaijan State Oil and Industry University. Email: amidmaliyev2001@gmail.com

ABSTRACT

The marine environment is recognized as one of the most aggressive natural conditions affecting the long-term performance of concrete structures. High concentrations of chloride and sulfate ions in seawater, continuous moisture exposure, fluctuating temperatures, and mechanical loading collectively contribute to the degradation of concrete. These factors weaken the internal structure of the material, increase porosity, accelerate ion migration, and progressively damage the passive protective layer of steel reinforcement. As a result, corrosion develops more rapidly, leading to cracking, expansion of corrosion products, and a gradual loss of load-bearing capacity—posing a significant threat to marine infrastructure.

This study synthesizes the findings of various researchers to identify and evaluate the modern laboratory, field, and analytical methods used to assess the durability of concrete in marine environments. Techniques such as electron microscopy for microstructural analysis, chloride diffusion tests for determining ion transport, permeability and porosity measurements for evaluating material density, and electrochemical methods for monitoring corrosion risk are examined. Field investigations complement laboratory observations, confirming that the splash zone is the most critical region where corrosion progresses at an accelerated rate.

The results demonstrate that improving the durability of concrete in aggressive marine environments requires an integrated engineering approach rather than reliance on any single protective measure. Enhancing resistance to chloride ingress, optimizing concrete cover thickness, increasing impermeability, and employing corrosion-resistant reinforcement and advanced protective coatings are essential strategies. The combination of experimental data with analytical modeling further enables accurate prediction of service life and supports the development of reliable and long-lasting marine engineering structures. Overall, a comprehensive understanding of concrete behavior under marine exposure forms a solid foundation for designing durable, safe, and efficient coastal and offshore infrastructure.

Keywords: Concrete, marine environment, corrosion, chloride diffusion, sulfate attack, microstructure analysis, water permeability, electrochemical testing.

Introduction

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

In modern construction practice, concrete is recognized as a primary structural material and plays a critical role in ensuring the reliability and service life of engineering structures. The availability of raw materials, cost-effectiveness, and technological versatility have enabled concrete to be widely used in both onshore and offshore infrastructure. However, the complex chemical and physical influences present in the marine environment substantially weaken the internal structure of concrete and reduce the corrosion resistance of reinforcing steel.[1]

The chemical composition of seawater is characterized by high concentrations of chloride ions, sulfate compounds, and other corrosive components.[2] Chlorides penetrate through the porous structure of concrete and disrupt the passive film on reinforcement surfaces.[4] Sulfate exposure triggers expansive reactions within the cement matrix, generating internal stresses that accelerate crack propagation. Long-term chloride diffusion may ultimately lead to the formation of corrosion products, delamination of the concrete cover, and loss of load-bearing capacity.[8]

The marine environment is divided into several exposure zones, each exhibiting a distinct level of aggressiveness toward concrete structures. Research indicates that the splash and spray zone is the most vulnerable to corrosion, as cyclic wetting and drying intensify chloride transport. In the atmospheric zone, marine aerosols enhance chloride deposition under high humidity, whereas in submerged regions, chloride diffusion produces sustained long-term effects.[6]

The relevance of this problem is acknowledged not only internationally but also within the scientific community of Azerbaijan.[12] Local studies emphasize that salinity, humidity, and temperature variations in the Caspian Sea basin significantly increase corrosion risks for concrete structures. Additionally, region-specific factors such as saline groundwater, marine fog, and fluctuating climatic conditions require detailed investigation for future offshore infrastructure projects. The AZS 409-2015 standard outlines the durability criteria that must be considered when using concrete in aggressive environments.[15]

Recent scientific literature, both global and regional, proposes new theoretical and practical approaches to improve concrete durability in marine environments.[4] These include advanced chloride diffusion models, probabilistic service-life prediction methods, corrosion inhibitors, protective surface coatings, and the use of corrosion-resistant reinforcement. Findings demonstrate that long-term protection of concrete in marine conditions cannot rely on a single method; instead, a combination of protective measures provides a significantly more effective solution.

Purpose of the Study

The primary aim of this study is to systematically investigate the main factors that reduce the durability of concrete structures in marine environments and to assess their impact on microstructure, chemical composition, and the corrosion resistance of embedded steel. The research focuses on:

- Identifying the mechanisms through which aggressive factors—such as chloride ions, sulfate compounds, high humidity, and wave impact—affect the internal structure of concrete and the passivity of reinforcement;
- Modelling and analytically evaluating the physicochemical processes responsible for service life reduction in concrete structures;
- Conducting a comparative analysis of risks associated with different marine exposure zones (atmospheric, splash, and submerged);

- Assessing the effectiveness of modern engineering solutions and protective technologies aimed at enhancing long-term durability;
- Developing a comprehensive strategy for improving the performance of concrete structures in the Caspian region and similar marine environments.

The overarching goal of this study is to support the development of scientifically grounded strategies to increase the service life, safety, and durability of concrete structures exposed to aggressive marine conditions.

Methodology

The methodological framework of the study is designed to provide a comprehensive and scientifically structured evaluation of the factors that diminish the durability of concrete when subjected to aggressive marine exposure. Its central purpose is to investigate—in a systematic and multilevel manner—the physical, chemical, electrochemical, and mechanical processes that govern deterioration in chloride- and sulfate-rich environments.[2] Marine zones are widely recognized as among the most destructive natural exposure conditions for cement-based materials due to the synergistic action of high salinity, continuous wetting and drying cycles, fluctuating temperatures, and the abrasive impact of waves. These environmental influences disrupt the integrity of the cementitious microstructure, weaken the passive oxide film protecting steel reinforcement, accelerate ion ingress, and ultimately result in cracking, spalling, and long-term loss of load-bearing capacity.[3]

Stage 1: Comprehensive Literature Review and Theoretical Assessment

The first stage of the research consisted of an expanded academic review encompassing international standards, regional studies, and peer-reviewed scientific literature. The goal was to construct a theoretical basis for identifying the dominant degradation mechanisms associated with marine exposure.[1] Works by multiple authors were compared to determine the quantitative and qualitative influence of chloride diffusion kinetics, sulfate crystallization, reinforcement depassivation, oxygen availability, and moisture transport processes. Special emphasis was placed on differentiating the behavior of concrete across the three main marine exposure zones—atmospheric, splash/tidal, and fully submerged regions—each of which presents distinct deterioration profiles.[5] The literature analysis revealed that atmospheric zones are characterized by slow diffusion but high carbonation risk, splash zones exhibit the most severe deterioration due to cyclic wetting and mechanical impact, while submerged zones maintain stable but continuous chloride penetration. These insights allowed the formulation of research hypotheses related to microstructural degradation, crack propagation, and corrosion dynamics.[7]

Stage 2: Experimental Investigation Under Controlled Marine Simulation

The second methodological stage involved a detailed program of laboratory experimentation aimed at reproducing marine exposure conditions with high accuracy. Concrete specimens of defined compositions and strength classes were prepared and subjected to accelerated aging procedures replicating real coastal environments. A combination of analytical and microstructural techniques was employed.[8]

Microscopic and spectroscopic examinations—including optical microscopy, SEM imaging, and porosity measurements—were conducted to assess pore connectivity, interfacial transition zone behavior, crack initiation, and morphological alterations within the cement matrix. Chloride ingress profiles were quantified using titration-based procedures, potentiometric methods, and

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

electrochemical monitoring to determine both the concentration gradient and the depth-dependent migration rate. To characterize fluid transport properties, permeability, sorptivity, and capillary absorption tests were performed under controlled temperature-humidity cycles, allowing evaluation of the effect of moisture saturation on ion movement.[10]

Electrochemical testing provided additional insight into reinforcement behavior. Measurements of corrosion potential, polarization resistance, and corrosion current density were used to determine corrosion initiation thresholds and evaluate the kinetics of steel deterioration once depassivation occurred. These experiments enabled the identification of relationships between chloride concentration, pore structure, and the rate of reinforcement deterioration.[2]

Stage 3: Field Observations and Validation Through Real-World Data

To ensure that laboratory findings corresponded to actual environmental conditions, the research incorporated an extensive field evaluation of existing reinforced concrete structures exposed to the Caspian Sea environment and other coastal regions.[4] Structures varying in age, functional purpose, and exposure level were inspected to document crack patterns, surface degradation, reinforcement corrosion symptoms, and depth-dependent chloride accumulation.

Non-destructive measurements and core sampling enabled direct comparison between laboratory simulations and real deterioration mechanisms.[9] The collected data provided a basis for validating the accelerated aging procedures, confirming that the experimental conditions reliably represented actual marine-induced deterioration. The correlation between field and laboratory results strengthened the overall methodological reliability and demonstrated how different exposure zones lead to distinct forms of physical and chemical degradation.[12]

Stage 4: Analytical Modeling and Long-Term Durability Prediction

The third major research stage consisted of analytical modeling aimed at predicting long-term service life under aggressive marine exposure. Established durability models—including Fickian diffusion models, reliability-based approaches, and prediction methodologies from the Fib Model Code (2006) and GB/T 50476-2019—were used to estimate chloride penetration depth, corrosion initiation time, and structural performance loss over the lifespan of concrete elements.[6]

Probabilistic analyses were conducted to consider variations in material quality, environmental parameters, and exposure intensity. These models allowed for the simulation of multiple deterioration scenarios, providing a scientifically grounded forecast of concrete longevity under the influence of chloride attack, sulfate expansion, and mechanical erosion. Through integration of probabilistic and deterministic modeling, the methodology produced robust estimates of service life and structural reliability.[7]

Integration of Results and Identification of Key Deterioration Mechanisms

The synthesis of literature findings, laboratory results, field observations, and analytical modeling enabled a holistic understanding of the degradation processes that dominate in marine settings. The primary mechanisms were identified as chloride diffusion, sulfate attack, persistent moisture exposure, reinforcement depassivation, and mechanical abrasion due to wave action. The combined analysis demonstrated that long-term durability is critically dependent on both material composition and environmental exposure severity.[14]

Overall, the research methodology offers a coherent and scientifically rigorous framework that integrates theoretical, experimental, field-based, and analytical approaches. This multilevel method provides a reliable foundation for evaluating the durability performance of concrete in aggressive marine conditions and forms an essential basis for developing predictive tools and effective durability-enhancing strategies such as surface coatings, corrosion-resistant reinforcement, and chemical admixtures.[8]

The primary purpose of the methodological framework is to systematically analyze the physical, chemical, and mechanical factors that reduce the durability of concrete in aggressive marine environments, and to determine their impact on microstructure, ion migration, water permeability, and mechanical behavior. The marine environment is classified among the most aggressive natural exposure conditions for concrete, as elevated chloride and sulfate concentrations, persistent moisture, and cyclic splash effects damage the passive layer of reinforcement and lead to crack formation within the concrete matrix.[13]

The first stage of the research involved an extensive review of international and local scientific sources. Studies by various authors were comparatively examined to evaluate chloride diffusion, sulfate reactions, mechanical loading, and moisture cycles affecting concrete durability. Distinct characteristics of different marine exposure zones—atmospheric, splash, and submerged—were investigated to determine their influence on microstructural degradation, cracking, and corrosion development.

The second stage consisted of laboratory testing. Concrete specimens were exposed to simulated marine conditions. Microscopic analysis was used to evaluate pore structure, crack formation, and microstructural changes within the cement matrix. The rate and distribution of chloride penetration were determined through titration and electroanalytical techniques.[15] Water permeability was measured using standard permeability and absorption tests under varying humidity and temperature conditions. Electrochemical testing assessed the initiation time and rate of reinforcement corrosion and its impact on the concrete cover.

To validate laboratory findings, field observations were conducted on existing concrete structures in the Caspian Sea region and other coastal areas. Measurements of corrosion levels, crack patterns, and chloride concentrations were performed.[9] The comparison of laboratory and field data provided essential insights into the actual intensity of deterioration across different exposure zones, confirming the relevance of simulated laboratory conditions.

The third stage involved analytical modeling. Chloride diffusion models and service-life prediction tools were applied to evaluate long-term durability. Reliability-based assessments and methodologies derived from Fib Model Code (2006) and GB/T 50476-2019 standards were used.[10] This approach allowed for scientifically grounded long-term durability predictions under aggressive marine exposure.[11]

The synthesis of laboratory, field, and analytical data enabled the identification of the primary degradation mechanisms in marine environments, including chloride diffusion, sulfate attack, prolonged moisture exposure, and mechanical wave action. Findings confirm that long-term durability requires integrated engineering solutions, including protective coatings, corrosion-resistant reinforcement, and corrosion inhibitors.[7]

Overall, the methodological framework combines experimental, field, and analytical approaches to provide a comprehensive and scientifically robust basis for evaluating concrete performance in marine conditions and predicting service life.

Conclusions

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

The results of the study demonstrate that aggressive marine conditions expose concrete structures to multiple degradation factors. Chloride ions and sulfate compounds penetrate the cement matrix, induce microstructural transformations, and accelerate crack development while compromising the passive layer of reinforcement. Cyclic wetting and drying in the splash zone intensify corrosion processes, while submerged and atmospheric zones are dominated by long-term chloride diffusion and high humidity.

Both laboratory and field results show that no single protective measure is sufficient to ensure concrete durability. Long-term performance in marine environments requires combined engineering strategies, including corrosion-resistant reinforcement, protective surface treatments, and the use of corrosion inhibitors. Analytical modeling confirmed that chloride diffusion analysis is essential for predicting structural service life and ensuring long-term safety.

Data integration from laboratory, field, and modeling studies highlights the importance of a holistic approach to durability assessment. Such integration supports optimized durability design, selection of appropriate protective measures, and scientifically based service-life prediction. Thus, understanding degradation mechanisms and implementing region-specific engineering solutions is crucial for ensuring safe and long-lasting marine infrastructure.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Mehta, P. K., & Monteiro, P. J. M. Concrete: Microstructure, Properties, and Materials. McGraw-Hill, 2014.
2. Neville, A. M. Properties of Concrete. Pearson Education, 2011.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

3. Thomas, M. D. A., & Bamforth, P. B. "Modelling Chloride Ingress into Concrete." Concrete International, 1999, pp. 51–56.
4. Bertolini, L., Elsener, B., Pedeferri, P., & Polder, R. Corrosion of Steel in Concrete: Prevention, Diagnosis, Repair. Wiley-VCH, 2013.
5. Song, H.-W., & Saraswathy, V. "Corrosion Monitoring of Reinforced Concrete Structures — A Review." Cement and Concrete Composites, 29(5), 2007, pp. 409–420.
6. International Federation for Structural Concrete (fib). Fib Model Code for Service Life Design, 2006.
7. Highways Agency. HTM 60: Durability of Concrete Structures Exposed to Marine Environment. UK, 2004.
8. Wu, Y., Shi, X., & Yang, Z. "Chloride Penetration in Concrete Exposed to Marine Environment." Construction and Building Materials, 252, 2020, pp. 119–123.
9. Wang, X., Zhang, Y., & Li, C. "Durability Analysis of Concrete Structures in Marine Environment Based on Chloride Diffusion and Reliability Theory." Ocean Engineering, 178, 2019, pp. 148–158.
10. Standardization Administration of China. GB/T 50476-2019: Standard for Durability Design of Concrete Structures. China Standard Press, 2019.
11. Aliyev, Sh. Q. Durability of Concrete and Reinforced Concrete Structures. Baku: ADNSU Publishing, 2018.
12. Khalilov, N. M. "Corrosion of Concrete Structures in Marine Environment and Methods for Its Prevention." Azerbaijan Engineering Journal, 2020, No. 2, pp. 45–53.
13. Rzayev, A. T. Concrete Technology and Durability Problems in Aggressive Environments. Baku: Elm və Təhsil Publishing, 2016.
14. Gasimov, E. R., & Mammadov, T. S. "Chloride Diffusion Characteristics of Concrete under Marine Exposure." Construction–Architecture Scientific Journal, 2021, No. 4, pp. 32–40.
15. Azerbaijan Institute of Standardization. AZS 409-2015: Concrete and Reinforced Concrete Structures — Durability Requirements. Baku, 2015.

AQRESSİV DƏNİZ ŞƏRAİTİNDƏ BETONLARIN DAYANIQLIĞINA TƏSİR EDƏN AMİLLƏR

Anar Comərdov[1], Amid Malıyev[2]
[1]Dosent, Neftin-Qazın Nəqli və Saxlanması kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: anarcomerdov1978@gmail.com
[2] Magistr, Neftin Qazın Nəqli və Saxlanması kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: amidmaliyev2001@gmail.com

XÜLASƏ

Dəniz mühiti beton konstruksiyaların uzunömürlülüyünə mənfi təsir göstərən ən aqressiv təbii faktorlar arasında xüsusi yer tutur. Seawater-də mövcud olan yüksək miqdarda xlorid və sulfat ionları, davamlı rütubət, dəyişən temperatur və mexaniki yüklənmələrin birgə təsiri betonun daxili quruluşunu zəiflədir və armaturun passiv qoruyucu qatını zədələyir. Bu kimyəvi və fiziki proseslər zamanla betonun mikrostrukturunda deqradasiya yaradır, məsaməliliyi artırır, ion

miqrasiyası üçün əlverişli şərait formalaşdırır və nəticədə korroziya prosesinin daha sürətlə inkişaf etməsinə səbəb olur. Armaturların korroziyası beton örtüyünün çatlamasına, genişlənməsinə və daşıyıcı qabiliyyətin tədrici itirilməsinə gətirib çıxardığından, bu problem dəniz infrastrukturu üçün ciddi təhlükə yaradır.
Aparılmış tədqiqat müxtəlif müəlliflərin işlərinin müqayisəli təhlili əsasında dəniz şəraitində betonun dayanıqlığını qiymətləndirmək üçün tətbiq edilən müasir metodları ümumiləşdirir. Mikrostrukturun analizində elektron mikroskopiya, ion köçməsini müəyyənləşdirmək üçün xlorid diffuziyası testləri, materialın sıxlığını qiymətləndirmək üçün sukeçirmə və porozite ölçmələri, həmçinin armaturların korroziya riskini müəyyənləşdirən elektrokimyəvi sınaqların əhəmiyyəti araşdırılmışdır. Sahə tədqiqatları laboratoriya nəticələrinin real şəraitlə uyğunluğunu qiymətləndirməyə imkan vermiş, dalğa-sıçrama zonasında korroziyanın daha intensiv inkişaf etdiyi bir daha təsdiqlənmişdir.
Tədqiqatın nəticələri göstərir ki, dəniz mühitində betonun davamlılığını təmin etmək üçün təkcə material seçimi deyil, həm də çoxsahəli mühəndislik yanaşmalarının eyni anda tətbiqi tələb olunur. Xloridlərin nüfuzunun azaldılması, beton örtüyünün optimallaşdırılması, sukeçirməzlik səviyyəsinin artırılması, korroziyaya davamlı armaturların və müasir qoruyucu örtüklərin tətbiqi dayanıqlığın yüksəldilməsi üçün əsas istiqamətlərdir. Müxtəlif sınaq üsullarından əldə edilən məlumatların analitik modellərlə birləşdirilməsi isə dəniz mühəndisliyi konstruksiyalarının xidmət müddətini daha dəqiq proqnozlaşdırmağa imkan verir. Beləliklə, betonun dəniz şəraitində davranışının kompleks şəkildə öyrənilməsi uzunömürlü və etibarlı mühəndislik həllərinin formalaşdırılması üçün mühüm elmi baza yaradır.
Açar sözlər: Beton, dəniz mühiti, korroziya, xlorid diffuziyası, sulfat təsirləri, mikrostruktur analizi, sukeçirməzlik, elektrokimyəvi sınaqlar.

ФАКТОРЫ, ВЛИЯЮЩИЕ НА ДОЛГОВЕЧНОСТЬ БЕТОНОВ В АГРЕССИВНОЙ МОРСКОЙ СРЕДЕ

Анар Джомардов[1], Амид Малыйев[2]
[1]Доцент, Кафедра Транспортировки и Хранения Нефти и Газа, Азербайджанский Государственный Университет Нефти и Промышленности. Email: anarcomerdov1978@gmail.com
[2]Магистр, Кафедра Транспортировки и Хранения Нефти и Газа, Азербайджанский Государственный Университет Нефти и Промышленности. Email: amidmaliyev2001@gmail.com

РЕЗЮМЕ

Морская среда относится к числу наиболее агрессивных природных факторов, существенно влияющих на долговечность бетонных конструкций. Повышенное содержание хлоридных и сульфатных ионов в морской воде, длительное воздействие влаги, колебания температуры и механические нагрузки совместно вызывают деградацию бетона. Под их воздействием ухудшается внутренняя структура материала, увеличивается пористость, ускоряется миграция ионов, а пассивный защитный слой арматуры постепенно разрушается. Это приводит к ускоренному развитию коррозии, образованию трещин, расширению коррозионных продуктов и постепенной потере несущей способности конструкций, что представляет серьёзную угрозу для объектов морской инфраструктуры.

В работе проведён анализ исследований различных авторов с целью систематизации современных лабораторных, полевых и аналитических методов оценки стойкости бетона в морских условиях. Рассмотрены такие методы, как электронная микроскопия для изучения микроструктуры, испытания на диффузию хлоридов для определения транспорта ионов, измерение проницаемости и пористости для оценки плотности материала, а также электрокимические испытания для контроля риска коррозии. Полевые наблюдения подтвердили лабораторные результаты, показав, что зона приливов и брызг является наиболее уязвимой областью с ускоренным развитием коррозионных процессов.

Полученные выводы свидетельствуют, что повышение долговечности бетона в агрессивной морской среде требует комплексного инженерного подхода, а не применения отдельных защитных мер. Снижение проникновения хлоридов, оптимизация защитного слоя бетона, повышение водонепроницаемости, использование коррозионно-стойкой арматуры и современных защитных покрытий являются ключевыми направлениями. Интеграция экспериментальных данных с аналитическим моделированием позволяет более точно прогнозировать срок службы конструкций и разрабатывать надёжные решения для морского строительства. Таким образом, всестороннее изучение поведения бетона в морской среде служит основой для проектирования долговечных и безопасных гидротехнических и прибрежных сооружений.

Ключевые слова: бетон, морская среда, коррозия, диффузия хлоридов, сульфатная коррозия, анализ микроструктуры, водонепроницаемость, электрохимические исследования.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

52-63

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-06

VOLUME 33 (08) ISSUE 02 2026

DEVELOPMENT OF A CONTROL SYSTEM FOR THE EPICHLOROHYDRIN PRODUCTION UNIT

Javida Damirova[1], Rugayya Ashurlu[2]
[1]PhD in Engineering, associate professor, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: cavida.damirova@asoiu.edu.az
[2]Master's degree student, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: rugayya.ashurlu30@gmail.com

ABSTRACT

The article addresses the development and improvement of the control system for the epichlorohydrin production unit. The epichlorohydrin production process is analyzed in detail from the perspective of automation of technological processes and evaluated as a control object. The key parameters affecting the technological process are identified, the functional structure of the unit is developed, and the main tasks of the control system are explained.

To ensure optimal control of the technological process, mathematical models were constructed, and process identification was performed based on regression analysis. Based on these models, an optimization problem was formulated, and the Simplex method of linear programming was applied to solve it. Optimization results allowed for determining more efficient parameters for the technological regime.

To maintain the required technological conditions, an automatic regulation system for the unit was designed. The dynamic characteristics of the control object were studied, a dynamic model was developed, and a single-loop automatic regulation system was synthesized for temperature control. The quality indicators of the regulation system were analyzed, ensuring its stable operation.

The article also describes the technical, software, and data support of the control system in detail. During the selection of technical equipment, high-reliability measurement and regulation devices from Fisher-Rosemount, widely used in modern automation, were employed. The study demonstrates the potential for increasing the efficiency of epichlorohydrin production control and improving product quality.

Keywords: Epixlorohydrin production, automation of technological processes, control system, automatic regulation system, mathematical modeling, regression analysis, optimization problem, simplex method, chemical reactor control automation, optimization, microprocessor-based systems.

Introduction

The process of producing epichlorohydrin occupies an important place in the chemical industry. The efficiency of production largely depends on how effectively this process is carried out. One

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

of the main ways to increase production efficiency in the chemical industry is the automation of the control process.

In the modern era, increasing production efficiency is considered one of the key means of ensuring economic development. Contemporary automation practice encompasses complex systems based on diverse engineering and technical developments. Ultimately, these developments are directed toward automating the control process and lead to an increase in production efficiency.

Improving the control process primarily involves the qualitative development of the automatic monitoring function. оператив monitoring of the state of a complex controlled technological process requires the use of new technical capabilities through the involvement of computer technology. The computerization of technological measurements further enhances the automatic monitoring function.

Another important factor in improving automation is the stabilization of the operating regime of the technological process. This function gains special significance under conditions where an optimization problem is solved, since the implementation of predefined optimal regimes requires the creation of advanced automatic control systems.

A characteristic feature of modern automation systems is the solution of optimization problems based on mathematical models and their practical implementation. Real-time implementation of optimization problems is particularly justified when the system is affected by significant disturbances. Such influences are especially noticeable in the technological process under consideration, since the consumption and quality of raw materials vary due to external factors.

Solving the optimization problem requires the development of a mathematical model. Mathematical models obtained using regression analysis methods prove to be more reliable in practice. The application of this method makes it possible to model the controlled object without studying its internal regularities. In many cases, the use of regression equations yields satisfactory results.

The solution of optimization problems often requires compliance with functional constraint conditions. In most cases, these constraints act as one of the factors determining the efficiency of the operating regime of the process. Therefore, an optimization algorithm should be applied that allows the consideration of functional constraints. Depending on the type of mathematical model, linear or nonlinear programming methods can be used to solve the optimization problem.

In order to implement these functions, automation systems must be designed to be technically advanced and well-engineered.

1.Explanation of the technological process

The purpose of the ECH production unit is to obtain epichlorohydrin from dichlorohydrin, and its simplified technological flow diagram is shown in (Figure 1.1.)

An aqueous dichlorohydrin solution with a concentration of 40–60 g/L is fed into the T-04 tanks and from there into the PC-245/1-4 saponification reactors. A 10% caustic soda solution and lime milk are fed into the T-242/1,2 tanks equipped with a mixer, and from there, by means of H-243/1-3 pumps, part of the stream is supplied to the PC-245/1-4 saponification reactors, where the dehydrochlorination process takes place. The resulting epichlorohydrin–water vapor mixture exits from the top of the reactors.

This mixture is condensed in the KC-246/1-4 condenser–coolers. From the bottom of the KC-246/1-4 condenser–coolers, the condensate is sent to the H-247/1-4 separators. From the top of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

these separators, a 6% epichlorohydrin stream is directed to the T-250 tank, while from the bottom, an 85% epichlorohydrin stream is sent to the T-260 tank.
The upper layer from the T-250 tank is heated in the T-251/1,2 heaters and returned to the PC-245/1-4 saponification reactors. From the T-260 tank, the 85% epichlorohydrin solution is sent either to the 350/2 unit or to the T-278 tank.
Non-condensed vapors from the KC-246/1-4 condenser–coolers are directed to the additional C-246a cooler. The condensed portion is sent to the H-247/1-4 separators, while the non-condensed portion is directed to the C-285 cooler.
High-temperature steam at a pressure of 10 atm is supplied to the bottom of the PC-245/1-4 saponification reactors. At the top of the PC-245/1-4 reactors, the product temperature is 93–96 °C, while at the bottom it is 105–110 °C. The product is sent to the C-245a scrubber and then to the spray pond.

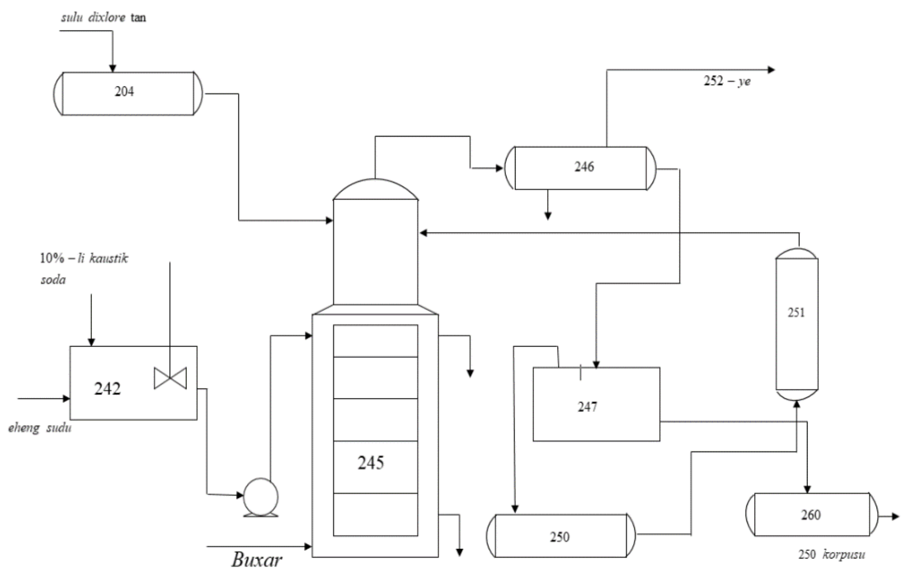


Figure 1: Process flow diagram of the epichlorohydrin production unit.

1.2. Functional structure of the control system

From the explanation of the junction, it becomes clear that such a technological mode should be selected that the output product is greater in quantity and higher in quality. For this purpose, the operating mode of the technological process must be optimized. After the optimal mode is determined, it must be implemented, that is, this mode must be maintained. To achieve this, information must be collected from the technological process, processed, and transmitted to the automatic control systems. The output of the automatic control system, in turn, must be transmitted to the technological process. As can be seen, the control system is hierarchical and consists of two levels: the lower and the upper levels. The lower level consists of technological data collection (TDC), primary data processing (PDP), and the automatic control system (ACS). The TDC periodically collects the current values of quantities characterizing the technological process from sensors and transmits them to the PDP task. The frequency of data collection from a

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

particular sensor depends on the frequency of changes in the corresponding parameter. Parameters that change rapidly are collected and processed at a high frequency, while parameters that change slowly are collected and rocessed at a lower frequency.The primary data processing (PDP) task calculates the actual values of technological parameters based on the codes collected from sensors, checks invalid codes, performs filtering operations, and thus prevents random errors from entering other tasks. The automatic control system (ACS), using various control laws and algorithms, ensures the required operating mode of the technological process.(Figure 2).

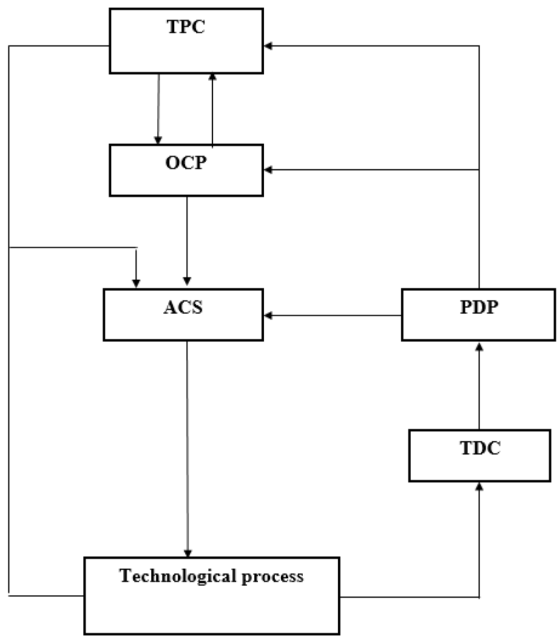


Figure 2: Functional diagram of the ACS.

2.Formulation of a mathematical model based on regression analysis

Mathematical models can be obtained using various methods. Among these, the most commonly used are passive and active experimental methods. The passive experiment is considered a traditional method. When deriving a mathematical model using this method, experiments are conducted sequentially for each variable. During a passive experiment, a normal experiment is carried out to collect static data, and in this case, mathematical models of the objects are constructed using classical regression and correlation methods based on the experimental data.

In the active experimental method, experiments are conducted according to a pre-designed plan, and it is possible to intervene in the course of the process at any time.

In both cases, the mathematical model relates the input and output parameters that characterize the results of the experiment, and the relationship between them is determined. In our process, the derivation of mathematical models is based on the passive experimental method. Since there is no need to determine correlation coefficients in our process, only regression coefficients were determined using the least squares method. The essence of the least squares method is as follows: The sum of the squares of the residual differences approaches a minimum.

The input and output parameters affecting the control object are shown in the static structure in

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

(Figure 2.)[2-5]

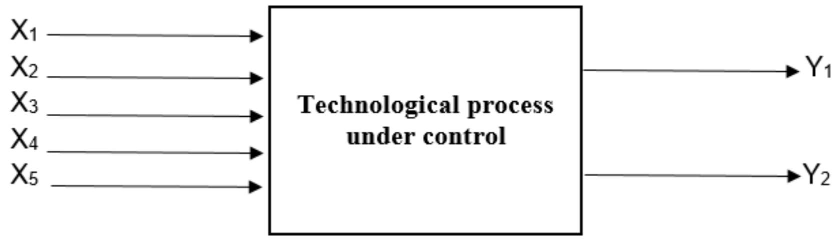


Figure 2: Technological process under control

Here,
X_1 – flow rate of dichlorohydrin (m³/h);
X_2 – flow rate of lime milk and caustic soda (m³/h);
X_3 – upper temperature of the reactor (°C);
X_4 – lower temperature of the reactor (°C);
X_5 – pressure in the reactor (kqq/cm²);
Y_1 – purity of epichlorohydrin at the outlet (%);
Y_2 – amount of epichlorohydrin obtained at the outlet (m³/h).
In practice, it is often observed that the variable **Y** depends on several independent **x** variables. When a linear stochastic relationship exists between the variable **Y** and **m** independent **x** variables, the function can be expressed in the form of the following $\bar{y} = f(x_1, x_2, \cdots\cdots\cdots, x_m)$ regression equation:

$$\bar{y} = a_0 + a_1 x_1 + a_2 x_2 + \cdots\cdots\cdots + a_m x_m \quad \textbf{(1)}$$

To account for the regression constant in expression (1), a fictitious variable $\mathbf{x_0}$, whose value is equal to one in all experiments, can be added to this expression. In this case, expression (1) can be written in the following form:

$$\bar{y} = a_0 x_0 + a_1 x_1 + a_2 x_2 + \cdots\cdots\cdots + a_m x_m \quad (2)$$

The derivation of mathematical models is based on the passive experimental method. The regime parameters were recorded at different moments with different values, and mathematical models were obtained on the basis of these values. After obtaining the regression equations, their adequacy is verified. The adequacy of the mathematical models is assessed using the Fisher criterion. To determine its calculated value, the residual variance $\boldsymbol{S_q^2}$ and the reproducibility variance $\boldsymbol{S_0^2}$ are determined. For this purpose, parallel experiments are conducted. During these parallel measurements, each of the input parameters $\boldsymbol{X_i}$ must be measured several times at fixed values.
The statistical analysis of the obtained regression equation is carried out in the following three stages:
1. Determination of the reproducibility variance;
2. Determination of the residual variance;

3. Verification of the adequacy of the mathematical model.

The reproducibility variance is calculated based on the values of the dependent variable $y$recorded during the parallel measurements.

$$S_0^2 = \frac{1}{N-1}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{3}$$

Using the same procedure, let us determine the residual variance based on the number of experiments.

$$S_q^2 = \frac{1}{N-K}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{4}$$

Here, the mean value of the output parameter is calculated as follows:

$$\hat{y}_i = \frac{1}{N}\sum_{i=1}^{n} y_i \tag{5}$$

N – the number of experiments;

K – the number of regression terms;

y_i – the experimental values of the output variables;

$\hat{y}_i$ – the calculated values of the output variables.

For the obtained regression equations, the number of regression terms is $k = m + 1$, where $m$is the number of input parameters included in the regression. Since the number of input variables in our mathematical models is $m = 5$, we obtain $k = 5 + 1 = 6$.

Finally, the calculated value of the **Fisher criterion** is determined according to the following ratio:

$$F = \frac{S_q^2}{S_0^2} \tag{6}$$

For the regression equation to be considered meaningful, that is, adequate, the condition$F > F_c$ must be satisfied.

3. Determination of regression coefficients using standard computer software

Mathematical models were obtained using the least squares method. The essence of this method is as follows: the regression coefficients $a_0, a_1, \ldots, a_n$ must be determined in such a way that the condition of minimizing the sum of the squares of the differences between the experimental and calculated values of the dependent variable $y$is satisfied. This principle is known as the Legendre principle.

The experimental values of the dependent variable y were obtained on the basis of statistical data. In this context, statistical data refers to data collected using the passive experiment method. The determination of the regression coefficients and the verification of the adequacy of the mathematical models are carried out using specialized computer software.

The experimental data required for obtaining the mathematical models are presented in (Figure 3.1.)[2-5-6]

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

№	X1	X2	X3	X4	X5	Y1	Y2
1	5.2	1.30	93.5	105.3	0.12	4.05	80.1
2	5.1	1.35	93.7	105.6	0.13	4.01	80.0
3	5.0	1.32	93.9	105.9	0.14	4.10	80.6
4	5.6	1.34	94.5	105.2	0.15	4.25	80.7
5	5.9	1.35	94.3	105.1	0.16	4.52	81.2
6	5.2	1.36	94.2	106.2	0.13	4.56	81.5
7	5.3	1.37	95.1	106.1	0.14	4.65	81.7
8	5.5	1.34	95.6	106.0	0.16	4.62	82.1
9	5.4	1.32	94.8	105.9	0.15	4.55	83.0
10	5.1	1.33	94.7	105.8	0.16	4.49	82.6
11	5.5	1.31	94.5	106.3	0.15	4.61	83.8
12	5.7	1.33	96.0	106.1	0.13	4.69	83.4
13	5.9	1.35	95.2	106.7	0.17	4.70	84.0
14	5.6	1.36	95.6	107.1	0.16	4.85	84.9
15	5.9	1.35	95.8	107.0	0.14	4.87	85.0
16	5.8	1.38	95.1	107.3	0.12	4.92	84.6
17	5.5	1.37	94.5	108.3	0.14	4.93	82.1
18	5.4	1.39	95.6	108.5	0.13	5.00	82.0
19	5.7	1.38	93.7	108.4	0.15	4.99	81.6
20	5.0	1.35	93.8	108.7	0.16	4.95	83.0
21	5.1	1.34	93.5	109.6	0.14	4.93	83.7
22	5.2	1.33	93.6	110.0	0.17	4.97	84.5
23	5.4	1.32	94.0	109.7	0.12	4.96	84.6
24	5.7	1.31	94.1	107.5	0.15	4.85	85.0
25	5.5	1.30	94.3	106.8	0.13	4.82	83.7
26	5.8	1.34	93.9	105.9	0.16	4.65	83.1
27	5.9	1.35	94.6	106.5	0.14	4.56	82.6
28	5.4	1.33	95.8	106.2	0.13	4.50	81.4
29	5.5	1.37	95.4	108.9	0.15	4.55	81.6
30	5.3	1.35	95.0	109.8	0.16	4.75	83.5

Figure 3: Statistical data.

The obtained regression parameters are expressed in the following form:

$a_0 = -17.0348$ $a_0 = -12.8340$
$a_1 = 0.3489$ $a_1 = 2.3612$
$a_2 = 0.4089$ $a_2 = -29.0878$
$a_3 = 0.0374$ $a_3 = 0.4890$
$a_4 = 0.1458$ $a_4 = 0.6889$
$a_5 = 0.6061$ $a_5 = 11.5210$

The regression equations obtained in accordance with the regression coefficients given above are as follows.

$$\bar{y}_1 = a_0+a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5 \quad (3.1)$$

$$\bar{y}_1 = -17.035+1.925x_1+0.574x_2+3.76x_3+15.622x_4+0.0915x_5 \quad (3.2)$$

$$\bar{y}_2 = a_0+a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5 \quad (3.3)$$

$$\bar{y}_2 = -12.83+12.98x_1-40.74x_2+47x_3+73.8x_4+1.728x_5 \quad (3.4)$$

For **Model I**:

$$S_{q1}^2 = 0.2476624 \qquad S_{01}^2 = 0.1250828$$

$$F_1 = \frac{S_{q1}^2}{S_{01}^2} = \frac{0.2476624}{0.1250828} = 1.98 \tag{3.5}$$

For **Model II**:

$$S_{q2}^2 = 0.5951673 \qquad S_{02}^2 = 0.2532627$$

$$F_2 = \frac{S_{q2}^2}{S_{02}^2} = \frac{0.5951673}{0.2532627} = 2.35 \tag{3.6}$$

The comparison of the obtained models with the tabulated Fisher (F) criterion is as follows.

$$F_1 > F_c = 1.98 > 1.74 \tag{3.7}$$
$$F_2 > F_c = 2.35 > 1.74 \tag{3.8}$$

Since the Fisher criterion is satisfied for all regression equations, the approximation of the experimental data points using these equations is considered to be of high quality. As the calculated values of both models exceed the tabulated Fisher criterion values, both models are regarded as adequate.

4. Optimization of the technological process

The development and implementation of systems with the most favorable optimal characteristics is currently one of the most important challenges. The solution of this problem has already become a standard practice in many fields. Examples include the selection of the optimal design or operating mode of a chemical reactor, maximization of enterprise profit, maximization of a rocket's flight range, minimization of energy consumption and time required for an object to reach a desired state, and estimation of system coordinates with minimal error.

The core concept of optimal control theory lies in the application of control strategies that enable achieving a predefined objective by determining the extremum (maximum or minimum) of a specified performance criterion of the system. Optimization is a purposeful activity aimed at obtaining the best possible results while satisfying given constraints.

Several methods of linear programming exist, among which the Simplex method is considered the most flexible and universal. This method makes it possible to solve virtually any linear programming problem.

The solution of the optimization problem is based on the Simplex method. The optimization problem is solved using specialized computer software designed for this purpose. In the optimization problem, the flow rate of dichlorohydrin supplied to the inlet of the 245 reactor is taken as a constant parameter (disturbance input). The operational constraints of the optimization problem are defined as follows:[1-6]

Constraint conditions:

$$x_{imin} \le x_i \le x_{imax}$$
$$y \ge f_k(x_i) \ge y_i$$

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Objective function:
$y_k = f(x_i) \to \min$ və ya $y_k = f(x_i) \to \max$
The linear constraint conditions of the optimization problem are given as follows:

$$X_1 = f = const = 6$$
$$1.3 \le X_2 \le 1.5$$
$$93 \le X_3 \le 96$$
$$105 \le X_4 \le 110$$
$$0.12 \le X_5 \le 0.17$$

The objective functions of the optimization problem are given as follows:

$$\bar{y}_1 = -17.035 + 1925X_1 + 0.574X_2 + 3.76X_3 + 15.622X_4 + 0.0915X_5 \to \max \qquad (4.1)$$

The functional constraint condition is given as follows:

$$\bar{y}_2 = -12.83 + 12.98X_1 - 40.74X_2 + 47X_3 + 73.8X_4 + 1.728X_5 \le 85\% \qquad (4.2)$$

With the help of the **MATLAB** program, the optimization problem was solved and the optimal value of the objective function was obtained as follows:
The obtained linear constraint conditions are given as follows:
$X_1^{opt} = 6\ m^3/saat$
$X_2^{opt} = 1.3\ m^3/saat$

$$X_3^{opt} = 93\ ^0C$$
$$X_4^{opt} = 110\ ^0C$$

$X_5^{opt} = 0.12 kqq/sm^2$
In the optimization problem, the obtained optimal values of the objective functions are given below:
$Y_1^{opt}{}_{max} = 4.94 m^3/saat$
$Y_2^{opt}{}_{min} = 81.92\%$

Conclusion
The article examines the issue of developing a control system for the epichlorohydrin production unit. By studying the technological scheme, reactor 245 was selected as the object of research. The efficiency indicators of the technological process, as well as the control and disturbance inputs, were determined. The functional tasks to be solved within the automation system were identified, the relationships between these functional tasks were established, and the functional structure of the automation system was developed. Mathematical models were constructed based on regression analysis, and the regression coefficients were determined using standard computer software.

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

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Rustamov, Gazanfar. Automatic Control Theory. Modeling in MATLAB/Simulink. Elm və Təhsil Publishing House, Baku, 2012.
2. Rustamov, Gazanfar. Automatic Control Theory. Part II. Baku, 2006.
3. Nagiyev, A. H. Technical Means of Automation. Baku, 2012.
4. Agayev U.Kh., Control of Chemical Industry Processes, Baku, 2010.
5. Balayev V.A., Rustamov G.A., Agakishiyev B.H., Identification and Modeling of Control Objects, Baku, 2001.
6. Iskandarov A.D., Tagiyev R.G., Yagubov G.Y., Optimization Methods, Baku, 1990.

EPİXLORHİDRİNİN ALINMASI QOVŞAĞININ İDARƏETMƏ SİSTEMİNİN İŞLƏNMƏSİ

Cavidə Dəmirova[1], Rüqəyya Aşurlu[2]
[1]T.ü.f.d. dosent, "Elektronika və Avtomatika" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: cavida.damirova@asoiu.edu.az
[2]Magistr, "Elektronika və Avtomatika" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: rugayya.ashurlu30@gmail.com

XÜLASƏ

Buraxılış işində epixlorhidrinin alınması qovşağının idarəetmə sisteminin işlənməsi və təkmilləşdirilməsi məsələlərinə baxılmışdır. İşdə epixlorhidrinin alınması prosesi texnoloji proseslərin avtomatlaşdırılması baxımından ətraflı şəkildə təhlil edilmiş, proses idarəetmə obyekti kimi qiymətləndirilmişdir. Texnoloji prosesə təsir göstərən əsas parametrlər müəyyən edilmiş, qovşağın funksional quruluşu işlənmiş və idarəetmə sisteminin əsas vəzifələri şərh olunmuşdur.
Texnoloji prosesin optimal idarə olunmasını təmin etmək məqsədilə riyazi modellər qurulmuş, prosesin identifikasiyası reqressiya analizi əsasında aparılmışdır. Alınmış modellər əsasında optimallaşdırma məsələsi formalaşdırılmış və bu məsələnin həlli üçün xətti proqramlaşdırmanın

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Simpleks üsulu seçilmişdir. Optimallaşdırma nəticəsində texnoloji rejimin daha səmərəli parametrləri müəyyən edilmişdir.
Zəruri texnoloji rejimin saxlanılması üçün qovşağın avtomatik tənzimləmə sistemi layihələndirilmişdir. Bu məqsədlə idarəetmə obyektinin dinamik xarakteristikaları öyrənilmiş, dinamik model qurulmuş və temperaturun tənzimlənməsi üçün birkonturlu avtomatik tənzimləmə sistemi sintez edilmişdir. Tənzimləmə sisteminin keyfiyyət göstəriciləri təhlil olunmuş və onun stabil işləməsi təmin edilmişdir.
İşdə həmçinin idarəetmə sisteminin texniki, proqram və məlumat təminatları ətraflı şəkildə təsvir edilmişdir. Texniki təminatın seçilməsi zamanı müasir avtomatlaşdırma sahəsində tətbiq olunan yüksək etibarlılığa malik Fisher-Rosemount firmasının ölçmə və tənzimləmə vasitələrindən istifadə edilmişdir. Görülmüş işlər nəticəsində epixlorhidrinin alınması prosesinin idarə olunmasının səmərəliliyinin artırılması və məhsulun keyfiyyətinin yaxşılaşdırılması imkanları göstərilmişdir.
Açar sözlər: Epixlorhidrin istehsalı, texnoloji proseslərin avtomatlaşdırılması, idarəetmə sistemi, avtomatik tənzimləmə sistemi, riyazi modelləşdirmə, reqressiya analizi, optimallaşdırma məsələsi, Simpleks üsulu, kimyəvi reaktorun idarə olunmasının avtomatlaşdırılması, optimallaşdırma, mikroprosessor əsaslı sistemlər.

РАЗРАБОТКА СИСТЕМЫ УПРАВЛЕНИЯ УЗЛОМ ПОЛУЧЕНИЯ ЭПИХЛОРГИДРИНА

Джавида Дамирова[1], Ругейя Ашурлу[2]
[1]К.т.н., доцент кафедры «Электроника и автоматика», Азербайджанский государственный университет нефти и промышленности, Email: cavida.damirova@asoiu.edu.az
[2]магистрант, кафедры «Электроника и автоматика», Азербайджанский государственный университет нефти и промышленности, Email: rugayya.ashurlu30@gmail.com

РЕЗЮМЕ

В выпускной работе рассмотрены вопросы разработки и совершенствования системы управления узлом получения эпихлоргидрина. Процесс получения эпихлоргидрина детально проанализирован с точки зрения автоматизации технологических процессов и оценен как объект управления. Определены основные параметры, влияющие на технологический процесс, разработана функциональная структура узла и раскрыты основные задачи системы управления.
С целью обеспечения оптимального управления технологическим процессом построены математические модели, проведена идентификация процесса на основе регрессионного анализа. На основе полученных моделей сформулирована задача оптимизации, для решения которой выбран метод линейного программирования — симплекс-метод. В результате оптимизации определены наиболее эффективные параметры технологического режима.
Для поддержания необходимого технологического режима спроектирована система автоматического регулирования узла. С этой целью исследованы динамические характеристики объекта управления, построена его динамическая модель и синтезирована

одноконтурная система автоматического регулирования температуры. Проведен анализ качественных показателей системы регулирования и обеспечена её устойчивая работа.
В работе также подробно описаны техническое, программное и информационное обеспечения системы управления. При выборе технических средств использованы высоконадежные измерительные и регулирующие приборы фирмы Fisher-Rosemount, широко применяемые в современной автоматизации. В результате выполненной работы показана возможность повышения эффективности управления процессом получения эпихлоргидрина и улучшения качества продукции.
Ключевые слова: производство эпихлоргидрина, автоматизация технологических процессов, система управления, система автоматического регулирования, математическое моделирование, регрессионный анализ, задача оптимизации, симплекс-метод, автоматизация управления химическим реактором, оптимизация, микропроцессорные системы.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
64-70

VOLUME 33 (08) ISSUE 02 2026

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-07

APPLICATION OF ARTIFICIAL INTELLIGENCE FOR TIME SERIES FORECASTING

Rena Zulfugarova
Associate professor of "Computer Engeeniring"department, Azerbaijan State Oil and Industry University,
E-mail:rana.zulfugarova@asoiu.edu.az
ORCID: https://orcid.org/0009-0005-3469-3700

ABSTRACT

Accurate time series forecasting plays a key role in decision support systems used in economics, industry, and engineering. This article discusses a time series forecasting model based on an adaptive neuro-fuzzy inference system (ANFIS), designed for modeling nonlinear relationships with limited historical data. Particular attention is paid to the model's implementation, taking into account compatibility with the MATLAB environment, which expands its practical application in the context of limited computing resources.
To assess forecast quality, the mean absolute error (MAE) and mean absolute percentage error (MAPE) metrics were used, allowing for an objective assessment of the accuracy and robustness of the resulting forecasts. Experimental results confirm that the proposed ANFIS model provides reliable short-term forecasting accuracy and demonstrates stable convergence during training. A significant advantage of the method is the interpretability of the model, ensured by the use of fuzzy rules and membership functions, which allows for analyzing the influence of past time series values on forecast formation.
The obtained results demonstrate the feasibility of using neuro-fuzzy systems in time series forecasting, particularly in situations where a combination of accuracy, robustness, and explainability is required. Further research areas include the development of hybrid models, optimization of ANFIS parameters, and comparative analysis with modern deep learning methods.
Keywords: Time series forecasting, adaptive neuro-fuzzy inference system (ANFIS), mean absolute error (MAE), mean absolute percentage error (MAPE), MATLAB.

1. Introduction

Time series forecasting is widely used in economics, engineering, and industrial systems for predicting future behavior based on historical observations. Classical statistical models often fail to capture nonlinear dependencies inherent in real-world data. As a result, intelligent models such as artificial neural networks and neuro-fuzzy systems have gained increasing attention [1,2,3].
Forecasting oil production is nothing more than the process of determining future values based on the analysis of a certain historical dataset that changes over time—in essence, an extrapolation process. Therefore, when deciding on a method for formally representing the forecasting

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

procedure, a time-series model is unambiguously used [4,5]. In real systems, a variable is observed at discrete intervals. From the perspective of the forecasting process itself, the system implementing it is assigned two main functions: forecast generation and forecast management. Forecast generation involves obtaining data to refine the forecasting model, conducting the forecast, and presenting the forecast results to the user [6]. The forecasting model must accurately represent observations in any local time segment close to the present. There is usually no particular need to have a model that adequately describes very old observations, since they are unlikely, generally speaking, to characterize the present moment. There is also no need to provide forecast values for the distant future, i.e., for a time period longer than the forecast horizon.

This study focuses on the application of ANFIS model for forecasting a univariate time series. Special attention is given to implementation stability in MATLAB environments, which are still widely used in academic and industrial contexts.

2. Methodology

The dataset is a single numerical time series containing 30 consecutive observations. The values represent discrete measurements of daily petroleum product production.

The ANFIS model was created using a first-order Sugeno-type fuzzy inference system. A three-lag autoregressive structure was adopted, with the previous three time steps serving as input and the current value as output. Each input variable was assigned a Gaussian membership function (fig.1).

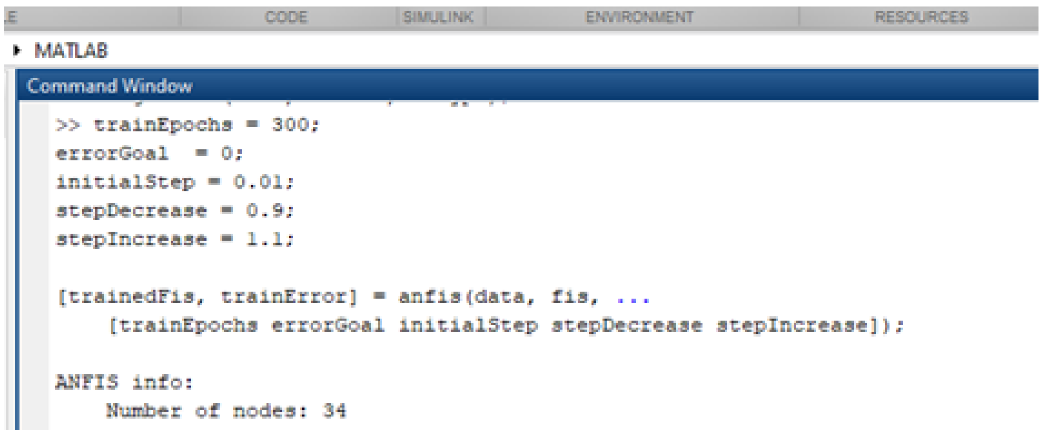
```
MATLAB
Command Window
>> y = [733 1089 794 786 667 806 806 946 667 968 ...
     690 806 774 971 974 1011 968 1054 662 823 ...
     756 750 784 750 807 714 881 946 812 950];
>> lag = 3;                       % number of time delays
N = length(y);

X = [];
T = [];

for i = lag+1:N
    X = [X; y(i-1) y(i-2) y(i-3)];    % inputs (lags)
    T = [T; y(i)];                    % target output
end
>> data = [X T];
>> numMFs = 2;                    % number of membership functions per input
mfType = 'gaussmf';            % Gaussian membership function

fis = genfis1(data, numMFs, mfType);
>> trainEpochs = 300;
errorGoal  = 0;
initialStep = 0.01;
stepDecrease = 0.9;
stepIncrease = 1.1;

[trainedFis, trainError] = anfis(data, fis, ...
    [trainEpochs errorGoal initialStep stepDecrease stepIncrease]);
```

Figure 1: Part of the ANFIS model creation program**.**

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

The model was trained using a hybrid learning algorithm combining least-squares estimation and gradient descent. The number of training epochs was set to 300. All available data was used for training to maximize training efficiency given the small size of the dataset.




```
>> trainEpochs = 300;
errorGoal   = 0;
initialStep = 0.01;
stepDecrease = 0.9;
stepIncrease = 1.1;

[trainedFis, trainError] = anfis(data, fis, ...
    [trainEpochs errorGoal initialStep stepDecrease stepIncrease]);

ANFIS info:
    Number of nodes: 34
```

Figure 3: Part of the ANFIS model training process.

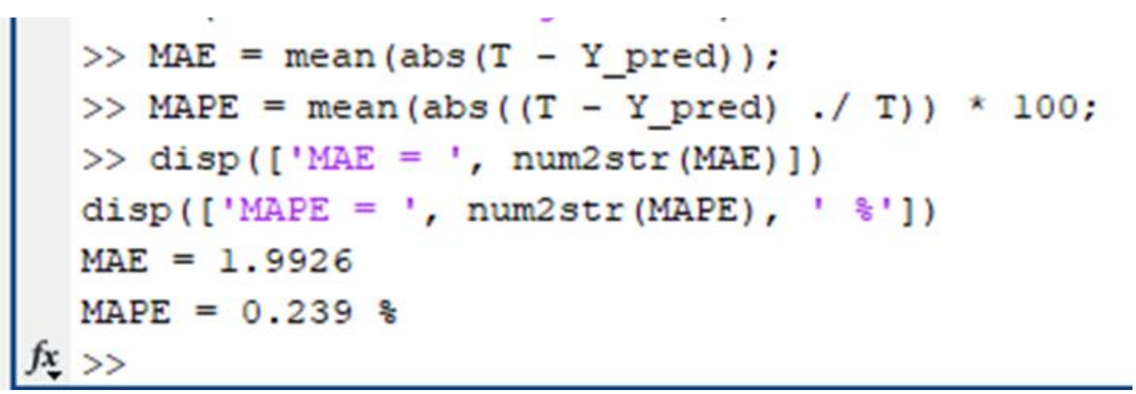
Two forecasting modes were employed:
• One-step-ahead forecasting for model evaluation
• Multi-step recursive forecasting for estimating future values
In recursive forecasting, the forecasted values were fed back into the model as input for subsequent steps. Once a forecasting model has been created, there is a need to evaluate this model. Forecasting accuracy was evaluates using the following metrics: Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE).
Mean Absolute Error (MAE)

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i| \quad (1)$$

Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{y_i-\hat{y}_i}{y_i}\right| \quad (2)$$

These metrics provide intuitive interpretations of absolute and relative forecasting errors (fig.3). In this code (fig.3) T — targets and Y_pred —ANFIS (one-step ahead prediction).



```
>> MAE = mean(abs(T - Y_pred));
>> MAPE = mean(abs((T - Y_pred) ./ T)) * 100;
>> disp(['MAE = ', num2str(MAE)])
disp(['MAPE = ', num2str(MAPE), ' %'])
MAE = 1.9926
MAPE = 0.239 %
fx >>
```

Figure 3: MAE and MAPE metrics.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Results and Discussion

The ANFIS model demonstrated stable convergence during training and produced accurate one-step ahead predictions. ANFIS offers the additional advantage of interpretability through fuzzy rules, making it particularly suitable for decision support systems where transparency is required.

The forecasting performance of the proposed model was quantitatively evaluated using Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE), which are widely accepted accuracy metrics in time series analysis.

- MAE shows the average absolute error of the forecast
- MAPE < 10% → high accuracy
- MAPE 10–20% → good accuracy
- MAPE > 20% → the model requires improvement

For the ANFIS model, the obtained **MAE of [MAE_ANFIS = 1.9926]** indicates a relatively small average absolute deviation between the predicted and observed values. In addition, the **MAPE value of [MAPE_ANFIS = 0.239]%** confirms good relative forecasting accuracy, remaining within the acceptable range for short-term prediction tasks. These results demonstrate that the neuro-fuzzy structure is capable of effectively modeling nonlinear temporal dependencies even with a limited number of observations.

It was also observed that forecasting accuracy decreases as the prediction horizon increases. This effect is reflected in the gradual growth of MAE and MAPE values during multi-step forecasting, caused by error accumulation in recursive prediction schemes. Such behavior is consistent with previous studies on autoregressive intelligent models and confirms that the proposed approaches are most effective for short-term forecasting.

Overall, the obtained MAE and MAPE values confirm that ANFIS model provide reliable forecasting performance. The lower error metrics and enhanced interpretability make ANFIS a more suitable choice for practical applications where transparency and robustness are required alongside prediction accuracy.

Conclusion

In this paper, we propose and evaluate a neuro-fuzzy time series forecasting model based on ANFIS. It is adaptable to the MATLAB environment, expanding its potential for practical application in scientific and applied research. Unlike most modern approaches focused on computationally complex deep learning architectures, the proposed model combines sufficient forecasting accuracy with moderate computational costs and high interpretability.

The scientific novelty of this paper lies in its comprehensive approach to constructing an ANFIS model for short-term time series forecasting with limited data, including selecting an autoregressive structure for input variables, tuning membership functions, and using a hybrid learning algorithm. It is demonstrated that even with a small number of observations, the neuro-fuzzy system is capable of effectively approximating the nonlinear dynamics of a time series, providing acceptable MAE and MAPE values.

The study's results confirm that ANFIS is robust to data uncertainty and highly sensitive to hyperparameter selection, which is particularly important for the practical implementation of forecasting models under limited information conditions.

The practical significance of these results lies in the potential application of the developed model in decision support tasks that require not only high forecast accuracy but also explainability of the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

results. The proposed approach can be used in economic, technical, and production systems for the rapid forecasting of indicators and the analysis of their dynamics.

Declarations
The manuscript has not been submitted to any other journal or conference.
Study Limitations
There are no limitations that could affect the results of the study.

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Zulfugarova Rena. Applying of Machine Learning Algorithms for prediction WORLD OF SCIENCE: сборник статей XII Международной научно-практической конференции. – Пенза: МЦНС «Наука и Просвещение». – 2025. – 340 с. ISBN 978-5-00236-856-3, p.29-35
2. Zulfugarova Rena. Application of neural networks to solving the problem of forecasting in production. Azərbaycan Ali Texniki Məktəblərinin Xəbərləri, №6(140), Bakı, 2022, s.63.
3. Rabchevskiy, A. N. Sinteticheskiye dannyye i razvitiye neyrosetevykh tekhnologiy : uchebnoye posobiye dlya vuzov / A. N. Rabchevskiy. – Moskva : Yurayt, 2024. – 187 s. – (Vyssheye obrazovaniye). – ISBN 978-5-534-17716-9. – URL: https://urait.ru/bcode/545036 (data obrashcheniya: 05.06.2024).
4. Kalinggo B. A. Time series forecasting for non-stationary data: A case study of petrochemical product price / B. A. Kalinggo // Proceedings of the 3rd Asia Pacific Conference on Research in Industrial and Systems Engineering 2020. – 2020. – C. 86-92.
5. Mustafayeva S.R., Fuzzy Modeling for Marketing Plan Development, 15th International Conference on Applications of Fuzzy Systems, Soft Computing and Artificial Intelligence Tools – ICAFS-2022, pp.616-619
6. Mustafayeva S.R., Determination of Connection Between Fractal Dimensions and Fuzzy Modeling, World Conference Intelligent System for Industrial Automation, 2024, pp. 223-228

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

ZAMAN SIRALARININ PROQNOZLAŞDIRMASI ÜÇÜN SÜNİ İNTELLEKTİN TƏTBİQİ

Rəna Zülfüqarova
Dosent, "Kompüter mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
Email: : rana.zulfugarova@asoiu.edu.az

XÜLASƏ

Dəqiq zaman seriyası proqnozlaşdırması iqtisadiyyat, sənaye və mühəndislik sahələrində istifadə olunan qərar dəstəyi sistemlərində mühüm rol oynayır. Bu məqalədə məhdud tarixi məlumatlar əsasında qeyri-xətti əlaqələrin modelləşdirilməsi üçün hazırlanmış adaptiv neyro-qeyri-səlis nəticə çıxarma sisteminə (ANFIS) əsaslanan zaman seriyası proqnozlaşdırma modeli təqdim olunur. Xüsusi diqqət modelin tətbiqi və məhdud hesablama resursları şəraitində onun praktik istifadəsinin genişləndirilməsinə yönəldilmişdir.
Proqnoz keyfiyyətini qiymətləndirmək üçün orta mütləq xəta (MAE) və orta mütləq faiz xətası (MAPE) metriklərindən istifadə edilmişdir ki, bu da nəticədə əldə edilən proqnozların dəqiqliyini və möhkəmliyini obyektiv qiymətləndirməyə imkan vermişdir. Təcrübə nəticələri təklif olunan ANFIS modelinin etibarlı qısamüddətli proqnozlaşdırma dəqiqliyini təmin etdiyini və təlim zamanı sabit konvergensiya nümayiş etdirdiyini təsdiqləyir. Metodun əhəmiyyətli üstünlüyü, qeyri-səlis qaydaların və üzvlük funksiyalarının istifadəsi ilə təmin edilən modelin interpretasiya edilə bilməsidir ki, bu da keçmiş zaman seriyası dəyərlərinin proqnozun formalaşmasına təsirini təhlil etməyə imkan verir.
Əldə edilən nəticələr, xüsusilə dəqiqlik, möhkəmlik və izahlılığın kombinasiyasının tələb olunduğu hallarda zaman seriyası proqnozlaşdırmasında neyro-qeyri-səlis sistemlərin istifadəsinin mümkünlüyünü nümayiş etdirir. Əlavə tədqiqat sahələrinə hibrid modellərin hazırlanması, ANFIS parametrlərinin optimallaşdırılması və müasir dərin öyrənmə metodları ilə müqayisəli təhlil daxildir.
Açar sözlər: Zaman seriyası proqnozlaşdırması, adaptiv neyro-qeyri-səlis nəticə çıxarma sistemi (ANFIS), orta mütləq xəta (MAE), orta mütləq faiz xətası (MAPE), MATLAB.

ПРИМЕНЕНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ПРОГНОЗИРОВАНИЯ ВРЕМЕННЫХ РЯДОВ

Рена Зульфугарова
Доцент кафедры «Компьютерная инженерия», Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. Email: rana.zulfugarova@asoiu.edu.az

РЕЗЮМЕ

Точное прогнозирование временных рядов играет ключевую роль в системах поддержки принятия решений, применяемых в экономике, промышленности и инженерных задачах. В данной статье рассматривается модель прогнозирования временных рядов на основе адаптивной нейро-нечёткой системы вывода (ANFIS), ориентированная на моделирование нелинейных зависимостей при ограниченном объёме исторических данных. Особое внимание уделено реализации модели с учётом совместимости со средой MATLAB, что расширяет возможности её практического применения в условиях ограниченных вычислительных ресурсов.

Для оценки качества прогнозирования использованы показатели средней абсолютной ошибки (MAE) и средней абсолютной процентной ошибки (MAPE), позволяющие объективно оценить точность и устойчивость получаемых прогнозов. Экспериментальные результаты подтверждают, что предложенная ANFIS-модель обеспечивает надёжную точность краткосрочного прогнозирования и демонстрирует устойчивую сходимость в процессе обучения. Существенным преимуществом метода является интерпретируемость модели, обеспечиваемая использованием нечётких правил и функций принадлежности, что позволяет анализировать влияние прошлых значений временного ряда на формирование прогнозов.

Полученные результаты свидетельствуют о целесообразности применения нейро-нечётких систем в задачах прогнозирования временных рядов, особенно в ситуациях, где требуется сочетание точности, устойчивости и объяснимости моделей. В качестве направлений дальнейших исследований рассматривается разработка гибридных моделей, оптимизация параметров ANFIS и проведение сравнительного анализа с современными методами глубокого обучения.

Ключевые слова: прогнозирование временных рядов, адаптивная нейро-нечеткая система вывода (ANFIS), средняя абсолютная ошибка (MAE), средняя абсолютная процентная ошибка (MAPE), MATLAB.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
71-79
Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-08

VOLUME 33 (08) ISSUE 02 2026

DESIGN OF SCALABLE ARCHITECTURE FOR MONITORING AND PREDICTIVE MAINTENANCE OF METAL-CUTTING EQUIPMENT

Natig Javadov[1], Ali Amirov[2], Vugar Ismayilov[3]
[1]National Aerospace Agency, Professor, Chairman of the Supervisory Board, cavadov-natiq@mail.ru
[2]Baku Engineering University, Associate Professor, ali.amirov@mail.com
[3]Research Institute of Aerospace Informatics, National Aerospace Agency, PhD Student, Researcher, ismailovvugar99@gmail.com

ABSTRACT

Monitoring the degree of cutting tool wear plays a key role in ensuring the quality of machined parts. Intelligent systems for monitoring technological equipment using machine learning can improve machining quality and reduce unexpected equipment downtime by enabling timely operator response to degrading cutting tool quality. Predictive maintenance, unlike classical approaches, allows for assessing the current state of the cutting tool and making replacement decisions based on real-time data. This article presents the development of a scalable architecture for monitoring metal-cutting equipment for predictive maintenance. The proposed architecture consists of three layers: a hardware layer for data collection and preprocessing using a Raspberry Pi microcomputer, a server layer with microservice architecture, and a visualization layer for displaying the current equipment condition. The architecture provides for collecting data from sensors, extracting features from raw signals, sending them to the server for input to a machine learning model, and visualizing classification results in a web interface. The research also shows a prototype web interface to demonstrate the system concept. The key advantage of the proposed architecture is modularity, scalability, and low implementation cost due to the use of open-source technologies, making it accessible for small and medium-sized manufacturing enterprises.
Keywords: system design, machine learning, predictive maintenance, condition monitoring, smart manufacturing, maintenance optimization.

Introduction

The main goal of modern manufacturing is to ensure high quality of produced products, increase productivity, and optimize costs. The cutting tool used in mechanical processing is the foundation of metalworking production, whose condition directly affects the quality of machined parts and equipment efficiency.

During mechanical processing, due to constant temperature fluctuations and impact effects, cutting tool wear occurs. Gradual wear of the cutting tool leads to a decrease in the quality of the machined surface; moreover, tool failure can lead to unplanned machine downtime, part damage, and may pose a threat to operating personnel. Accordingly, constant monitoring of the cutting tool

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

condition is a critically important task for timely action when a certain degree of degradation of the cutting tool or equipment is reached [1].

In the context of modern information technology development, the topic of intelligent equipment monitoring is attracting increasing attention [2]. Traditional CNC (Computer Numerical Control) machines do not account for cutting tool wear, vibrations, acoustic emission, machined surface quality, chip shape, etc., but only the geometric dimensions of the workpiece, motion trajectory, and cutting parameters. This consequently leads to the fact that the capabilities of mechanical processing equipment are not fully utilized to ensure optimal final quality [3].

In recent years, the National Aerospace Agency of Azerbaijan has been conducting research on the implementation of machine learning algorithms in monitoring the condition of industrial equipment. In studies [4-6], methods for preprocessing and feature extraction from signals were developed, and machine learning models were trained to classify the cutting tool condition in metalworking. The experiments tested both classical machine learning models and deep neural networks. These models serve to implement the concept of predictive maintenance, which, in the proposed implementation, assumes that in real-time the operator makes maintenance decisions based on the model's output.

However, a trained machine learning model is only one component of a complete equipment monitoring and predictive maintenance system [7]. To apply these models in real industry, it is necessary to develop an architecture that includes collecting data from sensors, their preprocessing, transmission to the server, machine learning model inference, and visualization of results for the operator in real-time.

Existing commercial systems for condition monitoring of technological equipment have a number of limitations that prevent their widespread implementation. First, the high cost of licenses and implementation makes systems inaccessible for small and medium-sized enterprises. Second, closed architecture limits the possibilities for adaptation to specific production conditions and integration of proprietary machine learning algorithms. Third, commercial monitoring systems are typically focused on equipment from a specific manufacturer and require the use of proprietary sensors and data transmission protocols. Furthermore, the cloud architecture of many commercial solutions creates dependence on external services and raises information security questions when transmitting production data outside the enterprise [8-9].

The goal of this study is to design a scalable software-hardware architecture for monitoring and predictive maintenance of metal-cutting equipment with an accessible hardware-software base. The proposed Metal Cutting Machines Monitoring System (MCMMS) is a modular architecture covering all stages of system operation from collecting raw signals to displaying model results in a web interface.

General architecture of the system.

From a systems engineering perspective [10], MCMMS is an integrated set of hardware, software, and human components united to solve a specific problem - monitoring the cutting tool condition and timely response to its degradation. According to systems engineering principles, when designing complex systems, decomposition is applied - breaking down the system into functional subsystems with clearly defined interfaces between them. This approach was applied in designing the MCMMS architecture.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The proposed system has a modular structure, allowing it to scale according to the requirements of the manufacturing enterprise. The MCMMS architecture consists of three main layers (Fig. 1):
1. Edge Layer - hardware level, including sensors for data collection and a Raspberry Pi microcomputer for preprocessing signals and sending them to the server.
2. Server Layer - server level, providing data acquisition from the hardware level, machine learning model inference for classifying the cutting tool condition, and storing the history of states in a database.
3. Presentation Layer - visualization level implementing a web interface for displaying model output results and notifying operators of the need for tool replacement.

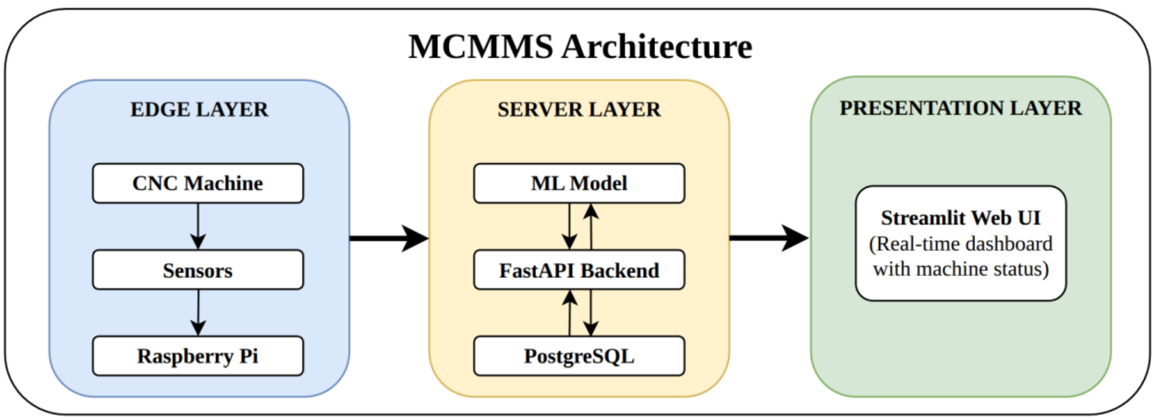


Figure 1: Three-level architecture of the MCMMS.

Edge Layer.
The hardware layer is designed for continuous data collection during metalworking, as well as for signal preprocessing. This level connects the physical and software parts of the entire system.
The data sources in the proposed system are sensors installed on the machine parts. In previously conducted experiments at the National Aerospace Agency, a multi-sensor dataset was used; accordingly, data can be collected from vibration sensors, acoustic emission, current, etc. The use of multi-sensor data in the monitoring system allows obtaining comprehensive information about the tool condition.
The central element of the hardware layer is the Raspberry Pi microcomputer, to which signals from sensors arrive (Fig. 2). Using an external analog-to-digital converter, signals are digitized, and on the microcomputer itself, further processing and feature extraction from signal time series occurs. Feature extraction strategies were described in works [3-5]. The feature extraction process in previously conducted works requires accumulating a certain volume of data; accordingly, after digitization, signals are written to a buffer until the specified window duration is reached. After feature extraction, a JSON data packet is formed, which is transmitted to the server level using the HTTP protocol.
The choice of the Raspberry Pi microcomputer is due to sufficient computational power and relatively low cost. This platform is a single-board computer based on an ARM processor with a clock frequency of up to 2.4 GHz, RAM of up to 8 GB, and support for GPIO, I2C, SPI interfaces for connecting sensors and external modules [11].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Server Layer.

The server level provides data acquisition from the hardware level, data transfer to the model, and storage of monitoring results. During the system development, a microservice architecture was chosen, which ensures the scalability of the entire system and increases its fault tolerance. Unlike monolithic architecture, in microservice architecture the system is divided into independent components that interact with each other through standardized interfaces.

The server part of the system consists of three components: API service, ML service, and database (Fig. 3). Each component operates in a separate Docker container, which ensures service isolation and the possibility of their independent updates.

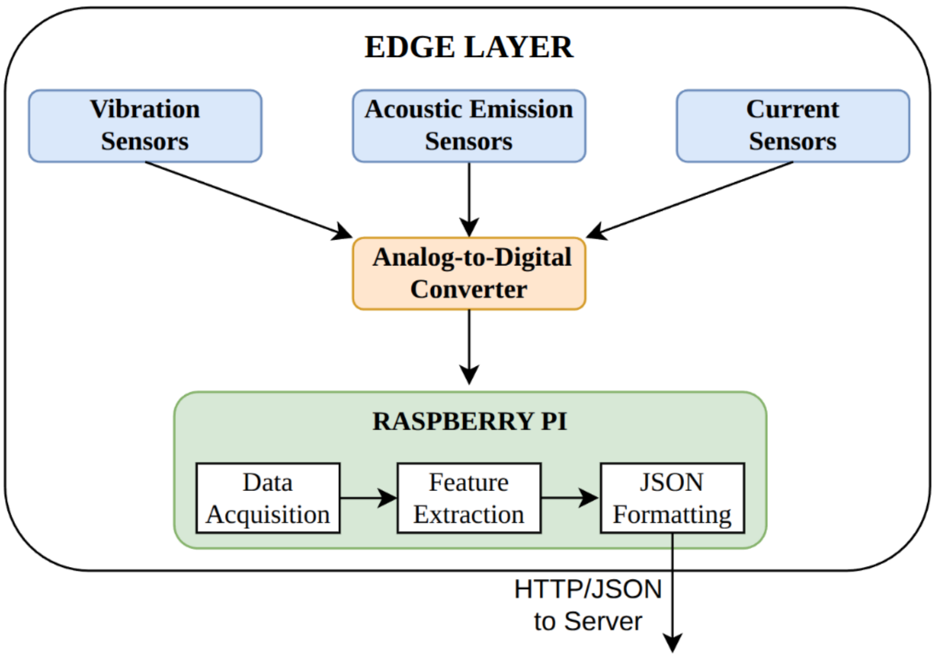


Figure 2: Edge Layer data flow and processing pipeline.

Docker is a platform that allows isolating an application in a separate environment called a container. Unlike traditional virtual machines, containers do not require running a separate operating system for each application, which significantly reduces the consumption of computational resources and ensures fast service initialization [12]. Separating the ML service into a separate container also allows updating the model without restarting the API service and, if necessary, scaling computational resources for inference independently of other components.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

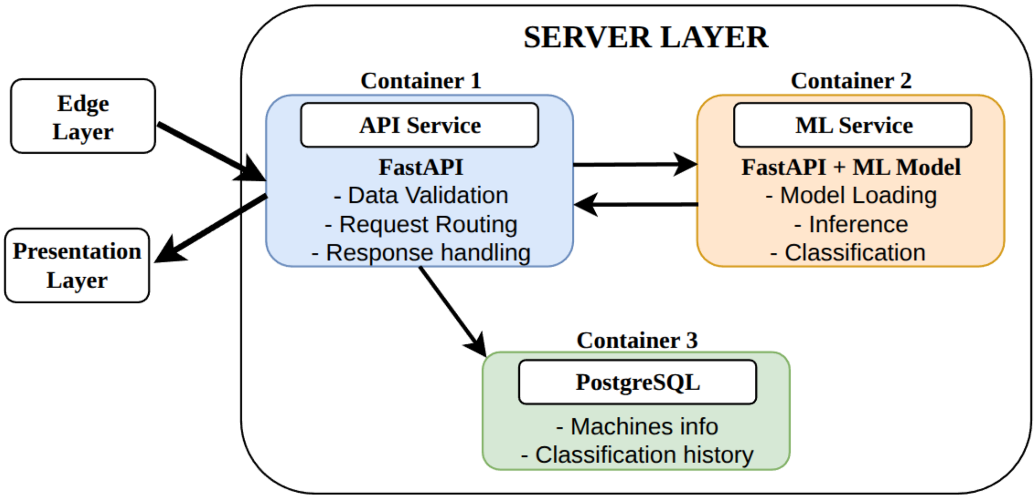


Figure 3: Server Layer architecture with Docker containers.

For implementing the API service, it is proposed to use the FastAPI framework, which receives data from the microcomputer, validates it, and passes it to the ML service. The ML model receives the processed data as input and outputs the degree of cutting tool wear. The FastAPI framework provides asynchronous request processing, i.e., simultaneously serving multiple connections [13]. The model's results and extracted features are saved to the database and passed further to the Presentation Layer. Accumulated data in the database can subsequently be used for model retraining. PostgreSQL is used as the database management system - a freely distributed relational DBMS with open source code [14].

Presentation Layer.

The visualization level is designed to display the output results of the classifier model regarding the cutting tool condition. Depending on the model's output, the web interface displays one of the cutting tool wear degree classes - initial, warning, or critical wear. The main requirement for the interface is simplicity of information perception and clarity for the machine operator for timely response and decision-making regarding the need for tool replacement. The web interface is implemented using the Streamlit framework, which allows relatively easy development and rapid prototyping of web applications in Python [15].

The interface prototype is shown in Figure 4, where a list of all machines connected to the monitoring system is displayed, as well as the current cutting tool condition. The tool condition is also visualized using color coding - green (normal) means initial wear and normal operation, yellow (warning) signals the need to plan tool replacement, red (critical) requires immediate machine shutdown and tool replacement. The interface provides the ability to filter machines by condition and by shop, and machines with critical tool condition are automatically displayed at the beginning of the list.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Figure 4: Web interface prototype for MCMMS.

Results

1. As a result of the work performed, a three-level architecture of the metal-cutting equipment monitoring system was designed and described. At this stage of research, the proposed system is a prototype demonstrating the concept of predictive maintenance system operation.
2. When developing the system, the main attention was paid to the accessibility and affordability of its components: Raspberry Pi is an inexpensive computing platform, FastAPI and Streamlit are open-source frameworks, PostgreSQL is a freely distributed DBMS, Docker is an open containerization platform. Unlike commercial equipment monitoring solutions, the proposed architecture allows deploying a monitoring system with minimal costs for hardware and software.
3. The modularity of the architecture ensures the scalability of the entire system. Each level can be modified independently of the others. For example, it is possible to integrate additional sensors or reduce them, it is possible to change the ML model, it is possible to modify the web interface without changing other parts of the system.
4. The system is not limited to monitoring one type of technological equipment. Depending on the enterprise requirements, the system can be adapted for monitoring various types of metal-cutting machines.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Munaro, R., A. Attanasio, and A. Del Prete. 2023. Tool wear monitoring with artificial intelligence methods: A review. J. Manuf. Mater. Process. 7(4):129. doi:10.3390/jmmp7040129
2. Kim P.T. Artificial Intelligence for Smart Manufacturing Methods, Applications, and Challenges. Springer, 2023. 271 p.
3. Grzesik W. Advanced Machining Processes of Metallic Materials. Theory, Modelling, and Applications, Second Edition, Amsterdam, Elsevier, 2017. 592 p.
4. Javadov, N. G., A. M. Amirov, and V. M. Ismayilov. 2025. Development of an SVM model for predictive maintenance of metal-cutting equipment. Trudy ISA RAN, 75(1):75–81.
5. Javadov N.G., Amirov A.M., Ismayilov V.M. A Window-Based Time Series Feature-Extraction and Classification Pipeline for Predictive Maintenance of Metal-Cutting Equipment // Proc. of the 2nd International Conference on Smart Environment and Green Technologies (ICSEGT2025). Lecture Notes in Networks and Systems. - Springer, 2025 (in press).
6. Ismayilov V.M., Javadov N.G., Amirov A.M. Application of Recurrent Neural Networks in Predictive Maintenance of Metal-Cutting Equipment // Information Systems and Technologies: Proc. of the XI International Scientific Congress on Computer Science (CSIST-2025). Part 2. - Minsk: BSU, 2025. - P. 152–156.
7. von Hahn, Tim, and Chris K. Mechefske. 2022. "Machine Learning in CNC Machining: Best Practices" Machines 10, no. 12: 1233. https://doi.org/10.3390/machines10121233
8. Zhu, K. 2022. Smart machining systems: Modeling, monitoring and informatics. Springer Series in Advanced Manufacturing. Cham: Springer. 420 p. doi:10.1007/978-3-030-87878
9. Javadov, N. G., A. M. Amirov, and V. M. Ismayilov. 2025. Application of machine learning algorithms for predictive maintenance of metal-cutting equipment: analysis of practical examples and development prospects. Equipment. Technology. Materials, 30(6).
10. Defense Acquisition University Press. 2001. Systems Engineering Fundamentals. Fort Belvoir, Virginia: Defense Acquisition University Press, 222 p.
11. Raspberry Pi Foundation. 2023. Raspberry Pi Documentation. Available at: https://www.raspberrypi.com/documentation/ (accessed: 23.01.2026).
12. Docker Inc. 2024. Docker Documentation. Available at: https://docs.docker.com/ (accessed: 23.01.2026).

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

13. Ramírez, S. 2024. FastAPI: modern, fast (high-performance), web framework for building APIs with Python. Available at: https://fastapi.tiangolo.com/ (accessed: 23.01.2026)
14. PostgreSQL Global Development Group. 2024. PostgreSQL Documentation. Available at: https://www.postgresql.org/docs/ (accessed: 23.01.2026).
15. Streamlit Inc. 2024. Streamlit Documentation. Available at: https://docs.streamlit.io/ (accessed: 23.01.2026).

METAL KƏSƏN AVADANLIQLARIN MONİTORİNQİ VƏ PROQNOZLAŞDIRICI TEXNİKİ XİDMƏTİ ÜÇÜN MİQYASLANA BİLƏN ARXİTEKTURANIN İŞLƏNMƏSİ

Natiq Cavadov[1], **Əli Əmirov**[2], **Vüqar Ismayılov**[3]
[1]Milli Aerokosmik Agentliyi, Professor, Müşahidə Şurasının sədri, cavadov-natiq@mail.ru
[2]Bakı Mühəndislik Universiteti, Dosent, ali.amirov@mail.com
[3]Elmi-Tədqiqat Aerokosmik İnformatika İnstitutu, Milli Aerokosmik Agentliyi, Doktorant, elmi işçi, ismailovvugar99@gmail.com

XÜLASƏ

Kəsici alətlərin yeyilmə dərəcəsinə nəzarət emal olunan hissələrin keyfiyyətinin təmin edilməsində əsas rol oynayır. Maşın öyrənməsindən istifadə edən texnoloji avadanlığın intellektual monitorinq sistemləri emal keyfiyyətini artıra, həmçinin operatorun kəsici alətlərin deqradasiya olunan keyfiyyətinə vaxtında reaksiya verməsi yolu ilə avadanlığın gözlənilməz qəza dayanmalarının vaxtını azalda bilər. Proqnozlaşdırıcı texniki xidmət, klassik yanaşmalardan fərqli olaraq, kəsici alətlərin cari vəziyyətini qiymətləndirməyə və real vaxt rejimində əldə edilən məlumatlara əsaslanaraq onun dəyişdirilməsi haqqında qərar qəbul etməyə imkan verir. Bu məqalədə proqnozlaşdırıcı texniki xidmət üçün metal kəsən avadanlığın monitorinqinin miqyaslana bilən arxitekturasının işlənməsi təqdim edilmişdir. Təklif olunan arxitektura üç səviyyədən ibarətdir: Raspberry Pi mikrokompüterindən istifadə edərək məlumatların toplanması və ilkin emalı üçün aparat səviyyəsi, mikroservis arxitekturalı server səviyyəsi və avadanlığın cari vəziyyətinin vizuallaşdırılması səviyyəsi. Arxitektura sensorlardan məlumatların toplanmasını, xam siqnallardan əlamətlərin çıxarılmasını, serverə maşın öyrənməsi modelinin girişinə göndərilməsini və təsnifat nəticələrinin veb-interfeysdə vizuallaşdırılmasını təklif edir. İşdə həmçinin sistemin konseptinin nümayişi üçün veb-interfeysin prototipi göstərilmişdir. Təklif olunan arxitekturanın əsas üstünlükləri modulluq, miqyaslana bilmə və açıq mənbə texnologiyalarından istifadə sayəsində aşağı tətbiq xərcləridir ki, bu da onu kiçik və orta istehsal müəssisələri üçün əlçatan edir.

Açar sözlər: sistem dizaynı, maşın öyrənməsi, proqnozlaşdırıcı texniki xidmət, vəziyyətinin monitorinqi, ağıllı istehsal, texniki xidmətin optimallaşdırılması

РАЗРАБОТКА МАСШТАБИРУЕМОЙ АРХИТЕКТУРЫ ДЛЯ МОНИТОРИНГА И ПРЕДИКТИВНОГО ОБСЛУЖИВАНИЯ МЕТАЛЛОРЕЖУЩЕГО ОБОРУДОВАНИЯ

Натиг Джавадов[1], **Али Амиров**[2], **Вугар Исмаилов**[3]
[1]Национальное Аэрокосмическое Агентство, Профессор, Председатель Наблюдательного совета, cavadov-natiq@mail.ru
[2]Бакинский Инженерный Университет, Доцент, ali.amirov@mail.com

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

[3]Научно-Исследовательский Институт Аэрокосмической Информатики, Национальное Аэрокосмическое Агентство, Докторант, научный сотрудник ismailovvugar99@gmail.com

РЕЗЮМЕ

Контроль степени износа режущего инструмента играет ключевую роль в обеспечении качества обрабатываемых деталей. Интеллектуальные системы мониторинга технологического оборудования с применением машинного обучения способны повысить качество обработки, а также сократить время неожиданных аварийных простоев оборудования путем своевременной реакции оператора на деградирующее качество режущего инструмента. Предиктивное обслуживание, в отличие от классических подходов, позволяет оценивать текущее состояние режущего инструмента и принимать решение о его замене на основе данных, получаемых в реальном времени. В данной статье представлена разработка масштабируемой архитектуры мониторинга металлорежущего оборудования для предиктивного обслуживания. Предлагаемая архитектура состоит из трех уровней: аппаратный уровень для сбора данных и предварительной обработки с помощью микрокомпьютера Raspberry Pi, серверный уровень с микросервисной архитектурой и уровень визуализации текущего состояния оборудования. Архитектура предлагает сбор данных с датчиков, извлечение признаков из сырых сигналов, отправку на сервер на вход модели машинного обучения и визуализации результатов классификации на веб-интерфейсе. В работе также показан прототип веб-интерфейса для демонстрации концепта системы. Ключевым преимуществом предлагаемой архитектуры является модульность, масштабируемость и низкая стоимость внедрения благодаря использованию технологий с открытым исходным кодом, что делает его доступным для малых и средних производственных предприятий.

Ключевые слова: системное проектирование, машинное обучение, предиктивное обслуживание, мониторинг состояния, умное производство, оптимизация обслуживания

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

80-90

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-09

STUDY OF MICROSTRUCTURAL CHARACTERISTICS OF GRINDING BALLS MADE FROM HIGH-QUALITY CAST IRON IN DIFFERENT ZONES

Rafiqa Shahmarova[1], Nargiz Gurbanli[2]
[1]Associate Professor, Ph.D., Department of "Materials Science and Processing Technologies", Azerbaijan State Oil and Industry University, E-mail: shahmarova_1970@mail.ru, https://orcid.org/0000-0002-2613-5742
[2]Master's student, Department of "Materials Science and Processing Technologies", Azerbaijan State Oil and Industry University, E-mail: nargiz.qurbanova03@mail.ru

ABSTRACT

This article presents a comprehensive analysis of the industrial relevance and manufacturing processes of grinding balls produced from high-quality cast iron. Owing to its superior mechanical characteristics, high density, hardness, and cost-effectiveness, cast iron has long been a material of choice across multiple industrial sectors. In particular, its application in the production of grinding balls is driven by its excellent wear resistance and durability under high-pressure and high-friction operating conditions. Surface-hardened cast irons are extensively utilized for manufacturing crushing and grinding components in mineral processing industries. Beyond these applications, grinding balls made from high-quality surface-hardened cast irons demonstrate outstanding mechanical performance in equipment such as spreader shafts, sand handling machinery, and refractory material workshops.
The study first explores the chemical composition and physical properties of cast iron, highlighting how carbon content and the incorporation of alloying elements influence hardness, toughness, and operational suitability. Enhancements to the cast iron matrix, through the addition of chromium, molybdenum, and other alloying elements, further improve resistance to wear and corrosion. The production process encompasses casting molten iron into molds followed by detailed microstructural analysis and optimization of the grinding balls. The technological parameters at each stage play a crucial role in determining the final mechanical properties, wear resistance, and overall service life of the products.
Keywords: cast iron, grinding balls, microstructure, surface hardening, wear resistance, mechanical properties, industrial applications.

Introduction

Grinding balls manufactured from cast iron are among the most widely utilized materials in various industrial processes. These components are predominantly employed in mills for the comminution of stones and ores, where their high density, mechanical strength, and superior wear resistance make them indispensable. Cast iron, an alloy primarily composed of iron and carbon, derives enhanced durability and wear resistance from its carbon content, enabling grinding balls to maintain effective performance over extended operational periods. The combination of high density, hardness, wear resistance, and thermal stability renders cast iron an ideal material for the production of grinding media.

The fabrication of cast iron grinding balls involves advanced metallurgical and technological procedures. This includes the precise preparation of raw materials, mold design and production, and the melting of iron and alloying elements in specialized furnaces. Molten cast iron is poured into purpose-designed molds and subsequently cooled under controlled conditions to ensure uniformity. The finished balls are then subjected to rigorous quality control, including dimensional verification, wear resistance evaluation, and microstructural examination to guarantee performance standards.

Cast iron grinding balls are extensively applied in industrial and mining sectors. Their primary usage spans mineral processing, construction, cement, and chemical industries, where the combination of mechanical durability and wear resistance is essential for efficient and reliable operations.

Aim / Objective

The aim of this study is to provide an in-depth evaluation of the role, manufacturing technologies, and industrial advantages of grinding balls made from cast iron, while exploring opportunities for their optimization according to modern technological standards. Although cast iron has been widely utilized across various industrial sectors for decades, the production of grinding balls as specialized components requires particular attention from both scientific and technological perspectives. This research adopts a comprehensive approach, covering all stages from the fabrication of cast iron grinding balls to their practical industrial applications.

A central focus of this study is to highlight the technological and economic benefits of using these grinding balls in sectors such as mining, construction, and chemical industries, while analyzing their contribution to enhancing operational efficiency and productivity. Moreover, the study examines how critical parameters—including dimensional accuracy, hardness, and wear resistance—are implemented and standardized across different industrial processes.

Additionally, the research aims to identify both the advantages and limitations of cast iron grinding balls, providing recommendations for improving their performance and expanding their future applications. While their high durability and exceptional wear resistance represent significant strengths, challenges such as high energy consumption during production and substantial weight remain. Accordingly, this study proposes strategies for optimizing manufacturing processes and developing more environmentally sustainable solutions.

Overall, this work seeks to consolidate existing scientific and technological knowledge on the production and application of cast iron grinding balls, contributing to the development of new approaches for their more effective and purposeful utilization in industrial practice.

Materials and methods

During the solidification of molten cast iron, it is possible to produce castings exhibiting both gray and white iron microstructures from the same alloy by carefully controlling the cooling conditions. Variations in the crystallization environment often result in a heterogeneous structure: the outer layer of the casting tends to form a cementite-rich eutectic, while the inner region

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

predominantly develops a graphite eutectic (Figure 1). The gradient of carbon distribution across the casting also influences the formation of these zones, as illustrated schematically in Figure 2.

The grinding balls analyzed in this study were manufactured from high-quality cast iron using conventional casting techniques. The raw materials, including pig iron and selected alloying elements such as chromium and molybdenum, were carefully prepared to achieve the desired chemical composition and mechanical properties. Molten cast iron was poured into pre-designed spherical molds and cooled under controlled conditions to promote the formation of distinct microstructural zones.

After solidification, the grinding balls were removed from the molds and prepared for metallographic analysis, including grinding, polishing, and chemical etching. Samples were extracted from three specific zones: the surface layer, transition zone, and core. Optical microscopy was employed to examine phase composition, graphite morphology, and matrix structure. Hardness measurements and wear resistance tests were also conducted to correlate microstructural features with mechanical performance.

a)

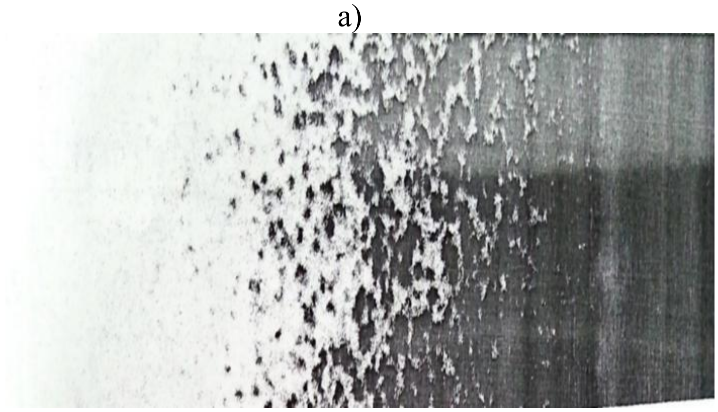
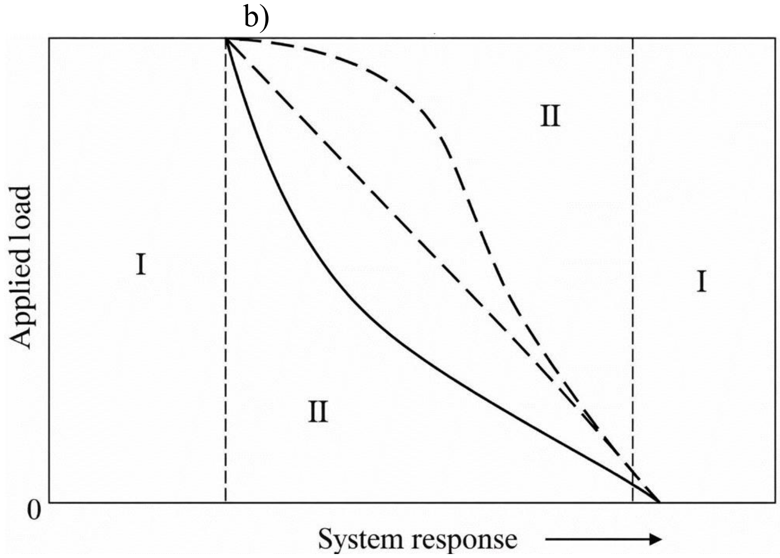


Figure 1: Microstructure of cast iron grinding balls showing a cementite-rich outer layer and graphite eutectic inner region.

b)



ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Figure 2: Schematic representation of carbon distribution across the casting during solidification, illustrating the formation of distinct microstructural zones (I – cementite-rich zone, II – graphite-rich zone).

This approach allowed a detailed assessment of how solidification behavior and cooling conditions influence the microstructure, mechanical properties, and wear resistance of high-quality cast iron grinding balls, providing insights for optimizing industrial production processes.
In surface-hardened castings, a transitional zone exists between the fully hardened outer layer and the softer core, characterized by a partially hardened cast iron microstructure. Within this zone, both graphite and cementite eutectics develop during solidification. Experimental studies reveal that the microstructure of a fully solidified surface comprises austenite dendrites interspersed with eutectic components. In low-carbon cast irons, graphite tends to accumulate between the arms of the eutectic austenite dendrites, whereas cementite is predominantly located within the dendrite branches. Conversely, in high-eutectic cast irons, ledeburite forms plate-like structures arranged in a honeycomb pattern. Overall, the microstructure of the transitional zone results from the relative formation and growth of the austenite-graphite assembly with respect to the cementite eutectic.
The grayish component observed in this transitional region primarily consists of a spheroidal austenite-graphite structure. The design objective behind producing surface-hardened grinding balls is to ensure that, during operation, once the hardened surface layer wears away, the core can fracture easily, facilitating rapid separation from the mill liners. According to industry standards, the chemical composition of grinding balls includes specific alloying elements, each expressed as a precise percentage.

Table 1. Chemical Composition of High-Quality Cast Iron Grinding Balls (wt.%).

Element (wt.%)	General Composition (wt.%)	Surface-Whitened Grinding Balls
C	0.5–3.5	2.9–3.0
Mn	0.6–2.6	0.5–0.6
Si	0.4–1.0 and higher	1.3–1.4
Cu	0.1–0.6	0.1–0.2
Cr	1.0–2.7	0.3–0.4
Mo	up to 1.0	—
P	≤ 0.10	≤ 0.07
S	≤ 0.04	≤ 0.02
Ni	≤ 0.30	≤ 0.10

The primary aim of the crystallization process is to promote the development of a cementite-like structure on the surface of the casting. The diameter of balls with a chilled outer layer varies between 40 and 60 mm. The surface layer must exhibit a hardness of 55–65 HRC, while the impact toughness should be within the range of KCU = 10–80 J/cm². In the transition zone, the required hardness is 40–45 HRC, whereas the core region should have a hardness of 15–20 HRC.

The production of surface-chilled balls is of considerable practical importance. To address this objective, the melt composition was modified by incorporating 45% recycled cast iron, 50% steel scrap, and 5% ferroalloys. The experimental results obtained from measurements taken from the surface toward the interior of the casting are summarized in Table 1. Melting was carried out in an IST-0.25 induction furnace. The chemical composition of the molten cast iron was determined to be (wt.%):

C = 2.9, Si = 1.5, Mn = 0.5, Cr = 0.32, P = 0.07, and S = 0.02.

Table 2. Hardness (HRC) values measured across the casting cross-section.

Measurement No.	Hardness (HRC)	Measurement No.	Hardness (HRC)
1	62	6	20
2	60	7	18
3	52	8	24
4	40	9	40
5	26	10	50

The chemical composition, microstructural characteristics, and mechanical properties of the castings were determined using standard testing methods. Wear resistance was evaluated using a CL-016 testing apparatus.

To examine the hardness distribution across the cross-section of castings with a surface-chilled layer, the balls were divided into two equal halves along the diameter. Hardness measurements were performed sequentially, starting from the surface layer and proceeding inward at intervals of 2–3 mm. The hardness values were determined according to the Rockwell C scale.

It is well known that surface chilling occurs as a result of the higher cooling rate of the outer layers of a casting compared to its inner regions. In castings with a chilled surface, a transition zone characterized by a mottled cast iron structure exists between the fully chilled outer layer and the inner region with a gray microstructure. During the solidification stage, both graphite and cementite eutectics are formed within this zone. As the distance from the surface toward the center increases, the fraction of the gray-structured region becomes more pronounced, while the white-structured area gradually diminishes.

Undoubtedly, the hardness level and wear resistance of this transition zone are lower than those of the fully chilled layer. The degree of chilling in cast iron is defined by the thickness of the transition region and the presence of a completely chilled surface layer. To evaluate the extent of chilling, metallographic techniques or chemical analysis are employed to determine the amount of carbon present in the combined form.

An increase in the cooling rate leads to a higher degree of chilling in cast iron. At the same time, the chilling tendency is influenced by the chemical composition of the alloy as well as by melting and pouring temperature parameters. The initial microstructure of the fully chilled layer is characterized by the formation of cementite layers between austenite dendrites. In the examined specimens, the microstructure of the fully chilled zone in balls with a diameter of 50 mm is illustrated in Figure 2.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Figure 3: Chilled-zone macrostructure (cementite+ledeburite), ×400.

The microstructure of the transition zone is primarily shaped by the formation of an austenite–graphite eutectic together with the concurrent crystallization of an austenite–cementite phase. It is well established that graphite formation requires high diffusivity of carbon and iron atoms. Consequently, during the cooling process of cast iron, graphite precipitates at relatively higher temperatures compared to cementite. With further temperature reduction, the remaining liquid phase solidifies into a cementite–austenite eutectic structure.
Thus, in cast iron cooled down to the eutectic temperature, the transition region develops according to this mechanism (Figure 3).

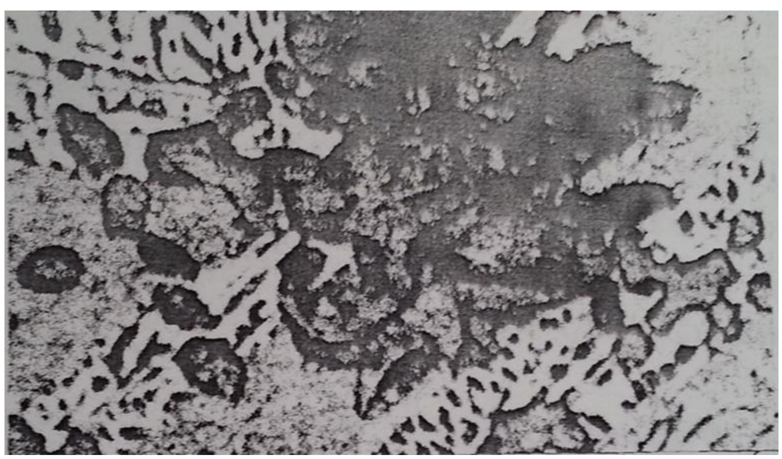


Figure 4. Microstructural features of the transition zone after etching with HNO_3, observed at ×100

During the eutectic transformation, the concurrent precipitation of both high-carbon phases plays a critical role, as it results in the development of incomplete microstructures. At this stage, at the final point of the eutectic reaction, the A+G and A+C phase combinations simultaneously separate from the remaining liquid phase.
It is well established that during the solidification of molten metal in a mold, the cooling rate governs phase formation, resulting in cementite development in the outer layer of the casting and

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

eutectic graphite formation in the inner regions. Castings produced under such conditions are commonly described as having a chilled surface

The main purpose of surface chilling is to provide a combination of high surface hardness and wear resistance together with sufficient toughness in the core. However, the final mechanical properties of the casting are significantly influenced by subsequent quenching and tempering treatments.

Following quenching, a high-carbon martensitic structure forms in the surface layer, while the core maintains relatively lower hardness and enhanced toughness. After quenching, the castings undergo low-temperature tempering in the range of 150–200 °C to reduce internal stresses. As a consequence of this heat treatment, the surface hardness attains values of approximately 56–60 HRC, whereas the core hardness remains within 15–25 HRC.

Surface-chilled castings are commonly obtained by applying the following heat-treatment conditions:

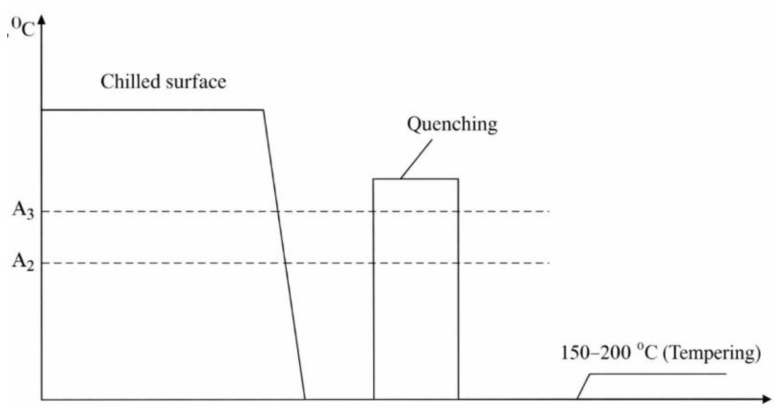


Figure 5: Schematic representation of the heat-treatment process for surface-chilled cast iron.

As a result of the surface chilling effect, austenite crystals in the outer layer transform into a coarse, needle-shaped martensitic structure, whereas the core region develops a rough and relatively coarse-grained microstructure. During the tempering treatment, which is conducted for 2 hours, finely dispersed carbides—specifically manganese, chromium, and iron carbides—precipitate within the martensitic matrix.

Conclusions

This study examined the microstructural features and mechanical properties of grinding balls manufactured from high-quality cast iron, with particular emphasis on the structural differences observed in the surface-hardened layer, transition zone, and core region. The results confirm that controlled cooling during solidification leads to the formation of a cementite- and ledeburite-rich chilled surface layer, while the inner regions predominantly develop a graphite-based microstructure.

A distinct transition zone was identified between the fully chilled outer layer and the gray cast iron core. This zone is characterized by the simultaneous formation of austenite–graphite and austenite–cementite eutectics, resulting in intermediate hardness and wear resistance compared to the surface and core. The gradual change in microstructure from the surface toward the center highlights the strong influence of cooling rate and chemical composition on phase formation during crystallization.

Hardness measurements revealed a pronounced gradient across the casting cross-section, with maximum values at the surface and a steady decrease toward the core. Subsequent quenching and low-temperature tempering resulted in the formation of a high-carbon martensitic structure with finely dispersed carbides in the surface layer, providing high hardness and improved wear resistance. In contrast, the core retained lower hardness and higher toughness, which is essential for resistance to impact loading during service.

Overall, the applied casting and heat-treatment conditions ensured an optimal combination of surface hardness, wear resistance, and core toughness. The findings demonstrate that surface-chilled grinding balls produced from high-quality cast iron are well suited for industrial applications operating under severe abrasive conditions, offering reliable performance and extended service life.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Fakhraddin, Y.F., 2021. Thermal behavior of N-Methylaniline modified phenolic friction composites. Polymers and Polymer Composites, 29(9_suppl), pp.S688-S695.
2. Yusubov, F.F., 2020. Influence of surface structure of sintered compositions with copper–graphite particles on their tribotechnical properties. Journal of Friction and Wear, 41(2), pp.125-128.
3. Çetin, M. (2019). Abrasive wear behavior of cast Al-Si-Mn alloys. Proc. Inst. Mech. Eng. Part E. J.Process Mech. Eng. (233)4, 908-918, DOI:10.1177/0954408918818735.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

4. Rambabu, P., Prasad, N.E., Kutumbarao, V.V.Wanhill, R.J.H. (2017). Aluminum alloys for aerospace applications, in Aerospace Materials and Material Technologies.Springer. 29-52. DOI: 10.1007/978-981-10-2134-32.
5. Çolak, M., Arslan, I. (2018). Investigation of Wear Properties of Grain Refined and Modified A319 Aluminum Alloy Produced with Sand and Permanent Mold. International Journal of Science and Engineering Investigations,7(83), 134-137.
6. Nosova, E., Erisov, Y., Grechnikov, F. (2017). Multi-cycle rolled aluminum alloy 3103 sandwiches: Mechanical properties and stamp ability. MATEC Web of Conferences.(129), 02021. DOI: 10.1051/matecconf/201712902021.
7. Geng, Y., Panchenko, I., Konovalov, S., Chen, X.Ivanov, Y. (2021). Effect of electron beam energy densities on the surface morphology and tensile property of additively manufactured Al-Mg alloy. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms. (498), 15-22. DOI: 10.1016/j.nimb.2021.04.008.
8. Osintsev, K., Konovalov, S., Gromov, V., Panchenko, I. Chen, X. (2021). Phase composition prediction of Al-Co-Cr-Fe-Ni high entropy alloy system based on thermodynamic and electronic properties calculations.Materials Today: Proceedings. (46), 961-965. DOI:10.1016/j.matpr.2021.01.079.
9. ASTM G44: Practice for evaluating stress corrosion cracking resistance of metals and alloys by alternate immersion in 3.5 % NaCl solution
10. Jambukar, G.B., Kharde, D.Y. (2014). Dry Sliding Wear Behavior of Al-Si-Ti Alloys Using Taguchi Method.International Journal of Science and Research. (3)11,6 p.
11. Kang, N., Coddet, P., Liao, H., Baur, T., Coddet, C.(2016). Wear behavior and microstructure of hypereutectic Al-Si alloys prepared by selective laser melting.Applied Surface Science. (378), 142-149. DOI:10.1016/j.apsusc.2016.03.221.
12. Vidyarthi, M.K., Ghose, A.K., Chakrabarty, I.(2013). Effect of deep cryogenic treatment on the microstructure and wear performance of Cr-Mn-Cu white cast iron grinding media. Cryogenics. (58). 85-92. DOI:10.1016/j.cryogenics.2013.10.005
13. Franco, V., Ashiuchi, E.S., Reißig, L., Araújo, J.A.(2016). Effect of a deep cryogenic treatment on wear and microstructure of a 6101 aluminum alloy.Advances inMaterials Science and Engineering. (2016). 12 p. DOI:10.1155/2016/1582490.
14. Valdés, R., Freulon, A., Deschamps, J.B., Qian,M., Lacaze, J. (2006). Phase equilibria and solidification of Mg-rich Al-Mg-Si alloys. Materials ScienceForum.(508),621628.DOI:10.4028/www.scientific.net/MSF.508.621.

MÜXTƏLİF ZONALARDA YÜKSƏK KEYFİYYƏTLİ ÇUQUNDAN HAZIRLANMIŞ ÜYÜDÜCÜ KÜRƏLƏRİN MİKROSTRUKTUR XÜSUSİYYƏTLƏRİNİN TƏDQİQİ

Rəfiqə Şahmarova[1], Nərgiz Qurbanlı[2]
[1]Dosent, texnika üzrə fəlsəfə doktoru, "Materialşünaslıq və emal texnologiyaları" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, E-mail: shahmarova_1970@mail.ru, https://orcid.org/0000-0002-2613-5742
[2]Magistrant, "Materialşünaslıq və emal texnologiyaları" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, E-mail: nargiz.qurbanova03@mail.ru

XÜLASƏ

Bu məqalə yüksək keyfiyyətli çuqundan hazırlanmış üyüdücü kürələrin sənaye əhəmiyyətinin və istehsal proseslərinin hərtərəfli təhlilini təqdim edir. Üstün mexaniki xüsusiyyətləri, yüksək sıxlığı, sərtliyi və iqtisadi səmərəliliyi sayəsində çuqun uzun müddətdir ki, bir çox sənaye sahələrində geniş istifadə olunan materialdır. Xüsusilə, onun üyüdücü kürələrin istehsalında tətbiqi yüksək təzyiq və yüksək sürtünmə şəraitində əla aşınmaya davamlılığı və dayanıqlığı ilə əlaqədardır. Səthi bərkidilmiş çuqunlar faydalı qazıntıların emalı sənayesində əzici və üyüdücü komponentlərin istehsalında geniş istifadə olunur. Bu tətbiqlərdən əlavə, yüksək keyfiyyətli səthi bərkidilmiş çuqundan hazırlanmış üyüdücü kürələr paylayıcı vallar, qum emalı avadanlıqları və odadavamlı material sexləri kimi avadanlıqlarda yüksək mexaniki göstəricilər nümayiş etdirir.
Tədqiqat ilk olaraq çuqunun kimyəvi tərkibini və fiziki xüsusiyyətlərini araşdırır, karbonun miqdarının və legirləyici elementlərin əlavə edilməsinin sərtliyə, möhkəmliyə və istismar uyğunluğuna təsirini vurğulayır. Xrom, molibden və digər legirləyici elementlərin əlavə edilməsi çuqun matrisinin aşınmaya və korroziyaya davamlılığını daha da artırır. İstehsal prosesi ərimiş çuqunun qəliblərə tökülməsini, ardınca isə üyüdücü kürələrin mikrostrukturunun ətraflı təhlilini və optimallaşdırılmasını əhatə edir. Hər mərhələdə texnoloji parametrlər məhsulların son mexaniki xüsusiyyətlərinin, aşınmaya davamlılığının və ümumi istismar müddətinin müəyyən edilməsində mühüm rol oynayır.
Açar sözlər: çuqun, üyüdücü kürələr, mikrostruktur, səthi bərkitmə, yeyilməyə davamlılıq, mexaniki xüsusiyyətlər, sənaye tətbiqləri.

ИССЛЕДОВАНИЕ МИКРОСТРУКТУРНЫХ ХАРАКТЕРИСТИК МЕЛЮЩИХ ШАРОВ ИЗ ВЫСОКОКАЧЕСТВЕННОГО ЧУГУНА В РАЗЛИЧНЫХ ЗОНАХ

Рафига Шахмарова[1], Наргиз Гурбанлы[2]
[1]Доцент, кандидат технических наук, кафедра «Материаловедение и технологии обработки», Азербайджанский государственный университет нефти и промышленности,
E-mail: shahmarova_1970@mail.ru, https://orcid.org/0000-0002-2613-5742
[2]Магистрант, кафедра «Материаловедение и технологии обработки», Азербайджанский государственный университет нефти и промышленности, E-mail: nargiz.qurbanova03@mail.ru

РЕЗЮМЕ

В данной статье представлен всесторонний анализ промышленной значимости и процессов производства мелющих шаров из высококачественного чугуна. Благодаря высоким механическим характеристикам, высокой плотности, твердости и экономической эффективности чугун на протяжении длительного времени широко применяется в различных отраслях промышленности. В частности, его использование при производстве мелющих шаров обусловлено высокой износостойкостью и долговечностью в условиях высокого давления и интенсивного трения. Поверхностно упрочнённые чугуны широко используются при изготовлении дробящих и измельчающих компонентов в горно-обогатительной промышленности. Помимо этого, мелющие шары из высококачественного поверхностно упрочнённого чугуна демонстрируют высокие механические показатели в

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

таком оборудовании, как распределительные валы, машины для обработки песка и цеха по производству огнеупорных материалов.

В исследовании вначале рассматриваются химический состав и физические свойства чугуна, подчёркивается влияние содержания углерода и введения легирующих элементов на твердость, прочность и эксплуатационную пригодность. Добавление хрома, молибдена и других легирующих элементов способствует дальнейшему повышению износостойкости и коррозионной стойкости чугунной матрицы. Производственный процесс включает заливку расплавленного чугуна в формы с последующим детальным анализом и оптимизацией микроструктуры мелющих шаров. Технологические параметры на каждом этапе играют важную роль в определении конечных механических свойств, износостойкости и общего срока службы изделий.

Ключевые слова: чугун, мелющие шары, микроструктура, поверхностное упрочнение, износостойкость, механические свойства, промышленное применение.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

91-95

Publication history
Article received: 09.02.2026
Article accepted: 23.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-10

WELL COMPLETION

Elmir Garagozov[1], Sadig Hasanli[2]
[1]Lecturer, Department of Petroleum Engineering, Azerbaijan State University of Oil and Industry, Azerbaijan, hesenlisadiq94@gmail.com
[2]Master's student, Petroleum Engineering, Azerbaijan State University of Oil and Industry, Azerbaijan, hesenlisadiq94@gmail.com

ABSTRACT

This article examines the technological aspects of oil and gas well completion and evaluates its impact on production efficiency and operational reliability. Well completion represents the final stage after drilling and plays a critical role in establishing a reliable connection between the productive formation and surface facilities, as well as ensuring safe, stable, and economically efficient hydrocarbon production. Inadequate or improperly designed completion operations may result in reduced well productivity, operational complications, and an increased risk of failures during field development.

The main objective of this study is to provide a theoretical understanding of the well completion process, systematize the principal completion methods, and analyze their technological advantages. The research is based on a comprehensive review and comparative analysis of relevant domestic and international scientific and technical literature related to well completion technologies.

The results of the analysis indicate that the selection of an appropriate completion method is governed by a combination of geological and technical factors, including reservoir structure, rock physical and mechanical properties, reservoir pressure, temperature conditions, and the overall development strategy of the field. Open-hole, cased-hole, and selective completion methods are identified as the most commonly applied approaches. Properly selected and well-designed completion technology contributes to improved hydrocarbon recovery, extended well service life, and reduced operational and safety risks. The findings of this study may be useful for students of petroleum engineering and professionals working in the oil and gas industry.

Keywords: Well completion, oil and gas wells, production, well equipment, cementing.

Introduction

Drilling oil and gas wells is a complex and costly operation in the petroleum industry. However, the activities carried out after drilling largely determine whether a well can be put into safe and efficient production. One of the most important of these stages is well completion. The completion process establishes a controlled connection between the reservoir and the wellbore, enabling hydrocarbons to be produced safely and efficiently.

If the completion process is not properly designed and implemented, uncontrolled fluid and gas flow may occur, wellbore instability can develop, and unwanted water production from the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

reservoir may take place. Therefore, well completion has significant technical and economic importance. With the increasing complexity of modern reservoirs, a customized approach to well completion is required. A single completion method cannot be effectively applied to all reservoirs or even to all wells within the same field. This article provides a general overview of well completion concepts, types, and application areas in a simplified and accessible manner, emphasizing the importance of the completion process in oil and gas production.

Materials and methods

Materials Used

This study is based on textbooks, scientific articles, and technical manuals related to oil and gas well completion. Special attention is given to the stages of the completion process, the equipment involved, and the technologies used in modern completion practices.

Research Method

The research is primarily theoretical in nature and employs the following methods:

- Review and analysis of scientific literature
- Comparison of different well completion techniques
- Generalization of practical field experience

Modern completion methods are described in greater detail, while conventional techniques are briefly summarized for comparison purposes.

Results

Open-Hole Completion

Open-hole completion is one of the simplest and oldest completion techniques. In this method, the reservoir is left directly exposed to the wellbore without the use of casing across the producing interval. Open-hole completion is typically applied in competent and stable formations. Its main advantage is low cost and operational simplicity. However, controlling the reservoir becomes more difficult, and the risk of wellbore collapse is relatively high.

Cased-Hole Completion

In cased-hole completion, the wellbore is lined with steel casing and cemented in place to isolate the formation. Perforations are then created to establish communication between the reservoir and the wellbore. This method provides better formation protection and improves operational safety. Due to its reliability and flexibility, cased-hole completion is widely used in most modern oil and gas fields.

Selective Completion

Selective completion allows the production of multiple reservoirs through a single well while controlling each zone independently. Flow from each layer can be regulated separately using specialized downhole equipment. Although this method is more complex and expensive, it offers significant advantages in terms of production optimization and economic efficiency

Discussion

The analysis demonstrates that there is no universal approach to well completion. Since each reservoir has unique geological and operational characteristics, the completion method must be selected accordingly. Compared to earlier studies, modern completion technologies have been shown to improve production performance and reduce technical risks. In the future, the application of intelligent well systems may further enhance completion practices. These advanced technologies enable real-time monitoring of reservoir conditions and automated production control, contributing to more efficient field development.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Mirzajanzadeh, A.Kh. Drilling and Completion of Oil and Gas Wells. Baku: Elm, 1987.
2. Ismayilov, Sh.A. Operation of Oil and Gas Wells. Baku: ADNA Publishing House, 2006.
3. Bourgoyne, A.T., Millheim, K.K., Chenevert, M.E., Young, F.S. Applied Drilling Engineering. Richardson, Texas: Society of Petroleum Engineers, 1986.
4. Economides, M.J., Hill, A.D., Ehlig-Economides, C. Petroleum Production Systems. New Jersey: Prentice Hall, 1994.
5. Lake, L.W. Petroleum Engineering Handbook, Volume II: Drilling Engineering.
6. Richardson, Texas: Society of Petroleum Engineers, 2006.
7. Schlumberger. Well Completion Engineering Manual. Houston: Schlumberger Limited, 1998.

ЗАВЕРШЕНИЕ СКВАЖИН

Эльмир Карагёзов[1], Садыг Гасанли[2]

[1]Преподаватель кафедры «Нефтегазовое дело», Азербайджанский государственный университет нефти и промышленности, Азербайджан, hesenlisadiq94@gmail.com

[2]Магистрант, специальность «Нефтегазовое дело», Азербайджанский государственный университет нефти и промышленности, Азербайджан, hesenlisadiq94@gmail.com

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

РЕЗЮМЕ

В статье исследуются технологические особенности процесса завершения нефтяных и газовых скважин и оценивается его влияние на эффективность и davamlılığı hasilat prosesinin. Завершение скважины представляет собой завершающий этап после бурения и играет ключевую роль в обеспечении надежной связи между продуктивным пластом и наземным оборудованием, а также в создании условий для безопасной, стабильной и экономически обоснованной добычи углеводородов. Ошибки, допущенные на стадии завершения, могут привести к снижению дебита скважины, возникновению осложнений в процессе эксплуатации и увеличению вероятности аварийных ситуаций.

Целью данной работы является теоретическое обоснование процесса завершения скважин, систематизация основных методов завершения и анализ их технологических преимуществ. В рамках исследования проведён обзор и сравнительный анализ отечественных и зарубежных научно-технических источников, посвящённых вопросам завершения скважин. Результаты исследования показывают, что выбор метода завершения определяется совокупностью геолого-технических факторов, включая строение пласта, физико-механические свойства пород, пластовое давление и температурный режим, а также стратегию разработки месторождения. Наиболее распространёнными являются методы открытого, обсаженного и селективного завершения скважин. Оптимально подобранная технология завершения способствует повышению коэффициента извлечения углеводородов, увеличению срока эффективной эксплуатации скважин и снижению производственных рисков. Материалы статьи могут представлять практический и учебный интерес для студентов нефтегазовых специальностей и специалистов отрасли.

Ключевые слова: завершение скважин, нефтяные и газовые скважины, добыча, скважинное оборудование, цементирование.

QUYULARIN TAMAMLANMASI

Elmir Qaragözov[1], Sadiq Həsənli [2]

[1]Neft-qaz mühəndisliyi, Neft-qaz mühəndisliyi departmenti, , Azərbaycan Dövlət Neft və Sənaye Universiteti, müəllim, Azərbaycan, hesenlisadiq94@gmail.com

[2]Magistrant, Neft-qaz mühəndisliyi, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, hesenlisadiq94@gmail.com

XÜLASƏ

Məqalədə neft və qaz quyularının tamamlanması prosesinin texnoloji xüsusiyyətləri araşdırılır və bu prosesin hasilatın səmərəliliyinə və davamlılığına təsiri qiymətləndirilir. Quyuların tamamlanması qazma işlərindən sonra həyata keçirilən son mərhələ olub, məhsuldar lay ilə yerüstü avadanlıqlar arasında etibarlı əlaqənin təmin edilməsində, həmçinin karbohidrogenlərin təhlükəsiz, stabil və iqtisadi cəhətdən səmərəli hasilatı üçün zəruri şəraitin yaradılmasında mühüm rol oynayır. Tamamlanma mərhələsində buraxılan texnoloji səhvlər quyu debitinin azalmasına, istismar zamanı müxtəlif ağırlaşmaların yaranmasına və qəza risklərinin artmasına səbəb ola bilər.

Bu işin məqsədi quyuların tamamlanması prosesinin nəzəri əsaslandırılması, əsas tamamlanma üsullarının sistemləşdirilməsi və onların texnoloji üstünlüklərinin təhlilindən ibarətdir. Tədqiqat

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

çərçivəsində quyuların tamamlanması problemlərinə həsr olunmuş yerli və xarici elmi-texniki mənbələrin icmalı və müqayisəli təhlili aparılmışdır.
Tədqiqat nəticələri göstərir ki, tamamlanma üsulunun seçimi layın geoloji quruluşu, süxurların fiziki-mexaniki xüsusiyyətləri, lay təzyiqi və temperatur rejimi, eləcə də yatağın işlənmə strategiyası kimi geoloji-texniki amillərin məcmusundan asılıdır. Ən geniş tətbiq olunan tamamlanma üsullarına açıq, kəmərlənmiş və selektiv tamamlanma metodları daxildir. Optimal seçilmiş tamamlanma texnologiyası karbohidrogenlərin çıxarılma əmsalının artırılmasına, quyuların səmərəli istismar müddətinin uzadılmasına və istehsalat risklərinin azaldılmasına şərait yaradır. Məqalənin materialları neft-qaz ixtisasları üzrə təhsil alan tələbələr və sahə mütəxəssisləri üçün elmi-praktik əhəmiyyət daşıyır.
Açar sözlər: Quyu tamamlanması, neft və qaz quyuları, hasilat, quyu avadanlıqları, sementləmə.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

96-105

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-11

RESEARCH ON THE TECHNOLOGY OF OPERATING PUMP-COMPRESSOR STATIONS IN THE OPERATION OF THE "GARADAGH" AND "GALMAZ" UNDERGROUND GAS STORAGE FACILITIES

Abdulagha Gurbanov[1], Ismail Valiyev[2]
[1]Doctor of Philosophy (Technical), "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: qabdulaga@mail.ru
[2]Master's Degree Student, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: valiyev630@icloud.com

ABSTRACT

This article examines in detail the technological processes, operating parameters and technical characteristics of pump-compressor stations used in the "Garadagh" and "Galmaz" underground gas storage facilities of Azerbaijan. Underground gas storage facilities are vital infrastructure facilities for seasonal and strategic storage of natural gas. The efficient operation of these storage facilities plays an important role in ensuring the country's energy security. The article analyzes the technical problems encountered in the operation of pump-compressor stations, the operating modes of equipment, the impact of pressure changes on the system and ways to increase energy efficiency. Also, technological solutions that ensure optimal operation of pump and compressor units in the processes of pumping and extracting gas from storage facilities are considered. The results of the study show that the application of modern automation systems, systematic monitoring of the technical condition of equipment and planning of preventive maintenance work significantly increase the reliability of pump-compressor stations. The article is intended for specialists and researchers working in the field of operation of underground gas storage facilities. The purpose of the article is to analyze in detail the technological processes, operational parameters, technical problems, and ways to increase energy efficiency of the pump-compressor stations used in the "Garadagh" and "Galmaz" underground gas storage facilities.
Keywords: underground gas storage, pump-compressor station, compressor units, pressure regime, energy efficiency, technical operation, automation systems, Garadagh, Galmaz.

Introduction

Underground gas storage facilities are an integral part of modern gas supply systems and are of strategic importance in ensuring the country's energy security. Underground gas storage facilities allow for the use of reserves during periods of increased seasonal demand for natural gas and ensure the continuity of production. The Garadagh and Galmaz underground gas storage facilities in Azerbaijan are the largest gas storage facilities created for this purpose.

The Garadagh underground gas storage facilities are located in the Garadagh district, southeast of Baku, and were commissioned in the 1960s. The total volume of the storage facility is approximately 1.2 billion cubic meters and the maximum operating pressure is in the range of 25-30 MPa. The Galmaz underground gas storage facilities are located in the western part of the Absheron Peninsula and were commissioned in the early 2000s. The volume of this storage facility is approximately 700 million cubic meters and the operating pressure is 20-25 MPa.
Pump-compressor stations (Pump-compressor stations) with high technical parameters have been built in both storage facilities to carry out gas injection and extraction processes. Pump-compressor stations ensure that gas is injected into the storage facilities under high pressure and, when necessary, extracted and transferred to the main gas pipelines. The effective management of these processes depends on the reliable operation of technical equipment, the selection of optimal operating modes and the application of modern monitoring systems.
The purpose of the article is to analyze in detail the technological processes, operational parameters, technical problems and ways to increase energy efficiency of the Pump-compressor stations used in the "Garadagh" and "Galmaz" underground gas storage facilities.

Purpose and structure of pump-compressor stations

Main functions of pump-compressor stations

Pump-compressor stations are the main technological node of underground gas storage facilities and perform the following functions:
1. Pressure Control and Compression Function. The main task of pump-compressor stations is to purposefully change the gas pressure. Natural gas entering from the main gas network is under a pressure of 5-8 MPa. However, for effective storage of gas in underground geological structures, the pressure must be raised to the range of 20-30 MPa. For this purpose, multi-stage compressor units sequentially compress the gas, and the pressure progressively increases at each stage.
2. Gas Quality Preparation. In the pump-compressor station system, the physicochemical parameters of the gas are adjusted to the standards:
- Mechanical cleaning: Solid particles and other impurities are separated from the gas through separators and multi-stage filter systems
- Dehydration (drying): The water vapor content is reduced by absorption or adsorption methods and the dew point is lowered to the range of -15°C - -25°C
- Fraction separation: The process of condensation and separation of heavy hydrocarbon compounds is carried out
3. Thermal Regime Regulation. During compression, the gas temperature rises sharply. Multiple cooling nodes are installed in the NKS. At this time, interstage coolers return the gas temperature to the range of 30-45°C. This process both increases the efficiency of the next compression stage and reduces thermal stresses. At the last stage, final cooling is performed and the gas is directed to the wells at the optimum temperature.
4. Hydraulic Control and Flow Management. The intensity and direction of the gas flow in the pump-compressor station complex is precisely controlled. The gas velocity is regulated by means of regulator valve systems, multi-branch pipe manifolds ensure the distribution of gas to various wells. In addition, the flow is continuously measured by debitometer devices
5. Energy Transformation. In the pump-compressor station, electrical energy is converted into mechanical energy, and then into the form of potential energy (pressure) of the gas. Electric

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

motors generate high power (5-15 MW), transmission mechanisms transmit this energy to the compressor shafts. Compressor rotors or pistons compress the gas and create pressure energy

6. Technological Safety Function. Multi-level protection mechanisms operate in the pump-compressor station system:

- Safety valves automatically open when the pressure limit is exceeded
- Temperature sensors stop the compressors in case of critical overheating
- Vibration detectors detect abnormal vibrations
- Gas leak detectors prevent gas from being released into the atmosphere
- Fire and explosion protection systems are installed

7. Data Collection and Monitoring. Modern pump-compressor stations are equipped with an extensive sensor network. 300-500 different types of sensors send information, pressure, temperature, vibration, flow rate and other parameters are monitored.

8. Environmental Control Function. Minimization of environmental impact during pump-compressor station operation:

Emission monitoring systems monitor gas emissions into the atmosphere, tightness tests are regularly carried out, noise levels are kept within the norm, and leakage of oil and chemicals into the soil is prevented.

Effective implementation of these functions ensures reliable and safe operation of underground gas storage facilities.

Types and technical characteristics of compressor units

Different types of compressor units are used in the "Garadagh" and "Galmaz" underground gas storage facilities. They differ in their productivity, pressure ranges and operating principles:

1. Centrifugal compressors: They have high productivity and operate efficiently in stable operation. This type of compressors compress gas in several stages, and the pressure increases by 4-6 MPa at each stage. Centrifugal compressors are mainly used in the "Garadagh" underground gas storage facilities. The installed capacity of these compressors is between 5-10 MW.

2. Piston compressors: They are capable of creating high pressure. Piston compressors are used in the "Galmaz" underground gas storage facilities to pump gas into the deep parts of the storage facility. These units can create a pressure of 30-35 MPa.

3. Screw compressors: They are distinguished by their compact size and low noise level. They are mainly used in auxiliary systems and for compressing small gas flows.

Table 1. provides technical characteristics of the main compressor units used in the "Garadagh" and "Galmaz" underground gas storage facilities.

Compressor type	Productivity (min m³/hour)	Outlet pressure (MPa)	Installed power (MW)
Centrifugal (Garadagh)	80-120	25-28	8-10
Piston (Galmaz)	30-50	30-35	5-7
Wintli (assistant)	10-20	15-20	2-3

As can be seen from the table, each type of compressor meets certain technological requirements and is selected according to the optimal operating mode.

Gas injection process and technological parameters

The process of injecting gas into the storage tank consists of several stages, and it is important to adhere to certain technological parameters at each stage.

Gas reception and initial preparation

The gas coming from the main gas pipeline undergoes a number of preparatory processes before entering the pump-compressor station:

Cleaning process: The gas is cleaned of mechanical impurities (dust, rust particles). For this purpose, cyclone and filter separators are used. The accuracy of the filters is 5-10 microns.

Drying process: Water vapor contained in the gas can cause corrosion and hydrate formation in compressor equipment. Therefore, the gas is dried in glycerine units. The moisture point of the gas is reduced to below -20°C.

Measurement and accounting: The volume and parameters of the gas (pressure, temperature, flow) are accurately measured and recorded. For this purpose, turbine and ultrasonic meters are used.

Compressor stages and pressure increase

After initial preparation, the gas is compressed in several stages:

First stage: The gas comes from the main pipeline at a pressure of 6-8 MPa and is raised to 12-15 MPa in the first stage compressor.

Intercooling: During compression, the gas temperature rises to 80-100°C. Since this temperature is high for the next stage, the gas is cooled to 30-40°C in the intercooler. Air or water coolers are used for cooling.

Second stage: The cooled gas is raised to a pressure of 20-23 MPa in the second stage compressor. At this stage, the temperature also increases and the gas is cooled again.

Third stage: In the final stage, the gas is brought to a pressure of 25-30 MPa and transmitted to the wells under high pressure. In this process, the gas temperature is controlled and does not exceed 60°C.

It is very important to monitor the pressure and temperature parameters in the compressor stages. For this purpose, pressure and temperature sensors are installed at each stage. The data received in real time is transmitted to the dispatch center and monitored by operators.

Gas injection into wells and reservoir pressure management.

The gas produced under high pressure is directed to the wells for injection into the underground storage. There are 8 gas injection wells in the "Garadagh" Underground Gas Storage Facility, and 6 in the "Galmaz" Underground Gas Storage Facility. The following parameters are monitored during gas injection into the wells:

Injection rate: The rate of gas injection into each well is selected according to the reservoir's capacity. In general, the injection rate varies between 20-40 thousand m³/day. Too high a rate can cause cracks to form in the reservoir and gas to pass into neighboring layers.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Bottom-hole pressure: The bottom-hole pressure is continuously measured and compared with the wellhead pressure. The hydrostatic pressure difference and friction losses are taken into account. Too high a bottom-hole pressure can cause mechanical damage to the reservoir.
Formation pressure monitoring: The total pressure of the reservoir is measured regularly. The goal is to maintain the pressure in the range of 25-30 MPa. Pressure outside this range can cause problems in the gas extraction process.

Gas removal process from storage
Gas is released from storage during periods of seasonal demand or in emergencies. This process works in the opposite direction to gas injection but is technologically simpler.

Gas extraction from wells
During the extraction process, gas rises to the surface from the wells due to its own formation pressure. Since the formation pressure is high enough, additional compression is not required. The gas is collected in wellhead manifolds and then undergoes cleaning and regulation stages:
Cleaning: Gas can come with mechanical impurities and water droplets when it comes out of the formation. For this reason, the gas undergoes re-cleaning and drying processes.
Pressure regulation: The pressure of the gas coming out of the reservoir is 20-25 MPa. However, this pressure must be reduced to 6-8 MPa to be supplied to the main pipelines. For this purpose, pressure regulating devices are used. During pressure reduction, the gas temperature drops and the gas is heated using heat exchangers.
Measurement and accounting: The volume and quality parameters of the extracted gas are measured and recorded. This data is used to calculate the gas balance of the reservoir.
Control of the extraction mode
In the extraction process, it is important to extract gas at an optimal speed. Too rapid extraction can lead to a sharp drop in reservoir pressure and a decrease in well productivity. Typically, the gas extraction rate is maintained at 50-80 thousand m^3/day. During the extraction period, the reservoir pressure can drop to 12-15 MPa, but it is not recommended to drop lower, as this can complicate the subsequent filling process.

Problems encountered during the operation of pump-compressor stations
Several technical problems arise during the operation of pump-compressor stations in underground gas storage facilities. These problems lead to a decrease in the efficiency of the equipment and an increase in operating costs.
Wear and corrosion of compressors.
Compressor units operate at high pressure and high temperature. Under these conditions, equipment parts wear out quickly. Valves, pistons and cylinders in piston compressors wear out quickly. The corrosion problem is due to the presence of sulfide and water vapor in the gas. As a result of corrosion, damage occurs in pipelines and compressor parts and repairs are required.
Vibration and noise.
High vibration and noise occur during the operation of compressors. This occurs as a result of equipment imbalance, bearing wear or mechanical damage. Vibration can weaken the design of the equipment and create a dangerous situation.
Violation of temperature regimes.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The gas temperature is high during the compression process. If the cooling systems do not work properly, the gas temperature can reach a critical level, which can lead to equipment breakdown. It is important to calibrate temperature sensors correctly and regularly check cooling systems.

Power outages.

Compressor stations consume a large amount of electricity. Power outages cause compressors to stop and processes to be disrupted. Backup generators are installed to prevent this problem. However, since backup power is also limited, prolonged power outages are dangerous.

Automation and monitoring systems

Modern pump-compressor stations use process automation and real-time monitoring systems. These systems reduce the workload of operators and help prevent accidents.

SCADA systems.

The SCADA (Supervisory Control and Data Acquisition) system provides control of pump-compressor stations from the dispatch center. The main functions of the system:

- Real-time collection and visualization of all sensor data
- Remote control of equipment operation
- Immediate delivery of accident signals to operators
- Recording and analysis of historical data

Accident protection systems.

Accident protection systems automatically intervene when critical parameters exceed limits. For example, if pressure or temperature exceeds limits, the system automatically stops the compressors and opens safety valves. These systems prevent potential explosions or equipment accidents.

Vibration and temperature monitoring.

Vibration and temperature sensors installed in compressor units continuously monitor the technical condition of the equipment. Based on this data, predictive maintenance plans are developed. If the vibration level exceeds the normal limit, it indicates wear of bearings or other parts. Thus, preventive repairs can be made before an accident occurs.

Ways to increase energy efficiency

Pump-compressor stations consume a large amount of electricity. The monthly electricity consumption during gas injection at the Garadagh Underground Gas Storage Facility is approximately 15-20 million kWh. Increasing energy efficiency is important in terms of reducing operating costs and minimizing environmental impact.

Optimization of compressor modes.

The operating mode of the compressors should be optimized according to demand. For example, when the gas injection rate is low, there is no need for all compressors to operate simultaneously. Operating several compressors in turn reduces energy consumption by 20-25%. Also, maintaining the compressor load mode in the range of 70-85% ensures optimal energy efficiency.

Heat recovery.

Part of the thermal energy generated during compression is lost without being used. Heat recovery systems allow this energy to be reused. For example, hot water is prepared with the cooling water of the compressors and this water is used to heat the buildings of the pump-compressor station. In this way, it is possible to reduce energy consumption by 10-15%.

Frequency converters.
The use of frequency converters (VFD - Variable Frequency Drive) in electric motors allows you to adjust the speed of compressors according to demand. Compared to compressors operating at a fixed speed, frequency converter compressors consume 15-30% less energy.
Improvement of cooling systems.
The efficiency of compressors depends on the quality of cooling systems. The use of modern air coolers, frequency converter control of cooling fans and the selection of optimal parameters of cooling fluids increase energy efficiency.

Conclusıons

1. Pump-compressor stations are the most important technological node of underground gas storage facilities, and their reliable operation ensures the country's energy security.
2. Correct selection of the type of compressor units, optimization of operating modes, and systematic monitoring of their technical condition extend the service life of the equipment and reduce costs.
3. Accurate control of pressure and temperature parameters during the process of pumping and extracting gas from the storage facility is essential for ensuring technological safety.
4. The main problems encountered during operation - corrosion, wear, vibration, and power outages - can be minimized by regular preventive maintenance and the use of modern monitoring systems.
5. The introduction of SCADA systems and emergency protection systems reduces the workload of operators and prevents accidents.
6. To increase energy efficiency, it is recommended to optimize compressor modes, install heat recovery systems, and use frequency converters.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Aliyev R.Sh., Hasanov T.M. "Creation and operation of underground gas storages in Azerbaijan". Journal of Oil and Gas Technology. Baku, 2021, No. 2, pp. 34-42.
2. Mammadov I.G. "Geological and technical characteristics of Garadagh and Galmaz underground gas storages". Scientific Works of ASOIU. Baku, 2020, No. 3, pp. 78-86.
3. Guliyev N.A., Abdullayev G.S. "Application of pump-compressor stations in underground gas storages". Journal of Energy and Technology. Baku, 2022, No. 1, pp. 56-64.
4. Rzayev F.H. "Technology of gas purification and drying at compressor stations". Journal of Chemistry and Oil and Gas. Baku, 2021, No. 4, pp. 102-109.
5. Ahmadov V.A. "Types and principles of selection of compressor units". Mechanics and Mechanical Engineering. Baku, 2020, No. 2, pp. 45-53.
6. Ismayilov Sh.Y. "Methods of measuring and accounting for gas flow". Metrology and Standardization. Baku, 2019, No. 3, pp. 67-74.
7. Hasanov R.M., Jafarov E.S. "Monitoring and management of reservoir pressure in underground gas storage facilities". Oil and Gas Engineering. Baku, 2022, No. 2, pp. 88-96.
8. Maharramov A.I. "Optimization of the process of gas extraction from the storage facility". Energy Problems Journal. Baku, 2021, No. 1, pp. 112-119.
9. Baghirov A.R. "Technical problems during the operation of NPS and their solutions". Technical Safety. Baku, 2020, No. 4, pp. 134-142.
10. Musayev E.K., Gasimov Y.H. "Automation and monitoring systems in compressor equipment". Automation and Control. Baku, 2022, No. 3, pp. 78-87.
11. Aliyev S.A. "Increasing energy efficiency in pump-compressor stations". Renewable Energy. Baku, 2021, No. 2, pp. 56-65.

"QARADAĞ" VƏ "QALMAZ" YERALTI QAZ ANBARLARININ ISTISMARINDA NASOS-KOMPRESSOR STANSIYALARININ IŞLƏNMƏSI TEXNOLOGIYASININ TƏDQIQI

Əbdülağa Qurbanov[1], İsmayıl Vəliyev[2]
[1]Texnika üzrə fəlsəfə doktoru, "Neftin-Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: qabdulaga@mail.ru
[2]Magistr, "Neftin Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: valiyev630@icloud.com

XÜLASƏ

Bu məqalədə Azərbaycanın "Qaradağ" və "Qalmaz" yeraltı qaz anbarlarında tətbiq olunan nasos-kompressor stansiyalarının texnoloji prosesləri, istismar parametrləri və texniki xüsusiyyətləri ətraflı şəkildə araşdırılmışdır. Yeraltı qaz anbarları təbii qazın mövsümi və strategik saxlanması üçün həyati əhəmiyyət kəsb edən infrastruktur obyektləridir. Bu anbarların səmərəli işləməsi ölkənin enerji təhlükəsizliyinin təmin olunmasında mühüm rol oynayır. Məqalədə Nasos-kompressor stansiyası-lərin istismarında qarşılaşılan texniki problemlər, avadanlıqların iş rejimləri, təzyiq dəyişmələrinin sistemə təsiri və enerji səmərəliliyinin artırılması yolları təhlil

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

edilmişdir. Habelə, qazın anbarlara vurulması və çıxarılması proseslərində nasos və kompressor qurğularının optimal işləməsini təmin edən texnoloji həllər nəzərdən keçirilmişdir. Tədqiqatın nəticələri göstərir ki, müasir avtomatlaşdırma sistemlərinin tətbiqi, avadanlıqların texniki vəziyyətinin sistemli monitorinqi və profilaktik təmir işlərinin planlaşdırılması Nasos-kompressor stansiyası-lərin etibarlılığını əhəmiyyətli dərəcədə artırır. Məqalə yeraltı qaz anbarlarının istismarı sahəsində çalışan mütəxəssislər və tədqiqatçılar üçün nəzərdə tutulmuşdur. Məqalənin məqsədi "Qaradağ" və "Qalmaz" yeraltı qaz anbarlarında istifadə olunan Nasos-kompressor stansiyasıların texnoloji proseslərini, istismar parametrlərini, texniki problemlərini və enerji səmərəliliyinin artırılması yollarını ətraflı təhlil etməkdir.

Açar sözlər: yeraltı qaz anbarı, nasos-kompressor stansiyası, kompressor qurğuları, təzyiq rejimi, enerji səmərəliliyi, texniki istismar, avtomatlaşdırma sistemləri, Qaradağ Yeraltı qaz anbarları, Qalmaz Yeraltı qaz anbarları

ИССЛЕДОВАНИЕ ТЕХНОЛОГИИ ЭКСПЛУАТАЦИИ НАСОСНО-КОМПРЕССОРНЫХ СТАНЦИЙ ПРИ РАБОТЕ ПОДЗЕМНЫХ ГАЗОХРАНИЛИЩ «ГАРАДАГ» И «ГАЛМАЗ»

Абдулага Гурбанов[1], Исмаил Валиев[2]
[1]Доктор философии (техническая специальность), “Кафедра транспорта и хранения нефти и газа”, “Азербайджанский Государственный Университет Нефти и Промышленности”, Азербайджан.
E-mail: qabdulaga@mail.ru
[2]Магистрант, “Кафедра транспорта и хранения нефти и газа”, “Азербайджанский Государственный Университет Нефти и Промышленности”, Азербайджан. E-mail: valiyev630@icloud.com

РЕЗЮМЕ

В данной статье подробно рассматриваются технологические процессы, рабочие параметры и технические характеристики насосно-компрессорных станций, используемых на подземных газохранилищах Азербайджана «Гарадаг» и «Галмаз». Подземные газохранилища являются жизненно важными объектами инфраструктуры для сезонного и стратегического хранения природного газа. Эффективная эксплуатация этих хранилищ играет важную роль в обеспечении энергетической безопасности страны. В статье анализируются технические проблемы, возникающие при эксплуатации насосно-компрессорных станций, режимы работы оборудования, влияние изменений давления на систему и пути повышения энергоэффективности. Также рассматриваются технологические решения, обеспечивающие оптимальную работу насосно-компрессорных агрегатов в процессах перекачки и извлечения газа из хранилищ. Результаты исследования показывают, что применение современных систем автоматизации, систематический мониторинг технического состояния оборудования и планирование работ по профилактическому техническому обслуживанию значительно повышают надежность насосно-компрессорных станций. Статья предназначена для специалистов и исследователей, работающих в области эксплуатации подземных газохранилищ. Цель статьи – детальный анализ технологических процессов, параметров эксплуатации, технических проблем и способов повышения энергоэффективности насосно-компрессорных станций, используемых на подземных газохранилищах «Гарадаг» и «Галмаз».

Ключевые слова: подземное газохранилище, насосно-компрессорная станция, компрессорные установки, режим давления, энергоэффективность, техническая эксплуатация, системы автоматизации, подземное газохранилище Гарадаг, подземное газохранилище Гальмаз.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

106-113

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-12

ENHANCING RESIDUAL OIL RECOVERY EFFICIENCY THROUGH THE APPLICATION OF WATER FLOW RESTRICTION TECHNOLOGIES IN OIL WELLS

Khasay Feyzullayev[1], Sanan Abdulkarimov[2]
[1]Doctor of technical sciences, chief scientific officer, Department of "Petroleum and Gas Engineering", Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: feyzullayevxasay@gmail.com
[2]Master's student, Department of "Petroleum and Gas Engineering", Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: senan.abdulkerimov.03@gmail.com

ABSTRACT

It is known that prolonged operation changes the heterogeneity of the formation in oil and gas fields. In areas with high permeability, water creates an intense flow channel, resulting in a rapid increase in water cut in production wells. This uncontrolled process simultaneously reduces productivity and leads to significant reserves of residual oil in the formation remaining unused. As part of the current study, technologies based on the principles of mechanical, chemical, and selective action, used to limit water flow, are compared in terms of their suitability for formation characteristics and field results; polymer gel systems, special reagents, zonal isolation approaches, and perforation solutions are evaluated according to the degree of heterogeneity. Such programs are considered one of the main tools for reducing technological risks and maintaining economic efficiency in the final stage of operation, since closing water flows and plugging high-permeability channels improves the water-oil balance, restores a stable production trajectory, and increases the potential for additional oil supply. In this regard, the article discusses the possibilities of increasing the efficiency of developing residual oil reserves using technologies that limit the inflow of water into oil wells. In connection with the above, the article considers the possibilities of increasing the efficiency of exploitation of residual oil reserves by applying technologies that limit water flow to oil wells. As a result, it is determined that limiting water flow is one of the main approaches that ensure more efficient extraction of residual oil reserves, and this method controls the heterogeneity of the reservoir, optimizes the flow trajectory and increases the mobility of oil; Polymer-gel systems, water-selective reagents and other technologies effectively limit the movement of water, preserves the fluidity of the oil phase and increases production; limiting the flow by interval creates conditions for protecting productive zones in areas with high water content and using the microstructural features of the reservoir, and through modern reservoir modeling and flow simulations, technological decisions are predicted and the application scheme is optimized, which leads to an increase in oil production, increases economic efficiency and extends the operational life of the field.

Keywords: Water flow control, residual oil recovery, polymer-gel systems, economic efficiency.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Introduction

At various stages of oil and gas field development, an increase in the proportion of water in wells disrupts the energy balance of production and represents a technological limitation that reduces economic efficiency to a minimum level. Although water inflow is considered important for maintaining reservoir pressure at an early stage, over time it weakens the oil recovery rate and increases processing, transportation, and disposal costs; in practice, most wells with water cut levels of 80–98% are shut down because they fail to reach the profitability threshold. This process is associated with permeability anisotropy within the reservoir, as well as the formation of preferential flow paths by tectonic fractures and high-permeability channels, causing water to selectively displace oil zones and rapidly advance toward the wellbore. The solution to this problem focuses on blocking water channels and creating new flow paths for the oil phase by using physicochemical materials that localize high-permeability zones and modify the flow profile, thereby extending the production life and improving the recovery of residual oil reserves. The article examines the potential for increasing the efficiency of residual oil recovery through the application of technologies that limit water inflow into oil wells.

Purpose

Problem relevance and related research

At a certain stage of oil field development, various types of water (including injected water and external water infiltrating from upper zones) enter high-permeability areas and reach production wells, increasing the water content in the produced fluids. This significantly deteriorates the technical and economic performance indicators of field development. In this regard, isolating water inflow into the well while maintaining oil production has become a key and highly relevant problem. Numerous methods and technologies have been developed and applied in this area [1–6]. However, these methods and technologies exhibit varying levels of application efficiency. In particular, existing conventional methods cannot be applied under certain geological and technical conditions and are generally characterized by relatively low effectiveness. There is a clear need to develop new isolation materials and application technologies for the isolation of formation water in production wells. It has been established that the effectiveness of many existing isolation materials and scientific-technical solutions is not considered satisfactory, and that similar isolation methods and materials are predominantly used for formation water control. Therefore, there is a necessity to further improve the currently applied isolation technologies [1–5]. At the same time, special attention is being given to the development of new methods based on temporary blocking reagents and gel compositions for the isolation of excessive water in oil and gas wells [6].

Methods

Technological Categories of Water Inflow Control

There are various types of methods for limiting water inflow:

1. Mechanical Methods

The application of packers enables hermetic isolation of specific intervals of the wellbore. Mechanical packers provide long-term stability when geological conditions remain unchanged and are used for selective production in multilayer systems.

Isolation by cementing is a downhole isolation measure applied to seal undesirable fluid-conducting channels formed between the production casing and the rock formation. During this

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

process, a specially formulated cement slurry is injected into the problematic interval, where it hardens within fractures and pores, physically blocking the movement of water.

In heterogeneous reservoirs, initial perforation may activate water-preferential zones. Re-perforation ensures the opening of intervals with high oil saturation in the wellbore, thereby altering the flow profile distribution. This method is applied as a minimally invasive option of mechanical isolation.

2. Chemical Methods

Gel systems based on polyacrylamide form a structural network in high-permeability channels. This network restricts water movement while maintaining relatively higher permeability for the oil phase.

In the presence of chromium ions, cross-links form between polymer chains, creating a more stable gel matrix under high-temperature conditions. This method is considered particularly suitable for thermal reservoirs in the 80–120°C range.

As a result of the reaction between silicate solutions and in-situ minerals, hydrogel-like structures are formed, ensuring physical sealing of microfractures. Silicate systems are resistant to high salinity and are often combined with buffering fluids to achieve effective results in carbonate reservoirs.

3. Physical Methods

An increase in temperature alters the rheological properties of the rock, leading to microscale precipitations in certain carbonate- and silicate-based minerals, which narrow water flow channels. Thermal stimulation also enhances the activity of applied chemical agents, strengthening their zone of influence.

The application of an electromagnetic field and potential difference changes the movement trajectories of ion-containing components in the reservoir, leading to the formation of cation accumulation zones on rock surfaces. This process reduces water propagation within the formation and regulates liquid-phase distribution. Electrochemical stimulation can also promote colloidal precipitation in fracture and pore systems.

Involvement of Residual Oil Reserves in Production through Water Inflow Control

In one of the mature oil fields operated by SOCAR, a production well has the following characteristics:

Well depth: 1850 m

Pay zone thickness: 18 m

Reservoir pressure: 14 MPa

Reservoir temperature: 62 °C

Average reservoir permeability:

High-permeability zone: k_1 = 850 mD

Low-permeability zone: k_2 = 120 mD

Total production rate: 80 m^3/day

Water cut: 88%

Oil viscosity: μ_o = 8 sP

Water viscosity: μ_w = 1 sP

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Observations indicate that the majority of the produced fluid consists of water entering from the high-permeability zone, while the low-permeability zone contains significant residual oil reserves that are not being produced.

According to Darcy's law, flow from the reservoir occurs according to the following relationship:

$$q \sim \frac{k}{\mu}$$

Flow intensity is directly proportional to permeability and inversely proportional to fluid viscosity. Comparison of flow intensity ratios:

For the high-permeability zone: $\frac{k_1}{\mu_w} = \frac{850}{1}\frac{mD}{sP} = \mathbf{850}\,\frac{mD}{sP}$**;**

For the low-permeability zone: $\frac{k_2}{\mu_o} = \frac{120}{8}\frac{mD}{sP} = \mathbf{15}\,\frac{mD}{sP}$**.**

Thus, the water zone has approximately $\frac{850}{15} \approx 57$ times higher flow capacity than the oil zone. For this reason, the entire hydrodynamic water flow practically "overwhelms" the oil zone. The purpose of applying water control technology is to increase flow resistance in the water zone and restore the relative flow toward the oil zone.For this purpose, a gel-polymer-based selective water control technology is selected. After application, the effective permeability in the high-permeability zone is reduced by a factor of five**:**

$k_1^{new} = \frac{850}{5} = 170$ mD

The post-treatment flow balance is calculated as follows::

Water zone: $\frac{k_1^{new}}{\mu_w} = \frac{170}{1}\frac{mD}{sP} = 170\frac{mD}{sP}$, while the oil zone remains unchanged: $\frac{k_2}{\mu_o}$. Thus, the new flow ratio becomes $\frac{170}{15} \approx 11$.

The flow dominance is reduced from 57 times to 11 times. This indicates that the oil zone becomes hydrodynamically active.

As a result of the treatment, changes in production performance are determined as follows.

Before treatment:

- Total production rate: 80 m³/day
- Water cut: 88% → 70,4 m³/day
- Oil production rate: 9,6 m³/day

After treatment:

- Total production rate: 75 m³/day
- Water cut: 60% → 45 m³/day
- Oil production rate: 30 m³/day

As a result, oil production increased by more than three times. The impact on residual oil reserves was evaluated as follows: the residual oil reserves in the well amount to 120 thousand tons; while the recovery factor was 0.28 before treatment, it increased to 0.34 after treatment.

The amount of additional oil produced was calculated as: 120000 × (0,34−0,28) = 7200 tons. This represents a real gain achieved without drilling new wells.

Economic Evaluation:

Cost of gel treatment: 90 000 AZN

Average revenue per ton of oil: 900 AZN

Additional revenue: 7200×900=6480000 AZN
The technology pays for itself many times over.
Recommendations for Improving Recovery Efficiency:

- Preliminary mapping of water-producing zones.

Identifying the intervals from which water enters the well only during production may be too late. Therefore, before perforation, permeability variations can be determined using gamma logging, acoustic logging, and mini-fracture tests. Once water-prone zones are accurately identified, selecting the appropriate perforation strategy can prevent costly chemical interventions at later stages.

- Stepwise isolation of water-bearing formations.

In conventional approaches, the formation is cemented once and considered treated. However, more efficient methods are available:

- first, installation of a physical barrier;
- then, application of gel-polymer treatment;
- finally, a low-rate injection test for monitoring.

This “three-stage approach” allows water flow to be blocked throughout the entire channel rather than at a single point.

- Technology selection based on operating costs.

Not all technological solutions have the same cost. In field practice, “targeted flow reduction” may be more appropriate than “complete shut-off” at the initial stage. This approach:

- reduces reagent costs;
- does not pose risks to the well;
- gradually improves economic indicators.

Economic and Environmental Evaluation:

- As a result of water flow localization and selective blocking, water handling and circulation costs are reduced. Lower water production decreases the load on separation equipment, minimizes energy and chemical reagent consumption, and reduces well treatment costs. The application of polymer-gel systems, packer technologies, and chemical plugs can enable 20–40% additional oil production, significantly improving investment efficiency.
- The application of selective water control is also environmentally important. Reducing and blocking water flow within the formation minimizes negative impacts on groundwater. In addition, produced water can be reused by reintegrating it into technological circulation systems, contributing to more efficient water resource management.

Conclusion

Water inflow control is one of the key approaches that enables more efficient recovery of residual oil reserves. This method manages reservoir heterogeneity, optimizes flow trajectories, and enhances oil mobility. Polymer-gel systems, water-isolating reagents, and other technologies effectively restrict water movement, preserve the flow capacity of the oil phase, and increase production. Interval-based flow control facilitates the protection of productive zones in areas with high water cut and allows for the utilization of the reservoir’s microstructural characteristics. Through modern reservoir modeling and flow simulations, technological decisions are forecast and application schemes are optimized. As a result, these approaches improve oil recovery, enhance economic efficiency, and extend the productive life of the field.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

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

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

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. D. E. İskenderov. Neft və Qaz Çıxarma Sənayesində Çalışan İşçilər üçün Məlumat Kitabı. Bakı, 2014, p. 280-287.
2. O. Kheshaifaty. Economic Evaluation of Water Management Solutions in Reservoir Engineering. SPE-KSA, Saudi Arabia, 2024, p. 2-13.
3. V. Alvarado, E. Manrique. Engineering Design Challenges and Opportunities beyond Waterflooding in Offshore Reservoirs" Offshore Technology Conference, USA, 2013, p. 1-8.
4. X. Sun, B. Bai. Comprehensive review of water shutoff methods for horizontal wells. Petroleum Exploration and Development, China, 2017, p. 1022-1029.
5. R. Seright, B. Brattekas. Water shutoff and conformance improvement: an introduction" Petroleum Science, China, 2021, p. 450-478.
6. E. F. Veliyev, E. D. Shovgenov. Neft-qaz quyularında izafi suyun izolyasiyası məqsədilə müvəqqəti bloklayıcı reagent və gel tərkibi əsaslı yeni metodun tədqiqi. SOCAR proceedings, Bakı, 2023, p. 96-99.

ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ИЗВЛЕЧЕНИЯ ОСТАТОЧНОЙ НЕФТИ ПОСРЕДСТВОМ ПРИМЕНЕНИЯ ТЕХНОЛОГИЙ ОГРАНИЧЕНИЯ ВОДОПРИТОКА В НЕФТЯНЫХ СКВАЖИНАХ

Хасай Фейзуллаев[1], Санан Абдулкеримов[2]
[1]Доктор технических наук, главный научный сотрудник, кафедра «Нефтегазовая инженерия», Азербайджанский государственный университет нефти и промышленности, Азербайджан.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

E-mail: feyzullayevxasay@gmail.com
[2]Магистрант, кафедра «Нефтегазовая инженерия», Азербайджанский государственный университет нефти и промышленности, Азербайджан. E-mail: senan.abdulkerimov.03@gmail.com

РЕЗЮМЕ

Известно, что в результате длительной эксплуатации изменяется неоднородность пласта на нефтегазовых месторождениях, на участках с высокой проницаемостью вода создает интенсивный проточный канал, в результате чего быстро увеличивается обводнение в добывающих скважинах; этот неконтролируемый процесс одновременно ослабляет производительность и приводит к тому, что значительные запасы остаточной нефти в пласте не используются. В рамках текущего исследования технологии, основанные на принципах механического, химического и селективного воздействия, применяемые с целью ограничения потока воды, сравниваются с точки зрения соответствия характеристикам пласта и полевых результатов; полимерно-гелевые системы, специальные реагенты, зональные изолирующие подходы и решения по перфорации оцениваются по степени неоднородности. Такие программы рассматриваются как один из основных инструментов снижения технологических рисков и поддержания экономической эффективности на заключительном этапе эксплуатации, поскольку закрытие водотоков и закупирование каналов с высокой проницаемостью улучшает водно-нефтяной баланс, восстанавливает стабильную траекторию добычи и увеличивает потенциал дополнительной подачи нефти. В связи с упомянутым, в статье рассматриваются возможности повышения эффективности освоения остаточных запасов нефти с применением технологий, ограничивающих поступление воды в нефтяные скважины.
Ключевые слова: Контроль водопритока, извлечение остаточной нефти, полимер-гель системы, экономическая эффективность.

NEFT QUYULARINA SU AXININI MƏHDUDLAŞDIRAN TEXNOLOGİYALARIN TƏTBİQİ İLƏ QALIQ NEFT EHTİYATLARININ MƏNİMSƏNİLMƏ SƏMƏRƏLİYİNİN ARTIRILMASI

Xasay Feyzullayev[1], Sənan Abdulkərimov[2]
[1]Texnika üzrə elmlər doktoru, baş elmi işçi, "Neft və qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: feyzullayevxasay@gmail.com
Magistrant, "Neft və qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
E-mail: senan.abdulkerimov.03@gmail.com

XÜLASƏ

Məlumdur ki, uzunmüddətli istismar nəticəsində neft-qaz yataqlarında layın heterogenliyi dəyişir, yüksək keçiricilikli sahələrdə su intensiv axın kanalı yaradır və nəticədə hasilat quyularında sulaşma sürətlə artır; idarə olunmayan bu proses həm məhsuldarlığı zəiflədir, həm də layda əhəmiyyətli qalıq neft ehtiyatının istifadəsiz qalmasına səbəb olur. Mövcud tədqiqat çərçivəsində su axınının məhdudlaşdırılması məqsədilə tətbiq olunan mexaniki, kimyəvi və selektiv təsir prinsiplərinə əsaslanan texnologiyalar lay xüsusiyyətlərinə uyğunluq və sahə nəticələri baxımından müqayisə edilir; polimer-gel tərkibli sistemlər, xüsusi reagentlər, zona üzrə təcrid yanaşmaları və perforasiya üzrə qərarlar heterogenlik dərəcəsinə görə qiymətləndirilir. Su axını yollarının bağlanması və yüksək keçiricilik kanallarının tıxanması su-neft balansını yaxşılaşdırdığı, sabit hasilat trayektoriyasını bərpa etdiyi və əlavə neftvermə potensialını artırdığı üçün bu tipli texnoloji həllər son istismar mərhələsində həm texnoloji risklərin azaldılması, həm də iqtisadi səmərəliliyin qorunması baxımından əsas yanaşmalardan biri kimi qəbul olunur. Qeyd olunanlarla əlaqədar olaraq, məqalədə neft quyularına su axını məhdudlaşdıran texnologiyaların tətbiqi ilə qalıq neft ehtiyatlarının mənimsənilmə səmərəliliyinin artırılması imkanları nəzərdən keçirilir.

Açar sözlər: Su axınının məhdudlaşdırılması, qalıq neft ehtiyatları, polimer-gel sistemləri, silikat məhlulları, iqtisadi səmərəlilik.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

114-122

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-13

VOLUME 33 (08) ISSUE 02 2026

RELIABILITY STUDY OF PISTON PUMPS IN MOBILE PUMPING UNITS

Ali Hikmat Ahmadov[1], Shahin Hasanov[2]

[1]Associate Professor at Azerbaijan State Oil and Industry University, Dean of the Oil-Mechanical Faculty. E-mail: alihikmat.ahmadov@asoiu.edu.az

[2]Master's Student of the Oil-Mechanical Faculty, specialization: Engineering of Technological Machines and Equipment.E-mail: hasanovshain@gmail.com

ABSTRACT

The article presents the results of a reliability study of piston pumps in mobile pumping units used in technological operations in the oil and gas industry. The relevance of the work is due to the operation of piston pumps under conditions of variable loads, vibration impact, temperature fluctuations, and varying intensities of factors affecting the service life of equipment, which leads to accelerated wear of components and an increased probability of failures. The aim of the study is a theoretical quantitative assessment of reliability indicators and prediction of the service life of the main elements of piston pumps in mobile pumping units.

The study employs methods of statistical processing of operational data, probabilistic modeling, and reliability function analysis. The Weibull distribution was used to describe the time-to-failure distribution; the shape and scale parameters were determined, and the reliability function, failure density function, and failure rate were calculated. An analysis of the most vulnerable components of the unit — the pumping section, drive, and valve system — was carried out.

The obtained results made it possible to determine the mean time to failure, assess the probability of failure-free operation over a specified time interval, and formulate recommendations for optimizing maintenance intervals. The practical significance of the study lies in the possibility of improving the operational reliability of piston pumps and reducing costs associated with unplanned repairs.

Keywords: piston pump, reliability, valve assembly, wear characteristics, Weibull distribution, failure rate, mean time to failure.

Introduction

The development of the modern oil and gas industry depends on several factors, such as increasing complexity of production conditions, growing drilling depths, specific features of developing hard-to-reach and remote fields, as well as increasing reservoir pressures. Considering these conditions, improving reliability as well as production and energy efficiency of technological equipment, including mobile reciprocating pumping units used in drilling and well operation processes, plays a particularly important role.

The widespread use of mobile reciprocating pumping units is due to their operation for pumping drilling fluids, hydraulic fracturing, well cementing, as well as performing various technological operations in oil and gas production. The design of such equipment must ensure and maintain high capacity under pressure, resistance to various types of wear, vibration loads, and variable operating modes.

During the analysis of existing designs and their operation in harsh climatic and production conditions, the main problems identified include increased wear of the cylinder-piston group, leakage of the working medium, vibration loads on the frame and drive mechanism, as well as certain energy losses. Moreover, as requirements for environmental safety and reduction of operating costs increase, there is a need to improve layout and design solutions.

Relevance of the research topic.

The relevance of the study is justified by the need to develop technical solutions aimed at increasing the service life of components and assemblies of reciprocating pumps, reducing dynamic (as well as static) loads, and optimizing kinematic and hydraulic parameters.

Purpose of the work.

Taking into account all the above factors, the main objective of the work is to improve the design of reciprocating pumps for oil production and drilling operations based on the analysis of the stress-strain state of elements, hydrodynamic processes in the pumping section, and optimization of design characteristics.

The work presents a theoretical study aimed at improving the internal design of reciprocating pumps in mobile pumping units in order to increase equipment reliability indicators and improve performance.

A primary analysis of the reciprocating pump operating process, for the purpose of reliability analysis, was performed by the author in [1], where the operating principle of the considered unit is discussed in detail. Analysis of drilling pump failures shows that pistons and valves of the hydraulic section are most susceptible to wear and sudden failures. According to statistical processing of operational data, the average operating time of pistons before failure is 97.6 hours, and valves — 72.5 hours, which indicates low durability of these elements. The coefficients of variation of operating time (0.83 and 0.77, respectively) indicate the random and sudden nature of failures, while high values of the standard deviation σ^* demonstrate the significant influence of numerous operational factors on the service life of components.

The main causes of failures are intensive wear of sealing elements and valves caused by high operating pressures, temperature, and abrasiveness of drilling fluid. When drilling deep wells, operating conditions become more complicated: with increasing depth, the viscosity and density of the working fluid increase, which increases the load on valves and piston rods of the reciprocating pump.

When designing sealing units, it is advisable to provide a leakage removal system with return to the suction line.

A pump-compressor with a similar operating principle to the equipment under consideration (Figure. 1), described in [2], is equipped with an additional valve that provides changes in the operational characteristics of the unit. The design of the described and studied equipment is similar; however, the main difference is the absence of the pump-compressor as a unit and its replacement by an additional hydraulic system for supplying fluid under pressure through suction and discharge valves 7 and 8.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

With permissible cylinder wear ensuring the service life of lubricated ring seals of about 20–25 thousand hours, cooling of the cylinder-piston group can be implemented using a liquid jacket with circulation of the working fluid. However, this design solution leads to increased structural complexity and additional hydraulic losses in the discharge line.

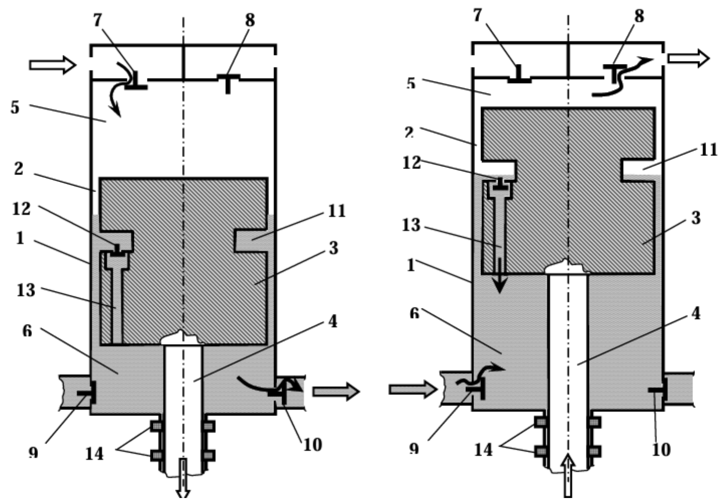


Figure 1: Diagram of a reciprocating pump-compressor with discharge of liquid leakage through the clearance of the piston seal into the low-pressure zone of the pump chamber during the suction process: (a) suction in the compressor chamber, discharge in the pump chamber; (b) discharge in the compressor chamber, suction in the pump chamber: 1 — cylinder, 2 — radial clearance between piston and cylinder, 3 — piston, 4 — rod, 5 — compressor chamber, 6 — pump chamber, 7 — gas suction valve, 8 — gas discharge valve, 9 — liquid suction valve, 10 — liquid discharge valve, 11 — separating groove, 12 — discharge valve, 13 — discharge channel, 14 — sealing assembly.

For reliability calculation, the Weibull distribution is used under equipment operation in the wear-out regime in order to determine the reliability function (Fig. 2), failure probability (Fig. 3), failure rate, as well as the mean time to failure (Fig. 4) of the reciprocating pump.
According to literature data [3] on reciprocating pumps, the following reliability characteristics were identified for the wear-out operating regime of the equipment:
- shape parameter: $k = 2.1$
- time to failure (scale parameter): $\lambda = 4500$ h
- operating time under consideration: $t = 3500$ h

The value $k > 1$ confirms gradual wear accumulation (valves, piston rings, seals).
The probability of failure-free operation for the reliability function is calculated using the following formula:

$$P(t) = exp\left[-\left(\frac{t}{\lambda}\right)^{k}\right] \quad (1)$$

Substituting the values:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$P(3500) = exp\left[-\left(\frac{3500}{4500}\right)^{2,1}\right] \approx exp[-(0,778)^{2,1}] \approx e^{-0,59} = 0,55 \quad (2)$$

The probability of failure during the operating period is calculated by the formula:

$$Q = 1 - P, \quad (3)$$

Substituting the values:

$$Q = 1 - 0,55 = 0,45, \quad (4)$$

That is:

$$Q = 45\%. \quad (5)$$

The failure rate is determined by the formula:

$$\omega(t) = \frac{k}{\lambda} * \left(\frac{t}{\lambda}\right)^{k-1}, \quad (6)$$

Substituting the values:

$$\omega = \frac{2,1}{4500} * (0,778)^{1,1} \approx \frac{2,1}{4500} * 0,75 \approx 0,00035 \text{ ч}^{-1}. \quad (7)$$

The mean time to failure of the equipment is calculated by the formula:

$$T_{cp} = \lambda * \Gamma\left(1 + \frac{1}{k}\right), \quad (8)$$

Substituting the values:

$$\mathrm{T_{cp}} = 4500 * \Gamma\left(1 + \frac{1}{2,1}\right) \approx 4050 \text{ ч}. \quad (9)$$

The obtained values show:
- Mean time to failure ≈ 4000 h
- Probability of failure-free operation over 3500 h ≈ 0.55
- Failure rate increases over time (wear-out behavior)

This corresponds to the conclusions regarding the need for:
- rational valve design;
- reduction of dynamic loads;
- optimization of the piston group mass.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

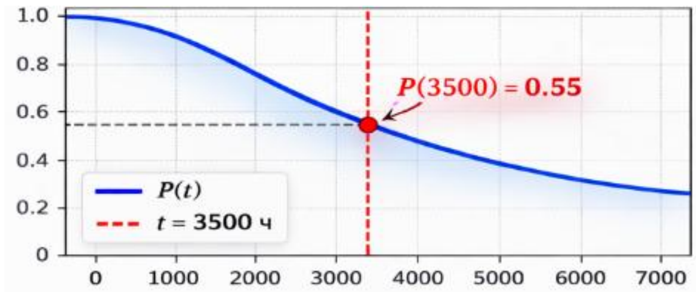


Figure 2: Reliability function graph of a reciprocating pump according to the Weibull distribution.

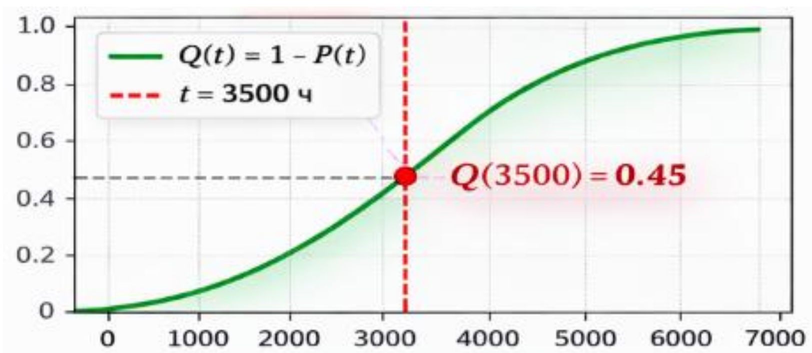


Figure 3: Failure probability of a reciprocating pump.

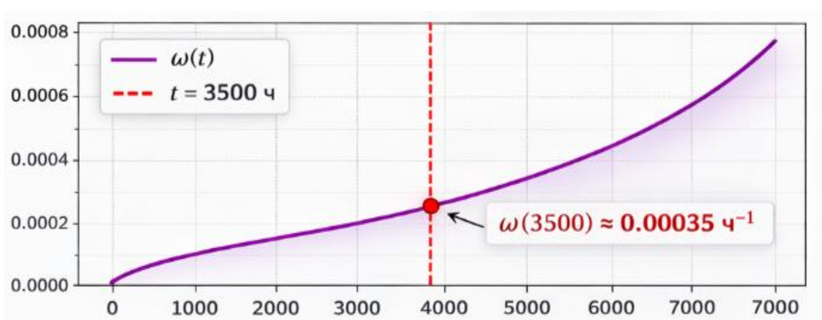


Figure 4: Mean time to failure of a reciprocating pump.

Also, in study [4], the author examined several brands and types of pumps (17) used in various fields of operation, specifically their service life under stable operating conditions until the onset of wear. The main rapidly wearing components were identified, which confirm the above-mentioned assemblies directly related to the reliability of reciprocating pumps. The study also included calculations based on the Weibull distribution. Also, in study [5], Stasiak described a dynamic model that makes it possible to analyze pump operation under various load conditions and design parameters. As a result, it becomes possible to evaluate the pressure in the discharge or

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

suction nozzle, as well as the flow velocity of the working fluid in the discharge or suction line of the pump.

One of the key elements of a reciprocating pump, the degree of design perfection of which determines such operational characteristics as suction head, volumetric efficiency, delivery coefficient, and dynamic performance parameters of the unit, is the valve assembly. As a result of the analysis, several approaches were employed to determine the key parameters, including an experimental method for evaluating the motion characteristics of the reciprocating pump valve disc, as presented by the author in study [6]. Furthermore, study [7] emphasizes the significance of analyzing the dynamic characteristics of the pump valve, noting that such an investigation enables the optimization and design of the valve structure, which in turn enhances the operational reliability of the reciprocating pump.

During the study of valve wear characteristics, it was found that the most common type of damage is mechanical wear of the elastic sealing element. This type of wear occurs regardless of the fastening method and the distribution of maximum contact stresses. The highest stresses are localized in the zones of interaction between the sealing element and the structural components of the valve. When the valve plate seats on the seat, extrusion and pinching of the sharpened part of the sealing element occur in the sealing clearance, which leads to tearing off the deformed material volume and loss of tightness of the valve pair.

In all investigated valves, wear of the sealing element caused by the action of abrasive particles was observed, which resulted in a decrease in the accuracy of the valve plate seating on the seat. As a result of cyclic pressure effects depending on the fluid velocity, destruction of the sealing element occurred, leading to valve failure. It was established that the guiding seating surfaces of the valves are subjected to intensive wear due to impact interaction of contacting elements.

During operation, when the valve plate moves, a reduction in the diameters of the guide bushings and the seat is observed, accompanied by the formation of dents and longitudinal cracks on the seating surface of the seat. The valve plate moving relative to the seat under high variable pressures and significant sliding velocities is characterized by intensive wear and destruction due to impact loads. The analysis showed that the stress–strain state of the sealing element is significantly influenced by the supporting seating surfaces of the valve plate and seat under impact loading conditions [8].

Table 1. Statistical parameters of lifetime distribution of hydraulic part components.

Component	**Distribution Law**	**Statistical Distribution Parameters**		
		t^*_{avg}, hours	σ^*, hours	$u^* = \sigma^* / t^*_{avg}$
Cylinder liners	Weibull	204.1	106.1	0.51
Rods	Lognormal	106.0	51.0	0.48
Pistons	Exponential	97.3	80.7	0.83
Valves	Exponential	72.5	55.9	0.77

Declarations

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Abdyukova R.Y. Research on the operating principles and types of drilling pump valves. 2019.
2. Korneev S.V., Baryshev S.V., Lysenko E.A., Nosov E.U. Design of a rational reciprocating pump-compressor structure. 2011.
3. Anvar H.S. Weibull analysis of time intervals between failures of pumps used at an oil refinery. 2002.
4. Anwar H. Sh., Muhammad Y., Daham M. A. Weibull analysis of time intervals between failures of pumps used in an oil refinery. 2003.
5. Stosiak M, Karpenko M. Dynamics of machines and hydraulic systems: mechanical vibrations and pressure pulsations. Cham, Switzerland: Springer Nature, 2024.
6. Pei J, Chao H, Lv M, et al. The valve motion characteristics of a reciprocating pump. Mech Syst Signal Process 2016.
7. Dong X. et al. Experimental and Numerical Study on Valve Dynamic Impact Contact Characteristics and Fault Diagnosis of a Reciprocating Piston Pump — Engineering research, 2024.
8. Abdyukova R.Y. Practical studies of wear characteristics of valves of drilling reciprocating pumps. Modern High Technologies, 2020.

ИСЛЕДОВАНИЕ НАДЕЖНОСТИ ПОРШНЕВЫХ НАСОСОВ В ПЕРЕДВИЖНЫХ НАСОСНЫХ УСТАНОВКАХ

Али Хикмат Ахмедов[1], Шахин Гасанов[2]
[1]Доцент Азербайджанского государственного университета нефти и промышленности, декан нефтемеханического факультета. E-mail: alihikmat.ahmadov@asoiu.edu.az

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

[2]Студент магистратуры нефтемеханического факультета, специальность инженер технологических машин и оборудований. E-mail: hasanovshain@gmail.com

РЕЗЮМЕ

В статье представлены результаты исследования надёжности поршневых насосов в передвижных насосных установках, применяемых при проведении технологических операций в нефтегазовой отрасли. Актуальность работы обусловлена эксплуатацией поршневых насосов в условиях переменных нагрузок, вибрационных воздействий, перепадов температур и интенсивностей воздействия факторов, влияющих на срок эксплуатации оборудования, что приводит к ускоренному износу узлов и увеличению вероятности отказов. Целью исследования является теоретически количественная оценка показателей надёжности и прогнозирование ресурса основных элементов поршневых насосов в передвижных насосных установках.
В работе использованы методы статистической обработки эксплуатационных данных, вероятностного моделирования и анализа функций надёжности. Для описания распределения времени наработки до отказа применено распределение Вейбулла, определены параметры формы и масштаба, рассчитаны функция безотказной работы, плотность распределения отказов и интенсивность отказов. Проведён анализ наиболее уязвимых узлов установки — насосной части, привода и системы клапанов.
Полученные результаты позволили определить среднюю наработку на отказ, оценить вероятность безотказной работы в заданный интервал времени и сформулировать рекомендации по оптимизации межремонтных интервалов. Практическая значимость исследования заключается в возможности повышения эксплуатационной надёжности поршневых насосов и снижения затрат на внеплановый ремонт.

Ключевые слова: поршневой насос, надёжность, клапанный узел, характер износа, распределение Вейбулла, интенсивность отказов, наработка на отказ.

SƏYYAR NASOS QURĞULARINDA PİSTONLU NASOSUN ETİBARLILIĞININ TƏDQİQİ

Əli Hikmət Əhmədov[1], Şahin Həsənov[2]
[1]Azərbaycan Dövlət Neft və Sənaye Universitetinin dosenti, Neft-mexanika fakültəsinin dekanı. E-mail: alihikmat.ahmadov@asoiu.edu.az
[2]Neft-mexanika fakültəsinin magistr tələbəsi, ixtisas: Texnoloji maşın və avadanlıqların mühəndisliyi.
E-mail: hasanovshain@gmail.com

XÜLASƏ

Məqalədə neft-qaz sənayesində texnoloji əməliyyatların aparılması zamanı istifadə olunan səyyar nasos qurğularında porşenli nasosların etibarlılığının tədqiqinin nəticələri təqdim olunur. İşin aktuallığı porşenli nasosların dəyişkən yüklər, vibrasiya təsirləri, temperatur fərqləri və avadanlığın istismar müddətinə təsir göstərən müxtəlif intensivlikli amillər şəraitində işləməsi ilə əlaqədardır ki, bu da qurğu elementlərinin sürətlə aşınmasına və nasazlıqların başvermə ehtimalının artmasına səbəb olur. Tədqiqatın məqsədi səyyar nasos qurğularında porşenli

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

nasosların əsas elementlərinin etibarlılıq göstəricilərinin nəzəri-kəmiyyət qiymətləndirilməsi və istismar resursunun proqnozlaşdırılmasıdır.
İşdə istismar məlumatlarının statistik emalı, ehtimal modelləşdirilməsi və etibarlılıq funksiyalarının təhlili metodlarından istifadə olunmuşdur. Nasazlığa qədər işləmə müddətinin paylanmasının təsviri üçün Veybull paylanması tətbiq edilmiş, forma və miqyas parametrləri müəyyən edilmiş, nasazlıqsız işləmə funksiyası, nasazlıqların sıxlıq funksiyası və nasazlıq intensivliyi hesablanmışdır. Qurğunun ən həssas qovşaqları — nasos hissəsi, ötürücü mexanizm və klapan sistemi — təhlil edilmişdir.
Əldə olunan nəticələr nasazlığa qədər orta işləmə müddətini müəyyən etməyə, verilmiş zaman intervalında nasazlıqsız işləmə ehtimalını qiymətləndirməyə və təmirarası intervalların optimallaşdırılması üzrə tövsiyələr formalaşdırmağa imkan vermişdir. Tədqiqatın praktik əhəmiyyəti porşenli nasosların istismar etibarlılığının artırılması və planlaşdırılmamış təmir xərclərinin azaldılması imkanında ifadə olunur.
Açar sözlər: porşenli nasos, etibarlılıq, klapan qovşağı, aşınma xarakteri, Veybull paylanması, nasazlıq intensivliyi, nasazlığa qədər işləmə müddəti.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

123-131

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-14

IMPROVEMENT OF PREVENTION AND CONTROL METHODS FOR WATER INFLUX IN PRODUCING OIL WELLS

Samira Mansurova[1], Javid Rahimov[2]
[1]Doctor of Technical Sciences, Professor, "Oil and Gas Transportation and Storage" Department, Azerbaijan State Oil and Industry University. E-mail: petrotech@asoiu.az
[2]Master's Degree Student, "Oil and Gas Transportation and Storage" Department, Azerbaijan State Oil and Industry University. E-mail: javid.rahimov@khazar.org

ABSTRACT

High rate of water production is one of the biggest problems in oil well exploitation that means less oil recovery, high operating costs, and a short well life. One of the major sources of undesirable water influx is the water coning due to high pressure drawdown and the high aquifer support. Other factors are reservoir heterogeneity, inappropriate design of completion and mechanical integrity.

This paper explores the process of oil wells production by water influx and assesses the means of water production prevention and control. Preventive and remedial measures such as chemical and mechanical water shutoff method are discussed. It is seen that the gaps and strengths of these methods are discussed with a goal to advance water control strategies and maximize oil recovery at the minimal use of water.

Keywords: water production in oil wells, water coning, water influx, oil recovery optimization, water control strategies, high water cut, pressure drawdown, aquifer support, reservoir heterogeneity, water shutoff techniques.

Introduction

The occurrence of unwanted water production is also one of the most severe threats to oil field development and production activities. On the growing field maturity, a substantial amount of oil well-produced water quantity increases rapidly, causing the lifting, separation, and oil discard expense to rise as the oil productivity and recovery efficiency reduce (both at the same time) [3,7]. Excessive production of water may result in wide scale abandonment of wells and losses in the economy in worst cases [1,9].

Water coning is deemed one of the most prevailing mechanisms among the many mechanisms that cause water influx. It takes place when the water in an underlying aquifer flows towards the wellbore under high pressure drawdown circumstances [4,10]. The rate and degree of water coning development is subject to various reservoir and operation conditions comprising a rate of production, contrast between the oil and water density, vertical permeability, reservoir thickness, and the geometry of completion [2, 6]. Besides coning, water may also be introduced in producing

wells via high-permeability streaks, natural or induced fractures, poor cement bonding and casing integrity failures [5,8].
Traditional water management methods like decline of the production rates can postpone the water breakthrough, but will tend to lead to economically non-viable oil production [6]. This has led to the current water control methods that are essentially based on preventive and remedial measures and solutions, such as optimal well completion methods, chemical water shut off solutions, mechanical isolation methods, and sophisticated intelligent well methods [1,4]. To make correct use of those approaches, it is necessary to implement a clear understanding of the mechanisms of producing water and critically assess the condition of the reservoirs and wells [7,10].

Literature Review

Water production is known to be a big problem in the operation of the oil fields, more so in the mature oil fields where the ratios between water and oil increase as days go by [2,8]. Over water production causes the process of oil recovery to be less and the cost of lifting, separation, and disposal to go up [5].
Past literature recognizes the presence of water coning as one of the most important processes of early breakthrough of water in reservoir where the underlying aquifer is active [1,6]. Several analytical, empirical, and numerical models that can predict coning behavior have been constructed with numerical simulations giving more sound responses under complicated conditions of the reservoir [4,9]. Reservoir heterogeneity, fractures and high-permeability zones promote water production even more and exclude sweep efficiency [3,7].
The preventive and remedial approaches to water control are listed in the literature. Optimism of placing wells and selective completions are the preventive methods whereas remedial methods involve chemical and mechanical water closure techniques like polymer gels, cement squeezes and mechanical isolators [1,8]. The recent studies point to the prospective opportunities of intelligent well technologies to have selective control of the water, but the method is not fully utilized due to its high costs and complexities [2,10].

Methodology

It turns out that this research applies qualitative and analytical research methodology, which is based on the systematic review and assessment of existing scientific literature on the topic of water production and water management in oil wells. Journal articles, technical papers, and academic theses based on the technique of water coning, water shutoff, and water conformance control were reviewed in order to define the prevalent water inflow systems and the typical methods of mitigation used [3,7].
A comparative analysis of effective water control methods, reported in literature between prevent and remedial ones will be used in the methodology. The preventative approaches, such as well placement policies and design of completion are considered together with the remedial approaches in the form of chemical and mechanical treatment given to the product at the production stage [1,8]. The focus is specifically placed on the polymer and gel types of treatments,, cementing methods, and mechanical isolation devices because they are commonly used [4,9].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Besides, the research examines the chosen case studies and simulation-based research on the performance and constraints of various water control technologies in different reservoir conditions [2,6]. The outcomes of this analysis help to determine the main factors affecting the success of treatment and suggest the ways of the further development of water control measures in the creation of wells [5,10].

Water Influx and Water Coning mechanisms

The influx of water in the production oil wells would be a result of a combination of reservoir, fluid, and operation factors. Water coning is one of the most prevalent processes that grow under the influence of the pressure drawdown around the wellbore that is greater than overcoming forces of gravity between oil and water, ensuring the appearance of the water, belonging to the underlying aquifer and being forced up to the perforations [4,9]. When breakthrough is realized in water, the rate of water production will be very high, with a resultant reduction in the production of oil [1].

The rate of production, reservoir thickness, vertical permeability, the ratio of oil-water viscosities and distance between the well completion and the oil-water contact are among the factors that determine the severity of water coning [2,6]. Streaks and reservoir heterogeneity may further upgrading movement of water by developing preferential flowways [7,10].

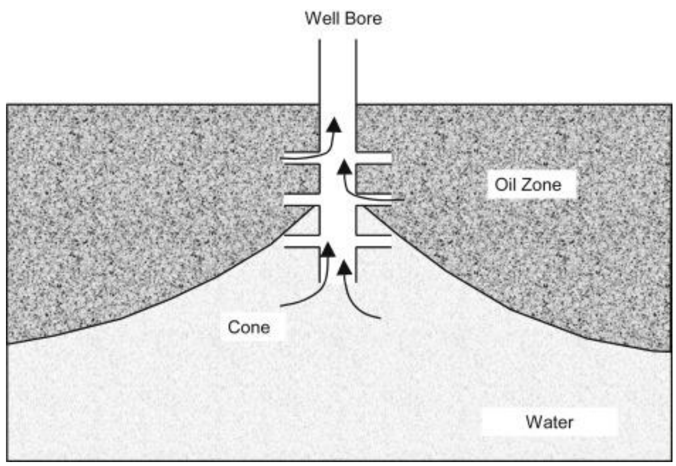


Figure 1: Schematic representation of water coning caused by pressure drawdown in a bottom-water drive reservoir.

Besides water coning, other techniques of water influx are channeling through natural or induced fractures, behind casing as a result of poor cementing, casing leakage and crossflow amongst layers [3,8]. The consequences of these mechanisms are usually high water breakthrough and low sweep limit, leaving large quantities of bypassed oil at the reservoir. It is thus imperative to observe the prevailing water influx process to make good water control and mitigation decisions [5].

Prevention and Control Techniques of Water Production.

Water prevention and control in oil wells is an issue that involves a combination of measures that ought to be exercised according to the characteristics of the reservoirs, the set of wells and the production strategy. Preventive techniques are used mainly in the planning and completion phases and they tend to defer or prevent the occurrence of the water breakthrough by reducing the undesirable pressure gradient and stifling the water movement close to the wellbore [6,9]. Such strategies tend to be less expensive than remediation measures and may greatly enhance the future production performance in case they are appropriately applied [2].

Some of the preventive measures are optimal well placement, regulated production levels, and proper completion design. The adoption of horizontal and deviated wells has been demonstrated to minimize pressure drawdown around the contact point of oil and water hence postponing the occurrence of water coning [4]. The further methods of restricting the entry of water include selective perforation and zonal isolation, which avoid direct communication between the wellbore and water-bearing intervals [7].

Preventive measures are inadequate or the water breakthrough has already ensued, then control strategies are taken at the production stage. These corrective strategies involve the minimization of water inflow coupled with promoting hydrocarbon productivity. The primary control that is frequently applied is the production rate control; it is likely to result into sub economic rates of oil and hence it is a short term remedy [1,5].

Successful management of water within the environment entails proper diagnostic of the source and inflow mechanism of the water. Diagnostic methods like production logging, pressure transient analysis and reservoir simulation are very important in choosing proper prevention or control methods [3,10]. Preventive and remedial strategies should be incorporated with sound diagnostic data to ensure the realization of sustainable water management and maximization of the oil recovery [8].

Since the chemical water shutoff is not a standard pillar, the data has been collected and organized into categories such as chemical interpretation, chemical designation, and taxonomy.

Chemical Water Shutoff Techniques

Selective reduction of water permeability within specific areas and retention of capacity in hydrocarbon flow is common in chemical water shutoff practices aimed at reducing excessive production of water. These techniques are especially practical in reservoirs of the type at which production of water is linked to high-permeability channel or fractures or near-wellbore heterogeneity [4,9]. Areas Compared to mechanical solutions, chemical treatments have a larger placement range, and the capacity to access complicated pore morphology and small flow channels [2].

Polymer and gel systems are most widely used chemical water shut off systems. HPAM polymer gels and partially hydrolyzed polymers are developed to create three dimensional systems where flow by water is limited preferentially in micro-cracks and high permeability pores [1,6]. The efficiency of these systems relies on the concentration of the polymer, cross-linking chemistry, cross-linking, reservoir temperature, salinity, and shear stability [7]. Polymer gels when designed appropriately are capable of achieving disproportional reduction in permeability where water flow can be reduced to a greater degree as compared to oil flow [3].

Other chemical agents that are under research to be used in water control applications include inorganic salts, resins, foams and relative permeability modifiers in addition to polymer gels

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

[5,10]. These materials are determined in accordance with the conditions of the reservoir and water production mechanisms. Nevertheless, the problem of chemical degradation, uncertainty in their placement, and poor long-term stability can hamper their performance [8].
Achievement of effective use of chemical water shutoff treatments needs effective diagnosis of water source, lab evaluation, and the controlled field performance. Misplaced and incorrect choice of chemical can lead to low oil output or failure to treat them [4]. Hence, the chemical ways of turning water off have to be added to the characterization of reservoirs along with the production history in order to attain an efficient and long-term water management [9].

Technologies of mechanical and advanced control of water.
Mechanical water control mechanisms seek to virtually isolate or to confine the areas of water production in the wellbore, and are often used when the source of water influx is known and localized. Those are specifically suitable when there is leakage of casing or flow behind the pipe or specific water-bearing intervals separated by competent barriers [6,9]. Most of the mechanical solutions possess instantaneous water reduction but are in most cases associated with well intervention and increased operational expenses in comparison to the chemical treatments [2].
Telegasmic methods of mechanical isolation are cement squeezes, bridge plugs, packers, liners and casing patches. Treatment using cement is commonly employed to close unwanted zones of water or fix annular flow paths as long as maintaining enough zonal isolation is known [1,7]. Bridge plugs and packers are used to close off water producing intervals mechanically in order to selectively produce based on the source of hydrocarbons [4]. Nevertheless, these mechanical approaches largely rely on the precision with which zones are identified and they should also have barriers in place [8].
Over the past years, high-technology water management has gained usability in order to achieve the flexibility of production and better administration of the long-term reservoir level. Smart wells, which have downhole sensors and inflow control tools enable dynamism and control of fluid entry in the wellbore in real time [3,10]. These technologies make it possible to choke off or block production of water in selective parts but without necessarily incurring the expensive workover processes [5].
Advanced water control systems are linked with the more expensive capital investment and more complicated operations, despite their technical advantages. They need to be, in detail, characterized with regard to the reservoir, well-designed control measures, and powerful data collection systems to be implemented successfully [6]. When adequately developed and installed, mechanical and sophisticated water control technologies can go a long way in water production reduction, enhanced sweep, and increasing the economical life of the producing wells [9].

Results and Discussion
The review of published articles and practical application of the process proved that high water extraction is a complex issue with specific solutions depending on the reservoir specifics and the nature of wells. Based on the reviewed results reveals that water coning is the prevailing method of early water breakthrough in reservoirs where the water table is supported by active aquifers especially at high rate of production and also where there are not favorable ratios of mobility [4,7]. As is often demonstrated in studies of numerical simulation, pressure drawdown control and

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

optimum placement of well locations are capable of greatly delaying water breakthrough and minimizing water cut [2,9].
In carrying out comparative analysis on prevention and control measures, it has been noted that prevention strategies tend to have more sustainable outcomes than remedial ones when used at an early stage in the development phases in the fields [1]. It has also been demonstrated that Horizontal wells and optimized completion designs can be used to postpone the inflow of the water but they are highly dependent on the heterogeneity within the reservoir as well as distribution of the vertical permeability [6]. When the breakthrough of water has taken place, additional control measures are ineffective and water control treatments have to be used.
The technique of chemical water shutoff shows positive results in the reservoirs with fractures and high-permeability channels, where selective reduction of the permeability is needed [3,10]. Polymer and gel based replies demonstrate capability to decrease the amount of water produced during treatment but remain stable at least in the long term, and their effectiveness is subject to correct choice of the chemical, high precision in their placement and compatibility to the reservoir [5]. Mechanical water management on the other hand offers an instant isolation of water-producing areas, but it works only in the situations when water entry points are not categorical [8].
The use of advanced technologies (i.e. intelligent well system) provides a better control over the production of water ensuring real-time monitoring and selective control of inflow based on the requirements [4]. Such systems have good outcomes such as reducing the amount of water and enhanced recovery of oil but limited use due to high expenses and complicated operations [9]. Generally, the findings show that there is no one approach which can tackle all the water production issues. The guidelines produced by an integrated prevention, chemical, mechanical, and advanced technology are the most reliable in the production of wells in the sustainable water management [1,7].

Conclusions and recommendations

The problem of excessive water production in oil wells is still a burning issue that negatively impacts oil recovery process, efficiency of operations and profitability of the hydrocarbon exploitation in general. The results of the present research prove that water coning, heterogeneity of reservoirs, and well integrity problems are considered to be one of the main mechanisms of unwanted inflow of waters in the producing wells [3,8]. Such intricacy of these processes make it necessary to have a multifaceted and systematic method of managing water instead of basing the practice upon a single method of water control.
It can be proven that preventive treatment of planning and completion phases (optimal placement of the well and control of production approaches) has greater long-term beneficial effects than remedial treatment performed after the water breakthrough [2,6]. Nevertheless, chemical and mechanical water shutoff techniques are important in reducing water inflow and also enhance the productive well life when the overproduction of water takes place [1,9]. Heterogeneous and fractured reservoirs are especially well treated chemically and their use excludes well-defined water entry zones treated using mechanical solutions [4,7].
Modern technologies in water control, such as smart wells, show great perspectives of better water management with real-time control and selective control of inflows in time [5,10]. Under the appropriate reservoir conditions, with such technologies, the flexibility of production can be

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

increased, the number of well intervention frequency may be reduced, which is characterized by a high cost of implementation.

According to the findings of the studies, it is suggested that water regulation techniques be chosen by the thorough diagnosis of water influx processes and reservoir properties. Further development of oil fields requires an integrated approach that incorporates preventive, chemical, mechanical, and sophisticated approaches when it comes to effective control of water, oil recovery, and sustainable development [6,8].

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Seright, R. S., & Brattekas, B. (2021). Water shutoff and conformance improvement: An introduction. Petroleum Science, 18(2), 450–478.
2. Taha, A., & Amani, M. (2019). Overview of water shutoff operations in oil and gas wells: Chemical and mechanical solutions. ChemEngineering, 3(2), 51.
3. Okon, A. N., Appah, D., & Akpabio, J. U. (2017). Water coning prediction review and control: Developing an integrated approach. Journal of Scientific Research & Reports, 14(4), 1–24.
4. Dabiri, A., Karaei, M. A., & Azdarpour, A. (2017). Simulation study of controlling water coning in oil reservoirs through drilling of horizontal wells. Bioscience Biotechnology Research Communications, 10(1), 132–136.
5. Nagem, A. S. A. (2021). Water production performance and control of oil field. Insights in Analytical Electrochemistry, 7(4), 1–5.

6. Raykov, T. T. (2008). Selective production possibilities to stabilize crude oil production. Master's Thesis, Montanuniversität Leoben, Austria.
7. Shaibu, R., Klewiah, I., Mahamah, M. A., Acquah, I. E., Cobbah, C., & Asiedu, S. W. (2017). An intelligent well approach to controlling water coning problems in horizontal production wells. International Journal of Engineering Research & Technology, 6(1).
8. Craig, F. F. (1971). The reservoir engineering aspects of waterflooding. Society of Petroleum Engineers.
9. Willhite, G. P. (1986). Waterflooding. Society of Petroleum Engineers.
10. Smith, C. F. (1990). Practical water control in oil fields. SPE Production Engineering.

İSTİSMAR QUYULARINDA SULAŞMANIN QARŞISININ ALINMASI VƏ MÜBARİZƏ ÜSULLARININ TƏKMİLLƏŞDİRİLMƏSİ

Samirə Mənsurova[1], Cavid Rəhimov[2]
[1]Texnika elmləri doktoru, professor, "Neftin və qazın nəqli və saxlanması" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti. E-mail: petrotech@asoiu.az
[2]Magistr tələbəsi, "Neftin və qazın nəqli və saxlanması" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti. E-mail: javid.rahimov@khazar.org

XÜLASƏ

İstismar quyularında baş verən həddindən artıq sulaşma neft hasilatının azalmasına, istismar xərclərinin artmasına və quyuların istismar müddətinin qısalmasına səbəb olan əsas problemlərdən biridir. Sulaşmanın əsas səbəblərindən biri yüksək hasilat rejimi və güclü akvifer təsiri nəticəsində yaranan su konuslaşmasıdır. Bundan əlavə, lay heterogenliyi, tamamlanma qüsurları və mexaniki problemlər sulaşma prosesini sürətləndirir.
Bu tədqiqat işində istismar quyularında sulaşmanın yaranma mexanizmləri araşdırılmış, sulaşmanın qarşısının alınması və onunla mübarizə üsulları təhlil edilmişdir. Kimyəvi və mexaniki suizolyasiya metodlarının üstün və zəif cəhətləri qiymətləndirilmiş, neft hasilatının optimallaşdırılması və su hasilatının azaldılması məqsədilə səmərəli həll yolları müəyyən edilmişdir.
Açar sözlər: istismar quyularında sulaşma, su konuslaşması, su hasilatı (water production), akvifer təsiri, lay heterogenliyi, suizolyasiya metodları, kimyəvi suizolyasiya, mexaniki suizolyasiya, neft hasilatının optimallaşdırılması, suya nəzarət texnologiyaları.

СОВЕРШЕНСТВОВАНИЕ МЕТОДОВ ПРЕДОТВРАЩЕНИЯ И БОРЬБЫ С ВОДОПРИТОКОМ В ЭКСПЛУАТАЦИОННЫХ НЕФТЯНЫХ СКВАЖИНАХ

Самира Мансурова[1], Джавид Рагимов[2]
[1]Доктор технических наук, профессор, кафедра «Транспортировка и хранение нефти и газа», Азербайджанский государственный университет нефти и промышленности. E-mail: petrotech@asoiu.az
[2]Магистрант, кафедра «Транспортировка и хранение нефти и газа», Азербайджанский государственный университет нефти и промышленности. E-mail: javid.rahimov@khazar.org

РЕЗЮМЕ

Высокая производительность воды на действующих нефтяных скважинах является одной из ключевых проблем, вызывающих низкий коэффициент извлечения нефти, высокие эксплуатационные расходы и высокую скорость износа скважин. Водяной конус является одним из основных факторов, позволяющих воде проникать при высоких перепадах давления и под активным воздействием подстилающего водоносного пласта. Другими факторами являются неоднородность пласта, конструктивные недостатки или механические повреждения скважин.
В данной статье рассматриваются процессы, связанные с проникновением воды в добывающие скважины, а также анализируются способы предотвращения и смягчения последствий проникновения воды. Рассматриваются химические и механические методы гидроизоляции, позволяющие производителям нефти максимально увеличить добычу нефти и минимизировать количество образующейся воды.
Ключевые слова: обводненность скважин, водяной конус, прорыв воды, водоносный пласт, неоднородность пласта, перепад давления, контроль водопритока, химическая изоляция воды, механическая изоляция воды, оптимизация нефтеотдачи.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

132-137

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-15

ANALYSIS OF PRODUCTIVITY CHANGES IN PRODUCTION WELLS DURING OPERATION

Arif Suleymanov[1], Sureyya Isayeva[2]
[1]Professor, Associate professor, Oil and Gas Engineering, Azerbaijan State Oil and Industry University.
Email: petrotech@asoiu.az
[2]Master's Degree Student, Faculty of Oil and Gas Production, Azerbaijan State Oil and Industry University.
Email: isayeva.sureya@icloud.az

ABSTRACT

The study determined that the interpretation of analyses obtained from permanent reference measuring devices installed on electric submersible pumps, together with the analysis of historical production indicators of wells, enables proper justification of planned production enhancement measures and evaluation of their effectiveness. This approach allows determining the current skin factor and reservoir pressure of the wells. According to the research, wells showing deterioration in skin factor over time were identified, and the optimal timing of re-intervention operations for these wells was selected. This contributes both to improving the skin factor and increasing production. The application of the method based on telemetry data of electric submersible pumps was recognized as another significant outcome of the study. Forecasts were carried out using fast 2D models developed in the "Topaze" software. Compared to 3D modelling, this method considerably reduced the time required to complete the work while maintaining a high level of forecast accuracy. As a result, the causes of production decline were identified, and well-founded technical recommendations aimed at increasing production were developed based on well test interpretation algorithms, thus preventing production.
Keywords: electric submersible pumps, 2D models, reservoir pressure, 3D modeling, well test interpretation, time-dependent skin factor variation, "Topaze" software, telemetry and reference measurement data, analysis of well production indicators.

Introduction

Methods Used for Production Analysis

The processing of data obtained from the pressure gauge integrated into the electric submersible pump and the additional analysis of production indicators are carried out using specialized software. All calculations are performed taking into account the existing saturation level. After pressure and flow rate data are entered into the software, a test curve is generated based on the model, and this curve must be matched to all filtration regimes observed in the reservoir. A typical example of such a well test is presented in Figure 1.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

For a drawdown test, the well being recorded must be operated at a constant production rate for at least 2–3 days. During this period, it is essential for the well to reach a steady- state regime; that is, variations in production and drawdown indicators must not exceed 5–10%. [2,4]

Methodology

The Role of Interwell Interference in Productivity Variation. Measurement While Drilling (MWD) method is used for the quantitative assessment of interwell interactions and for processing monitoring data aimed at optimizing the pressure maintenance system. [5]

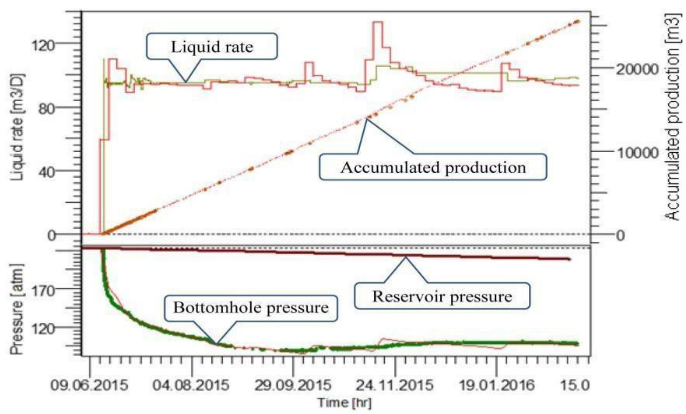


Figure 1. Example of a drawdown test recorded by the pressure gauge installed on the electric submersible pump.

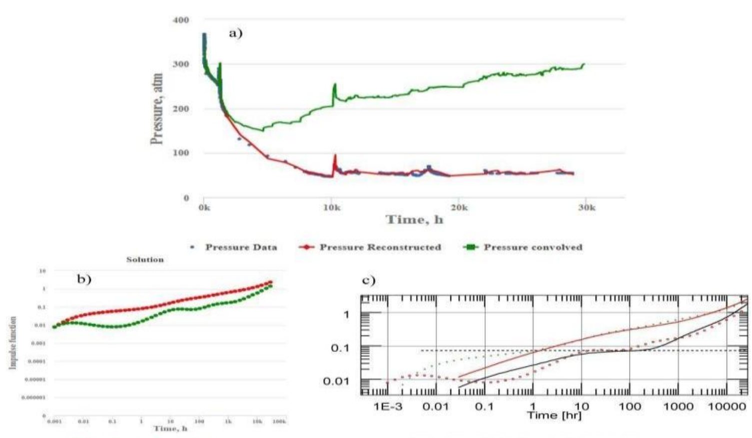


Figure 2: Analysis for Well No. 1 (central well for the studied area).

a) General view of the change in bottomhole pressure;
b) Transient response;
c) Position of radial flow regime in the interpretation of the transient response.[1,7] Using MWD technology and the algorithms of the PolyGon software by Sofoil company, the bottomhole pressure curve for the well's operation under a hypothetical condition without environmental

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

influence was obtained by solving a system of multi- well deconvolution equations (Figure 2). An example of such data is presented in Figure 3. [9]

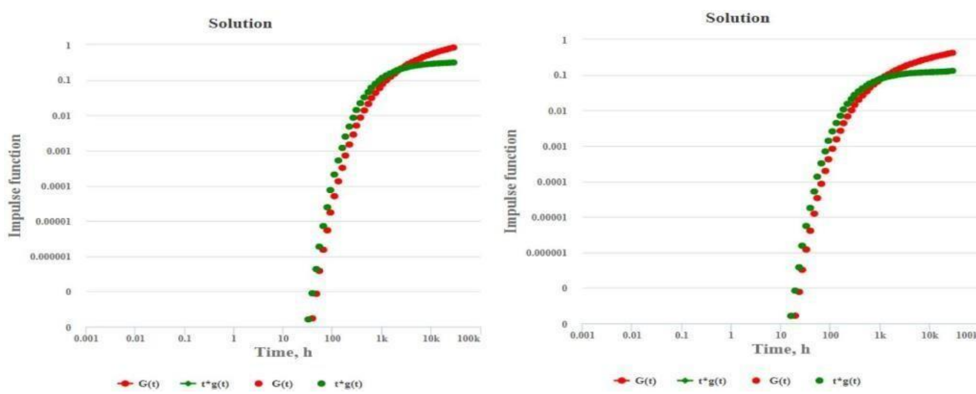


Figure 3: Example of inter-well transient characteristics in log-log coordinates.

The convolution of inter-well transient characteristics allows the derivation of curves characterizing the impact amplitude of surrounding wells (expressed in pressure units) on the studied well during its operation.
Table 1 shows a comparison of the inter-well impact.[10]

Table 1. Final values for inter-well intervals.

	Interval	Total pressure change due to inter-well intervention	Pressure changes due to inter-well intervention over the last month	Well-to-well transmission
1	2 → 1	−37	−0.8	45.4
2	3 → 1	+64	+3.1	31.3
3	4 → 1	−61.4	−1.5	78.1
4	5 → 1	−209.3	−31.5	28.5
5	6 → 1	−12.7	−0.5	147.4

Conclusion

The overall results of the analyses conducted can be summarized as follows:

• Data obtained from permanently installed monitoring devices on ESP, as well as the tracking of actual production changes, can be interpreted as a well test without causing production loss. Based on the analyzed indicators, various technological measures to increase production can be recommended, and it is also possible to quantitatively assess production forecasts and the effectiveness of production enhancement operations.

• In this context, the following cases should be particularly noted:

A. If a negative trend in the well's skin factor is observed over time, recommendations are prepared for intervention operations such as reperforation, acidizing, or hydraulic fracturing.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

B. If a significant drop in reservoir pressure is recorded, relevant proposals are developed for optimizing the pressure maintenance system.
C. If an increase in transmissibility and water cut is detected, it is recommended to conduct PLT (Production Logging Tool) studies to determine the flowing interval and locate inter-well flow.
• MWD technology enables prompt evaluation of inter-well interactions without the need to suspend well operations. This method also allows for determining transmissibility by intervals, the dynamics of reservoir pressure, and the quantitative impact of each surrounding well on the process.

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Aliyev A.A. Interpretation of well tests and methods of production optimization. Journal of Geology and Geophysics, No. 4, 2018, pp. 72-81.
2. Gasimov F.R. Restoration of reservoir pressure and changes in productivity indicators. Oil and Gas Science Journal, No. 1, 2021, pp. 29-36.
3. Isayeva S.M. Productivity variation and technological solutions in wells equipped with ESP systems. Gas-Oil Field Operations Journal, No. 6, 2023, pp. 11-19.
4. Humbatov R.H. Productivity assessment based on telemetry data from electric submersible pumps. Oil and Gas Engineering Journal, No. 2, 2020, pp. 41-50.
5. Mammadov A.R. Use of 2D models for diagnosing production decline. Journal of Petroleum Engineering Research, No. 5, 2022, pp. 58-67.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

6. Mammadhasanov T.Sh. Analysis of time-based changes in skin factor in production wells. Azerbaijan Oil Industry Journal, No. 3, 2019, pp. 15-22.
7. Rzayev K.M. Hydrodynamic analysis of well productivity. Baku: Science and Education, 2017, 198 p.
8. Isayev A.H. Artificial lift systems and their application. Baku: Maarif, 2019, 225 p. Khalilov M.A. Reservoir development and production management. Baku: Nafta- Press, 2020, 312 p.
9. Rzayev K.M. Hydrodynamic analysis of well productivity. Baku: Science and Education, 2017, 198 p.

İSTİSMAR ZAMANI HASİLAT QUYULARININ MƏHSULDARLIĞININ DƏYİŞMƏSİNİN TƏHLİLİ

Arif Süleymanov[1], Sürəyya İsayeva[2]
[1]Professor, Dosent, Neft-Qaz Mühəndisliyi, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: petrotech@asoiu.az
[2]Magistr, Qaz-Neft Mədən Fakültəsi, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: isayeva.sureya@icloud.az

XÜLASƏ

Tədqiqatda təyin olunmuşdur ki, elektriklə işləyən dalğıc nasosların üstündə quraşdırılmış daimi referens ölçü cihazlarından əldə edilən təhlillərin interpretasiyası, bununla yanaşı, quyuların tarixi hasilat göstəricilərinin analizi birlikdə tətbiq edildikdə, hasilatın artırılması üzrə planlaşdırılan tədbirlərin düzgün əsaslandırılması və onların səmərəliliyinin qiymətləndirilməsi mümkündür. Bu yanaşma nəticəsində quyuların cari skin-faktoru və lay təzyiqi müəyyən edilir. Araşdırmaya görə zamanla skin-faktorunda pisləşmə müşahidə olunan quyular müəyyən edilmiş və həmin quyular üzrə təkrar müdaxilə işlərinin optimal vaxtı seçilmişdir ki, bu da həm skin-faktorun yaxşılaşmasına, həm də hasilatın artırılmasına şərait yaradır. Elektrik dalğıc nasoslarının telemetriya məlumatlarına əsaslanan metodunun tətbiqi tədqiqatın başqa əhəmiyyətli nəticəsi kimi qəbul edilmişdir. Proqnozlar “Topaze” proqramında hazırlanan sürətli 2D modellər ilə aparılmışdır. Bu üsul 3D modelləşdirmə ilə müqayisədə işin yerinə yetirilmə müddətini kifayət qədər azaltmış, həmçinin proqnoz dəqiqliyini yüksək səviyyədə saxlamışdır. Nəticədə, hasilat itkisinin qarşısı alınmaqla hasilat azalmasının səbəbləri müəyyən olunmuş və quyu sınaqlarının interpretasiya alqoritmləri əsasında hasilatın artırılması məqsədilə əsaslandırılmış texniki tövsiyələr hazırlanmışdır.
Açar sözlər: elektrik dalğıc nasosları,2D modellər,lay təzyiqi,3D modelləşdirmə,quyu sınaqlarının interpretasiyası, skin-faktorun zamanla dəyişməsi, “Topaze” proqram təminatı, telemetriya və referens ölçü məlumatları, quyu hasilat göstəricilərinin təhlili.

АНАЛИЗ ИЗМЕНЕНИЯ ПРОДУКТИВНОСТИ ДОБЫВАЮЩИХ СКВАЖИН ВО ВРЕМЯ ЭКСПЛУАТАЦИИ

Ариф Сулейманов[1], Сюрейя Исаева[2]
[1]Профессор, Доцент, Нефтегазовой инженерии, Азербайджанский Государственный Университет Нефти и Промышленности. Эл. адрес:petrotech@asoiu.az

[2]Магистр, факультет Нефтегазодобычи, Азербайджанский Государственный Университет Нефти и Промышленности. Эл. адрес: isayeva.sureya@icloud.az

РЕЗЮМЕ

В ходе исследования установлено, что интерпретация данных, полученных от постоянных референс-измерительных приборов, установленных на электроцентробежных насосах, в сочетании с анализом исторических показателей добычи скважин позволяет обоснованно планировать мероприятия по увеличению добычи и оценивать их эффективность. Такой подход даёт возможность определить текущий скин-фактор и пластовое давление скважин. Согласно проведённому анализу, были выявлены скважины, у которых со временем наблюдается ухудшение скин-фактора, и для них был выбран оптимальный срок повторных вмешательств, что способствует как улучшению скин-фактора, так и увеличению добычи. Прогнозные расчёты были выполнены с использованием быстрых 2D-моделей, созданных в программе «Topaze». Данный метод существенно сократил время выполнения работ по сравнению с 3D-моделированием, при этом сохранив высокую точность прогноза.
Ключевые слова: электроцентробежные насосы, двумерные (2d) модели, пластовое давление, трехмерное (3d) моделирование, интерпретация испытаний скважин, изменение скин-фактора во времени, программное обеспечение «topaze», телеметрические и референтные измерительные данные, анализ показателей добычи скважин.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

138-149

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-16

IMPROVING THE CYBERSECURITY OF SCADA SYSTEMS

Nazim Huseynov[1], Humay Zahmati[2]
[1]PhD in Economics, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: nazim.huseynov.to@asoiu.edu.az
[2]Master's degree student, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: zehmetihumay@gmail.com

ABSTRACT

This paper focuses on improving the cybersecurity of Supervisory Control and Data Acquisition (SCADA) systems, which play a critical role in managing industrial and critical infrastructure processes. Due to increasing connectivity and the integration of legacy systems with modern networks, SCADA systems have become attractive targets for cyberattacks, particularly Denial of Service (DoS) attacks.
The study analyzes common cybersecurity measures used to protect SCADA systems, including network segmentation, firewalls, strong authentication mechanisms, intrusion detection and prevention systems (IDS/IPS), and secure communication protocols. Special attention is given to the operational principles and impacts of DoS attacks on SCADA environments.
A simulation-based approach is employed to demonstrate a DoS attack against a SCADA system deployed in a virtual environment. Network traffic analysis is performed using the Wireshark tool to detect abnormal packet flows, while the Snort IDS/IPS is configured to identify and block malicious traffic in real time. The results show that the implemented IDS/IPS mechanisms effectively detect, mitigate, and prevent DoS attacks, significantly reducing their impact on system availability and resource consumption.
The findings highlight the importance of layered security approaches and real-time monitoring tools in enhancing the resilience of SCADA systems against cyber threats.
Keywords: SCADA systems, cybersecurity, Denial of Service (DoS), IDS/IPS, Wireshark, Snort, network security, critical infrastructure.

Introduction

Supervisory Control and Data Acquisition (SCADA) systems are widely used to monitor and control critical industrial processes such as power generation, oil and gas production, water distribution, and manufacturing systems. These systems are designed to ensure continuous operation, high reliability, and real-time control of physical processes. However, the rapid integration of information technologies and increased connectivity with corporate and external networks have significantly expanded the attack surface of SCADA environments.
Traditionally, SCADA systems were isolated and relied on proprietary hardware and communication protocols, which provided a certain level of inherent security. In modern

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

industrial environments, this isolation has largely disappeared due to the adoption of standard networking technologies and remote access solutions. As a result, legacy SCADA components often coexist with modern IT infrastructures, creating complex hybrid systems that are difficult to secure and maintain.

Cyber threats targeting SCADA systems have become more frequent and sophisticated. These attacks may be motivated by financial gain, political objectives, or attempts to disrupt critical infrastructure services. Regardless of the motivation, successful cyberattacks can lead to serious consequences, including loss of system availability, unauthorized control actions, data manipulation, and physical damage to industrial processes. Among various cyber threats, Denial of Service (DoS) attacks pose a significant risk by overwhelming system resources and preventing legitimate control operations.

As industrial systems grow in complexity, the number of system states and control decisions also increases. This makes SCADA systems more vulnerable to attacks that exploit incorrect system behavior or force unintended state transitions. A compromised system may operate based on false or manipulated information, leading to unsafe operating conditions and costly disruptions.

Therefore, ensuring the cybersecurity of SCADA systems has become a critical requirement. This includes the implementation of layered security strategies such as network segmentation, access control mechanisms, intrusion detection and prevention systems, and continuous monitoring. Understanding the behavior of cyberattacks and evaluating effective defense mechanisms are essential steps toward improving the resilience and reliability of modern SCADA infrastructures.

1. Cybersecurity foundations for scada systems

Supervisory Control and Data Acquisition (SCADA) systems form the backbone of modern industrial operations, managing and monitoring critical processes in sectors such as energy, manufacturing, and transportation. The cybersecurity of these systems is a fundamental requirement due to their direct with physical infrastructure and their increasing exposure to network-based threats.

Unlike traditional information technology systems, SCADA environments prioritize availability, reliability, and real-time performance. This operational focus introduces unique security challenges, particularly as legacy industrial components are integrated with modern communication networks. The convergence of operational technology (OT) and information technology (IT) has expanded the attack surface, making SCADA systems more vulnerable to unauthorized access and cyberattacks.

Establishing a strong cybersecurity foundation requires the implementation of core security mechanisms that limit exposure, control access, and reduce the impact of potential attacks. These mechanisms include logical separation of network segments, strict traffic control, robust authentication techniques, and well-defined access control policies. Together, they form the baseline security architecture upon which advanced detection and prevention methods can be built.

The following subsections discuss key foundational security mechanisms for SCADA systems, focusing on network segmentation and firewall technologies, as well as strong authentication protocols and access control strategies.

1.1. Network segmentation and firewalls

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Network segmentation and firewall technologies represent essential security mechanisms for protecting SCADA systems against cyber threats. Network segmentation involves dividing a large industrial network into multiple smaller and logically separated zones based on function, security level, and operational importance. This approach limits communication between different segments and helps reduce the potential impact of a cyberattack by preventing unauthorized lateral movement within the network.

In SCADA environments, segmentation is commonly applied to separate operational technology (OT) networks from corporate IT networks. Furthermore, critical components such as control servers, human-machine interfaces (HMIs), programmable logic controllers (PLCs), and remote terminal units (RTUs) can be placed in distinct network segments. By isolating these components, a security breach in one segment does not automatically compromise the entire system.

Firewalls play a crucial role in enforcing the boundaries created by network segmentation. They monitor and control data traffic passing between network zones according to predefined security rules. Firewalls can restrict access based on IP addresses, communication protocols, and port numbers, allowing only authorized and necessary traffic to flow between segments. This reduces exposure to malicious traffic and blocks unauthorized connection attempts.

When properly configured, firewalls can also help detect and mitigate known attack patterns by filtering abnormal or suspicious traffic. In SCADA systems, firewall rules are often designed with strict policies that permit only essential communication, ensuring system stability and availability. This controlled communication model supports the concept of “defense in depth,” where multiple layers of security work together to protect critical infrastructure.

Overall, the combination of network segmentation and firewall technologies enhances the resilience of SCADA systems by limiting attack surfaces, preventing unauthorized access, and minimizing the consequences of potential cyber incidents.

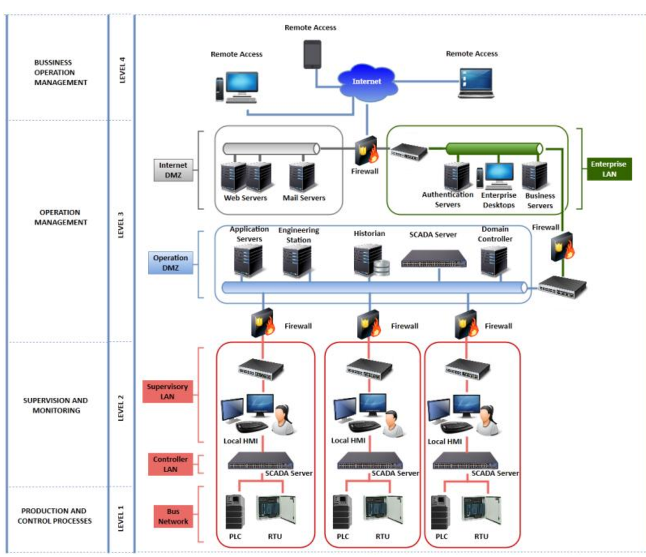


Figure 1.1: ISA95 levels implemented in SCADA architecture.

1.2. Strong authentication protocols and access controls

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Strong authentication mechanisms and effective access control policies are critical components in securing SCADA systems against unauthorized access and misuse. These measures ensure that only verified users and trusted devices can interact with sensitive industrial control resources. As SCADA systems increasingly support remote access and integration with enterprise networks, traditional single-factor authentication methods are no longer sufficient to provide adequate protection.

Modern authentication approaches commonly rely on multi-factor authentication (MFA), which combines two or more independent verification factors such as passwords, hardware tokens, or biometric identifiers. In SCADA environments, MFA significantly reduces the risk of unauthorized access by ensuring that compromised credentials alone are not enough to gain system entry. This approach is especially important for remote operators and engineers accessing control systems from external locations.

In addition to authentication mechanisms, access control strategies define what actions an authenticated user is permitted to perform within the system. Role-Based Access Control (RBAC) is widely adopted in SCADA systems to manage permissions based on predefined roles rather than individual users. Each role is assigned a specific set of privileges aligned with operational responsibilities, such as monitoring system status, modifying control logic, or managing system configurations. This minimizes the risk of accidental or malicious actions by limiting user privileges to only what is necessary.

Centralized access management further enhances security by allowing administrators to monitor user activity, enforce security policies, and rapidly revoke access if a compromise is suspected. Security policies such as regular credential updates, account lockout after repeated failed login attempts, and restricted administrative access points also contribute to strengthening overall system protection.

Overall, the implementation of strong authentication protocols and well-defined access control mechanisms plays a vital role in maintaining the integrity, availability, and reliability of SCADA systems.

Figure 1.2: Example of an RSA SecurID hardware authentication token.

2. Methods and tools for dos attack analysis

The analysis of Denial of Service (DoS) attacks requires a combination of theoretical understanding and practical investigation techniques. In industrial control environments such as SCADA systems, DoS attacks pose a serious threat by disrupting communication channels and exhausting system resources, which can directly affect system availability and operational continuity.

This study adopts a structured approach to analyze DoS attacks by examining their fundamental operating principles and evaluating practical detection methods. Understanding how DoS attacks are generated and how they impact network behavior is a critical first step toward effective detection and mitigation. For this purpose, network traffic characteristics and abnormal packet patterns are closely examined.

To support the analysis, widely used network monitoring and packet inspection tools are employed. These tools enable detailed observation of traffic flows, identification of anomalous behavior, and assessment of attack intensity. Packet-level analysis provides valuable insights into the source, destination, and volume of traffic, which are essential for recognizing DoS attack patterns.

The following subsections present a detailed explanation of DoS attack mechanisms and introduce the capabilities of the Wireshark tool for detecting DoS-related network anomalies within SCADA environments.

2.1. Explanation of dos attack

Denial of Service (DoS) attacks are a common form of cyberattack aimed at disrupting the normal operation of a system by overwhelming its resources and rendering it unavailable to legitimate users. Rather than exploiting vulnerabilities to gain unauthorized control, DoS attacks focus on exhausting network bandwidth, processing power, or memory resources, preventing the system from responding to valid requests.

In the context of SCADA systems, DoS attacks pose a particularly serious threat due to the critical nature of industrial control operations. SCADA environments rely on continuous communication between control centers, field devices, and monitoring interfaces. An excessive volume of malicious traffic can interrupt this communication, leading to delayed responses, loss of visibility, or complete system unavailability.

DoS attacks are typically executed by sending a large number of packets to a target system within a short period of time. These packets may exploit standard network protocols such as TCP, UDP, or ICMP, forcing the target to process each request until its resources are depleted. In more advanced scenarios, attackers may use Distributed Denial of Service (DDoS) attacks, where traffic is generated simultaneously from multiple compromised devices, significantly increasing the attack intensity.

The impact of a DoS attack on SCADA systems can extend beyond network disruption. Resource exhaustion may prevent operators from issuing control commands, monitoring system states, or responding to emergency situations. In industrial environments, such disruptions can result in operational downtime, safety risks, and financial losses.

Understanding the fundamental behavior and characteristics of DoS attacks is essential for effective detection and mitigation. By analyzing traffic patterns, packet rates, and protocol behavior during an attack, abnormal conditions can be identified and distinguished from normal operational traffic. This understanding forms the basis for applying network monitoring and packet analysis tools, which are discussed in the following section.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

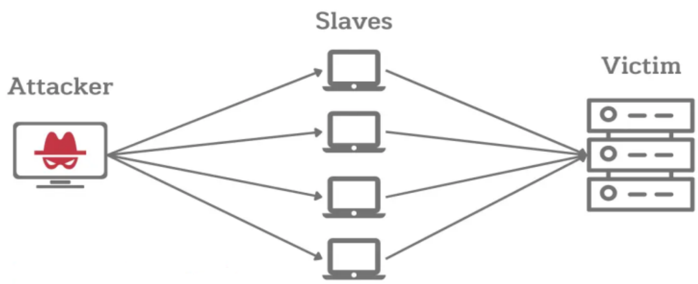


Figure 2.1: Illustration of a distributed denial-of-service attack using a botnet

2.2. Wireshark capabilities to detect dos attack

Effective detection of Denial of Service (DoS) attacks relies on detailed analysis of network traffic behavior. Since DoS attacks are characterized by abnormal packet volumes and repetitive traffic patterns, packet-level inspection plays a crucial role in identifying such threats. Wireshark is a widely used open-source network protocol analyzer that provides deep visibility into network communications and supports detailed traffic analysis.

Wireshark captures and displays individual network packets in real time, allowing analysts to examine essential packet attributes such as timestamps, source and destination IP addresses, transport protocols, and packet sizes. This level of detail enables the identification of unusual traffic characteristics, including sudden increases in packet rate or repetitive packet sequences originating from a single or multiple sources.

One of Wireshark's key capabilities is its advanced filtering functionality, which allows specific traffic flows to be isolated based on protocol type, IP address, port number, or packet flags. During a DoS attack, filters can be applied to highlight excessive TCP, UDP, or ICMP traffic directed toward a targeted system. By analyzing traffic within a defined time window, abnormal packet rates can be distinguished from normal operational behavior.

Wireshark also provides statistical tools, such as packet count analysis and protocol distribution views, which help quantify traffic anomalies. These features enable the comparison of normal and attack traffic patterns, offering clear visual evidence of DoS activity. Such analysis supports early detection and situational awareness during an ongoing attack.

Although Wireshark is highly effective for detecting and analyzing DoS attacks, it functions solely as a passive monitoring tool and does not have the capability to block or mitigate malicious traffic. Therefore, once an attack is identified through packet analysis, additional security mechanisms are required to actively prevent further impact. This limitation highlights the need for intrusion detection and prevention solutions, which are discussed in the following section.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

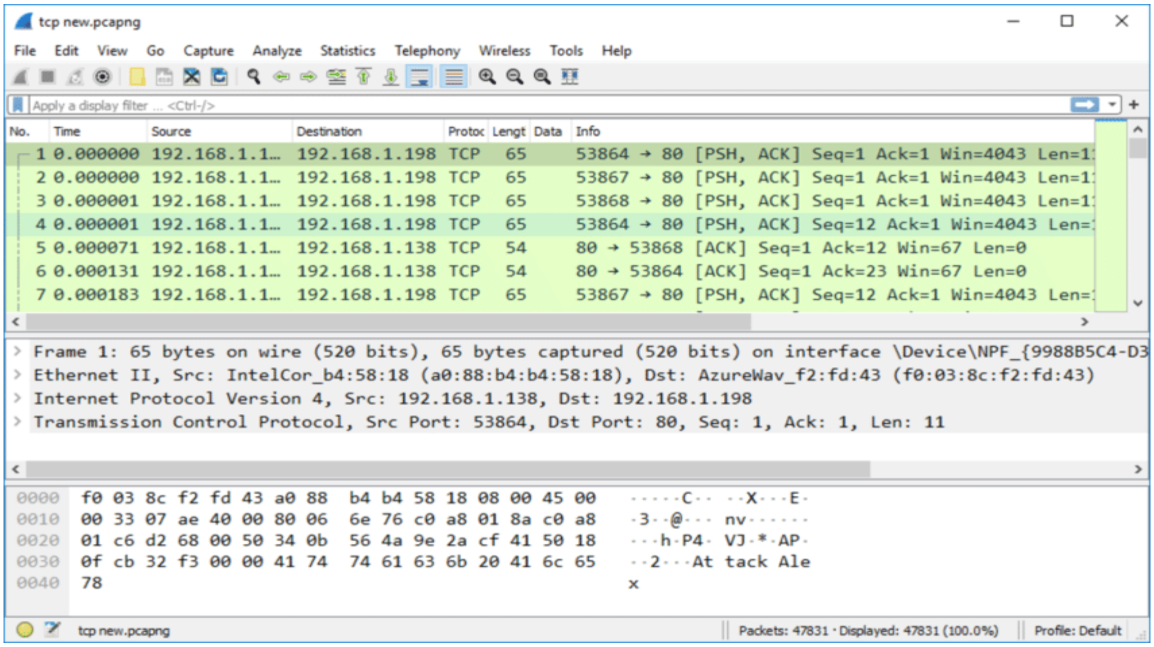


Figure 2.2.1: Overview of the Wireshark user interface.

2.3. Protection against dos attacks using snort ids/ips

While packet analysis tools are effective for identifying Denial of Service (DoS) attacks, active mitigation requires intrusion detection and prevention mechanisms capable of responding in real time. Snort is a widely adopted open-source Intrusion Detection and Intrusion Prevention System (IDS/IPS) that is frequently used to protect networked systems against a wide range of cyber threats, including DoS attacks.

Snort operates by inspecting network traffic and comparing captured packets against predefined rule sets that describe known attack patterns or abnormal behaviors. These rules can be customized to monitor specific traffic characteristics such as excessive packet rates, repeated connection attempts, or unusual protocol usage. When deployed in IDS mode, Snort generates alerts upon detecting suspicious activity, enabling administrators to assess the severity of the threat.

In IPS mode, Snort provides proactive defense by blocking or dropping malicious traffic as it is detected. This capability is particularly valuable in SCADA environments, where maintaining system availability is critical. By placing Snort inline with network traffic or directly on the target system, it can prevent DoS packets from consuming system resources and disrupting normal operations.

For DoS attack mitigation, Snort rules are commonly configured to define threshold-based conditions, such as limiting the number of packets allowed from a specific source within a given time interval. When these thresholds are exceeded, Snort can automatically discard the offending packets and log the incident for further analysis. This approach allows rapid response to high-volume attacks while preserving legitimate traffic.

The integration of Snort with traffic analysis tools, such as Wireshark, enhances the overall effectiveness of DoS defense strategies. Wireshark supports detailed attack identification, while

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

Snort enforces automated prevention measures. Together, these tools form a practical and efficient framework for detecting and mitigating DoS attacks in SCADA systems, contributing to improved system resilience and operational stability.

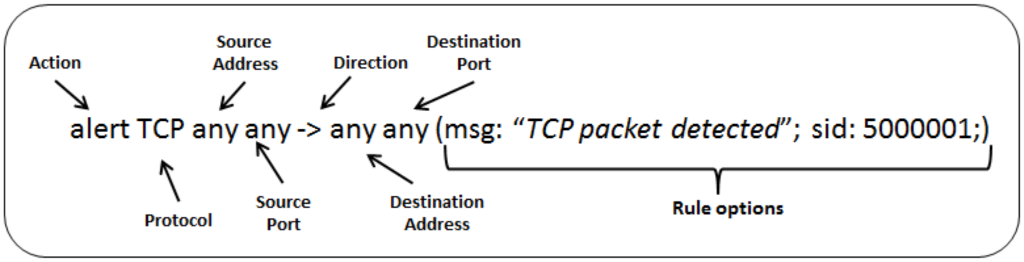


Figure 2.3.1: General structure of a Snort detection rule.

3. Experımental setup and results

This section presents the experimental setup, simulation environment, and obtained results related to the analysis, detection, and mitigation of DoS attacks in a SCADA system. A virtualized test environment is used to replicate realistic attack scenarios and evaluate the effectiveness of the applied detection and prevention mechanisms.

3.1 experimental environment and simulation setup

The experimental evaluation is conducted using a virtualized environment to simulate a SCADA system and an attacker machine. Virtualization technology allows controlled experimentation without affecting real industrial infrastructure while maintaining realistic network behavior. The SCADA system is deployed as a virtual machine running a Linux-based operating system, representing a typical control system environment. An attacker machine, configured with a penetration testing operating system, is used to generate DoS traffic toward the target system. Both virtual machines are hosted on the same virtualization platform and connected through a virtual network to enable direct communication.

The network configuration is designed to simulate a local industrial network, where the SCADA system operates as a server and the attacker machine acts as an external threat source. Packet capture and intrusion prevention tools are installed directly on the SCADA system to monitor incoming traffic and respond to malicious activity.

3.2 Dos attack simulation scenario

To evaluate the impact of a DoS attack, a controlled attack scenario is implemented against the simulated SCADA system. An open network service is enabled on the target machine to represent a typical service exposed within industrial environments. The attacker machine generates high-volume traffic directed toward the target service, aiming to exhaust system and network resources. The DoS attack is executed using a traffic generation tool capable of sending large numbers of packets within a short time frame. Attack parameters such as protocol type, destination port, and traffic rate are configured to simulate a realistic flooding attack. During the attack, system resource usage and network behavior are closely observed to assess the effects of resource exhaustion.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

3.3 Detection and mitigation results

During the attack simulation, network traffic is monitored using a packet analysis tool to identify abnormal traffic patterns associated with DoS activity. A significant increase in packet rate and repetitive traffic originating from the attacker machine is observed, clearly distinguishing attack traffic from normal operational behavior.
To mitigate the attack, an intrusion detection and prevention system is activated with predefined rules designed to detect excessive traffic within a specific time window. Once the attack traffic exceeds the defined threshold, malicious packets are automatically dropped, preventing further resource exhaustion on the SCADA system.
The results demonstrate that, prior to mitigation, system resource utilization increases noticeably under attack conditions. After enabling the prevention mechanism, resource usage stabilizes, and normal system operation is maintained despite the ongoing attack. Alert logs generated during the process confirm successful detection and blocking of malicious traffic.

Conclusion

This study examined the impact of Denial of Service (DoS) attacks on SCADA systems and evaluated practical methods for detecting and mitigating such attacks using network analysis and intrusion prevention tools. Due to their critical role in industrial environments, SCADA systems require continuous availability, making them particularly vulnerable to resource exhaustion attacks.
Through a simulation-based experimental setup, the behavior of DoS attacks was analyzed in a controlled environment. Packet-level traffic analysis using Wireshark enabled the identification of abnormal traffic patterns and excessive packet rates associated with DoS activity. While effective for detection and investigation, packet analysis alone was insufficient to actively protect the system from ongoing attacks.
To address this limitation, the Snort IDS/IPS was deployed as an active defense mechanism. The results demonstrated that properly configured Snort rules can successfully detect and block malicious traffic in real time, significantly reducing the impact of DoS attacks on system resources and maintaining operational stability. The combination of traffic analysis and automated prevention proved to be an effective and practical approach for enhancing SCADA system resilience.
Overall, the findings highlight the importance of integrating monitoring and prevention mechanisms within SCADA cybersecurity architectures. Future work may focus on extending this approach with anomaly-based detection techniques, machine learning methods, or large-scale distributed attack scenarios to further improve detection accuracy and system robustness.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Zhang, Y., Wang, L., Xiang, Y., & Ten, C. (2015). Power system reliability evaluation with SCADA Cybersecurity considerations. IEEE Transactions on Smart Grid, 6(4), 1707–1721. https://doi.org/10.1109/tsg.2015.2396994
2. Teixeira, M. A., Salman, T., Zolanvari, M., Jain, R., Meskin, N., & Samaka, M. (2018). SCADA system testbed for cybersecurity research using machine learning approach. Future Internet, 10(8), 76. https://doi.org/10.3390/fi10080076
3. Falco, G., Caldera, C., & Shrobe, H. (2018). IIOT Cybersecurity Risk Modeling for SCADA systems. IEEE Internet of Things Journal, 5(6), 4486–4495. https://doi.org/10.1109/jiot.2018.2822842
4. Marcio Andrey Teixeira (2018) SCADA System Testbed for Cybersecurity Research Using Machine Learning Approach. Future Internet journal
5. Kumar, S. S., & Kulothungan, K. (2017). An Anomaly Behavior based Detection and Prevention of DoS Attack in IoT Environment. https://doi.org/10.1109/icoac.2017.8441322

SCADA SİSTEMLƏRİNİN KİBERTƏHLÜKƏSİZLİYİNİN TƏKMİLLƏŞDİRİLMƏSİ

Nazim Hüseynov[1], Humay Zəhməti[2]
[1]İqtisad üzrə fəlsəfə doktoru, Elektronika və Avtomatika kafedrası,
Azərbaycan Dövlət Neft və Sənaye Universiteti, Email: nazim.huseynov.to@asoiu.edu.az
[2]Magistr tələbəsi, Elektronika və Avtomatika kafedrası,
Azərbaycan Dövlət Neft və Sənaye Universiteti, Email: zehmetihumay@gmail.com

XÜLASƏ

Bu məqalə sənaye və kritik infrastruktur proseslərinin idarə olunmasında mühüm rol oynayan Supervisory Control and Data Acquisition (SCADA) sistemlərinin kibertəhlükəsizliyinin təkmilləşdirilməsinə həsr olunmuşdur. Artan şəbəkə bağlantıları və köhnə (legacy) sistemlərin

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

müasir şəbəkələrlə inteqrasiyası nəticəsində SCADA sistemləri, xüsusilə Xidmətdən İmtina (Denial of Service – DoS) hücumları üçün əsas hədəflərə çevrilmişdir.
Tədqiqatda SCADA sistemlərinin qorunması üçün istifadə olunan əsas kibertəhlükəsizlik tədbirləri, o cümlədən şəbəkənin seqmentasiyası, firewall-lar, güclü autentifikasiya mexanizmləri, müdaxilənin aşkarlanması və qarşısının alınması sistemləri (IDS/IPS), həmçinin təhlükəsiz rabitə protokolları təhlil olunur. DoS hücumlarının SCADA mühitində işləmə prinsiplərinə və təsirlərinə xüsusi diqqət yetirilmişdir.
Virtual mühitdə yerləşdirilmiş SCADA sisteminə qarşı DoS hücumunu nümayiş etdirmək üçün simulyasiya əsaslı yanaşma tətbiq edilmişdir. Şəbəkə trafiki Wireshark aləti vasitəsilə analiz olunaraq anormal paket axınları müəyyən edilmiş, Snort IDS/IPS sistemi isə zərərli trafikin real vaxt rejimində aşkarlanması və bloklanması üçün konfiqurasiya edilmişdir. Nəticələr göstərir ki, tətbiq olunan IDS/IPS mexanizmləri DoS hücumlarını effektiv şəkildə aşkarlayır, zəiflədir və qarşısını alır, bununla da sistemin əlçatanlığına və resurs sərfiyyatına olan mənfi təsiri əhəmiyyətli dərəcədə azaldır.
Əldə olunan nəticələr SCADA sistemlərinin kibertəhlükələrə qarşı dayanıqlılığının artırılmasında çoxsəviyyəli təhlükəsizlik yanaşmalarının və real vaxt monitorinq alətlərinin vacibliyini vurğulayır.
Açar sözlər: SCADA sistemləri, kibertəhlükəsizlik, Xidmətdən İmtina (DoS), IDS/IPS, Wireshark, Snort, şəbəkə təhlükəsizliyi, kritik infrastruktur.

СОВЕРШЕНСТВОВАНИЕ КИБЕРБЕЗОПАСНОСТИ СИСТЕМ SCADA

Назим Гусейнов[1], Хумай Зехмети[2]
[1]PhD по экономике, кафедра электроники и автоматизации,
Азербайджанский государственный университет нефти и промышленности,
Email: nazim.huseynov.to@asoiu.edu.az
[2]Магистрант, кафедра электроники и автоматизации,
Азербайджанский государственный университет нефти и промышленности,
Email: zehmetihumay@gmail.com

РЕЗЮМЕ

Данная статья посвящена совершенствованию кибербезопасности систем Supervisory Control and Data Acquisition (SCADA), которые играют ключевую роль в управлении промышленными процессами и объектами критической инфраструктуры. В связи с ростом сетевой взаимосвязанности и интеграцией устаревших (legacy) систем с современными сетями системы SCADA стали привлекательной целью для кибератак, особенно атак типа «Отказ в обслуживании» (Denial of Service, DoS).
В исследовании анализируются основные меры кибербезопасности, применяемые для защиты систем SCADA, включая сегментацию сети, межсетевые экраны (firewall), надежные механизмы аутентификации, системы обнаружения и предотвращения вторжений (IDS/IPS), а также защищенные протоколы связи. Особое внимание уделяется принципам функционирования и последствиям DoS-атак в среде SCADA.
Для демонстрации DoS-атаки на систему SCADA, развернутую в виртуальной среде, используется моделирование. Анализ сетевого трафика проводится с помощью

инструмента Wireshark для выявления аномальных потоков пакетов, а система Snort IDS/IPS настраивается для обнаружения и блокирования вредоносного трафика в режиме реального времени. Результаты показывают, что реализованные механизмы IDS/IPS эффективно обнаруживают, смягчают и предотвращают DoS-атаки, существенно снижая их влияние на доступность системы и потребление ресурсов.
Полученные результаты подчеркивают важность многоуровневых подходов к обеспечению безопасности и использования инструментов мониторинга в реальном времени для повышения устойчивости систем SCADA к киберугрозам.
Ключевые слова: системы SCADA, кибербезопасность, отказ в обслуживании (DoS), IDS/IPS, Wireshark, Snort, сетевая безопасность, критическая инфраструктура.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

150-157

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-17

VOLUME 33 (08) ISSUE 02 2026

INVESTIGATION OF THE OLEFIN CONVERSION PROCESS OVER HCBM AND HCBM + 3% ZN CATALYSTS

Alakbar Hasanov[1], Yunis Guliyev[2]
[1]Doctor of Chemical Sciences, Professor, Azerbaijan State University of Oil and Industry (ASOIU), Department of Petrochemical Technology and Industrial Ecology, Azerbaijan. E-mail: alakbar48-48@mail.ru
[2]Master's Student, Azerbaijan State University of Oil and Industry (ASOIU), Azerbaijan.
E-mail: yunisquliyev05@gmail.com

ABSTRACT

In the petroleum refining industry, particularly in catalytic cracking units, the efficient utilization of hydrocarbon gases obtained as by-products is of special importance in terms of the effective use of derived products, environmental improvement, and conservation of energy resources. It is well known that hydrocarbon gases produced at oil refineries are mainly combusted to meet internal energy demands. One of the promising directions for the efficient utilization of these gases is the conversion of C_3–C_4 hydrocarbons into alkenes, arenes, and motor fuel components. In this study, propylene and butylene were selected as feedstocks, and a zinc-modified zeolite catalyst belonging to the pentasil family was employed. The conversion reactions of the above-mentioned hydrocarbons were investigated in the presence of this catalyst. As a result of the research, it was established that the zinc-modified catalyst exhibited high activity, and it was determined that aliphatic compounds are formed from olefins.The article presents results reflecting the influence of space velocity and temperature on the course of the process. The effects of temperature and feedstock space velocity on target product yield, catalyst selectivity, and conversion were investigated in detail. It was shown that, in the presence of a zinc-modified zeolite-based catalyst, aliphatic hydrocarbons are formed from olefins at a temperature of 300 - 350°C.

Keywords: Propylene, butylene, aliphatic hydrocarbons, aromatic hydrocarbons, HCBM Catalyst, HCBM + 3 wt.% Zn catalyst.

Introduction

The study of propylene and butylene conversion processes is motivated on one hand by the accumulation of surplus propylene and butylene in oil refineries (OR), and on the other hand by the expanding applications of their oligomers. Research has shown that catalytic transformations of olefins lead not only to aliphatic but also to aromatic hydrocarbons, which is largely determined by the operating temperature of the process. Within the temperature range of 100–500°C, in the presence of zeolite catalysts, the following reactions of olefin hydrocarbons are particularly pronounced: oligomerization, isomerization, cracking, dehydrocyclization, hydrogen redistribution, carbon disproportionation, and other side reactions. Most of these reactions

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

proceed simultaneously, resulting in a broad spectrum of products. The choice of catalyst has a direct impact on process efficiency. Catalytic conversions of olefin hydrocarbons have been investigated using high-silica, pentasil-type decationized zeolite catalysts (HCBM), as well as samples modified with zinc. Experiments indicate that zinc modification enhances the selectivity of the oligomerization reaction while reducing the formation of undesired by-products. Moreover, optimizing temperature and pressure parameters is crucial for controlling both product yield and composition. Increasing the temperature favors cracking and dehydrocyclization reactions, whereas lower temperatures promote oligomerization and isomerization pathways.Thus, studies on the catalytic conversion of propylene and butylene are of significant importance for both the efficient utilization of surplus refinery hydrocarbons and the production of novel chemical products.

Methods

It is well established in scientific and technical literature that zeolites exhibit catalytic activity in the conversion of lower hydrocarbons at temperatures above 200°C: at lower temperatures, predominantly aliphatic hydrocarbons are formed, whereas at higher temperatures, aromatic hydrocarbons are mainly produced. For this reason, the catalytic conversion of propylene and butylene was investigated within the temperature range of 245–540°C. The results of experiments on propylene conversion over the HCBM catalyst are presented in Table 1.

Table 1. Catalytic conversion of propylene over the HCBM catalyst (space velocity 500 h^{-1}).

Temperature °C	Conversion C_3H_6 %	Products, wt.%			
		Liquid products		Gaseous products	Coke
		Aliphatic hydrocarbons	Aromatic hydrocarbons		
245	50,1	35,7	3,2	59,1	1
290	95,6	63,8	15,8	17,2	1,2
330	94,8	53,2	17,8	26,2	1,5
380	95,1	40,2	20,2	37,1	1,6
430	93,6	25,5	25,5	44,8	2,1
485	94,2	15,7	32,3	48,4	2,1
540	92,5	5,8	34	54,8	1,8

As can be seen from the table, at a temperature of 245°C, mainly gaseous products are formed, consisting of C_2–C_4 hydrocarbons, methane, and hydrogen. Starting from 290°C, the yield of condensate increases, and aliphatic hydrocarbons become predominant in its composition. The maximum yield of aliphatic hydrocarbons is observed at 290°C and reaches 63.8%. Aliphatic hydrocarbons are mainly represented by olefins, among which propylene dimers and trimers prevail. At the same time, paraffinic hydrocarbons are also formed in an amount of 7–8%. Along with olefin oligomerization and the accompanying processes—such as cracking, isomerization, and hydrogen redistribution—pentasil-type zeolites also actively catalyze the aromatization of olefins. However, as shown in the table, aromatic hydrocarbons are selectively formed at temperatures above 430°C. These products consist of benzene, toluene, xylenes, ethylbenzene, and C_9^+ hydrocarbons. In the conversion processes of C_3–C_4 hydrocarbons, zinc-modified HCBM samples were also tested as catalysts. As is well known, modification of zeolite catalysts with zinc cations enhances their activity and stability. However, it should be noted that the catalytic activity of zeolites is influenced not only by the nature of promoters but also by other factors. Not only the nature of zinc cations but also their concentration plays an important role. Many authors suggest that the optimal zinc content in the modified samples should be 2.8–3,1wt.%. It is assumed that at this zinc loading, a finely dispersed metal state is achieved, which ensures both the blocking of strong acid sites and the maintenance of zinc in its catalytically active form.

Incorporation of zinc into the zeolite reduces the number of strong Brensted acid sites on the zeolite surface by a factor of 1.5 compared to the H-form. When the zinc content is below 3 wt.%, only partial and insufficient weakening of strong acid sites occurs, and the amount of metal centers is not optimal. In cases where the zinc content in the zeolite exceeds 3 wt.%, aggregation of metal particles is observed, which leads to a decrease in the catalytic efficiency of metal centers while the high acidity of the zeolite is preserved.Taking the above considerations into account, the decationized HCBM sample was modified with 3 wt.% zinc. The results of experiments on propylene conversion over the zinc-modified zeolite catalyst are presented in Table 2.

Table 2. Catalytic conversion of propylene over the HCBM + 3 wt.% Zn catalyst (space velocity 500 h^{-1}).

Temperature °C	Conversion C_3H_6 %	Products, wt.%			
		Liquid products		Gaseous products	Coke
		Aliphatic hydrocarbons	Aromatic hydrocarbons		
245	52,2	35,2	4,4	58,3	1,1
290	95,9	63,5	18,1	16	1,3
330	95,6	52,8	21,4	22,1	1,7
380	95,3	38,3	24,3	34,2	1,8
430	95	26,1	28,1	41,9	2,1
485	94,7	14,7	34,6	46,7	2,6
540	93	5,2	40,4	51,2	2,8

As can be seen from the table, the incorporation of zinc into the HCBM catalyst does not have a significant effect on its overall activity, and the degree of propylene conversion remains nearly unchanged. During the process, the catalyst is required to be highly selective, resistant to coking, and stable at elevated temperatures. However, the aromatization performance of the catalyst increases noticeably. While the yield of aromatic hydrocarbons at 540°C is 34% for the unmodified samples, this value increases to 40.4% for the zinc-containing catalysts.

It is well known that refinery gases contain a certain amount of butylenes. For example, the butane–butylene fraction obtained from pyrolysis contains approximately 34-35% butylenes. Due to the presence of dienes and n-butane, this fraction is unsuitable for alkylation and is therefore considered a non-utilized fraction. Investigation of the possibilities for converting butylenes into valuable petrochemical products is of considerable interest. For this purpose, the catalytic conversion of butylenes over HCBM and HCBM + 3 wt.% Zn catalysts was studied. The butylenes were obtained by dehydration of butyl alcohol over Al_2O_3. The feedstock contained 94,5-96% 1-butene. The experimental results for butylene conversion over the HCBM catalyst are presented in Table 3.

Table 3. Catalytic conversion of butylene over the HCBM catalyst (space velocity 500 h^{-1}).

Temperature °C	Conversion C_4H_8	Products, wt.%			
		Liquid products		Gaseous products	Coke
		Aliphatic hydrocarbons	Aromatic hydrocarbons		
245	54,9	40,2	3,8	52,2	1,3
290	98,7	70,7	14,6	10,7	1,7
330	98,8	60,8	16,8	18,4	1,8
380	99	48,4	21,6	25	1,7
430	97,2	33,1	27,1	35,3	2,3
485	95,8	20,6	32,8	40,5	2,5
540	94,5	5,1	38,7	50,2	3,1

The data indicates that during the conversion of butylenes over the studied catalyst, the yield of liquid products is higher compared to that observed for propylene. This can be attributed to the higher reactivity of butylenes relative to C_2–C_3 hydrocarbons.The yield of aliphatic hydrocarbons reaches a maximum of 70.7 wt.% at 290°C. Further increasing the temperature leads to a decrease in aliphatic product yield and an increase in aromatic product formation. This occurs against the background of a decreasing condensate yield. It should be noted that during the catalytic conversion of butylenes, the coke formation is slightly higher compared to cases where propylene is used as the feedstock. Analysis of the products shows that the composition of the condensate is almost the same whether propylene or butylene is used as the raw material. In other words, under these conditions, along with oligomerization and aromatization, significant cracking and copolymerization reactions also occur. The study of butylene conversion over the HCBM + 3 wt.% Zn catalyst (Table 4) has shown that zinc modification primarily enhances the aromatization activity of the catalyst. Specifically, at 540°C, the yield of aromatic products increases to 42.5%.

Table 4. Catalytic conversion of butylene over the HCBM + 3 wt.% Zn catalyst (space velocity 500 h^{-1}).

Temperature °C	Conversion C_4H_8	Products, wt.%			
		Liquid products		Gaseous products	Coke
		Aliphatic hydrocarbons	Aromatic hydrocarbons		
245	55,6	40,7	4,7	50,3	1,9

290	98,6	70,8	16,1	9,7	1,8
330	98,8	60,0	18,5	17,1	2,1
380	98,1	48,3	24,2	22,7	2,3
430	97,6	32,7	29,6	32,7	2,4
485	95,5	18,2	36,7	40,2	2,8
540	94,8	5,8	42,5	45,6	3,2

The maximum yield of liquid products is observed at 290°C and, as shown in the table, reaches 86,9%. However, the majority of this yield consists of aliphatic products. It should be noted that, for both propylene and butylene, the incorporation of zinc into the zeolite catalyst leads to a slight increase in coke formation. Some researchers suggest that, during the initial stages of olefin conversion, the condensation products formed accumulate on the catalyst surface and facilitate the activation of the catalyst. In a sense, they act to modify the surface of the catalyst, resulting in changes in its specificity and activity. However, as the degree of carbonaceous deposits increases, regeneration of the catalyst becomes necessary.Based on studies of catalytic conversion of propylene and butylene over zeolite catalysts, two distinct temperature intervals can be distinguished: at 300–340°C, aliphatic hydrocarbons are formed with high selectivity, whereas in the 500–540°C range, aromatic hydrocarbons are predominantly produced.Catalytic conversion of olefins over pentasil-type zeolites can occur both on the external surface and within the channels, depending on the structure and reactivity of the olefins as well as the reaction temperature. In this case, condensation products are formed on the external surface of the zeolite and can easily transform into highly graphitized "coke" during thermo-oxidative treatment. Aromatization of olefins primarily occurs within the zeolite channels. At elevated temperatures, the aromatic compounds formed during olefin conversion are weakly bound to the zeolite channels and do not lead to the formation of condensation products.

Conclusion

1. The conversion of propylene and butylene into aliphatic and aromatic hydrocarbons over HCBM and HCBM + 3 wt.% Zn catalysts has been investigated.
2.The influence of temperature and space velocity on the course of the process has been determined.
3.The study determined the formation of aromatic hydrocarbons at 500°C.
4.At optimal values of temperature and space velocity, the yield of aliphatic hydrocarbons ranges from 42 to 53%.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. 1.Phung, T. K., Pham, T. L. M., Vu, K. B., Busca, G. (2021). (Bio) Propylene production processes: A critical review. Journal of Environmental Chemical Engineering, 9(4), 105673.
2. 2.Hoveyda, A. H., Zhugralin, A. R. (2007). The remarkable metal-catalysed olefin metathesis reaction. Nature, 450, 243–251.
3. 3.Pawelec, B., Guil-López, R., Mota, N., Garcia Fierro, J. L., Navarro Yerga, R. M. (2021). Catalysts for the conversion of CO_2 to low molecular weight olefins-A review. Materials (Basel), 14(22), 6952.
4. 4.Cnudde, P.; de Wispelaere, K.; Vanduyfhuys, L.; Demuynck, R.; van der Mynsbrugge, J.; Waroquier, M.; van Speybroeck, V. How Chain Length and Branching Influence the Alkene Cracking Reactivity on H-ZSM-5. ACS Catal. 2018, 8, 9579–9595.
5. 5.Zahara, Z.; Krisnandi, Y.K.; Wibowo, W.; Nurani, D.A.; Rahayu, D.U.C.; Haerudin, H. Synthesis and characterization of hierarchical ZSM-5 zeolite using various templates as cracking catalysts. AIP Conf. Proc. 2018, 2023, 020088.
6. 6.Zhang, M.; Liu, Q.; Long, H.; Sun, L.; Murayama, T.; Qi, C. Insights into Au Nanoparticle Size and Chemical State of Catalyst for Catalytic Cracking of n-Octane to Increase Propylene Production. J. Phys. Chem. C 2021, 125, 16013–16023.
7. 7.Wu, C.; Wang, L.; Xiao, Z.; Li, G.; Wang, L. Understanding deep dehydrogenation and cracking of: N -butane on Ni(111) by a DFT study. Phys. Chem. Chem. Phys. 2020, 22, 724–733.
8. 8.Yun, Y.; Araujo, J.R.; Melaet, G.; Baek, J.; Archanjo, B.S.; Oh, M.; Alivisatos, A.P.; Somorjai, G.A. Activation of tungsten oxide for propane dehydrogenation and its high catalytic activity and selectivity. Catal. Lett. 2017, 147, 622–632.
9. 9.Paula Pérez-Uriarte, Ainara Ateka, Andrés T. Aguayo, Ana G. Gayubo, Javier Bilbao. Kinetic model for the reaction of DME to olefins over a zeolite catalyst. Chemical Engineering Journal 2016, 302 , 801-810.
10. 10.Wang, G.; Zhu, X.; Li, C. Recent Progress in Commercial and Novel Catalysts for Catalytic Dehydrogenation of Light Alkanes. Chem. Rec. 2020, 20, 604–616

HCBM VƏ HCBM + 3% ZN KATALİZATORLARI İŞTİRAKI İLƏ OLEFINLƏRİN ÇEVRİLMƏ PROSESİNİN TƏDQİQİ

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Ələkbər Həsənov[1], Yunis Quliyev[2]
[1]Kimya Elmlər Doktoru, Professor, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU) Neft-kimya texnologiyası və sənaye ekologiyası kafedrası, Azərbaycan.
E-mail: alakbar48-48@mail.ru
[2]Magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), Azərbaycan.
E-mail: yunisquliyev05@gmail.com

XÜLASƏ

Neft emalı sənayesində, xüsusilə katalitik krekinq qurğularında, yan məhsul kimi əldə olunan karbohidrogen qazların səmərəli istifadəsi, əldə edilən məhsulların effektiv istifadəsi, ətraf mühitin qorunması və enerji ehtiyatlarının qorunması baxımından xüsusi əhəmiyyət kəsb edir. Məlumdur ki, neft emalı zavodlarında əmələ gələn karbohidrogen qazlar əsasən daxili enerji tələbatının ödənilməsi üçün yanır. Bu qazların səmərəli istifadəsi üçün perspektiv istiqamətlərdən biri C_3–C_4 karbohidrogenlərinin alkenlərə, arenlərə və mühərrik yanacağı komponentlərinə çevrilməsidir. Bu prosesdə katalizator kimi propilen və butilen seçilmiş və pentasil ailəsinə aid sinklə modifikasiya olunmuş zeolit katalizatoru tətbiq edilmişdir. Yuxarıda qeyd olunan karbohidrogenlərin çevrilmə reaksiyaları bu katalizatorun iştirakı ilə öyrənilmişdir. Tədqiqat nəticəsində müəyyən edilmişdir ki, sinklə modifikasiya olunmuş katalizator yüksək aktivlik nümayiş etdirir və olefinlərdən alifatik birləşmələrin əmələ gəldiyi müəyyən edilmişdir. Məqalədə prosesin gedişinə məkan sürəti və temperaturun təsirini əks etdirən nəticələr təqdim olunmuşdur. Məhsul verimi, katalizatorun selektivliyi və çevrilmə üzərində temperaturun və qida maddəsinin məkan sürətinin təsirləri ətraflı şəkildə araşdırılmışdır. Göstərilmişdir ki, sinklə modifikasiya olunmuş zeolit əsaslı katalizatorun iştirakı ilə 300-350 °C temperaturda olefinlərdən alifatik karbohidrogenlər əmələ gəlir.
Açar sözlər: Propilen, butilen, alifatik karbohidrogenlər, aromatik karbohidrogenlər, HCBM katalizatoru, HCBM + 3 wt.% Zn katalizatoru.

ИССЛЕДОВАНИЕ ПРОЦЕССА ПРЕВРАЩЕНИЯ ОЛЕФИНОВ НА КАТАЛИЗАТОРАХ НСВМ И НСВМ + 3% Zn

Алякбар Гасанов[1], Юнис Гулиев[2]
[1]Доктор химических наук, профессор, Азербайджанский государственный университет нефти и промышленности , Кафедра нефтехимических технологий и промышленной экологии, Азербайджан.
E-mail: alakbar48-48@mail.ru
[2]Магистрант, Азербайджанский государственный университет нефти и промышленности , Азербайджан.
E-mail: yunisquliyev05@gmail.com

РЕЗЮМЕ

В нефтеперерабатывающей промышленности, особенно на установках каталитического крекинга, эффективное использование углеводородных газов, получаемых в качестве побочных продуктов, имеет особое значение с точки зрения рационального использования получаемых продуктов, охраны окружающей среды и сохранения энергетических ресурсов. Известно, что углеводородные газы, образующиеся на нефтеперерабатывающих заводах, в основном сжигаются для удовлетворения внутренних потребностей в энергии. Одним из перспективных направлений эффективного использования этих газов является превращение углеводородов C_3–C_4 в алкены, ареновые соединения и компоненты моторного топлива.В данном процессе в качестве сырья были выбраны пропилен и бутилен, а в качестве катализатора применялся цеолитный катализатор семейства пентасилов, модифицированный цинком. Реакции превращения вышеупомянутых углеводородов были исследованы в присутствии этого катализатора. Результаты исследования показали, что цинком модифицированный катализатор проявляет высокую активность, а из олефинов образуются алифатические соединения.В статье представлены результаты, отражающие влияние пространственной скорости потока и температуры на ход процесса. Влияние температуры и пространственной скорости подачи сырья на выход целевого продукта, селективность катализатора и степень превращения было подробно изучено. Показано, что при участии цеолитного катализатора, модифицированного цинком, при температуре 300-350°C из олефинов образуются алифатические углеводороды.

Ключевые слова: пропилен, бутилен, алифатические углеводороды, ароматические углеводороды, катализатор НСВМ, катализатор НСВМ + 3 wt.% Zn

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

158-166

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-18

COMBATING SEVERE LOST CIRCULATION USING LOW-DENSITY LCM

Shukurali Kazimov[1], Yusif Aslanli[2]
[1]Associate Professor, Oil and Gas Engineering Department, Azerbaijan State Oil and Industry University, Azerbaijan, E-mail: shukurali.kazimov@asoiu.edu.az
[2]Master, Department of Oil and Gas Engineering, Azerbaijan State Oil and Industry University, Azerbaijan, yusiffaslanli@gmail.com

ABSTRACT

Lost circulation is one of the most common and costly drilling problems, especially in formations with weak rock strength, natural fractures, or high permeability. If drilling fluid losses are not controlled quickly, they can lead to serious operational complications such as wellbore instability, stuck pipe, reduced drilling efficiency, and in extreme cases, well control risks. For this reason, predicting and managing potential lost circulation zones is a key part of safe and efficient drilling planning. One effective method used by drilling engineers is evaluating the mud weight window, which helps identify intervals where the formation is more likely to absorb drilling fluid.

The mud weight window represents the safe range of drilling fluid density between pore pressure and fracture pressure. Maintaining mud weight within this window allows the well to be drilled with sufficient pressure control while avoiding formation breakdown. When mud weight or equivalent circulating density exceeds the fracture pressure, the formation may crack and begin to take fluid. This is especially critical in narrow mud weight windows, where even small changes in density or circulating pressure can trigger losses. By analyzing the mud weight window before drilling, engineers can estimate which depths have a higher risk of losses and prepare mitigation plans in advance.

In zones where losses are expected, a common preventive practice is to prepare a Lost Circulation Material (LCM) pill and keep it ready in the active mud system. This approach reduces response time, allowing the drilling crew to treat losses immediately once they are detected. LCM pills are specially designed mixtures containing materials that bridge and seal fractures, pores, and weak intervals in the formation. Depending on the formation type and the severity of the losses, LCM blends may include fibrous, granular, and flaky components. These materials work together to create an effective sealing barrier, restoring circulation and reducing further mud losses.

Selecting the correct LCM blend requires careful consideration of both formation characteristics and drilling equipment limitations. The type of loss zone, estimated fracture size, mud system compatibility, and past offset well experience all influence material selection. Additionally, particle size is a critical factor when downhole tools such as mud motors, MWD (Measurement While Drilling), and LWD (Logging While Drilling) systems are present in the bottom hole assembly. Oversized LCM particles can plug internal flow passages, damage tool components,

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

and cause motor or sensor failures. Therefore, many LCM pills are designed as "tool-safe" blends, ensuring particles can pass through the smallest tool restrictions while still providing effective sealing performance.

Overall, combining mud weight window analysis with proactive LCM preparation offers a practical and efficient strategy for lost circulation management. This integrated approach improves operational readiness, minimizes non-productive time, protects expensive downhole equipment, and enhances drilling safety. By identifying risky intervals early and applying appropriate preventive and corrective measures, drilling teams can significantly reduce the impact of lost circulation and improve the overall success of drilling operations.

Keywords: Mud weight window, LCM, ECD, mud motor, MWD, LWD.

Introduction

During drilling operations, one of the major challenges is dealing with potential lost circulation zones, which are formations that can absorb drilling fluid. If these zones are not predicted early, they may cause serious problems such as reduced wellbore stability, non-productive time, and increased operational costs. For this reason, engineers try to identify possible absorption zones before drilling reaches them. One of the most practical ways to do this is by using the mud weight window.

The mud weight window (fig. 1) is the safe range of drilling fluid density that allows the well to be drilled without causing formation damage or creating well control risks. It is usually defined between the pore pressure gradient and the fracture pressure gradient. If the mud weight is too low, the well may experience kicks or instability because the formation fluids can enter the wellbore. On the other hand, if the mud weight is too high, the pressure applied to the formation can exceed the fracture pressure, leading to cracks in the rock and loss of drilling mud into the formation. This is exactly how lost circulation often begins.

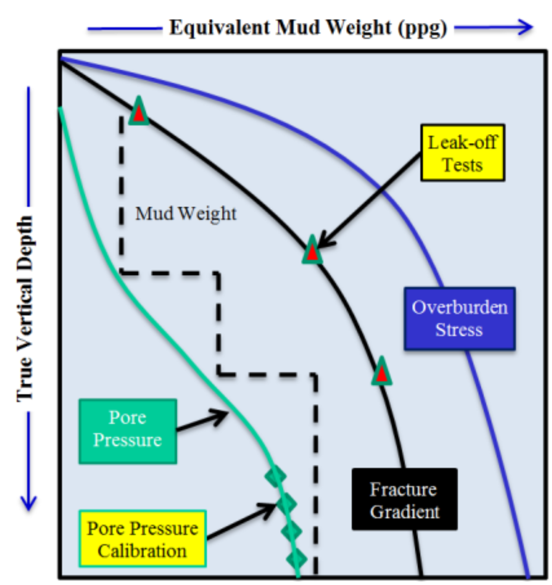


Figure 1: Simple mud weight window.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

By calculating the mud weight window in advance, engineers can estimate where absorption zones are most likely to appear. Narrow mud windows, where the difference between pore pressure and fracture pressure is small, are especially risky. In such intervals, even a small increase in mud density or equivalent circulating density (ECD) can break down the formation. This makes it easier for the drilling fluid to escape into the rock. Therefore, these zones are treated as potential lost circulation intervals before drilling starts.

In addition, mud weight window analysis is supported by offset well data, geological information, and formation strength models. When engineers combine these sources, they can create a more reliable prediction of weak formations and fractured layers. As a result, they can plan suitable drilling parameters, select proper mud systems, and prepare preventive solutions such as lost circulation materials (LCM) or managed pressure drilling techniques. Overall, predicting absorption zones using the mud weight window helps drilling teams reduce risks, protect the well, and improve the efficiency of the entire drilling process.

When drilling reaches depths where lost circulation is likely to occur, the drilling team usually prepares an LCM pill and keeps it ready in the active mud system. This is done as a preventive measure, because lost circulation can happen suddenly and may quickly become more severe if it is not treated immediately. Having the LCM mixture prepared in advance saves valuable time and helps the crew respond faster when mud losses begin.

LCM stands for Lost Circulation Material. An LCM pill is a specially prepared mud mixture that contains materials designed to reduce or stop the loss of drilling fluid into the formation. In simple terms, it acts like a “plug” that helps seal fractures, pores, or weak zones in the rock. When mud is being absorbed by the formation, the LCM pill is pumped down the well so that it can reach the loss zone and form a barrier. This barrier prevents the drilling fluid from escaping and allows normal circulation to return.

Table 1. LCM materials.

LCM Type	**Material Form**	**Main Purpose**	**Where It Works Best**	**Key Advantage**	**Risk / Limitation**
Fibrous	Fibers, string-like particles	To bridge and bind fractures, helping form a plug	Micro-fractures and medium-size fractures	Fast plugging effect and good bridging support	Large fibers may plug mud motor or MWD/LWD flow paths
Granular	Hard particles (sand-like grains)	To fill voids and create a stable bridge	Porous formations and fractured intervals	Very effective for bridging and filling gaps	Wrong particle size can plug nozzles and internal tool channels
Flaky (Plate-like)	Thin flat flakes	To cover and seal fracture openings	Wide fractures and naturally fractured formations	Strong sealing ability and good coverage	Oversized flakes may cause tool plugging or flow restriction
Blended (Mixed LCM)	Combination of fibrous + granular + flaky	To build a stronger and more reliable seal	Severe losses and uncertain loss zones	Higher success rate due to combined mechanisms	If poorly designed, it can affect mud properties and circulation

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

LCM materials can be made from different types of substances depending on the severity of the losses and the formation characteristics (table 1). Common examples include fibrous materials, granular particles, and flaky components. Fibrous LCM helps bridge and bind the loss zone, granular particles fill the gaps, and flaky materials can cover and seal fractures. In many cases, engineers use a combination of these materials to increase the chance of successful sealing. The selection of LCM is usually based on previous well data, mud properties, and the expected size of fractures or openings.
The main advantage of keeping an LCM pill ready in the active tank is that it allows the drilling crew to act immediately once losses are detected. Quick treatment can prevent larger fractures from developing and can reduce the risk of further complications such as wellbore instability, stuck pipe, or even well control issues. Overall, LCM pills are an important part of lost circulation management, and their proper preparation and use can significantly improve drilling safety and efficiency.
When an LCM pill is prepared, the selection of materials is not random. Engineers choose the type and size of lost circulation materials by considering both the formation conditions (fig. 2) and the drilling equipment that will be exposed to the mixture. The main goal is to stop mud losses effectively, but at the same time the LCM must not create new problems such as plugging the drill string, damaging downhole tools, or reducing drilling performance.
First, the formation itself is analyzed. If losses are caused by small pores or micro-fractures, fine granular or fine fibrous materials may be enough to seal the zone. However, if the well is drilled through naturally fractured rock or highly permeable layers, larger particles and stronger bridging materials are usually required. Engineers also consider the severity of the loss (partial, severe, or total loss), because heavy losses often need a stronger and more aggressive LCM blend. Offset well data and previous loss records are also important, because they help predict what type of loss zones are expected at a certain depth.

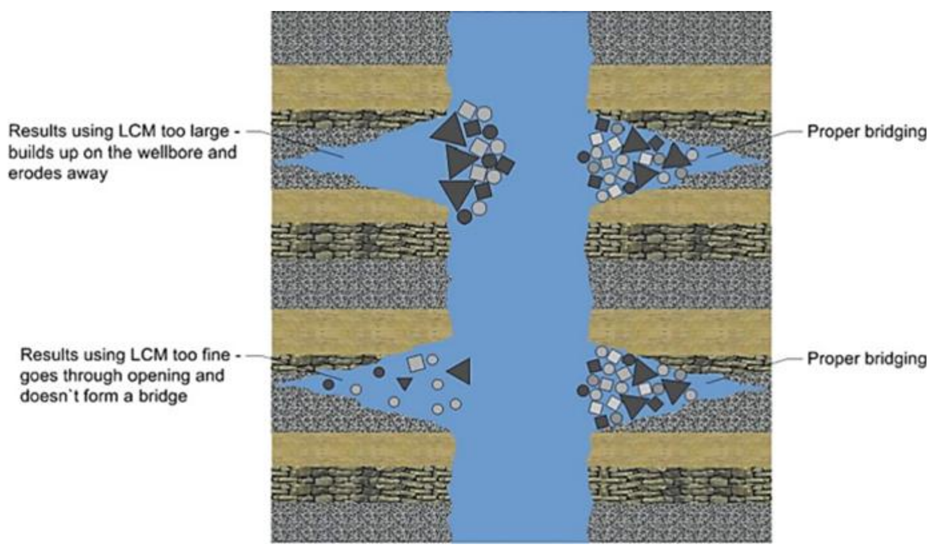


Figure 2: Choosing the size of lost circulation materials considering formation conditions.

Another key factor is the mud system and its properties. LCM must be compatible with the drilling fluid, whether it is water-based mud, oil-based mud, or synthetic mud. Some materials

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

work better in certain mud types, and some can affect viscosity, filtration, or rheology if the concentration is too high. Therefore, engineers try to balance sealing efficiency with stable mud performance.

Most importantly, LCM particle size must be selected carefully so it does not harm the drilling tools. In many wells, the bottom hole assembly includes a mud motor and measurement tools such as MWD (Measurement While Drilling) and LWD (Logging While Drilling). These tools contain internal flow passages, turbines, sensors, and nozzles that can be blocked or damaged by large particles. If the LCM particles are too big, they may plug the motor, reduce the flow rate, damage the bearings, or cause tool failure. For this reason, engineers choose LCM with a particle size that can safely pass through the motor and through the MWD/LWD tool string.

In practice, the maximum LCM particle size is usually limited based on the smallest restriction inside the downhole tools, such as the motor's internal ports or the MWD flow channel. This is why many LCM pills used during drilling are designed as "motor-safe" or "MWD-safe" blends. These blends still contain bridging particles, but they are sized carefully so they can travel through the tool without causing blockage. If a stronger LCM is required and larger particles are needed, the drilling team may first pull the tools out of hole or use special treatment methods that reduce the risk of tool damage.

Overall, choosing the right LCM material depends on formation type, loss severity, mud system compatibility, and tool limitations. By selecting an effective but tool-safe LCM blend, the drilling team can control lost circulation while protecting expensive downhole equipment like mud motors and MWD/LWD systems.

Conclusion

1. Mud weight window analysis is an effective method for predicting potential lost circulation zones in advance and helps identify high-risk depths before drilling reaches them.
2. In intervals with a narrow mud weight window, even a small increase in ECD can cause formation breakdown, which can quickly trigger drilling fluid losses.
3. Keeping an LCM pill pre-mixed and ready in the active system allows the crew to respond immediately when losses occur, reducing non-productive time.
4. When selecting LCM materials, engineers must consider not only formation conditions and loss severity, but also the internal flow restrictions of the mud motor, MWD, and LWD tools.
5. Using a properly designed tool-safe LCM blend improves lost circulation control while also protecting expensive downhole equipment and enhancing overall drilling safety.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Bourgoyne, A. T., Millheim, K. K., Chenevert, M. E., & Young, F. S. (1991). Applied Drilling Engineering. Richardson, TX: Society of Petroleum Engineers (SPE).
2. Mitchell, R. F., & Miska, S. Z. (2011). Fundamentals of Drilling Engineering. Richardson, TX: Society of Petroleum Engineers (SPE).
3. Rabia, H. (2001). Well Engineering & Construction. London: Entrac Consulting.
4. Lyons, W. C., & Plisga, G. J. (Eds.). (2005). Standard Handbook of Petroleum and Natural Gas Engineering. Burlington, MA: Elsevier.
5. Caenn, R., Darley, H. C. H., & Gray, G. R. (2017). Composition and Properties of Drilling and Completion Fluids (7th ed.). Houston, TX: Gulf Professional Publishing.
6. Aadnøy, B. S., & Looyeh, R. (2019). Petroleum Rock Mechanics: Drilling Operations and Well Design (2nd ed.). Cambridge, MA: Gulf Professional Publishing.

БОРЬБА С ИНТЕНСИВНЫМИ ПОГЛОЩЕНИЯМИ С ПРИМЕНЕНИЕМ ТАМПОНИРУЮЩЕЙ СМЕСИ НИЗКОЙ ПЛОТНОСТИ

Шукурали Кязимов[1], Юсиф Асланлы[2]
[1]Доценты, Департамент Нефтегазовой Инженерии, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан, yusiffaslanli@gmail.com
[2]Магистрант, Департамент Нефтегазовой Инженерии, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджанагистр, yusiffaslanli@gmail.com

РЕЗЮМЕ

Поглощение бурового раствора (lost circulation) является одной из наиболее распространённых и затратных проблем при бурении, особенно в пластах со слабой прочностью пород, естественными трещинами или высокой проницаемостью. Если потери бурового раствора не контролируются своевременно, это может привести к серьёзным осложнениям, таким как нарушение устойчивости стенок скважины, прихват бурильной колонны (stuck pipe), снижение эффективности бурения и в некоторых случаях риски, связанные с контролем скважины. Поэтому прогнозирование и управление потенциальными зонами поглощения является важной частью безопасного и эффективного

планирования буровых работ. Одним из практичных методов для выявления таких интервалов является анализ окна плотности бурового раствора (mud weight window).
Окно плотности бурового раствора представляет собой безопасный диапазон плотности между пластовым давлением (pore pressure) и давлением гидроразрыва (fracture pressure). Поддержание плотности раствора в пределах этого диапазона позволяет контролировать давление в скважине и одновременно избегать разрушения пласта. Если плотность раствора или эквивалентная циркуляционная плотность (ECD) превышает давление гидроразрыва, порода может треснуть, и буровой раствор начнёт уходить в пласт. Этот риск особенно высок в интервалах с узким окном плотности, где даже небольшие изменения давления или плотности могут привести к поглощению. Предварительный анализ mud weight window помогает инженерам прогнозировать глубины, где вероятность потерь наиболее высока, и заранее планировать меры по предотвращению осложнений.
В интервалах, где ожидаются потери, часто заранее готовят порцию раствора с Lost Circulation Material (LCM) и держат её в активной ёмкости. Такой подход сокращает время реакции и позволяет немедленно приступить к обработке при первых признаках поглощения. LCM — это специально подобранные материалы, предназначенные для уменьшения или полного прекращения потерь бурового раствора. Они работают как «пробка», перекрывая трещины, поры и слабые зоны в пласте. В зависимости от типа пород и степени поглощения в состав LCM могут входить волокнистые, гранулированные и пластинчатые компоненты. В комплексе они создают эффективный барьер, способствуя восстановлению циркуляции.
Подбор LCM требует учёта как характеристик пласта, так и ограничений бурового оборудования. На выбор материалов влияют тип зоны поглощения, предполагаемый размер трещин, совместимость с системой бурового раствора и опыт по соседним скважинам. Кроме того, важнейшим параметром является размер частиц, особенно если в компоновке низа бурильной колонны используются забойные двигатели, а также системы MWD (Measurement While Drilling) и LWD (Logging While Drilling). Слишком крупные частицы LCM могут закупорить внутренние каналы, повредить элементы двигателя, вызвать сбои в работе датчиков и привести к выходу инструмента из строя. Поэтому во многих случаях применяются “tool-safe” LCM-смеси, где размер частиц подбирается так, чтобы они могли безопасно проходить через самые узкие проходные сечения оборудования.
В целом, сочетание анализа mud weight window и заранее подготовленного LCM является эффективной и практичной стратегией управления поглощением. Такой комплексный подход повышает готовность к осложнениям, снижает непроизводительное время, защищает дорогостоящее забойное оборудование и повышает безопасность бурения. Предварительное выявление рискованных интервалов и своевременное применение корректирующих мер позволяет существенно уменьшить влияние поглощения и повысить общий успех буровых операций.
Ключевые слова: Mud weight window, LCM, ECD, mud motor, MWD, LWD.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

İNTENSİV UDULMAYA QARŞI AZ SIXLIQLI TAMPONLAYICI KÜTLƏ İLƏ MÜBARİZƏ

Şükürəli Kazımov[1], Yusif Aslanlı[2]
[1]Dosent, Neft-Qaz Mühəndisliyi Kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, yusiffaslanli@gmail.com
[2]Magistrant, Neft-Qaz Mühəndisliyi Kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, yusiffaslanli@gmail.com

XÜLASƏ

Udulma (lost circulation) qazma prosesində ən çox rast gəlinən və ən çox xərc yaradan problemlərdən biridir. Xüsusilə zəif möhkəmliyə malik laylarda, təbii çatlı süxurlarda və ya yüksək keçiriciliyə malik formasiya zonalarında bu problem daha tez-tez müşahidə olunur. Qazma məhlulunun itkiləri vaxtında nəzarət altına alınmasa, quyu divarının stabilliyinin pozulması, alətin sıxılması (stuck pipe), qazma səmərəliliyinin azalması və bəzi hallarda quyu nəzarəti ilə bağlı risklər kimi ciddi fəsadlara səbəb ola bilər. Buna görə də, potensial udulma zonalarının əvvəlcədən proqnozlaşdırılması və idarə olunması təhlükəsiz və səmərəli qazma planlamasının əsas hissələrindən sayılır. Bu məqsədlə qazma mühəndisləri mud weight window analizindən istifadə edərək riskli intervalları müəyyənləşdirirlər.

Mud weight window qazma məhlulunun təhlükəsiz sıxlıq diapazonunu göstərir və adətən lay təzyiqi (pore pressure) ilə çatlama təzyiqi (fracture pressure) arasında müəyyən olunur. Qazma məhlulunun sıxlığı bu pəncərə daxilində saxlanıldıqda, quyu təzyiqə nəzarət edə bilir və eyni zamanda layın çatlamasının qarşısı alınır. Əgər məhlulun sıxlığı və ya dövriyyə zamanı yaranan ekvivalent dövriyyə sıxlığı (ECD) çatlama təzyiqini aşarsa, formasiya çatlayaraq məhlulu udmağa başlaya bilər. Bu risk xüsusilə dar mud window olan zonalarda daha yüksəkdir, çünki çox kiçik sıxlıq və ya təzyiq dəyişiklikləri belə udulmaya səbəb ola bilər. Mud weight window analizinin əvvəlcədən aparılması sayəsində mühəndislər udulma ehtimalı olan dərinlikləri proqnozlaşdırır və qabaqlayıcı tədbirləri planlaşdırırlar.

Udulma ehtimalı yüksək olan dərinliklər qazılarkən Lost Circulation Material (LCM) məhlulu əvvəlcədən hazırlanaraq aktiv çəndə hazır vəziyyətdə saxlanılır. Bu yanaşma reaksiyanın gecikməsinin qarşısını alır və udulma başladıqda dərhal müdaxilə etməyə imkan verir. LCM məhlulları laydakı çatları, məsamələri və zəif zonaları bağlamaq üçün hazırlanmış xüsusi qarışıqlardır. Layın xüsusiyyətindən və udulmanın səviyyəsindən asılı olaraq LCM tərkibinə lifli, dənəvər və layvari (flake) materiallar daxil edilə bilər. Bu materiallar birlikdə işləyərək effektiv bir "tıxac" yaradır və dövriyyənin bərpasına kömək edir.

LCM seçimi həm lay xüsusiyyətləri, həm də qazma avadanlıqlarının texniki məhdudiyyətləri nəzərə alınaraq aparılmalıdır. Udulma zonasının tipi, çat ölçüsünün təxmini, istifadə olunan məhlul sisteminə uyğunluq və əvvəlki quyulardan əldə olunan təcrübə material seçiminə təsir göstərir. Bundan əlavə, quyu altı yığımında mud motor, MWD (Measurement While Drilling) və LWD (Logging While Drilling) kimi alətlər olduqda, LCM hissəciklərinin ölçüsü xüsusi əhəmiyyət daşıyır. Həddindən artıq böyük hissəciklər alətlərin daxili axın kanallarını tıxaya, motorun işini poza və sensorların sıradan çıxmasına səbəb ola bilər. Buna görə də, bir çox hallarda "tool-safe" LCM qarışıqları seçilir, yəni hissəcik ölçüləri alətlərin ən dar keçidlərindən təhlükəsiz keçə biləcək şəkildə müəyyən edilir.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Ümumilikdə, mud weight window analizinin LCM-in qabaqlayıcı hazırlanması ilə birgə tətbiqi udulmanın idarə olunmasında effektiv və praktik strategiya hesab olunur. Bu inteqrasiya olunmuş yanaşma əməliyyat hazırlığını artırır, qeyri-məhsuldar vaxtı azaldır, bahalı quyu altı avadanlıqlarını qoruyur və qazma təhlükəsizliyini yüksəldir. Riskli zonaların əvvəlcədən müəyyən edilməsi və uyğun tədbirlərin vaxtında görülməsi udulmanın təsirini əhəmiyyətli dərəcədə azaldaraq qazma əməliyyatının ümumi uğurunu artırır.

Açar sözlər: Mud weight window, LCM, ECD, mud motor, MWD, LWD.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

167-173

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-19

VOLUME 33 (08) ISSUE 02 2026

FORECASTING OF GEOLOGICAL AND TECHNOLOGICAL INDICATORS OF OIL RESERVOIR DEVELOPMENT CONSIDERING THE DYNAMIC INTERACTION OF THE LAYER–WELL SYSTEM

Khasay Feyzullayev[1], Vusal Heydarov[2]
[1]Lecturer, Department of Oil and Gas Engineering, Azerbaijan State Oil and Industry University, Doctor of Technical Sciences, Senior Researcher, E-mail: feyzullayevxasay@gmail.com
[2]Master's Student, Department of Oil and Gas Engineering, Azerbaijan State Oil and Industry University,
E-mail: vusalheyderov.8111@gmail.com

ABSTRACT

This article is devoted to the forecasting of key geological and technological indicators of oil reservoir development with explicit consideration of the dynamic interaction within the layer–well system. In modern reservoir engineering practice, accurate prediction of reservoir behavior requires not only static geological characterization but also a comprehensive understanding of time-dependent processes occurring during field exploitation. Variations in reservoir pressure, changes in oil and water production rates, the advancement of waterflood fronts, and alterations in well operating regimes represent interconnected factors that directly influence reservoir performance and recovery efficiency. The dynamic interaction between reservoir layers and producing wells plays a decisive role in shaping production trends over time. Ignoring this interaction may lead to significant deviations between forecasted and actual production indicators. Therefore, this study emphasizes the necessity of integrating geological heterogeneity, filtration properties, and fluid flow dynamics with technological parameters such as well operation modes, injection strategies, and production control measures. Such integration enables a more realistic assessment of reservoir behavior under varying development scenarios. A combined analysis of geological parameters and technological interventions allows for improved monitoring of reservoir development stages, including pressure depletion, water breakthrough, and changes in production efficiency. By evaluating these processes in a unified framework, it becomes possible to identify critical moments when corrective actions are required. Forecasting results obtained through this approach provide a reliable basis for optimizing well operation regimes, adjusting injection rates, and selecting additional geological and technological measures aimed at improving reservoir performance. The proposed methodology contributes to enhancing the reliability of long-term production forecasts and supports informed decision-making in reservoir management. By accounting for the dynamic nature of the layer–well system, the study offers practical insights into maintaining stable oil production, mitigating premature water cut, and maximizing the ultimate oil recovery factor. The results demonstrate that the application of integrated dynamic forecasting techniques is an effective tool for improving the efficiency and sustainability of oil reservoir development under complex geological conditions. Furthermore, the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

findings of this study may serve as a methodological foundation for the development of adaptive reservoir management strategies under conditions of geological uncertainty. The proposed approach enhances the ability to promptly respond to changes in reservoir behavior and supports the implementation of data-driven decisions aimed at improving field development efficiency and long-term production sustainability.

Keywords: Oil reservoir, layer–well system, dynamic interaction, production forecasting, reservoir pressure, geological and technological indicators, reservoir management.

Introduction

The dynamic interaction of the layer–well system is ne of the fundamental issues in reservoir development. This is because any change occurring within the reservoir (pressure decline, water advancement, change in filtration regime) directly affects the production performance of wells. At the same time, the operating regime of wells influences the reservoir energy balance and the formation of the pressure field.

The layer–well system is characterized by the following parameters:

- Reservoir porosity (ϕ) and permeability (k)
- Viscosity of reservoir fluids (μ)
- Reservoir pressure (P_l) and water saturation level (S_w)
- Well operating regime and production rate (q)

As these parameters change, fluid flow within the reservoir and production dynamics are formed. The mathematical basis of flow from the reservoir to the well is Darcy's law. Main equation – Darcy's law (single-phase flow):

$$q = -\frac{kA}{\mu}\frac{dP}{dL}$$

This formula explains the impact of factors such as reservoir permeability, pressure differential, and fluid viscosity on production. Note: Since flow in oil fields typically occurs in a multiphase (oil–water–gas) state, the formula is written in the following form:

$$q_i = -\frac{k k_{ri}}{\mu_i} A \frac{dP_i}{dL}, \qquad i = s, q, n$$

Here, the relative permeability coefficient (k_{ri}) indicates the mobility of each phase within the reservoir.

Geological-Technical Indicators and Their Forecasting

During the development of oil fields, key geological-technical indicators are used to assess the state of the reservoir and the progress of the production process. These indicators allow for the determination of changes in production, the development of the water injection process, and the operational efficiency of the field. One of the primary indicators is oil production. Oil production is related to reservoir porosity, oil saturation levels, and recovery efficiency:

$$Q_n = \phi \cdot V \cdot S_o \cdot E$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Here, ϕ represents the reservoir porosity, V represents the reservoir volume, S_o represents the oil saturation level, and E represents the recovery efficiency. As field development progresses, the water injection process intensifies and water production increases:

$$Q_s = Q_t \cdot W_f$$

Here, represents the total fluid production, and represents the water cut. To evaluate the overall results of the field development, the oil recovery factor is used:

$$E_o = \frac{Q_n}{\phi \cdot V \cdot S_o} \cdot 100\%$$

In practice, one of the most frequently monitored indicators is the water injection percentage. As the water injection percentage increases, well productivity decreases:

$$W_f = \frac{Q_s}{Q_s + Q_n} \cdot 100\%$$

Additionally, to evaluate the impact of gas on production in the field, the gas-oil ratio indicator is used:

$$G_f = \frac{V_g}{Q_n}$$

Thus, these indicators help in monitoring the field development process, forecasting future production dynamics, and more accurately selecting well operating regimes.

Hydrodynamic modeling

During the development of oil fields, the processes occurring within the reservoir are not fully explained by simple calculations alone. This is because pressure changes in the reservoir, fluid movement, and the mutual interference between wells are complex and dynamic in nature. Therefore, hydrodynamic modeling is considered one of the most widely used methods in modern field development. Hydrodynamic modeling allows for a more accurate assessment of the formation of the pressure field within the reservoir, the direction of oil and water flow, and the development of the water injection process. This approach is particularly essential for forecasting future stages of production. One of the primary mathematical models applied in this field is the analysis of radial flow around a well. To demonstrate how pressure changes over time during production from a well, transient flow formulas are utilized.

- **Transient radial flow (Theis equation):**

$$\Delta P(r,t) = \frac{q\mu B}{4\pi kh}\,\mathrm{Ei}\left(-\frac{r^2\phi\mu c_t}{4kt}\right)$$

This expression shows how the pressure drop is formed at various distances within the reservoir. The main objective here is to evaluate the decline of reservoir pressure over time as a result of well operations. Another crucial issue during field development is the water injection process. In many fields, as production progresses, water moves within the reservoir and gradually reaches the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

wells, increasing water production. To explain this process, the Buckley–Leverett model is widely applied.

- **Water injection flow (Buckley–Leverett equation):**

$$\frac{\partial S_w}{\partial t} + v\frac{\partial f_w(S_w)}{\partial x} = 0$$

This equation shows how water advances within the reservoir and how the water saturation level changes over time. In practice, this model is used to estimate the velocity of the water displacement front.

Production Forecasting and Reservoir Pressure

During the development of oil fields, one of the most critical issues addressed is how reservoir pressure changes over time. This is because as reservoir pressure declines, well flow rates also drop, leading to a gradual weakening of production. Therefore, correctly assessing the relationship between reservoir pressure and production plays a vital role in establishing the future operational plan of the field.

The decline in reservoir pressure is typically related to the volume of fluid extracted from the field. In other words, the more oil produced from the reservoir, the more the reservoir energy decreases. To evaluate this process, the material balance approach is used in reservoir engineering. The material balance formula allows for a simple expression of the interaction between the existing reserves in the field and the production:

$$N = \frac{(B_o \cdot \Delta P \cdot \phi \cdot V)}{B_{oi} \cdot (1 - S_{wi})}$$

Where:

- N— recoverable oil reserves from the reservoir,
- B_o— oil formation volume factor,
- ΔP— reservoir pressure drop,
- ϕ— reservoir porosity,
- V— total reservoir volume,
- S_{wi}— initial water saturation level.

Through this formula, the potential reserves the reservoir can yield are estimated based on the changes in reservoir pressure. In practice, this approach is widely used to assess future stages of production and to correctly select the field development strategy. Thus, the joint analysis of reservoir pressure and production indicators allows for increasing the efficiency of field development and determining the optimal operating regimes for the wells.

Conclusion

The analyses conducted show that considering the dynamic interaction of the reservoir-well system plays a crucial role in forecasting geological-technical indicators during oil field development. Changes in reservoir pressure, the development of the water injection process, and well operating regimes are key factors that directly impact the field's production dynamics. Investigating these factors together allows for a more accurate assessment of the field development stages. Hydrodynamic modeling methods and material balance approaches explain the processes occurring in the reservoir more realistically and increase the accuracy of future production indicators. Through these methods, the interference between wells, changes in the pressure field, and the distribution of water within the reservoir can be evaluated in advance. The core formulas and graphical recommendations presented in the article hold practical significance for the efficient organization of field development. Based on the forecast results, it becomes possible to optimize well operating regimes, select additional technological measures, and increase the oil recovery factor. Thus, considering the dynamic relationship of the reservoir-well system is regarded as an essential direction, both scientifically and practically, for the more effective development of fields and the long-term stabilization of production.

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Mirzecanzade E. Kh., Hasanov R. E., Bakhtiyarov I. S., Neft ve qaz chixarilmasinin texnika ve texnologiyasi, 1983, s. 173–179.
2. T. Ahmed, Reservoir Engineering Handbook, Gulf Publishing, USA, 2018, p. 736–755.
3. James W. Craft & M. Hawkins, Applied Petroleum Reservoir Engineering, 2014, p. 56–67.
4. Wilson C. Chin & Xiaoying Zhuang, Reservoir Simulation and Well Interference, 2023, p. 9–27.
5. L. W. Lake, Enhanced Oil Recovery, Prentice Hall, USA, 1989, p. 93–122.
6. Djebbar Tiab & Erle C. Donaldson, Petrophysics, 2024, p. 861–918.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

ПРОГНОЗИРОВАНИЕ ГЕОЛОГО-ТЕХНОЛОГИЧЕСКИХ ПОКАЗАТЕЛЕЙ РАЗРАБОТКИ НЕФТЯНОГО ПЛАСТА С УЧЕТОМ ДИНАМИЧЕСКОГО ВЗАИМОДЕЙСТВИЯ СИСТЕМЫ ПЛАСТ–СКВАЖИНА

Хасай Фейзуллаев[1], Вусал Гейдаров[2]
[1]Преподаватель, кафедра «Нефтегазовая инженерия», Азербайджанский государственный университет нефти и промышленности, Доктор технических наук, старший научный сотрудник, feyzullayevxasay@gmail.com
[2]Магистрант, кафедра «Нефтегазовая инженерия», Азербайджанский государственный университет нефти и промышленности, vusalheyderov.8111@gmail.com

РЕЗЮМЕ

В статье подробно рассматриваются вопросы прогнозирования геологических и технологических показателей разработки нефтяных месторождений с учетом динамического взаимодействия системы «пласт–скважина». В условиях современной эксплуатации месторождений изменение пластового давления, поэтапное снижение добычи нефти, динамика развития процессов заводнения, а также выбор режимов работы скважин рассматриваются как основные факторы, непосредственно влияющие на эффективность разработки. Изучение взаимосвязей между этими факторами позволяет глубже понять причины изменений, происходящих в процессе добычи, и повысить точность прогнозирования будущих показателей. Комплексный анализ геологических параметров в сочетании с технологическими мероприятиями обеспечивает последовательное отслеживание различных стадий разработки месторождения и создает условия для получения достоверной информации о фактическом состоянии пласта. На основе результатов прогнозирования становится возможной оптимизация режимов эксплуатации скважин, рациональное регулирование систем заводнения и выбор дополнительных геолого-технологических мероприятий. Предлагаемый подход способствует поддержанию стабильного уровня добычи, повышению эффективности управления процессами заводнения и увеличению коэффициента нефтеотдачи пласта.
Ключевые слова: нефтяное месторождение, система пласт–скважина, динамическое взаимодействие, прогнозирование добычи, пластовое давление, процесс заводнения, геолого-технологические показатели, разработка месторождения.

LAY–QUYU SİSTEMİNİN DİNAMIK ƏLAQƏSİ NƏZƏRƏ ALINMAQLA NEFT LAYININ İŞLƏNMƏSİNİN GEOLOJİ-TEXNOLOJİ GÖSTƏRİCİLƏRİNİN PROQNOZU

Xasay Feyzullayev[1], Vüsal Heydərov[2]
[1]Müəllim, “Neft-qaz mühəndisliyi” kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Texnika üzrə elmlər doktoru, baş elmi işçi, feyzullayevxasay@gmail.com
[2]Magistrant, “Neft-qaz mühəndisliyi” kafedrası , Azərbaycan Dövlət Neft və Sənaye Universiteti, vusalheyderov.8111@gmail.com

XÜLASƏ

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Məqalədə neft yataqlarının işlənməsi prosesində lay–quyu sisteminin dinamik qarşılıqlı təsiri nəzərə alınmaqla geoloji və texnoloji göstəricilərin proqnozlaşdırılması məsələləri ətraflı şəkildə araşdırılmışdır. Müasir yataqların istismarı zamanı lay təzyiqinin dəyişməsi, neft hasilatının mərhələli şəkildə azalması, su vurma proseslərinin inkişaf dinamikası və quyuların istismar rejimlərinin seçimi yatağın işlənmə səmərəliliyinə birbaşa təsir edən əsas amillər kimi qiymətləndirilir. Bu amillər arasında mövcud olan qarşılıqlı əlaqələrin öyrənilməsi hasilat prosesində baş verən dəyişikliklərin səbəblərini daha dərindən anlamağa və gələcək göstəriciləri daha dəqiq proqnozlaşdırmağa imkan verir.Geoloji parametrlərin texnoloji tədbirlərlə birlikdə kompleks təhlili yatağın işlənməsinin müxtəlif mərhələlərinin ardıcıl şəkildə izlənməsini təmin edir və layın faktiki vəziyyəti haqqında etibarlı informasiya əldə olunmasına şərait yaradır. Proqnoz nəticələrinə əsaslanaraq quyuların istismar rejimlərinin optimallaşdırılması, su vurma sistemlərinin səmərəli tənzimlənməsi və əlavə geoloji-texnoloji tədbirlərin seçilməsi mümkün olur. Təklif olunan yanaşma hasilatın sabit saxlanılmasına, suvarılma proseslərinin idarə olunmasının yaxşılaşdırılmasına və neftvermə əmsalının artırılmasına xidmət edir.

Açar sözlər: Neft layı, lay–quyu sistemi, dinamik əlaqə, hasilat proqnozu, lay təzyiqi, geoloji-texnoloji göstəricilər, yatağın işlənməsi.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
174-82

Publication history
Article received: 10.02.2026
Article accepted: 24.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-20

ANALYSIS OF THE EFFECTIVENESS OF OIL PRODUCTION INTENSIFICATION METHODS APPLIED AT THE X OIL FIELD

Samira Abbasova[1], **Farid Karimov**[2]
[1]Azerbaijan State Oil and Industry University, Associate Professor of the "Oil and Gas Engineering" Department.
[2]Azerbaijan State Oil and Industry University, Master's Student of the "Oil and Gas Engineering" Department.

ABSTRACT

This article provides a comprehensive analysis of the effectiveness of oil production intensification methods applied at the X oil field. Within the scope of the study, the geological and physical characteristics of the field, existing production indicators, and reservoir pressure dynamics were systematically investigated. The main technological methods applied for production enhancement — waterflooding, hydraulic fracturing, acid treatment, gas injection, and chemical agent injection — were analyzed in detail, and the technological process, application mechanism, and performance indicators of each method were comparatively evaluated. The analysis revealed that the application of complex intensification measures increased reservoir permeability by 2–3 times, raised oil production in wells by an average of 35–40%, and significantly improved the reservoir pressure maintenance coefficient. The study demonstrates that the proper selection and combined application of intensification methods is of decisive importance for extending the productive life of the field and increasing economic efficiency.
Keywords: oil production intensification, waterflooding, hydraulic fracturing, acid treatment, reservoir pressure, effectiveness analysis, oil field.

Relevance of the Topic

The efficient development of oil fields and increasing production levels is one of the priority issues in the modern oil and gas industry. As a result of long-term exploitation, a decline in reservoir pressure, an increase in the water cut, and depletion of the natural production potential are observed in the majority of fields [1]. The X oil field is no exception, and in recent years a declining trend in production dynamics has been recorded here. Under these conditions, the need to apply various intensification methods to maintain and increase production arises.

Oil production intensification methods are based on the principles of increasing reservoir permeability, maintaining reservoir pressure, and more effectively displacing hydrocarbons within the reservoir [2]. The proper selection and application of these methods depends on the geological structure of the field, rock properties, the composition of reservoir fluids, and their physicochemical characteristics [3]. World experience shows that intensification measures applied through a comprehensive approach can increase production by 30–50% and significantly extend the operational life of the field [4].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

For this reason, the analysis of the effectiveness of intensification methods applied at the X oil field, the evaluation of their technological and economic indicators, and the identification of directions for improvement are of significant scientific and practical importance . This research will contribute to the development of a more efficient field development strategy and to increasing production in the future.

Objective of the Study

The objective of the study is to comprehensively analyze the effectiveness of various technological methods applied for production intensification at the X oil field, to comparatively evaluate their results, and to identify the most optimal intensification strategy.

Research Discussion

Geological and Physical Characteristics of the X Oil Field and Production Status

The X oil field is a tectonically anticlinal structure, with productive horizons comprising three main reservoir series. The average depth of the field ranges from 2,800 to 3,200 meters. Initial reservoir pressure was 340–360 atm, but declined to 180–200 atm as a result of long-term exploitation [5]. Rock permeability ranges from 0.08 to 0.25 μm^2, and the porosity coefficient is 18–24%. Oil density ranges from 0.86 to 0.89 g/cm^3, and viscosity ranges from 12 to 18 mPa·s.

Field exploitation began in 1975, and the field is currently in the declining stage of production. Over the past 5 years, a declining trend in production dynamics has been observed — daily oil production has fallen from 850 tonnes to 620 tonnes. The water cut has increased from 42% to 67%, indicating a weakening of the field's natural energy potential and the need for the application of enhanced recovery methods [6].

Classification and Application of Oil Production Intensification Methods

The following main methods have been applied at the X oil field for the purpose of production intensification:

Waterflooding Method

Waterflooding is based on the principle of maintaining reservoir pressure and intensifying the movement of oil toward production wells under the influence of injected water. At the X field, a water injection system was established using 12 injection wells. The volume of injected water is 2,800–3,200 m^3 per day. After the system was put into operation, reservoir pressure increased from 180 atm to 220 atm within 8–9 months, and oil production in neighboring production wells increased by an average of 28% [7]. The main advantages of waterflooding are the restoration of reservoir energy, stabilization of production, and long-term effective impact [13]. Figure 1 presents a schematic view of the waterflooding system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

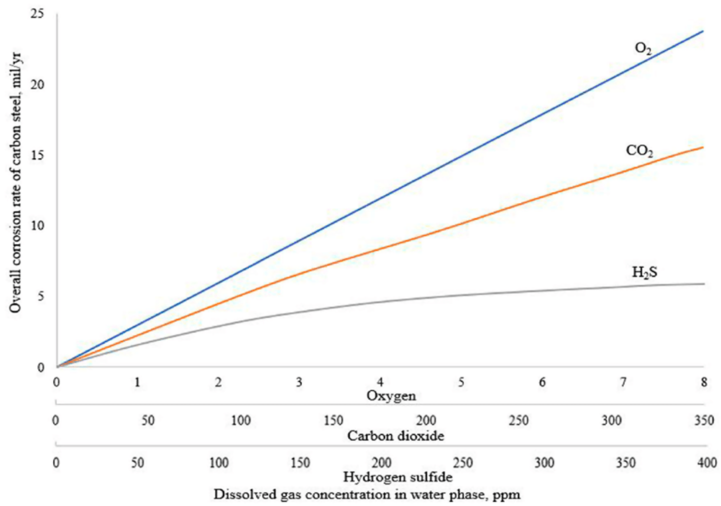


Figure 1: Schematic view of the waterflooding system.

Hydraulic Fracturing Method

Hydraulic fracturing (HF) aims to increase permeability by creating artificial fractures in reservoir rocks. Hydraulic fracturing operations were carried out in 8 wells at the X field. During the process, a special fracturing fluid and proppant (gravel) are injected into the reservoir under high pressure, causing fractures to open and stabilize in the rock [8]. As a result of HF, well productivity increased by 2.5–3 times and production remained at a high level for an additional 6–8 months. The method is particularly effective in horizons with low permeability [14]. Figure 2 shows the technological scheme of the hydraulic fracturing process.

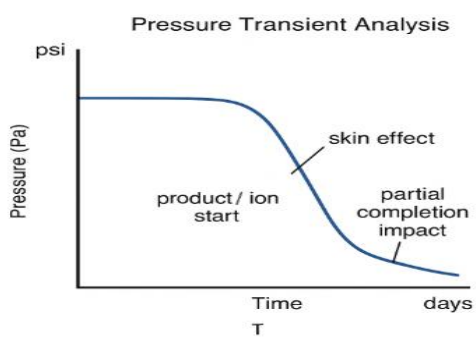


Figure 2: Scheme of the hydraulic fracturing process.

Acid Treatment Method

Acid treatment aims to clean the near-wellbore zone and improve permeability. The method is mainly applied in wells with carbonate reservoir rocks. Acid treatment was carried out in 6 wells at the X field using hydrochloric acid (HCl) and hydrofluoric acid (HF) based reagents. When the acid solution is injected into the well, it dissolves blockages in the reservoir rocks, opens micro-fractures and increases permeability [9]. As a result of treatment, oil production in wells increased by 40–55% and the skin factor was significantly reduced. The effectiveness of the method directly depends on the proper selection of acid composition and concentration.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Gas and Chemical Agent Injection

The injection of natural gas or nitrogen into the reservoir is used to reduce oil viscosity and facilitate easier extraction of oil from rock pores. Gas injection operations were carried out in 4 wells at the X field within a pilot project. Gas injection stabilized reservoir pressure and increased oil mobility [10]. Chemical agents — polymer solutions, surfactants (SAM) and foam-forming agents — enhance the displacement of oil within the reservoir. The application of surfactants reduced interfacial tension at the oil-water boundary, increasing oil recovery by 20–30%. Figure 3 illustrates the mechanism of chemical agent injection into the reservoir.

Comparative Analysis of Method Effectiveness

A comparative analysis of technological and economic indicators was conducted to evaluate the effectiveness of intensification methods applied at the X oil field. The main evaluation criteria used were the percentage increase in production, the duration of method impact, the cost payback period, and additional oil production.

The waterflooding method had the longest-lasting impact, providing stability over 18–24 months. Hydraulic fracturing provided the maximum production increase (2.5–3 times), but the effect lasted only 6–8 months [11]. Acid treatment showed high results over a period of 3–4 months and proved to be the most cost-effective option. Gas and chemical agent injection showed moderate but stable effects.

In summary, maximum effectiveness is achieved through a comprehensive approach — the combined application of waterflooding together with hydraulic fracturing and acid treatment increased production by 45–50% and significantly enhanced the reservoir development potential. This approach is considered the most optimal strategy both technologically and economically [12].

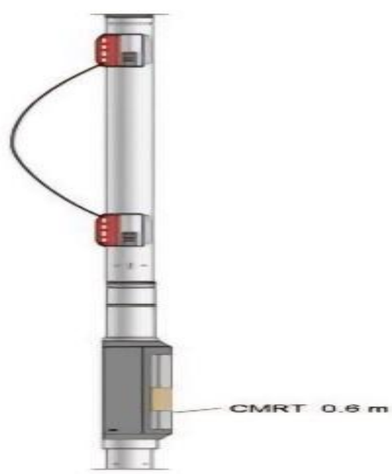


Figure 3: Process of chemical agent injection into the reservoir.

Conclusion

Based on the research and analyses conducted, it has been established that the complex application of oil production intensification methods at the X oil field is of great importance for the efficient development of the field and increasing production potential. The main results obtained can be summarized as follows:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

1. The waterflooding method is the most efficient base technology, ensuring the restoration of reservoir pressure and long-term production stability. The method has shown effect over 18–24 months and increased production by an average of 28%.
2. Although hydraulic fracturing provides the maximum production increase (2.5–3 times), the duration of effect is limited to 6–8 months. The method is particularly effective in horizons with low permeability.
3. Acid treatment has shown high results with a 40–55% increase in production in terms of cleaning the near-wellbore zone and improving permeability, and is the most optimal method in terms of cost-benefit ratio.
4. Gas and chemical agent injection provided an additional 20–30% in production through reducing oil viscosity and enhancing displacement efficiency.
5. The comprehensive approach — the combined application of waterflooding, hydraulic fracturing and acid treatment — showed the highest results and increased production by 45–50%. This strategy is recommended for the long-term efficient development of the field.

Economic Evaluation of Intensification Indicators

Alongside the technological effectiveness of each intensification method, its economic efficiency is also of great importance. The proper evaluation of the additional oil production obtained from the application of each method at the X oil field enables the optimization of investment decisions [3].

Although the initial capital costs of the waterflooding method are high, the return on investment (ROI) is comparatively attractive from a long-term operational perspective. Among the applied methods, acid treatment presents the most cost-effective result in terms of the cost-benefit ratio, while hydraulic fracturing is characterized by maximum production increase alongside high capital requirements [3].

The combined application of the chemical agent injection method with other methods has a positive impact on overall investment efficiency. The combined application of surfactants (SAM) with waterflooding is considered promising in terms of preventing water cut increase and significantly increasing oil recovery [10].

Reservoir Pressure Dynamics and Production Forecast

The dynamics of reservoir pressure as a result of the application of intensification methods at the X oil field has been analyzed in detail. Before the implementation of intensification measures, reservoir pressure was recorded at 180–200 atm. Twelve months after the application of the waterflooding system, pressure increased to 240–260 atm and was maintained at this level for 24 months.

Based on production forecast models, it has been determined that the continuation of the existing intensification strategy provides the opportunity to stabilize daily oil production at the X field in the medium-term perspective. The application of complex intensification or other enhanced oil recovery (EOR) methods has the potential to significantly extend the operational life of the field [3].

Comparative scenario analyses show that based on a passive management strategy, field production will show a declining trend. The complex intensification scenario provides the opportunity to maintain production at a stable level, which constitutes a significant economic advantage [4].

Directions and Prospects

Based on the results of research conducted at the X oil field, several priority directions for future application have been identified. The implementation of smart field concepts as the first direction, and the pilot testing of CO_{22} injection into the reservoir as the second direction are among the leading priorities [1].

The application of digital technologies — real-time well monitoring, integrated geological modeling, and machine learning-based optimization — has the potential to additionally increase the effectiveness of intensification methods by 15–25% [4]. The application of dataset analysis and deep learning algorithms enables the determination of optimal well intervention timing.

Finally, based on the geological and physical characteristics of the X field, the microbial enhanced oil recovery (MEOR) method has also been noted as promising. In some world practices, the application of the MEOR method has increased the oil recovery factor by 8–12% and provided additional effective production in wells with high water cut [9].

Sequence of Application of Intensification Methods

During the research, it was determined that the effectiveness of intensification methods depends not only on their individual application, but also on their correct sequence and combined application at specific time intervals. For example, the application of acid treatment 30–45 days after the HF operation provides a significant effectiveness advantage compared to performing acid treatment beforehand [6].

Within the framework of the complex intensification schedule, the optimal sequence is proposed as follows: in the first phase (months 1–6) the establishment and optimization of the waterflooding system; in the second phase (months 7–12) the implementation of HF operations in potential wells; in the third phase (months 13–18) the performance of acid treatments; in the fourth phase (months 19–24) the application of chemical agents and polymer solutions. This sequence has been noted as one of the main reasons for the high results achieved at the X field [12].

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Lake L.W. Enhanced Oil Recovery. Prentice-Hall, Englewood Cliffs, New Jersey, 1989. 550 p.
2. Willhite G.P. Waterflooding. SPE Textbook Series, Vol. 3. Society of Petroleum Engineers, Richardson, TX, 1986. 326 p.
3. Ahmed T. Reservoir Engineering Handbook. 5th ed. Gulf Professional Publishing, Elsevier, Cambridge, MA, 2019. 1492 p.
4. Taber J.J., Martin F.D., Seright R.S. EOR Screening Criteria Revisited — Part 1: Introduction to Screening Criteria and Enhanced Recovery Field Projects. SPE Reservoir Engineering, Vol. 12, No. 3, 1997, pp. 189-198. DOI: 10.2118/35385-PA.
5. Surguchev, A. Li, Water Injection Into a Gas Cap, Journal of Petroleum Technology, 58(11), 2006, pp. 62-68.
6. Economides M.J., Nolte K.G. (Eds.) Reservoir Stimulation. 3rd ed. John Wiley & Sons, Chichester, England, 2000. 856 p.
7. Hydraulic Fracturing: Fundamentals and Advancements, Mohamed Y. Soliman, SPE Monograph Series, 2020.
8. Matrix Acidizing of Carbonate Reservoirs, M. J. Economides, SPE Reprint Series, 2018.
9. Chemical Enhanced Oil Recovery (cEOR): A Practical Overview, Laura Romero-Zeron, InTech Publishers, 2016.
10. Sorbie K.S. Polymer-Improved Oil Recovery. Blackie and Son / CRC Press, Glasgow, 1991. 359 p.
11. Qasımov R.Ə., Neft yataqlarının işlənməsi və hasilat artırma metodları, ADNSU Elmi Xəbərlər, 2022.
12. Əhmədov T.İ., Şahbazov S.M., Neft yataqlarında subasmanın effektivliyi: NQETLİ-nin nəşriyyatı, Bakı, 2021. 198 səh.
13. Alizade E. Numerical Simulation Study on Enhanced Oil Recovery Treated with a Magnetic Field. Equipment Technologies Materials, Volume 30(07), Issue 06, 2025, pp. 177-189.
14. Lyubushkin N.A. Analiz effektivnosti primeneniya metodov intensifikatsii dobychi nefti na "X" neftyanom mestorozhdenii. Magisterskaya dissertatsiya, Tomskiy Politekhnicheskiy Universitet, Tomsk, 2022.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

АНАЛИЗ ЭФФЕКТИВНОСТИ МЕТОДОВ ИНТЕНСИФИКАЦИИ НЕФТЕДОБЫЧИ, ПРИМЕНЯЕМЫХ НА НЕФТЯНОМ МЕСТОРОЖДЕНИИ X

Самира Аббасова[1], Фарид Каримов[2]
[1]Азербайджанский государственный нефтегазовый университет, доцент кафедры «Нефтегазовое машиностроение».
[2]Азербайджанский государственный нефтегазовый университет, магистрант кафедры «Нефтегазовое машиностроение».

РЕЗЮМЕ

В данной статье представлен всесторонний анализ эффективности методов интенсификации нефтедобывающей промышленности, применяемых на нефтегазовом месторождении X. В рамках исследования систематически изучены геологические и физические характеристики месторождения, существующие показатели добычи и динамика пластового давления. Подробно проанализированы основные технологические методы повышения добычи — заводнение, гидроразрыв пласта, кислотная обработка, закачка газа и закачка химических реагентов, а также проведена сравнительная оценка технологического процесса, механизма применения и показателей эффективности каждого метода. Анализ показал, что применение комплексных мер интенсификации увеличило проницаемость пласта в 2–3 раза, повысило добычу нефти в скважинах в среднем на 35–40% и значительно улучшило коэффициент поддержания пластового давления. Исследование демонстрирует, что правильный выбор и комбинированное применение методов интенсификации имеет решающее значение для продления срока эксплуатации месторождения и повышения экономической эффективности.
Ключевые слова: интенсификация нефтедобычи, заводнение, гидроразрыв пласта, кислотная обработка, пластовое давление, анализ эффективности, нефтяное месторождение.

X NEFT YATAĞINDA TƏTBİQ OLUNAN NEFT HASİLATINI İNTENSİFİKASİYA METODLARININ SƏMƏRƏLİLİYİNİN ANALİZİ

Samira Abbasova[1], Fərid Kərimov[2]
[1]Azərbaycan Dövlət Neft və Sənaye Universiteti, "Neft və Qaz Mühəndisliyi" kafedrasının dosenti.
[2]Azərbaycan Dövlət Neft və Sənaye Universiteti, "Neft və Qaz Mühəndisliyi" kafedrasının magistr tələbəsi.

XÜLASƏ

Bu məqalədə X neft yatağında tətbiq olunan neft hasilatını intensivləşdirmə metodlarının effektivliyinin hərtərəfli təhlili təqdim olunur. Tədqiqat çərçivəsində yatağın geoloji və fiziki xüsusiyyətləri, mövcud istehsal göstəriciləri və lay təzyiqi dinamikası sistematik şəkildə araşdırılmışdır. Hasilatın artırılması üçün tətbiq olunan əsas texnoloji metodlar - su basması, hidravlik qırılma, turşu təmizlənməsi, qaz vurulması və kimyəvi agent vurulması - ətraflı təhlil edilmiş və hər bir metodun texnoloji prosesi, tətbiq mexanizmi və performans göstəriciləri

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

müqayisəli şəkildə qiymətləndirilmişdir. Təhlil göstərdi ki, mürəkkəb intensivləşdirmə tədbirlərinin tətbiqi lay keçiriciliyini 2-3 dəfə artırıb, quyularda neft hasilatını orta hesabla 35-40% artırıb və lay təzyiqinin saxlanılması əmsalını əhəmiyyətli dərəcədə yaxşılaşdırıb. Tədqiqat göstərir ki, intensivləşdirmə metodlarının düzgün seçilməsi və birgə tətbiqi yatağın məhsuldar ömrünü uzatmaq və iqtisadi səmərəliliyi artırmaq üçün həlledici əhəmiyyət kəsb edir.

Açar sözlər: neft hasilatının intensivləşdirilməsi, su basması, hidravlik çatlama, turşu təmizlənməsi, lay təzyiqi, effektivlik təhlili, neft yatağı.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

183-189

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-21

VOLUME 33 (08) ISSUE 02 2026

ENSURING STABLE OPERATION OF A POSITIVE DISPLACEMENT DOWNHOLE MOTOR BY REGULATING DRILLING PARAMETERS IN DEVIATED WELLS

Azad Bagirov[1], Alexey Lobko[2]
[1]Associate Professor, Department of Oil and Gas Engineering, Azerbaijan State Oil and Industry University. E-mail: azad-baqirov@mail.ru
[2]Master student, Department of Oil and Gas Engineering, Azerbaijan State Oil and Industry University. E-mail: lobkoaleksey2@gmail.com

ABSTRACT

Positive displacement downhole motors (PDMs) are widely applied in modern drilling due to their ability to provide efficient rock destruction and precise trajectory control, especially in directional and horizontal well drilling. However, drilling inclined sections introduces additional operational challenges, including increased hydraulic losses, intensified vibration, elevated lateral loads, and accelerated wear of bottom hole assembly (BHA) components. Under such conditions, maintaining stable and reliable motor performance becomes a critical task. This paper examines the operating principles of positive displacement motors and analyzes how drilling parameters influence their performance. Particular emphasis is placed on key operational variables such as bit rotational speed, weight on drill bit (WOB), pressure difference across the motor, and flow rate of the drilling fluid, as well as the BHA structural features. Optimal operating ranges deviations occurring may lead to rotor stalling, increased torsional and lateral vibrations, reduced rate of penetration (ROP), and premature motor failure. Special attention is given to hydraulic conditions in deviated well sections, where inefficient cuttings transport and uneven drilling fluid distribution significantly affect motor stability. The role of drilling fluid rheology and its adaptation to specific geological and technical conditions is also highlighted.
Keywords: Positive displacement motor, deviated well, drilling parameters, drilling fluid, weight on bit, flow rate, rotational speed, vibration.

Introduction

Modern oil well drilling is characterized by increasingly complex geological and technical conditions, accompanied by a growing share of directional and horizontal wellbores and stricter requirements for the accuracy of trajectory control. In this context, downhole tools capable of efficiently destroying rock formations without the need of continuous rotation of drill string become especially important.

One of the most widely used downhole instruments is the positive displacement motor. By this hydraulic volumetric device, drilling fluid passing through its power generating part creates energy that is transformed into mechanical motion rotating rock cutting instrument. This

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

mechanism significantly improves rock-breaking efficiency and enhances directional control essential for construction of inclined well sections. Application of PDMs enables drilling in inconvenient conditions, where drill string rotation from surface is restricted or impractical.

PDM design and operating principle

The core working element of PDM is the spiral power section consisting of an internally vulcanized elastomer-lined steel tube with several helical segments (stator) and a unit interposed into it (rotor). This arrangement creates alternating pressure chambers while drilling mud flows through it. Elastomer is developed to combine elasticity with high wear resistance, allowing tool to withstand significant friction forces as well as abrasive particles present in fluid. The rotor is manufactured from alloyed steel containing elevated concentrations of chromium, nickel, and manganese (typically 10–11% or higher), providing enhanced strength, corrosion resistance, wear resistance, and thermal stability. The rotor has a left-handed helical profile with one fewer lobe than the stator and is positioned eccentrically within it.

Figure 1: Cross-section of a 7/8 power section: 1 – stator, 2 – rotor, 3 – elastomer [7].

The kinematic ratio of the power section follows an *n: n+1* relationship, where *n* represents the number of rotor lobes. During operation, the rotor performs a planetary motion along the stator lobes, forming sealed chambers that move axially along the motor. Throughout the motor's length, there is a continuous interaction between the rubber element of the stator and the rotor protrusions, providing torque production and pressure integrity. Eventually, the driving shaft rotates the drill bit by transmitting its rotational motion through a universal connection.

Factors affecting PDM performance

Drilling parameters, the geology of the drilled rock, and motor design characteristics all affect the efficiency of a downhole assembly operation. The drilling fluid's flow rate is the most important of these factors since it controls how quickly the drill bit rotates. Rotational velocity and flow rate are directly correlated as the engine is a volumetric hydraulic system. Increasing pump output

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

results in higher rotor speed, allowing surface personnel to control bit RPM (rotations per minute) by adjusting circulation rates. However, elevated concentrations of solid particles in the drilling fluid, particularly abrasive sand exceeding 1%, significantly accelerate wear of motor components and reduce operational lifespan.

In deviated well sections, hydrodynamic anomalies arise in the annular space. One of the most critical phenomena is the “narrow-gap effect,” caused by gravitational displacement of the drill string toward the lower side of the wellbore. This creates asymmetric flow conditions: high fluid velocity in the upper annulus and stagnant or near-zero flow beneath the pipe. As a result, cuttings accumulate in the lower section, reducing effective flow area and increasing annular pressure losses.

For inclination angles between 30° and 60°, the upward fluid velocity required for effective cuttings transport must be 20–50% higher than in vertically drilled wells. Accumulated rock cuttings result in mud density and viscosity rise, creating larger pressure difference and increasing the value of torque needed. Some severe cases provide pressure fluctuations caused by cuttings accumulation producing a piston-like effect that generates sudden pressure spikes.

These conditions may cause:

- Rotor misalignment, due to uneven transverse hydraulic forces;
- Stator deformation, accelerated by vibration and pressure cycling, leading to elastomer wear.

Mechanical, hydraulic and thermal loads

The change in pressure caused by the passage of drilling fluid through the power unit creates momentum by exerting force over the rotor's components. As a result, torque output is increased by a greater difference in pressure. Power section geometry also plays a significant role: higher force is produced by a unit with more lobes, although it operates at lower rotational speeds. Power of an engine is defined as the torque multiplied by rotational speed; therefore, at constant torque, increasing mud flow rate causes a linear rise in power production. Each motor design has an optimal range of flow rates that ensure maximum hydraulic efficiency. Operating below this range reduces drilling performance, while exceeding it accelerates deterioration also causing overheating of the tool.

The heaviness of the drill string generates a force necessary to destroy rock formation, which is referred to as weight on bit. A higher load increases rotational obstruction, requiring more motor torque. In order to generate power capable of overcoming greater resistance, the engine increases pressure differential in operating chambers, necessitating additional volume of drilling fluid. If this is not achieved, the rotational speed drops and the pressure within the operational part rises. Elevated pressure intensifies the interface between the rotor lobes and rubber element of the stator, causing more heat production and accelerating elastomer breakdown. Furthermore, when resistance exceeds the motor's maximum torque capacity, rotor stall occurs, resulting in a sudden pressure surge which in severe situation may transcend the strength limitations of elastomers, thereby causing the rubber to detach off the metal body. Each stall incident has a micro-effect on a stator inner lining, diminishing its service life by approximately 5-10%. In inclined and horizontal sections, weight transfer to the bit becomes uneven due to friction between the drill string and the wellbore. Excessive surface-applied load may induce sinusoidal or helical buckling, preventing effective force transmission and increasing the risk of stuck pipe and mechanical failure.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Temperature and vibration effects

Bottomhole temperature significantly affects elastomer properties. As temperature increases, elastomer expansion exceeds that of steel, reducing internal clearances. While moderate heating may temporarily improve efficiency, excessive temperatures lead to overstressing, swelling, and potential seizure of the power section. Standard motors typically operate up to 100–120 °C, while high-temperature designs can withstand 150–160 °C. Exceeding these limits accelerates chemical degradation and reduces fatigue resistance.

Vibrations are classified into three main types:

- Axial vibrations, resulting from intermittent bit-rock interaction and damaging thrust bearings;
- Torsional vibrations, caused by uneven torque transmission and manifested as stick-slip, which may negatively impact on shafts and threaded joints;
- Lateral vibrations, the most destructive type resulting in early stabilizer wear and assembly deformation.

To mitigate vibration, there are shock absorbers and rotor stabilization systems installed over the bit, reducing oscillation amplitudes and protecting motor components.

Conclusion

Modern drilling technique relies heavily on positive displacement downhole engines, which effectively transform fluid power into mechanical rotation of the tool. Both the rotor-stator drive section design and rigorous adherence to optimal operation parameters affect motor performance and service life.

According to the investigation, sustainable PDM operation depends on the appropriate selection and management of the drilling mud, load on bit, and overall regime of operation. Deviations from optimal conditions lead to reduced drilling efficiency, accelerated elastomer wear, and increased risk of motor failure. Rotor stall, excessive temperature, and vibration are particularly detrimental to motor longevity.

Therefore, effective use of positive displacement motors requires an integrated approach that accounts for hydraulic, mechanical, and geological factors, combined with continuous monitoring of drilling parameters. Proper control of motor operating conditions improves rate of penetration, enhances reservoir exposure quality, and significantly extends motor service life, contributing to safer and more cost-effective drilling operations.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Bobrov M.G., Trapeznikov S.G. Features of Using Positive Displacement Motors (PDM) in Well Drilling. Bulletin of the Drilling Contractors Association. 2009.
2. Ismakov R.A., Zakirov N.N., Al-Soukhili M.K., Toporov Y.S. Study of the "Elastomer-Metal" Pair Operation in the Power Section of a Downhole Screw Motor. Modern Problems of Science and Education. 2015.
3. Koulidis A., Abdullatif M., Ahmed S. Drilling monitoring system: Mud motor condition and performance evaluation. In: SPE Middle East Oil & Gas Show and Conference. 19-21 February 2023. 2023. DOI: 10.2118/213422-MS
4. Morozov V.A., Dvoynikov M.V. Justification for the Selection of Parameters for Directional Drilling with Downhole Motors. Construction of Oil and Gas Wells on Land and Offshore. 2019.
5. Motahhari H.R., Hareland G., Nygaard R., Bond B. Method of optimizing motor and bit performance for maximum ROP. In: Canadian International Petroleum Conference. 12-14 June 2007. Calgary, Alberta.2007. DOI: 10.2118/2007-088
6. Samuel R, Baldenko D.F. Positive Displacement Motors – Theory and Applications. SigmaQuadrant Publisher. 2015.
7. Shutenkov A.A., Krivosheev A.V., Petukhov A.V., Kuznetsov A.V. Downhole motor with a profiled power section: productive drilling at low flow rate. LLC Firm Radius-Service Perm, 614990, Russian Federation. January 2025. DOI: 10.62994/2072-4799.2024.54.43.008

ОБЕСПЕЧЕНИЕ УСТОЙЧИВОЙ РАБОТЫ ВИНТОВОГО ЗАБОЙНОГО ДВИГАТЕЛЯ ПУТЕМ РЕГУЛИРОВАНИЯ ПАРАМЕТРОВ РЕЖИМА БУРЕНИЯ НАКЛОННЫХ СКВАЖИН

Азад Багиров[1], Алексей Лобко[2]
[1]Доцент, Кафедра Нефтегазовой Инженерии, Азербайджанский государственный университет нефти и промышленности. E-mail: azad-baqirov@mail.ru
[2]Магистрант, Кафедра Нефтегазовой Инженерии, Азербайджанский государственный университет нефти и промышленности. E-mail: lobkoaleksey2@gmail.com

РЕЗЮМЕ

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Забойные двигатели, которые обеспечивают эффективное разбуривание горных пород и крайне высокую управляемость траектории скважины, становятся все более распространенными в условиях быстрого развития в сфере наклонно-направленного и горизонтального бурения. Тем не менее, рост гидравлических потерь, вибрационных процессов, увеличение боковых нагрузок и износ компонентов нижней конструкции бурильной колонны являются некоторыми из специфических проблем, с которыми сталкивается ВЗД при бурении наклонных интервалах. Таким образом, обеспечение надежной и стабильной работы мотора становится чрезвычайно важным. В данной статье рассматриваются закономерности функционирования винтового забойного двигателя, а также анализируется влияние режима бурения на характеристику работы. Особое внимание уделяется таким ключевым параметрам, как частота вращения долота, осевая нагрузка, расход промывочной жидкости и перепад давления на забое, а также конструктивным особенностям КНБК. Отклонение указанных параметров от оптимальных значений приводит к возникновению режима остановки ротора (stall), усилению крутильных и поперечных вибраций, снижению механической скорости проходки и преждевременному выходу двигателя из строя. Отдельно рассмотрены особенности гидравлического режима бурения в наклонных участках скважин, где ухудшение условий выноса шлама и неравномерное распределение потока промывочной жидкости оказывают существенное влияние на стабильность работы ВЗД. Отмечается роль реологических свойств раствора и их адаптации к геолого-техническим условиям скважины.
Ключевые слова: Винтовой забойный двигатель, наклонная скважина, параметры режима бурения, буровой раствор, осевая нагрузка, расход бурового раствора, частота вращения, вибрация.

MAİLİ QUYULARIN QAZMA REJİMİNİN PARAMETRLƏRİNİ TƏNZİMLƏMƏKLƏ VİNTLİ QUYU MÜHƏRRİKİNİN DAYANIQLI İŞLƏMƏSİNİN TƏMİN EDİLMƏSİ

Azad Bağırov[1], Aleksey Lobko[2]
[1]Dosent, "Neft-qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
E-mail: azad-baqirov@mail.ru
[2]Magistr tələbəsi, "Neft-qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti.
E-mail: lobkoaleksey2@gmail.com

XÜLASƏ

Səmərəli süxur qırma və quyu lüləsinə yüksək nəzarət təmin edən vintli quyu mühərriklər (VQM) istiqamətli və üfüqi qazma texnologiyalarının sürətli inkişafı ilə getdikcə daha çox yayılmaqdadır. Lakin, yan yüklərin artması, hidravlik itkilərin və vibrasiyanın artması, eləcə də qazma kolonunun struktur komponentlərində aşınması VQM-lərin maili intervallarında qazma zamanı üzləşdiyi bəzi spesifik çətinliklər arasındadır. Buna görə də, VQM-lərin etibarlı və sabit işləməsini təmin etmək çox vacibdir. Bu məqalədə istiqamətli qazma zamanı VQM işləməsinin əsas prinsipləri araşdırılır və qazma parametrlərinin onun işinə təsirini təhlil edir. Xüsusi diqqət balta üzərində çəki, qazma baltanın fırlanma sürəti, qazma mayesinin axın sürəti və təzyiq dəyişməsi kimi əsas parametrlərə, eləcə də dib quyu qurğusunun dizayn xüsusiyyətlərinə yönəldilir. Bu parametrlərin optimal dəyərlərindən sapmalar rotorun dayanmasına, burulma və eninə titrəmələrin artmasına, ROP-un azalmasına və mühərrikin vaxtından əvvəl sıradan çıxmasına səbəb olur. Bu məqalədə quyuların maili hissələrində hidravlik qazma şəraiti araşdırılır, burada qazılmış hissəciklərin çıxarılması şəraitinin pisləşməsi və qazma mayesinin axınının qeyri-bərabər paylanması quyudibi mühərrikin sabitliyinə əhəmiyyətli dərəcədə təsir göstərir. Qazma mayesinin reoloji xüsusiyyətlərinin və onun geoloji və texniki qazma şəraitinə uyğunlaşmasının rolu vurğulanır. Quyu trayektoriyasının və meyl bucağının mühərrik komponentlərinə ötürülən təmas və sürtünmə yüklərinin səviyyəsinə təsiri də təhlil edilir.

Açar sözlər: Vintli quyu mühərriki, maili quyu, qazma rejimin parametrləri, qazma məhlulu, qazma məhlulunun sərfi, fırlanma sürəti, vibrasiya.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
190-198

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-22

DESIGN ANALYSIS OF FISHING TOOLS USED IN WELL WORKOVERS

Amir Mustafaev[1], Aqil Murtuzov[2]
[1]Associate Professor, Department of Mechanics, Azerbaijan State Oil and Industry University, Azerbaijan.
Email: mustafaev-1959@mail.ru
[2]Faculty of Oil Mechanical Engineering, Master's Student, Azerbaijan State Oil and Industry University, Azerbaijan.
Email: aqilmurtuzoff@gmail.com

ABSTRACT

In the present time in oil and gas fields, inactive form of wells is characterized. Known technologies are used for resuscitation of inactive wells. Such as lowering a column of pump-compressor pipes of a small diameter into a well or extracting trapped pipes from their wells with the help of new flexible pipes lowered into an emergency well [1, 2, 3, 4]. Disadvantages of these technologies is the impossibility of extracting the trapped flexible pipe from the well with the help of pump-compressor or flexible pipes lowered into the emergency new one due to the lack of displaced middle and surface equipment. To solve this problem, the author offers specific tasks. The use of the tap as a catch is possible due to the fact that the extraction of flexible pipes takes place when you grab it, and not when it breaks and falls. When the flexible pipe undergoes significant deformation and damage, when the appearance of cracks in the body is possible. When cutting the thread in the body of the pipe, further development and expansion of cracks is possible, leading to subsequent breakage of flexible pipes due to engagement with the tap. For the convenient use of the construction of the taps, a physical model of the process of forming a threaded connection, which ensures the reliability of fixing the tool in the body of the pipe and a specified load capacity during repair work, as well as a model of the process of surface hardening of the thread with microballs, has been developed. Suggested recommendations for improving the technological process of manufacturing a fishing tool.
Keywords: idle well, flexible pipe, tap, fishing thread, residual tension, extraction.

Introduction

When repairing oil and gas wells, specialized gripping tools such as bells, pipe cutters, jumpers, taps, and so on are used to extract stuck drill pipe, tubing, or casing. These are connected directly to the stuck part to free it. If the top of the stuck string cannot rotate and ends in a nipple or smooth surface, high twisting forces are required, so taps prove very useful. Taps with right-hand threads grip the entire remaining section of the string, while taps with left-hand threads unscrew and pull it out piece by piece. Universal taps have a long, tapered surface with a special, sharp thread capable of gripping pipes of various diameters along their entire length. They are made of strong, ductile steels such as 12KhN2 or 12KhN3A. The engagement threads are heat-treated, case-hardened to a depth of 0.4 to 0.7 mm, and then hardened to low-

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

temperature martensite with a hardness of 58 to 64 HRC. Most of them have a central channel for the passage of drilling fluid. In real-world conditions, when the tap enters the drill string, the pressure increases sharply. Once engaged, the load drops, and the fluid circulates down the borehole. But frankly, this doesn't always seem to ensure reliable engagement.[5] Using taps for emergency well interventions is superior to other methods of retrieving stuck equipment using a jacking rig. This allows for working under high hydrostatic pressure in the wellbore, accelerates tool lowering, allows for quicker installation and removal of the rig and additional equipment, and requires less pipe and materials. The objective is to study the wear or breakage of the tap threads during use. It is necessary to simulate the stress in the most heavily loaded tooth at different stages, as well as the deformation of the working surface during microbead hardening.

The task: Analysis of the fracture pattern of a tap thread surface under operating conditions. Modeling the stress state in the most heavily loaded tool tooth at various stages of its operation and modeling the stress-strain state of the tap working surface during microballoon hardening.

Theoretical part: Removing stuck flexible tubing using taps is a complex mechanical task, requiring the tool to simultaneously cut and clamp the pipe. Unlike conventional tubing used in pump and compressor systems, flexible tubing undergoes numerous bends during operation, changing shape (for example, becoming oval) and developing microcracks due to fatigue. Selecting the right tapping tool for stuck flexible tubing is crucial for successful repairs. Taps have their own advantages and disadvantages, which are worth noting.
Their advantages include their ability to grip pipes with damaged or bent ends, as well as pipes with uneven internal diameters, which often occurs with flexible pipes. When tightened correctly, the threaded connection reliably prevents strain on the pipe. Their design is relatively simple compared to overflow devices or pipe catchers, making them easier to manufacture and operate. They operate in challenging conditions, such as high well pressure, and allow fluid to flow through the central channel.

Pros:
- Gripping versatility: Taps are capable of gripping pipes with damaged or deformed ends, as well as those with inconsistent internal diameters, which are common with flexible pipes.
- Connection reliability: When screwed on correctly, the tap provides a strong threaded connection with the pipe body, capable of withstanding significant axial loads during extraction.
- Simplicity of design: Compared to more complex overshots or pipe spears, the tap has a relatively simple design, which makes it easier to manufacture and operate.
- Possibility of working in difficult conditions: The use of taps allows work to be carried out under increased hydrostatic pressure in the wellbore and ensures the possibility of circulation of drilling fluid through the central channel

Cons:
- Irreversibility of grip: The main disadvantage of taps is the impossibility of releasing the gripped object without destroying it, which can lead to complications in the event of an unsuccessful attempt at extraction.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

- Risk of damage to the damaged facility: The process of threading a flexible pipe body already weakened by fatigue cracks and deformations can contribute to further damage and loss of the facility.
- Chip Formation: When a tap is driven, metal chips are created that can clog the borehole bottom or interfere with the operation of other equipment.
- High demands on material strength: The working surface of the tap is subjected to extreme loads, which requires the use of high-strength steels and complex heat treatment, but even then there is a risk of tooth fracture.

Theoretically, engagement occurs by screwing into the stuck object through plastic flow and some metal shear. The key is matching the cutting edge radius to the depth of engagement. This condition must be met for the tooth to engage the object without chipping prematurely. The engagement depth for a single tooth is determined by the tap's technical specifications and is calculated as follows.:

$$t = \frac{S*K}{n} \quad (1)$$

Where, S is the pitch of the fishing thread, mm; K is the taper of the threaded surface; n is the number of longitudinal grooves (feathers) of the tap.
When a tap is screwed onto the inner surface of a pipe, contact stresses arise, the distribution of which is extremely uneven. According to the theory of elastic-plastic deformation, the greatest stress concentration is observed in the first 2-3 working threads.
The total force acting on the tap tooth consists of the torque M_{kp} (necessary for thread cutting)

and the axial force P (necessary for taper insertion). The theoretical failure stress in the critical section of the tooth (at the base of the profile) must not exceed the yield strength of the material after thermochemical treatment:

$$\sigma_{eq} = \sqrt{\sigma_b^2 + 3\tau_s^2} \leq [\sigma], (2) \quad (2)$$

When a tap is screwed into the inner wall of a pipe, contact stresses are uneven and unevenly distributed. According to elastic-plastic theory, the greatest increase in stress occurs during the first two to three working revolutions. The total force acting on the tooth adds torque for thread cutting and axial force for the taper. The breaking stress at the root of the tooth should not exceed the yield strength after machining. However, experience shows that a brittle carburized layer with a hardness of 58-64 HRC on 12KhN3A steel contradicts standard plasticity models. Residual stresses from heat treatment are of greatest importance. Analysis shows that the peak tensile stress during machining coincides with the most brittle zone, requiring technical solutions such as sharpening and microball hardening, which will be discussed later.
Tests and field trials show that failures occur on the rake face of the most stressed tooth. The greatest stress occurs during threading into a pipe, when the teeth are subject to heavy loads. Therefore, optimization of these loads is of interest. To determine where and how high the stresses causing failure are, a rough finite element analysis of the stress state in the loaded section of the thread during threading was conducted.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

According to the recommendations [2], the following conditions $a_z > \rho$. Here $\rho = 0{,}015$ мм – the rounding value of the cutting edge of the tap; a_z – cutting depth, which for one tooth is taken to be equal to:

$$a_z = \frac{S}{n} * \frac{k_0}{2} = 0{,}035 \text{ мм} \quad (3)$$

Where S = 4.5 is the thread pitch; n = 4 is the number of teeth.; $k_0 = 1:16$ – thread taper.

The contact of the tap thread with the pipe body during the cutting process is modeled by setting constraints on displacement, rotation and loads – torque and axial force.

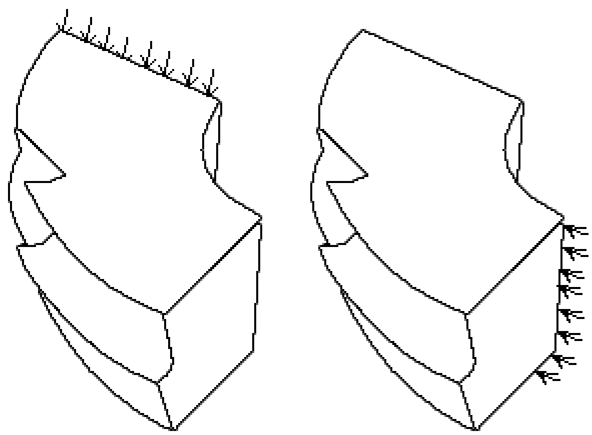


Figure 1: Setting constraints and loads.

The primary requirement for the resulting threaded connection is to ensure sufficient strength not only to thread the pipe but also to remove it from the borehole.
The modeling task in this case is to analyze the process of retrieving the drill pipe without breaking it. The model is constructed under the assumption that the weight of the drill pipe does not exceed the nominal lifting capacity of the tap, equal to 300 kN, and that it is secured at N = 3 rotor revolutions and at maximum cutting depth.

$$t = a_z * n * N \quad (4)$$

Considering the above values, the depth t is 0,42 mm.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

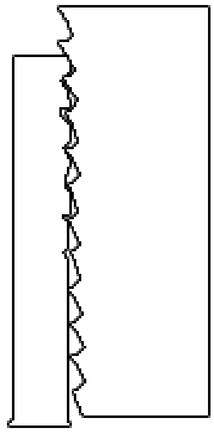


Figure 2: View of the finite element model of the engagement of the tap and pipe with a symbolic representation of loads and constraints.

An analysis of the presented models shows that cutting forces during tapping into the pipe significantly influence the formation of destructive stresses at the crest of the fishing thread profile. Therefore, improving cutting conditions during tap operation is the primary objective to ensure reliable tool performance. This objective was addressed using technological methods.

As already noted, a hard, thin layer on the rake face, depleted of ductility, can lead to brittle fracture. To increase strength after hardening, sharpening and surface plastic hardening should be added. Sharpen taps from the front or back side. In this case, sharpen the leading edge without weakening the tooth, removing a layer 0.1-0.12 mm thick (see Figure 3). Typically, 0.5-0.6 mm is required for such dimensions, but this is too much [3].

It is known [4] that hardening hardened steels with a martensitic structure, even with minor degrees of deformation, leads to an increase in their strength. The manufacturer's goal of increasing the degree of deformation by 20% was achieved using technological methods, namely, microball-bead treatment of the tool's front face. The selection of processing modes that would provide the required improvement in surface quality and, consequently, an increase in the service life of the tap was carried out according to the methodology given in [5], where the relative degree of plastic deformation was taken to be

$$U = \frac{L-d}{d} \tag{5}$$

here L and d are the length of the cross-sectional arc and the diameter of the plastic imprint of the microball, respectively.

Taking into account the geometric relationship between the dimensions L and d, the physical and mechanical properties of the contacting bodies and the collision velocity, the formula is transformed into the following form:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$U = \frac{\pi * \arcsin 2 * \sqrt{k * v * \left(\frac{\gamma}{6gHB}\right)^{0.5} * \left[1 - k * v * \left(\frac{\gamma}{6gHB}\right)^{0.5}\right]}}{360 * \sqrt{k * v * \left(\frac{\gamma}{6gHB}\right)^{0.5} * \left[1 - k * v * \left(\frac{\gamma}{6gHB}\right)^{0.5}\right]}} - 1 \quad (6)$$

here v is the flight speed of the microballs; γ – density of the microball material; HB – surface hardness of the material being processed. The hardness of the thread surfaces is 60–64 HRC equivalent to the Brinell hardness of 627–652 HB [6].

The corresponding depth of the work-hardened layer was found using the formula:

$$a = 3D\sqrt{k * v * \left(\frac{\gamma}{6gHB}\right)^{0.5}} \quad (7)$$

here D is the diameter of the microball; k is the coefficient that takes into account the influence of multiple impacts on the change in depth (from experimental data k = 1.3 – 1.6).

The microball's flight velocity was calculated using a Microsoft Excel solution based on the specified degree of plastic deformation U = 1.2. Graphs of the dependence of the degree of relative plastic deformation U and the depth of the work-hardened layer on the microball's flight velocity are shown in Figure 3.

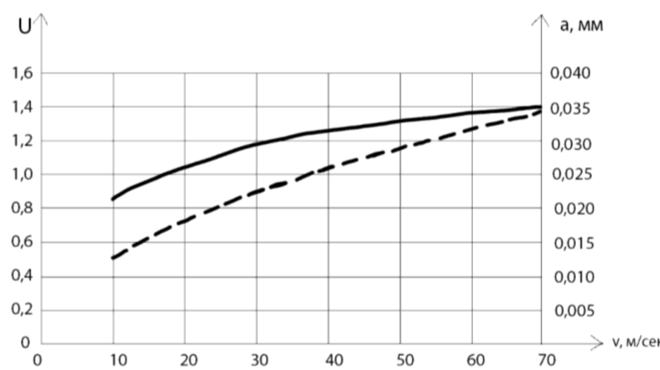


Figure 3: Dependences of the degree of plastic deformation U and the depth of the work-hardened layer, and on the flight speed of the microballs.

The minimum time required to ensure the continuity of the work hardening of the surface included in the shot spray core is calculated using the formula [5]

$$t = \frac{F}{DR_zN} \quad (8)$$

here $F = 5652\ mm^2$ is the surface area included in the shot spray core; $D = 0.1$ mm is the shot diameter; $R_z = 20$ mkm – initial height of microroughness; $N = 74 * 10^6 \frac{1}{c}$ – the per-second flow rate of microbeads through the nozzle.

Calculations show that two seconds are enough to cover the required area with prints [7].

The residual stresses in the plastically deformed layer were determined using the ANSYS software package. When formulating the volumetric problem, it was assumed that a steel ball is pressed into the working face of a tap at a specified velocity of 40 m/s. It was also assumed that repeated imprints left on the surface by other pellets do not have a noticeable effect on the thickness of the hardened layer and the depth of residual stresses. Both elastic and plastic properties were applied to the material of the linearly hardened surface made of case-hardened 12KhN3A steel [8]. Transient processes in the system cease 10 microseconds after the impact.

Summary

1. The highest design stresses, exceeding the material's tensile strength, occur at the apex of the tap thread profile as it penetrates the pipe body. The peak stress occurs at a depth of 0.1–0.12 mm from the tool's leading edge.
2. Recommendations have been developed for improving the fishing tap manufacturing process. These include the introduction of two additional operations: sharpening the front surface to the depth specified above and subsequent hardening with microbeads. Sharpening removes the extremely brittle layer and prepares the surface for subsequent SPD processing.
3. Microbead treatment provides additional strengthening of the tool material by creating favorable compressive residual stresses in the surface layer. These stresses reach a maximum of 1720 MPa and are located at a depth of 0.15 mm from the surface. Residual compressive stresses of up to 580 MPa are formed directly on the surface.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Gafiev R. R., Habibullin M. Ja. Issledovanie naprjazhennogo sostojanija lovil'nogo instrumenta pri likvidacii avarij v skvazhinah // Jelektronnyj nauchnyj zhurnal «Neftegazovoe delo». — 2016. — № 4. — S. 45–58.
2. Basarygin Ju. M., Bulatov A. I., Proselkov Ju. M. Proektirovanie i provedenie KRS: Uchebnik dlja vuzov. — M.: OOO «Nedra-Biznescentr», 2005. — 516 s. (Analiz konstrukcij i materialov lovil'nyh instrumentov).
3. Abdullaev T. B., Gusejnov Je. S. Povyshenie resursa raboty lovil'nogo instrumenta v slozhnyh geologicheskih uslovijah // Azerbajdzhanskoe neftjanoe hozjajstvo. — Baku, 2019. — № 11. — S. 28–33.
4. Gadzhiev N. M. Mehanika razrushenija lovil'nyh metchikov pri likvidacii prihvatov gibkih trub // Izvestija vuzov. Neft' i gaz. — 2021. — № 2. — S. 74–81.
5. Walker S., Watts R. J. Advanced Fishing Techniques for Coiled Tubing Operations // SPE International Conference on Coiled Tubing & Well Intervention. — 2021. — SPE-204456-MS.
6. Avramenko A. N. Modelirovanie processa poverhnostnogo uprochnenija detalej neftepromyslovogo oborudovanija mikrosharikami // Mashinostroenie i neftegazovye tehnologii. — 2018. — T. 3. — S. 112–119.
7. Jasashin V. A., Kateev R. I. Povyshenie nesushhej sposobnosti lovil'nogo instrumenta s zahvatom za vnutrennjuju poverhnost' // Stroitel'stvo neftjanyh i gazovyh skvazhin na sushe i na more. — 2017. — № 8. — S. 34–39.
8. Mahmudov T. M., Ismailov F. S. Analiz prichin polomok lovil'nyh metchikov pri KRS na mestorozhdenijah so slozhnym profilem // Neftjanoe hozjajstvo Azerbajdzhana. — 2020. — № 5. — S. 41–45.

QUYU TƏMİRİNDƏ İSTİFADƏ OLUNAN BALIQÇILIQ ALƏTLƏRİNİN DİZAYN ANALİZİ

Amir Mustafayev[1], Aqil Murtuzov[2]

[1]Dosent, «Mexanika» kafedrası, Azərbaycan Dövlət Neft və Senayə Universiteti, Azərbaycan.
E-mail: mustafaev-1959@mail.ru

[2]«Neft-mexanika» fakultəsi, Magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
E-mail: aqilmurtuzoff@gmail.com

XÜLASƏ

Hazırda neft və qaz yataqlarında qeyri-aktiv quyular geniş yayılmışdır. Qeyri-aktiv quyuları reanimasiya etmək üçün tanınmış texnologiyalardan istifadə olunur. Bunlara kiçik diametrli boru kəmərinin quyuya endirilməsi və ya nasaz quyuya endirilmiş yeni elastik borulardan istifadə edərək quyudan ilişib qalmış boruların çıxarılması daxildir [1, 2, 3, 4]. Bu texnologiyaların mənfi

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

cəhətləri arasında, ofset orta və səth avadanlıqlarının olmaması səbəbindən yeni borulardan və ya nasaz quyuya endirilmiş elastik borulardan istifadə edərək ilişib qalmış elastik boruların quyudan çıxarılmasının mümkün olmaması da var. Bu problemi həll etmək üçün müəlliflər konkret tapşırıqlar təklif edirlər. Kranı tutucu kimi istifadə etmək mümkündür, çünki elastik boru qırılıb düşəndə deyil, ilişib qaldıqda çıxarılır. Çevik boru əhəmiyyətli dərəcədə deformasiya və zədələnməyə məruz qaldıqda, gövdədə çatlar əmələ gələ bilər. Borunu yivləyərkən çatlar əmələ gələ və genişlənə bilər ki, bu da elastik borunun krandan sonradan qırılmasına səbəb olur. Kran dizaynlarının istifadəsini asanlaşdırmaq üçün, boru gövdəsində alətlərin etibarlı bərkidilməsini və təmir zamanı göstərilən yük tutumunu təmin edən yiv əmələ gətirmə prosesinin fiziki modeli hazırlanmışdır. Yivlərin mikromuncuqlarla səthi bərkidilməsi modeli də hazırlanmışdır. Balıqçılıq alətlərinin istehsal prosesini təkmilləşdirmək üçün tövsiyələr təklif olunur.
Açar sözlər: qeyri-aktiv quyu, çevik boru, kran, balıqçılıq sapı, qalıq gərginlik, çıxarışlar.

АНАЛИЗ КОНСТРУКЦИИ ЛОВИЛЬНЫХ ИНСТРУМЕНТОВ ПРИМЕНЯЕМЫХ В КАПИТАЛЬНОМ РЕМОНТЕ СКВАЖИН

Амир Мустафаев[1], Агиль Муртузов[2]
[1]Доцент, Кафедра «Механика», Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: mustafaev-1959@mail.ru
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: aqilmurtuzoff@gmail.com

РЕЗЮМЕ

В настоящем времени в нефтяных и газовых месторождениях характеризуются бездействующая форма скважин. Для реанимации бездействующих скважин применяются известные технологии. Такие как спуск в скважину колонну насосно-компрессорных труб малого диаметра или извлечение прихваченных труб их скважины с помощью, спускаемой в аварийную скважину новые гибкие трубы [1, 2, 3, 4]. Недостатками этих технологий является невозможность извлечь прихваченную гибкие трубы из скважины с помощью спускаемой в аварийную новую насосно-компрессорных или гибких труб по причини отсутствия смещенного среднего и поверхностного оборудования. Для решения этой задачи авторы предлагают конкретные задачи. Применения метчика в качества ловителя возможно в связи с тем, что извлечения гибких труб проходит при её прихвате, а не при обрыве и падении. Когда гибкая труба притерпивает значительную деформацию и повреждения, когда возможно появление трещин в теле. При нарезании резьбы в теле трубы возможно дальнейшее развитие и расширение трещин, приводят к последующему обрыву гибких труб из зацепления с метчиком. Для удобного использования конструкции метчиков разработана физическая модель процесса образования резьбового соединения, обеспечивающего надежность закрепления инструмента в теле трубы и заданную грузоподъемность при проведении ремонтных работ, а также модель процесса поверхностного упрочнения резьбы микрошариками. Предложены рекомендации по совершенствованию технологического процесса изготовления ловильного инструмента.
Ключевые слова: бездействующая скважина, гибкая труба, метчик, ловильная резьба, остаточные напряжения, извлечения.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

199-208

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-23

VOLUME 33 (08) ISSUE 02 2026

IMPROVING THE EFFICIENCY OF A MILLING REAMER USED FOR CUTTING A "WINDOW" IN A SIDETRACK WELLBORE

Amir Mustafayev[1], Jahid Guliyev[2]
[1]Associate Professor, Department of Mechanics, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: mustafaev-1959@mail.ru
[2]Master's student, Faculty of Oilfield Mechanics, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: dzhakhid.kuliev@mail.ru

ABSTRACT

This article is devoted to solving problems related to improving the design and enhancing the cutting performance of a milling reamer used for cutting a "window" in sidetrack oil and gas wells. The paper addresses scientific and technical problems and identifies structural shortcomings of existing milling reamers. A preliminary study examined design solutions and selected the most effective structural option to improve the cutting performance of the milling reamer. The main requirements for modern milling reamer designs are presented and were taken into account in the development of the improved design. Based on the conducted research and considering new requirements, a fundamentally new technical solution is proposed with regard to the parameters of the base design. Improved versions of milling reamers were developed on the basis of these solutions. Descriptions of new design solutions implemented in the form of full-scale prototype models are provided.
Keywords: casing string, milling reamer, window cutting, composite material, well.

Introduction

Under modern conditions of oil and gas field development, technologies for drilling multilateral and multi-branch wells are widely applied, enabling increased efficiency in the development of hydrocarbon reserves [3]. One of the key stages in constructing an additional wellbore is milling a "window" in the production casing string [14].

To perform this operation, milling reamers are used to cut a section of the casing wall and subsequently enlarge the milled interval. However, when milling casing strings made of high-strength steels, intensive wear of the cutting elements, failure of carbide reinforcement, and overheating of the cutting zone are observed, which significantly reduce the operational efficiency of the tool [11].

An analysis of existing designs shows that insufficient cutting efficiency of the cutting elements and imperfections in the cooling system do not ensure process stability during milling and prevent the rational utilization of the tool's cutting resource.

The objective of this study is to enhance the cutting performance and operational reliability of the milling reamer used for window milling in a sidetrack wellbore by improving the design of the cutting head and the cooling system, as well as to substantiate and experimentally validate the proposed technical solutions.

Theoretical Part

The process of milling a "window" in the production casing during sidetrack well construction differs significantly from conventional rock drilling processes. In this case, the object of destruction is a metal casing pipe made of high-strength steel characterized by high ductility, thermal conductivity, and resistance to cutting. Milling of the casing string is accompanied by intense friction, substantial contact loads, and localized heat generation in the cutting zone [5].

Metal cutting is performed under conditions of intermittent contact between the cutting elements and the casing surface, which results in impact loads and cyclic stresses in the carbide reinforcement [6]. The nature of the interaction between the cutting tool and the metal is determined by the geometry of the cutting head, the penetration depth of the cutting elements, the axial load, and the rotational speed of the tool.

One of the key factors determining the efficiency of the window milling process is the contact pressure in the cutting zone. At insufficient pressure, the cutting elements operate in a friction and sliding mode, leading to intensive wear and overheating of the tool. At excessive loads, the probability of chipping and pull-out of carbide elements from the binder matrix increases.

The main types of wear affecting the cutting elements of milling reamers are abrasive wear, thermal chipping, and mechanical failure of the carbide reinforcement. During milling of the production casing, the cutting elements are simultaneously exposed to high temperatures, contact stresses, and vibrational loads. Experimental and field studies indicate that the temperature in the "miller–casing" contact zone can reach 900–1100 °C [10], resulting in reduced strength of carbide materials, the development of thermal stresses, and deterioration of adhesion between the reinforcement and the binder. Consequently, premature pull-out of cutting elements from the cutter body occurs. Insufficient cooling efficiency aggravates these processes, as the circulating flushing–cooling fluid does not provide adequate heat removal from the working surface of the tool.

The operational efficiency of a milling reamer is largely determined by heat transfer conditions in the cutting zone [1]. In most existing designs, the flushing–cooling fluid is supplied through a central channel of the tool, while the main portion of the flow does not participate in intensive heat exchange with the heated sections of the cutting head. Increasing the flow path of the fluid along the surface of the cutting tool and redistributing the flow from the center to the periphery makes it possible to enhance the heat transfer coefficient and reduce thermal stresses in the carbide reinforcement. From this standpoint, the application of spiral flushing channels, which ensure a directed flow of fluid directly into the contact zone, appears to be a promising solution.

Analysis of Existing Research and Designs

An analysis of modern scientific and technical publications shows that the problem of improving the efficiency and durability of milling tools used in sidetrack well construction has been widely discussed in recent years. Modern drilling engineering studies emphasize the complexity of section milling and window milling operations in high-strength casing strings [3], [13].

Research devoted to the mechanics of cutting processes demonstrates that the stress state of cutting elements and their fixation strength significantly influence tool reliability under high

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

contact loads [8], [10]. Studies on cutting tool geometry indicate that the optimization of cutting edge configuration directly affects contact pressure distribution and cutting stability [6], [9]. These findings are particularly relevant for milling reamers operating under intermittent contact conditions during casing cutting.
Investigations in the field of hard alloys and composite cutting materials confirm that tool wear resistance strongly depends on carbide composition, bonding strength, and thermal stability [12], [15]. Surface integrity and thermal effects during material removal processes have also been shown to play a critical role in tool life and failure mechanisms [11].
In drilling practice, section milling and sidetracking operations require not only mechanical strength of the cutting structure but also effective cooling of the cutting zone [1], [2]. Heat transfer conditions significantly affect temperature distribution in the contact zone and the durability of carbide-reinforced cutting crowns [5], [13].
However, despite the considerable number of studies on drilling mechanics and metal cutting processes, insufficient attention has been paid to the combined influence of stepped cutting crown geometry and directed cooling flow on the cutting performance and thermal condition of milling reamers. This determines the scientific relevance of the present research.
When cutting windows in casing strings made of high-strength steels, the milling process is characterized by severe thermal loading, vibration, and cyclic impact stresses [4], [14]. Field and laboratory studies indicate premature wear and pull-out of carbide elements under high axial loads and insufficient cooling efficiency. Analysis of serial milling reamer designs shows that conventional face cutting assemblies do not always provide optimal load redistribution and heat removal conditions, which leads to incomplete utilization of cutting elements and reduced tool life.
Therefore, the task of improving milling reamer design by optimizing the cutting crown geometry and enhancing the cooling system remains relevant and represents both scientific and practical interest.

Design Improvement of the Milling Reamer

In order to enhance the cutting capacity of the milling reamer and improve the stability of the window milling process in the production casing, the main requirements for the improved tool design were formulated based on theoretical analysis of cutting conditions and the results of preliminary studies.
According to these requirements, the milling reamer must ensure effective destruction of the casing metal, reduce the wear intensity of the cutting elements, and provide improved heat removal conditions from the cutting zone. In accordance with the stated objectives, the milling reamer is equipped with an annular cutting head forming the lower section of the tool. The cutting head is reinforced with a composite material based on crushed hard alloy grade VK-8 using brass brazing alloy No. 7 [12].
The contact surface of the face cutting head is made stepped and consists of lower and upper stages, which makes it possible to modify the interaction between the cutting elements and the casing metal by redistributing the contact pressure. The geometric and operating parameters of the tool are selected in accordance with the dimensional characteristics of the well and the operating conditions.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Based on these requirements, a design solution for the milling reamer was developed on the basis of the standard FRL-type design (Fig. 1). The FRL milling reamer consists of a hollow body reinforced with VK-8 hard alloy. The upper part of the body is cylindrical, while the lower part has a conical shape. In the lower section of the body, an annular cutting element reinforced with a carbide composite material is installed. Inside the body, a mechanism for capturing the milled metal strip is provided.

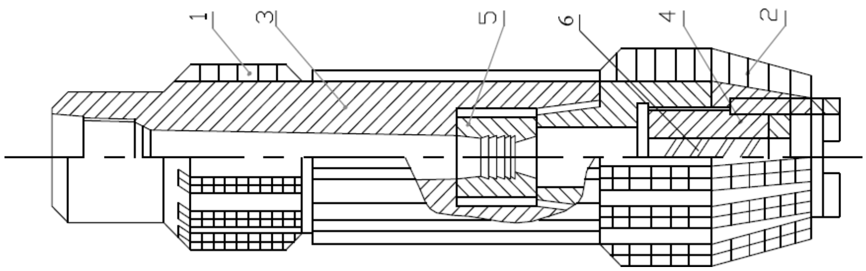


Figure 1: Milling reamer: 1 – cylindrical section; 2 – conical section; 3 – annular element; 4 – sub; 5 – capture assembly; 6 – flushing channels;

The cutting head is positioned below the annular mill and comes into contact with the production casing after the conical section of the tool has passed. Such a structural configuration ensures the sequential engagement of the milling reamer elements and creates favorable conditions for a stable cutting process. The stepped shape of the cutting head increases the metal strip cutting rate due to the staged penetration of the cutting elements and the increase of contact pressure in specific areas of the cutting surface. In addition to improving the cutting head, particular attention was given to increasing the efficiency of the tool's cooling system. During window milling in the production casing, high temperatures arise in the contact zone between the mill and the metal, reaching 900–1100 °C, which leads to accelerated wear and destruction of the carbide reinforcement. In most milling reamer designs, the flushing–cooling fluid supplied through the central channel does not provide sufficient heat exchange in the cutting zone, since the main portion of the flow does not come into contact with the heated surfaces of the cutting head.
To improve heat removal efficiency in the proposed design, it is suggested to modify the flow path of the flushing–cooling fluid by forming spiral grooves on the inner annular surface of the cutting head, which function as flushing channels (Fig. 1, position 6). This design solution increases the fluid flow path, promotes redistribution of the flow from the center toward the periphery, and ensures more intensive heat removal directly from the cutting zone. The proposed design improvements create the prerequisites for enhancing the cutting capacity of the milling reamer, reducing thermal and mechanical loads on the cutting elements, and increasing the service life of the tool. The effectiveness of the improved design was evaluated on the basis of analytical calculations and experimental studies, the results of which are presented in the following sections of this work.

Experimental Studies for the Improvement of the Milling Reamer

To verify the operability and evaluate the efficiency of the improved milling reamer design, experimental studies were conducted under conditions simulating the window milling process in a production casing string. Prior to the experiment, the tool was mounted on the drill string and lowered into the wellbore until it contacted a pre-installed whipstock. Industrial water was used as the flushing–cooling fluid. When the pump and rotor were activated, the milling reamer was set into rotation at a specified speed.

During the experiment, the following parameters were varied: axial load applied to the tool, rotational speed of the milling reamer, and flow rate of the flushing–cooling fluid. The tool performance was evaluated according to the indicators as rate of window cutting in the production casing, stability of the cutting process, nature and intensity of wear of the cutting head.

The experiment demonstrated that the use of a stepped cutting head combined with an improved cooling system ensures a more stable milling process and reduces the wear rate of the carbide reinforcement compared with standard designs.

The conducted theoretical analysis makes it possible to qualitatively assess the thermal processes occurring within the tool. For quantitative substantiation of the obtained conclusions, calculations of heat transfer parameters in the cooling system of the milling reamer were performed.

The heat transfer mechanism can be described as follows: the flushing fluid, moving along the spiral channel, travels a longer path since a helical line is longer than its generatrix. Upon exiting the spiral flushing channel, the directed flow continues along a spiral trajectory at an angle relative to the axis of the bore, being directed toward the contact zone. As a result, the intensity of heat removal from the cutting zone increases, providing direct cooling of the heated section of the cutting head.

The cutting part of the face cutting head is designed in a stepped configuration. The lower step first comes into contact with the inner surface of the casing string and, during preliminary milling, removes a small chip layer. Then, as the reamer advances along the whipstock surface and the casing string, the upper step of the face cutting head engages the pre-machined section of the casing and enters the cutting process.

The stepped design of the cutting portion of the face head increases the rate of metal strip removal from the casing body due to the increased contact pressure generated by each step. After the metal strip is cut and captured, the conical section, followed by the cylindrical surface of the milling reamer, engages in cutting. Once the end face of the milling reamer exits beyond the casing, enlargement of the milled window begins.

To substantiate the operability of the improved milling reamer design, calculations of the main operational parameters were performed, including cutting forces, torque, axial load, heat removal, and strength of the carbide reinforcement. These relationships are fundamental in the design of cutting tools operating during casing milling.

The cutting force during production casing milling is determined considering the cutting depth and rotational speed of the tool and may be expressed by an empirical relationship [5]:

$$F = K \cdot h^{m} \cdot v^{n} \quad (1)$$

here, h— cutting depth; v — linear cutting speed; K,m,n — empirical coefficients depending on the properties of the casing material and the carbide reinforcement. This relationship accounts for the nonlinear nature of cutting force variation and may be used to construct analytical and graphical dependencies.

The temperature in the cutting zone is determined by the heat removal efficiency of the flushing fluid. The heat transfer coefficient is calculated using the Nusselt number [5]:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4} \quad (3)$$

here, Re — Reynolds number;Pr — Prandtl number.
The heat transfer coefficient is expressed as:

$$\alpha = Nu \cdot \frac{\lambda}{d_h} \quad (4)$$

here, α – heat transfer coefficient.

$$T = T_0 + \frac{Q}{\alpha \cdot A_t} \quad (5)$$

here, T – temperature in the cutting zone.

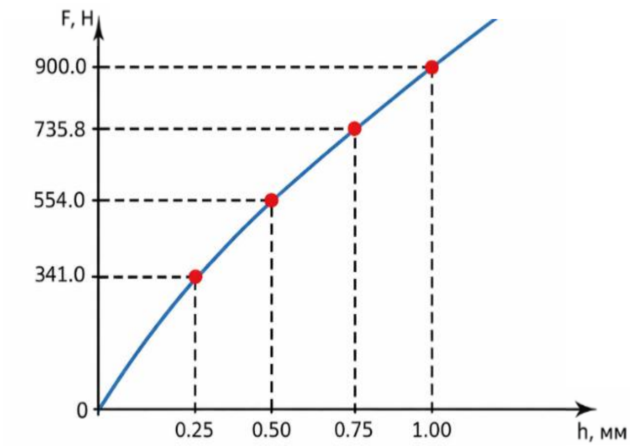


Figure 2: Dependence of cutting force (F) on cutting depth (h)

The use of spiral flushing channels increases the Reynolds number and the heat transfer coefficient, thereby reducing the temperature of the cutting head.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

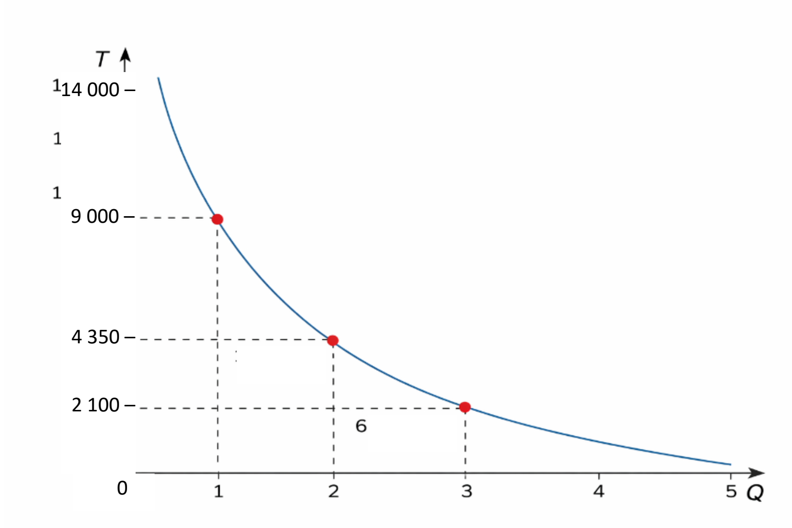


Figure 3: Dependence of temperature (T) on flushing fluid flow rate.

The **wear intensity** of the cutting elements may be estimated by the relationship [12]:

$$W = k \cdot p^{a} \cdot v^{b} \cdot T^{c} \tag{6}$$

here, p — contact pressure, T — temperature in the cutting zone, k,a,b,c — wear coefficients. This expression makes it possible to analyze the influence of operating modes and tool design parameters on the durability of the cutting head.

Conclusions

1. The operating conditions of the milling reamer during window milling for a sidetrack wellbore were analyzed, and the main factors reducing the efficiency of standard designs were identified.
2. The feasibility of applying a stepped cutting head to modify the cutting mechanism and increase contact pressure was substantiated.
3. An improved cooling system incorporating spiral flushing channels was proposed.
4. Calculations of cutting forces, torque, heat removal, and cutting head wear were performed taking into account nonlinear relationships.
5. Experimental studies confirmed improved stability of the cutting process and reduced wear intensity of the tool.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Aadnøy, B. S., & Looyeh, R. (2011). Petroleum Rock Mechanics: Drilling Operations and Well Design. Gulf Professional Publishing.
2. API (2019). API Recommended Practice 7G-2: Drill Stem Design and Operating Limits. American Petroleum Institute.
3. Bourgoyne, A. T., Millheim, K. K., Chenevert, M. E., & Young, F. S. (2003). Applied Drilling Engineering. Society of Petroleum Engineers.
4. Byrne, G., Dornfeld, D., & Denkena, B. (2003). Advancing cutting technology. CIRP Annals – Manufacturing Technology, 52(2), 483–507.
5. Childs, T., Maekawa, K., Obikawa, T., & Yamane, Y. (2004). Metal Machining: Theory and Applications. Butterworth-Heinemann.
6. Denkena, B., & Biermann, D. (2014). Cutting edge geometries. CIRP Annals – Manufacturing Technology, 63(2), 631–653.
7. Ezugwu, E. O., & Wang, Z. M. (2005). Titanium alloys and their machinability: A review. Journal of Materials Processing Technology, 68(3), 262–274.
8. Gasanov, A. P. (2006). Improving the Efficiency of Milling Tools in Sidetrack Well Construction. Baku: Oil and Gas Publishing House.
9. Gasanov, A. P., & Neymatov, D. T. (2003). Theoretical evaluation of cutting element fixation stability in milling reamers. Azerbaijan Oil Industry Journal, (1), 46–49.
10. Jawahir, I. S., & Brinksmeier, E. (2016). Surface integrity in material removal processes. CIRP Annals – Manufacturing Technology, 65(2), 597–620.
11. Klocke, F. (2011). Manufacturing Processes 1: Cutting. Springer.
12. Kovalev, V. V. (2008). Hard Alloys and Composite Materials for Cutting Tools. Moscow: Metallurgy Publishing.
13. Mitchell, R. F., & Miska, S. Z. (2011). Fundamentals of Drilling Engineering. Society of Petroleum Engineers.
14. Popov, A. N. (Ed.). (2004). Directional and Horizontal Well Drilling. Moscow: Nedra Publishing.
15. Upadhyay, V., Jain, P. K., & Mehta, N. K. (2013). A review of hard coatings for cutting tools. Journal of Materials Processing Technology, 213(12), 2199–2210.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

QUYULARDA ƏLAVƏ LÜLƏNİN QAZILMASINDA QUYUNUN KONSTRUKSİYASINA UYĞUN OLARAQ RAYBER VƏ YÖNƏLDİCİLƏRİN İŞİNİN KEYFİYYƏTİNİN YÜKSƏDİLMƏSİNİN TƏSDİQİ

Əmir Mustafayev[1], Cahid Quliyev[2]
[1]Mexanika kafedrası"nın dosenti, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
E-mail: mustafaev-1959@mail.ru
[2]Neft-mexanika fakültəsi, magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
E-mail: dzhakhid.kuliev@mail.ru

XÜLASƏ

Bu məqalə neft və qaz quyularında əlavə lülənin açılması zamanı "pəncərə"nin kəsilməsi üçün istifadə olunan frezer-reyberin konstruksiyasının təkmilləşdirilməsi və kəsici qabiliyyətinin artırılması məsələlərinin həllinə həsr olunmuşdur. Məqalədə elmi-texniki məsələlər həll edilmiş və mövcud frezer-reyberlərin konstruktiv çatışmazlıqları əsaslandırılmışdır. İlkin araşdırmada konstruktiv həllər nəzərdən keçirilmiş və frezer-reyberin kəsici qabiliyyətinin artırılması üçün ən səmərəli konstruksiya variantı seçilmişdir. İşdə müasir frezer-reyber konstruksiyalarına qoyulan əsas tələblər göstərilmiş və təkmilləşdirilmiş konstruksiyanın hazırlanması zamanı nəzərə alınmışdır. Aparılmış tədqiqatlar və yeni tələblər əsasında baza konstruksiyasının parametrləri nəzərə alınmaqla prinsipial olaraq yeni texniki həll təklif edilmişdir. Qeyd olunan həllər əsasında frezer-reyberin təkmilləşdirilmiş variantları hazırlanmışdır. Yeni konstruktiv həllərin natural ölçüdə model nümunələri şəklində həyata keçirilməsi təsvir edilmişdir.
Açar sözlər: istismar kolonu, frezer-reyber, "pəncərə"nin açılması, kompozit material, quyu.

ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ФРЕЗЕРА-РАЙБЕРА, ПРИМЕНЯЕМОГО ПРИ ЗАРЕЗКЕ «ОКНА» ДОПОЛНИТЕЛЬНОГО СТВОЛА СКВАЖИНЫ

Амир Мустафаев[1], Джахид Гулиев[2]
[1]Доцент "Кафедра Механики", Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: mailto:mustafaev-1959@mail.ru
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: dzhakhid.kuliev@mail.ru

РЕЗЮМЕ

Данная статья посвящена решению задач по усовершенствованию конструкции и повышению режущей способности фрезера-райбера, применяемого при зарезке «окна» дополнительного ствола нефтяных и газовых скважин. В статье решены научно-технические задачи и доказаны конструктивные недостатки фрезеров-райберов. В предварительном расследование было рассмотрено конструкторное решение и выбран наиболее эффективный вариант конструкций по повышению режущей способности фрезера-райбера. В данной работе были приведены основные требования к современным конструкциям фрезеров-райберов, которые были учтены при разработке усовершенствованной конструкции. На основании проведенных исследований, с учетом новых требований, предложены принципиально новое техническое решение с учетом параметров базовой конструкции. На базе указанных решений разработаны усовершенствованные варианты фрезеров-райберов. Приведены описания новых конструкторских решений, реализованных в виде модельных образцов в натурных размерах.

Ключевые слова: эксплуатационная колонна, фрезер-райбер, зарезка “окна”, композиционный материал, скважина.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

209-216

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-24

OPTIMIZATION OF WELL REMEDIATION OPERATIONS USING MILLING TOOLS

Amir Mustafayev[1], Islam Mahammadov[2]
[1]Associate Professor, Department of Mechanics, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: mustafaev-1959@mail.ru
[2]Faculty of Oil Mechanical Engineering, Master's student, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: mahammadov.islam@mail.ru

ABSTRACT

Improving the efficiency of workover operations in the Caspian region fields is closely associated with the advancement of technologies for removing metallic obstructions in casing strings. The article presents a refined mathematical model of the milling process that accounts for the stress–strain state of the cutting elements and the effect of surface hardening of the material. Using the finite element method (FEA), the distribution of equivalent stresses was analyzed according to the von Mises criterion. The application of the Lagrange multiplier method made it possible to substantiate the optimal cutting conditions. Implementation of the proposed parameters ensures an increase in the mechanical rate of penetration and an average 48% growth in the service life of the tool, as confirmed by the results of a comparative analysis with contemporary field data.
Keywords: well, milling tool, stress, cutting, strength, hardening, optimization.

Introduction

For the oil and gas sector of the Caspian region, the problem of maintaining the well stock in operational condition remains a priority. According to current statistical data, more than 65% of wells in operation for over 20 years require complex workover operations (WWO) involving casing deformation, recovery of fish, or sidetracking [2].

Restoring wellbore drift capacity by milling is an energy-intensive and technically complex process. Operating experience shows that the limiting factor here is not only the overall strength of the mill but also the local stress concentration on the cutting edges, leading to their premature chipping [11, 12]. Research confirms a direct link between forcing drilling parameters and a reduction in the fatigue life of the tool. Consequently, finding a balance between productivity and reliability is an urgent task, requiring the development of multi-parameter optimization models [8, 14].

Previous studies have shown that increasing the rate of penetration (ROP) is often accompanied by accelerated fatigue failure of the cutting edges [7, 10]. Research in the field of fishing and milling tools confirms the need for a comprehensive consideration of the stress-strain state, contact dynamics, and thermal factors [9, 13]. Despite a significant number of publications, the problem of multi-parameter optimization of milling remains unresolved, considering: Von Mises

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

equivalent stresses, residual stresses after hardening, cutting kinematics, fatigue life, and the thermal influence on material plasticity.

Problem Statement

The aim of this study is to develop an algorithm for selecting rational milling parameters that ensure maximum ROP while minimizing the destructive impact on the cutting apparatus.

The main constraint is formulated based on the strength condition of the carburized layer of 12KhN3A steel:

$$\sigma_{eq} \leq \sigma_T \tag{1}$$

here, σ_T – The yield strength of the material varies between 1200 and 1400 MPa depending on the quality of heat treatment.

The objective function of the problem includes optimization of the axial load (WOB), rotational speed (RPM) feed per tooth (f_z) while complying with the limit values for cutting forces (F_c) and the required tool durability (T_{tool}).

$$maxROP(WOB, RPM, f_z) \tag{2}$$

$$\sigma_{eq}(WOB, f_z) \leq \sigma_T \tag{3}$$

$$F_c \leq F_{dop} \tag{4}$$

$$T_{tool} \geq T_{min} \tag{5}$$

here, WOB — axial load, RPM — rotational speed, f_z — feed per tooth, F_c — cutting forces, T_{tool} — tool durability [5, 9].

Problem solution

To solve this problem, it is necessary to construct a cutting force model [6, 10].

A fracture mechanics model has been used to describe the force interaction between the tool and the casing metal [3, 10]:

$$Fc = C_p \cdot t^m \cdot f_z^q \cdot K_v \tag{6}$$

here, the coefficient C_p is taken in the range of 2000-4000N/mm^2, t — the cutting depth, $m = 1.0$, $q = 0.8$, $K_v = 1.1$ — the vibration coefficient [10].

The cutting depth t is considered as a function of the axial load and contact characteristics:

$$t = \frac{WOB}{z \cdot b \cdot \sigma_s} \tag{7}$$

here, z — the number of teeth, b — the contact width.

The calculation of equivalent stresses is performed according to the classical Von Mises theory:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$\sigma_{eq} = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \quad (8)$$

According to the results of numerical simulation (FEA) [1, 8], under a load $WOB = 50\ kN$, the maximum stresses reach 1720 MPa, which critically exceeds the yield threshold. In this regard, the influence of residual compressive stresses formed by the surface work hardening method (shot peening) has been introduced into the model:

$$\sigma_{eq}^{max} = 1720\ MPa$$

According to the surface work hardening model [14], without accounting for shot peening strengthening, we have the formula:

$$\sigma_{res}(x) = \sigma_0 e^{-kx} \quad (9)$$

here, σ_0 = -555 MPa — represents the residual stresses on the surface, and k = 1.4.

$$\sigma_{eff} = \sigma_{eq} + \sigma_{res} \quad (10)$$

After shot peening, the resulting effective stress decreases:

$$\sigma_{eff} = 1720 - 555 = 1165\ MPa$$

This value is within the safe range relative to σ_T [8].
According to the empirical dependence of the rate of penetration (ROP) model, we obtain the formula:

$$ROP = k \cdot WOB^{0.8} \cdot RPM^{0.6} \quad (11)$$

here k = 0.15.
The Lagrange multiplier method was used to find the optimal parameters:

$$L = ROP + \lambda(\sigma_T - \sigma_{eff}) \quad (12)$$

$$\frac{\partial L}{\partial WOB} = 0, \frac{\partial L}{\partial RPM} = 0, \frac{\partial L}{\partial \lambda} = 0$$

Differentiation of the function allowed for the determination of rational values: $RPM = 185\ rt/min$, $WOB = 36\ kN$, $f_z = 0.075\ mm/tooth$. the same time, the predicted rate of penetration is $ROP = 6.3 m/h$, which is 40% higher than the baseline indicators.
Performance growth compared to:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$\Delta = \frac{6.3-4.5}{4.5} \cdot 100\% = 40\% \qquad (13)$$

Literature Review:
The optimization of workover operations (WWO) has been addressed by many authors, yet their approaches vary significantly. Specifically, Voevidko I.V. and Chudyk I.I. in their works (notably their 2014 study) provide a detailed analysis of the technological aspects of sidetracking in production casings, focusing on the kinematics of the process.
Gasanov A.P. (2020) proposes empirical ROP dependencies adapted to the specific conditions of Azerbaijani wells; while these offer high practical value, they require more profound theoretical support regarding stress-strain state (SSS) assessment.
Gilyazov R.M. (2019) made a significant contribution to understanding the physics of metal failure during milling, though his models do not fully account for the temperature factor. Conversely, Shestakova E.V. et al. (2024) recently demonstrated the potential of numerical analysis for tool condition monitoring using diagnostic criteria, which aligns with our chosen focus on FEA analysis. International colleagues, such as Walker S. and Watts R.J. (2021), emphasize the critical role of contact dynamics when operating fishing tools in complicated conditions. The fundamental principles established by Von Mises (1913), Miner (1945), and Lagrange (1788) remain the bedrock for all modern strength calculations and optimization.

Theoretical Framework: Milling a casing string is a process of elastoplastic deformation accompanied by local fracture. According to the theory of plasticity [4]:

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl} \qquad (14)$$

A triaxial stress state is formed in the contact zone. A plastic zone emerges upon reaching:

$$\sigma_{eq} \geq \sigma_T \qquad (15)$$

Thermal energy is inevitably generated in the cutting zone:

$$Q = F_c \cdot V_c \qquad (16)$$

The temperature increase in the contact zone leads to thermal softening of the material:

$$\sigma_T(T) = \sigma_{T0}(1 - \alpha T) \qquad (17)$$

here $\alpha = 0.0015\ 1/°C$ is the temperature coefficient.

Fatigue wear analysis according to Miner's rule of linear cumulative damage [7]:

$$D = \sum \frac{n_i}{N_i} \qquad (18)$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

Failure occurs at $D \geq 1$ Analysis shows that preliminary hardening reduces the rate of micro-defect accumulation by approximately 30–32%.

Experimental part

The experimental part was conducted to verify the adequacy of the developed mathematical model [9] and to assess the influence of the main technological parameters on the milling process during well workover. Numerical simulation was performed in ANSYS using the finite element method (FEM) for a depth of 4000 m at a temperature of 110°C. The following variables were adjusted in the calculations: axial load $WOB = 30 - 60\ kN$, $rotational\ speed = 120 - 220\ rp/min$, and $feed\ per\ tooth = 0.05 - 0.1\ mm$.

As a result of the experiment, the influence of the axial load on the cutting tool was determined. It was established that the dependence of the rate of penetration (ROP) on the axial load is exponential in nature. Increasing the load to 50 kN leads to an increase in ROP up to 6.3 m/h. However, with a further increase, a sharp rise in equivalent stresses (up to 1720 MPa) is observed, which exceeds the yield strength and reduces the tool life (Fig. 1).

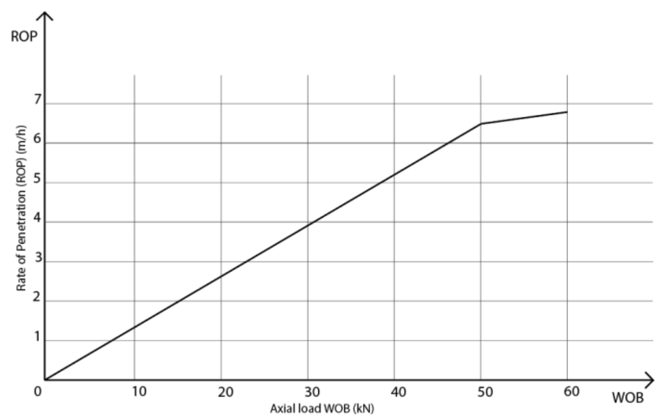
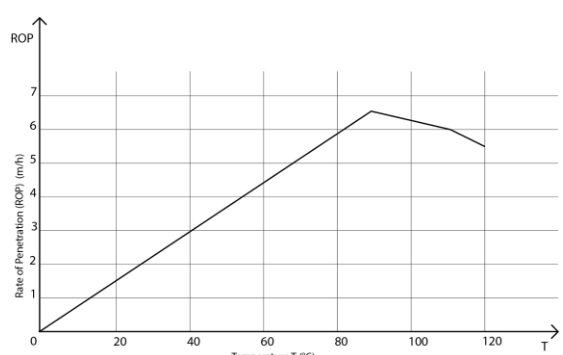


Figure 1: Graphical dependence of the rate of penetration (ROP) on axial load.

As the temperature increases from 90 to 120°C, the rate of penetration decreases by 12–15%. This is due to a reduction in yield strength and an increase in the plastic deformation of the cutting edges (Fig.2).



ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Figure 2: Graphical dependence of the rate of penetration (ROP) on temperature.

After shot peening treatment, stresses decrease from 1720 to 1165 MPa, which increases the estimated tool life by 45–52% (Fig. 3).

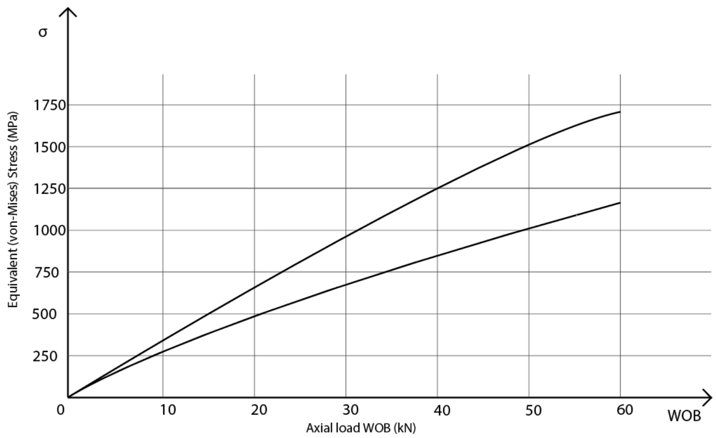


Figure 3: Graphical dependence of equivalent stress on axial load before (1) and after (2) shot peening treatment.

The conducted experimental work and simulation confirm the validity of the proposed model and demonstrate that the optimization of parameters must account for not only productivity but also stress constraints.

Conclusions

1. A comprehensive mathematical model for the optimization of milling tools for well workover has been developed. In contrast to existing studies, the proposed approach integrates stress-strain state analysis, plasticity theory, residual stresses after hardening, and multi-criteria optimization of cutting parameters.
Numerical simulation shows that without hardening, equivalent stresses reach 1720 MPa, which exceeds the yield strength of 12KhN3A steel. The application of surface work hardening reduces effective stresses to 1165 MPa, providing a 45–52% increase in fatigue life. Parameter optimization allowed for an increase in the rate of penetration (ROP) up to 6.3 m/h and a reduction in workover time by 25–40%.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. ANSYS Inc. ANSYS Mechanical APDL Theory Reference. Canonsburg, PA, USA, 2023.
2. Gasanov A.P. Analysis of mechanical rate of penetration during major well workover operations under the conditions of Azerbaijan // Azerbaijan Oil Industry. 2020. No. 4. P. 33–39.
3. Gilyazov R.M. Modeling of metal fracture processes during casing milling // Vestnik Mashinostroeniya. 2019. No. 7. P. 18–24.
4. Hill R. The Mathematical Theory of Plasticity. Oxford: Clarendon Press, 1950.
5. Lagrange J.L. Analytical Mechanics. Paris, 1788 (Russian edition: Moscow: Nauka, 1989).
6. Merchant M.E. Mechanics of the metal cutting process // Journal of Applied Physics. 1945. Vol. 16. P. 267–275.
7. Miner M.A. Cumulative damage in fatigue // Journal of Applied Mechanics. 1945. Vol. 12. P. A159–A164.
8. Shestakova E.V., Lyagov I.A. et al. On the operational state of the tool during the process of casing milling with downhole motors // News of the Tula State University. Technical Sciences. 2024. No. 5. P. 526–532.
9. SPE Drilling Engineering. Casing milling and section milling operations: field applications and optimization. SPE Technical Papers Collection.
10. Treskov V.V., Reznikov A.N. Theory of Metal Cutting. Moscow: Mashinostroenie, 1982.
11. Voevidko I.V., Chudyk I.I. Features of cutting an additional trunk in the production well column // Construction of oil and gas wells on land and sea. 2014. No. 3. P. 15–18.
12. von Mises R. Mechanics of solid bodies in the plastically deformable state // Göttingen. 1913.
13. Walker S., Watts R.J. Performance evaluation of downhole milling and fishing tools in casing remediation operations // SPE Drilling & Completion. 2021. Vol. 36(3). P. 512–523.
14. Withers P.J. Residual stress and its role in failure // Reports on Progress in Physics. 2007. Vol. 70. P. 2211–2264.

FREZ ALƏTLƏRİNDƏN İSTİFADƏ ETMƏKLƏ QUYULARIN TƏMİR İŞLƏRİNİN OPTİMALLAŞDIRILMASI

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Əmir Mustafayev[1], İslam Məhəmmədov[2]
[1]"Mexanika kafedrası"nın dosenti, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: mustafaev-1959@mail.ru
[2]Neft-mexanika fakültəsi, magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: mahammadov.islam@mail.ru

XÜLASƏ

Xəzər regionu yataqlarında quyuların əsaslı təmirinin (ƏTQ) səmərəliliyinin artırılması, qoruyucu kəmərlərdə (obsad kolonlarında) metal maneələrin aradan qaldırılması texnologiyalarının təkmilləşdirilməsi ilə sıx bağlıdır. Məqalədə frezeləmə prosesinin dəqiqləşdirilmiş riyazi modeli təqdim edilmişdir. Model kəsici elementlərin gərginlik-deformasiya vəziyyətini və materialın səthi möhkəmlənməsi effektini nəzərə alır. Sonlu elementlər metodu (FEM/FEA) vasitəsilə Mizes meyarına əsasən ekvivalent gərginliklərin paylanması təhlil edilmişdir. Laqranj vurucuları metodunun tətbiqi optimal kəsmə rejimlərini əsaslandırmağa imkan vermişdir. Təklif olunan parametrlərin tətbiqi mexaniki qazma (keçmə) sürətinin artımını və alətin istismar resursunun orta hesabla 48% yüksəlməsini təmin edir ki, bu da müasir mədən məlumatları ilə aparılmış müqayisəli təhlilin nəticələri ilə təsdiqlənir.
Açar sözlər: quyu, frez aləti, gərginlik, kəsmə, möhkəmlik, möhkəmləndirmə, optimallaşdırma.

ОПТИМИЗАЦИЯ РЕМОНТНЫХ РАБОТ СКВАЖИН С ИСПОЛЬЗОВАНИЕМ ФРЕЗЕРНЫХ ИНСТРУМЕНТОВ

Амир Мустафаев[1], Ислам Магомедов[2]
[1]Доцент “Кафедра Механики“, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: mailto:mustafaev-1959@mail.ru
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail mahammadov.islam@mail.ru

РЕЗЮМЕ

Повышение эффективности капитального ремонта скважин (КРС) на месторождениях Каспийского региона тесно связано с совершенствованием технологий ликвидации металлических препятствий в обсадных колоннах. В статье представлена уточненная математическая модель процесса фрезерования, учитывающая напряженно-деформированное состояние режущих элементов и эффект поверхностного упрочнения материала. С помощью метода конечных элементов (FEA) проведен анализ распределения эквивалентных напряжений по критерию Мизеса. Применение метода множителей Лагранжа позволило обосновать оптимальные режимы резания. Внедрение предложенных параметров обеспечивает прирост механической скорости проходки и увеличение эксплуатационного ресурса инструмента в среднем на 48%, что подтверждается результатами сравнительного анализа с современными промысловыми данными.
Ключевые слова: скважина, фрезерный инструмент, напряжение, резание, прочность, упрочнение, оптимизация.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

217-227

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-25

CONTROL OF COMPRESSOR AND PUMPING SYSTEMS IN THE OIL AND GAS INDUSTRY USING SCADA

Javida Damirova[1], Vagif Salmanov[2]
[1]PhD, Dosent, Azerbaijan State Oil and Industry University. Email: cavida.damirova@asoiu.edu.az
[2]Master, Faculty of Information Technologies and Management, Azerbaijan State Oil and İndustry University. Email: salmanovvaqif12@gmail.com

ABSTRACT

The article examines the technical and functional aspects of controlling pumping and compressor systems in the oil and gas industry through the use of SCADA systems. The capabilities of SCADA systems for real-time acquisition, transmission, and processing of process data, as well as for remote and centralized control of technological equipment at facilities of varying complexity and geographical distribution, are analyzed in detail. Particular attention is given to the role of SCADA systems in ensuring industrial safety, improving energy efficiency, and enhancing the operational reliability of pumping and compressor installations. The paper presents the main levels of SCADA system architecture, the principles of their interaction with primary measuring transducers, sensors, and actuators, as well as issues related to integration with programmable logic controllers and higher-level systems. Special emphasis is placed on technical diagnostics and predictive maintenance functions based on the analysis of operational parameters and their changing trends, which enable timely detection of potential faults and prevention of emergency situations. The conducted analysis demonstrates that the implementation of SCADA systems contributes to ensuring the continuity of production processes, reducing operational and technological risks, and optimizing the operating modes of pumping and compressor units. The use of SCADA systems is regarded as an important element of digitalization in oil and gas enterprises, aimed at improving management efficiency, reducing costs, and ensuring the sustainable development of the industry.
Keywords: SCADA systems, industrial automation, pumping systems, compressor units, oil and gas industry, remote control, energy efficiency

Introduction

The reliability, safety, and uninterrupted operation of production processes in the modern oil and gas industry largely depend on the level of development and effectiveness of applied automation and control systems. Under conditions of continuous technological complexity, increasing volumes of hydrocarbon extraction and transportation, and stricter industrial and environmental safety requirements, the implementation of intelligent control systems capable of providing continuous equipment monitoring and real-time operational control becomes particularly important.

Oil and gas infrastructure is generally characterized by extensive geographical distribution and includes trunk pipelines, compressor and pumping stations, field facilities, product treatment units, and auxiliary technological systems. Managing such geographically dispersed assets involves a number of challenges caused by equipment remoteness, limited access to facilities, and increased requirements for operational reliability and safety. Under these conditions, the use of local or fragmented control systems proves insufficient, which necessitates the deployment of centralized automated systems capable of acquiring, transmitting, and analyzing data from remote facilities. The key technological platform that meets these requirements is SCADA systems (Supervisory Control and Data Acquisition). SCADA represents a multi-level automation architecture designed for centralized monitoring, supervisory control, and analysis of critical technological processes at industrial facilities. In the oil and gas industry, SCADA systems perform a wide range of functions, including continuous monitoring and diagnostics of technological processes, ensuring the safe operation of pumping and compressor equipment, remote control of installations, automation of start-up and shutdown procedures, reduction of accident risks, and optimization of energy consumption. An additional advantage of SCADA systems is their capability to accumulate and analyze large volumes of production data, which provides a foundation for the implementation of technical diagnostics, predictive maintenance, and intelligent decision-support methods. Modern research studies and practical experience in the deployment of SCADA systems confirm that their application significantly improves production efficiency, reduces losses associated with equipment failures, and ensures the sustainable long-term operation of oil and gas enterprises (IJRASET, 2024).

Role of scada systems in the oil and gas industry

Processes of oil and gas extraction, processing, transportation, and refining are carried out under conditions of high technological complexity and increased industrial safety requirements. Operation of equipment under high pressures, significant temperature fluctuations, exposure to aggressive chemical environments, as well as the considerable remoteness and extensive geographic distribution of production facilities create serious operational and emergency risks. Under such conditions, the organization of continuous real-time monitoring of equipment condition and technological process parameters becomes critically important. SCADA systems provide integrated and centralized management of oil and gas facilities by combining measurement, control, and analytical functions within a unified information environment. Their application enhances the transparency of technological processes, enables rapid response to deviations from specified operating modes, and significantly reduces the impact of the human factor in managerial decision-making.

Real-Time Data Acquisition

By using an extensive network of sensors and measuring instruments, SCADA systems ensure continuous transmission of data on pressure, level, temperature, flow rate, vibration, and energy consumption to the control center. In addition, the current operational status of pumping and compressor units, pressure drops, indications of potential pipeline leaks, and signals from industrial safety systems—including emergency shutdown, gas detection, and flame detection—are recorded. This allows the formation of a comprehensive view of facility conditions and enables timely identification of potentially hazardous situations.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Diagnostics and Analysis of Technological Processes

The collected data are processed using trend analysis tools, alarm and warning systems, and reporting modules. Such analysis makes it possible to detect deviations and faults at early stages, develop preventive maintenance plans, and make informed decisions aimed at optimizing equipment operating modes and reducing energy consumption. The application of SCADA analytical functions supports the transition from a reactive to a preventive approach in managing the technical condition of equipment.

Automated Equipment Control

SCADA systems provide automated control of pumping and compressor installations through the execution of start and stop commands, load regulation, and speed control using variable frequency drives (VFD/VSD), as well as the implementation of emergency shutdown functions in abnormal operating conditions. This enhances process stability, reduces equipment wear, and lowers the probability of emergency failures.

Remote Control and Digital Transformation

Next-generation SCADA systems are integrated with Industrial Internet of Things (IIoT) technologies, cloud computing, and edge computing, opening new opportunities for digital transformation in the oil and gas industry. Such integration makes it possible to reduce the number of maintenance personnel, minimize work in hazardous production areas, and significantly increase data processing speed. As a result, the quality of managerial decision-making is improved, operational efficiency is enhanced, and conditions are created for the implementation of intelligent control systems and decision-support solutions.

Overall, SCADA systems play a key role in ensuring the safe, reliable, and efficient operation of oil and gas facilities, serving as an integral component of the modern digital infrastructure of the industry.

Scada-based control of pumping systems

Pumping systems are among the key components of the oil and gas industry infrastructure and are widely used at all stages of the technological chain—from oil and gas gathering at fields to transportation and preparation for further processing. They are applied for pumping crude oil and petroleum products, maintaining pressure in main pipelines, water injection into reservoirs, as well as for performing auxiliary technological operations. Reliable and efficient operation of pumping installations is crucial for ensuring production continuity and meeting industrial safety requirements. SCADA systems provide automated and centralized control of pumping installations based on data received from pressure, level, flow, and other process sensors. Depending on current operating conditions, the system generates control actions aimed at maintaining optimal pump operating modes. In multi-pump systems, sequential or parallel operation of units is implemented, which contributes to uniform load distribution among pumps, reduced equipment wear, and extended overall service life. An important function of SCADA systems is the protection of pumps against operation in emergency and abnormal modes. Based on data from flow sensors, dry-run protection functions are implemented. In the absence or sharp decrease of process fluid flow, the SCADA system automatically issues a command to shut down the pump, preventing overheating and mechanical damage. In addition, vibration and temperature monitoring of bearings and electric motors is carried out, enabling the detection of dangerous

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

operating conditions and the generation of early warning or alarm signals at initial stages. Integration of SCADA systems with variable frequency drives (VFD/VSD) provides flexible control of pump capacity by adjusting the rotational speed of electric motors according to actual load and process demand. This approach significantly improves the energy efficiency of pumping systems, reduces electrical power consumption, and decreases dynamic loads on equipment. Furthermore, the accumulation and analysis of operational data within SCADA systems form the basis for implementing technical diagnostics and predictive maintenance functions for pumping equipment. Trend analysis of pressure, flow, vibration, and temperature parameters allows prediction of component wear and scheduling of maintenance activities based on the actual condition of the equipment. Overall, the application of SCADA systems in pumping system control enhances the reliability, safety, and economic efficiency of oil and gas facility operations.

Scada-based control of compressor systems

Compressor installations are critically important equipment for gas compression, transportation, and maintenance of stable pressure in main pipeline systems of the oil and gas industry. Reliable operation of compressors directly affects the safety, productivity, and energy efficiency of gas transmission systems. Control of compressor installations requires high regulation accuracy, rapid response to changes in process parameters, and strict compliance with industrial safety requirements. SCADA systems provide automated and centralized control of compressor units based on continuous data acquisition from pressure, flow, temperature, vibration, and other key sensors. Based on the received information, the system performs gas flow regulation, maintains the required pressure level, monitors equipment loading, and provides overload protection. The implementation of automatic control algorithms enables compressors to operate in optimal modes across a wide range of operating conditions. Of particular importance in compressor control is the anti-surge protection function, which is aimed at preventing a dangerous reverse gas flow condition. The SCADA system analyzes pressure and flow sensor data in real time and, when surge conditions are detected or anticipated, automatically opens the bypass valve or adjusts the compressor operating mode. This prevents mechanical damage to equipment and significantly reduces the risk of emergency situations. An essential component of SCADA-based control is the implementation of emergency protection and automatic emergency shutdown functions. When process parameters exceed permissible limits, the system generates commands for immediate compressor shutdown, activates protective devices, and notifies operational personnel. This approach significantly enhances industrial safety and reduces the likelihood of severe consequences during abnormal operating conditions. The use of vibration analysis modules, bearing temperature monitoring, and other diagnostic parameters within SCADA systems forms the basis for predictive maintenance of compressor equipment. Early detection of wear in bearings, rotors, and seals allows maintenance activities to be scheduled based on the actual condition of equipment, substantially reducing the probability of unexpected failures and unplanned shutdowns. In addition, SCADA systems enable remote monitoring and control of compressor stations located at considerable distances from control centers. This reduces the number of on-site personnel, minimizes human presence in potentially hazardous areas, and improves overall operational safety. Overall, the application of SCADA systems in compressor control is a key factor in enhancing the reliability, safety, and efficiency of gas transmission and oil and gas facilities.

Architecture and operating principles of scada systems

SCADA systems used in the oil and gas industry are based on a multi-level architectural approach that ensures effective control of complex and geographically distributed technological processes. Such an architecture is designed to meet the requirements for high reliability, industrial safety, scalability, and continuity of production, which is especially critical for facilities involved in oil and gas extraction, processing, and transportation. The operating principle of SCADA systems is based on centralized acquisition of technological information from the lower levels, its transmission through secure communication channels, subsequent processing and visualization at the dispatching control level, as well as the generation of control actions aimed at maintaining specified operating modes of equipment. This concept makes it possible to achieve end-to-end control of the technological process—from primary measurements to managerial decision-making at the operator and enterprise management levels. The architecture of SCADA systems is founded on the functional separation between several levels. The lower, or field, level is responsible for direct interaction with the controlled process and the generation of primary data. The communication and data transmission level ensures reliable information exchange between remote facilities and control centers using modern telecommunication technologies. The control and monitoring level implements dispatching control functions, visualization, alarm handling, and analysis of the current state of equipment and processes. In modern SCADA solutions, the architecture is further enhanced by an analytical level that includes big data processing, equipment performance evaluation, and intelligent decision-support algorithms. The operation of SCADA systems is based on the principles of continuous monitoring, rapid response, fault tolerance, and information security. The use of server redundancy, duplication of communication channels, and secure data transmission protocols minimizes the impact of failures of individual components on overall system performance. In addition, the integration of SCADA systems with higher-level systems and analytical platforms creates conditions for the transition from traditional dispatching control to intelligent and proactive management of production processes. Thus, the architecture and operating principles of SCADA systems form the technological foundation for the effective control of pumping and compressor installations in the oil and gas industry. A more detailed discussion of the structure and functions of individual SCADA system levels is presented in the following section devoted to the multi-level SCADA architecture.

Multi-level scada system architecture

A multi-level SCADA system architecture represents a hierarchical structure designed to ensure reliable monitoring, control, and analysis of industrial processes, particularly at large-scale and geographically distributed facilities typical of the oil and gas industry. Each architectural level performs strictly defined functions and interacts with adjacent layers, providing end-to-end transparency of technological processes, stability of control, and prompt decision-making throughout all stages of the production cycle.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

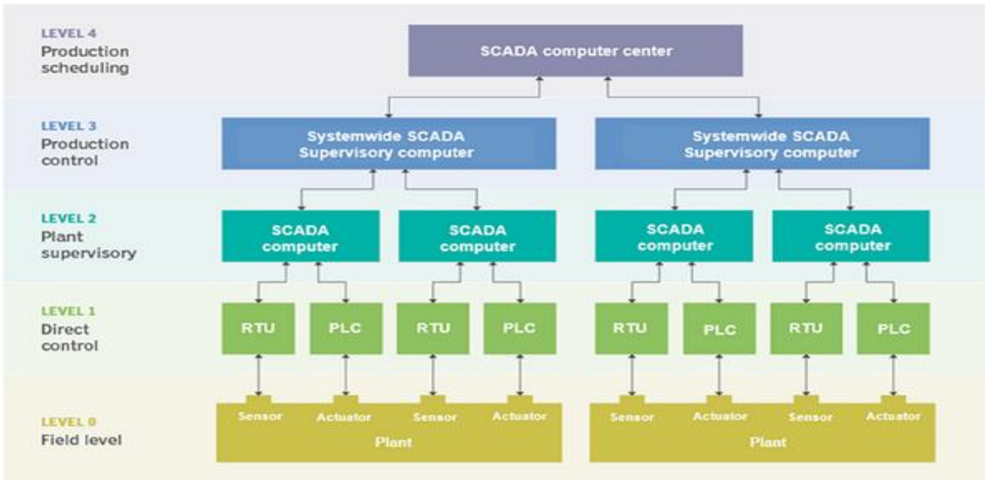


Figure 1: SCADA computer center.

Field Level

This level includes primary measuring transducers and sensors for technological parameters such as pressure, temperature, flow rate, level, and vibration, as well as actuators, control valves, and local control devices. Programmable logic controllers (PLCs) and remote terminal units (RTUs) are used as the core elements. The field level is responsible for real-time acquisition of process information, initial signal processing, and execution of control actions directly on technological equipment, ensuring process stability and accuracy.

Communication and Data Transmission Level

This level is intended to ensure reliable, secure, and uninterrupted data transmission between field devices and control centers. Fiber-optic communication lines, radio modems, telemetry systems, and mobile communication networks (4G/5G) with VPN protection and encryption mechanisms are employed. The reliability of communication channels at this level is critically important for timely data acquisition and effective control of remote facilities.

Control and Monitoring Level

At this level, SCADA servers and HMI/SCADA operator workstations operate to provide centralized control and dispatching of technological processes. Functions such as real-time visualization of parameters, alarm management, trend analysis, report generation, and data archiving are implemented. Operators interact with the system through graphical interfaces, enabling rapid assessment of equipment status and well-informed operational decision-making.

Analytics and Cloud Computing Level (Next-Generation SCADA)

The top level of the architecture integrates advanced analytics tools, big data processing, energy efficiency assessment modules, and AI-based predictive maintenance algorithms. The use of cloud and edge computing ensures scalability, high computational performance, and comprehensive data analysis capabilities, supporting equipment optimization and proactive management of production processes.

Collectively, these levels form a unified and coherent SCADA system architecture that enhances industrial safety, operational efficiency, and production continuity, while also serving as a technological foundation for the implementation of digital transformation concepts and Industry 4.0 initiatives in the oil and gas sector.

Advantages of scada system implementation

The implementation of SCADA systems ensures a significant increase in the level of industrial safety through continuous monitoring of process parameters, automatic detection of deviations from permissible operating conditions, and prompt notification of personnel about potentially hazardous situations. This enables timely corrective actions to be taken and substantially reduces the likelihood of accidents and abnormal equipment operating modes. One of the key advantages of SCADA systems is the capability for centralized and remote control of technological processes. Operators and dispatchers gain access to up-to-date information on equipment status in real time, which is especially important for geographically distributed oil and gas facilities. Remote control shortens response times to changes in process conditions and reduces the need for constant presence of maintenance personnel in hazardous production areas. SCADA systems also contribute to improved energy efficiency by optimizing the operating modes of pumping and compressor installations, analyzing energy consumption, and identifying inefficient operating conditions. The use of analytical tools makes it possible to reduce specific energy consumption and, consequently, lower overall operating costs. An additional advantage is the extension of equipment service life through the implementation of technical diagnostics and predictive maintenance functions. The analysis of operational data allows wear and potential faults to be detected at early stages, enables maintenance planning based on the actual condition of equipment, and helps prevent unexpected failures. Taken together, these advantages ensure high reliability and stability of production processes, minimize downtime, and support the continuity of production. Thus, the implementation of SCADA systems represents a strategically important step toward improving efficiency, competitiveness, and sustainable development of industrial enterprises, particularly in the oil and gas industry.

Challenges and risks of scada system implementation

One of the main challenges in the implementation and operation of SCADA systems is cybersecurity threats. Modern industrial control systems are increasingly connected to corporate and external networks, which raises the risk of unauthorized access, cyberattacks, and interference with technological processes. Insufficient protection of communication channels, outdated data transmission protocols, and configuration errors may lead to information leakage, disruption of equipment control, and, in critical cases, emergency situations with serious production and environmental consequences. Significant difficulties also arise when integrating modern SCADA solutions with existing and legacy automation and control systems. At many oil and gas facilities, controllers, sensors, and actuators from different manufacturers and generations are in operation, often using incompatible communication protocols and standards. This complicates the process of integrating equipment into a unified system and requires additional costs for modernization, interface development, and software adaptation. Another major risk is ensuring reliable and stable communication between SCADA system components across geographically extended and remote facilities. The large length of pipelines, remote pumping stations and compressor units, as well as harsh climatic and geographical conditions, can adversely affect the stability of communication channels. Data transmission failures result in the loss of real-time information, reduced quality of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

control, and increased response time to abnormal situations. In addition, challenges include the high cost of implementation and maintenance of SCADA systems, the need for training qualified personnel, and risks associated with the human factor in system operation and administration. Taken together, these challenges require a comprehensive approach to the design, implementation, and operation of SCADA systems, including measures to ensure information security, phased modernization of equipment, and the development of reliable communication infrastructure.

Conclusion

SCADA systems currently represent one of the key technological foundations for reliable, safe, and economically efficient control of pumping and compressor installations in the oil and gas industry. Their application ensures continuous acquisition and processing of process data in real time, centralized and remote control of equipment, as well as prompt response to deviations of operating parameters from specified regimes, which significantly enhances the stability and controllability of production processes. An important advantage of SCADA systems is the integration of industrial safety functions, technical diagnostics, and predictive maintenance of equipment. Through the analysis of large volumes of operational data, early identification of potential failures becomes possible, the likelihood of emergency situations is reduced, and preventive maintenance schedules are optimized. This, in turn, contributes to minimizing downtime, reducing operating costs, and extending the service life of pumping and compressor units. In the context of modern industrial digitalization, SCADA should be regarded not only as a monitoring and dispatching tool, but also as a multifunctional digital platform for strategic management of production processes. The integration of SCADA with higher-level systems such as MES, ERP, and analytical modules provides a basis for improving energy efficiency, optimizing technological operating modes, and supporting well-informed managerial decision-making. Thus, the implementation and further development of SCADA systems constitute a crucial factor in enhancing the competitiveness and ensuring the sustainable long-term development of oil and gas enterprises.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Kuznetsov, YU. N. ASU TP i SCADA-sistemy. Moskva: Forum, 2018.
2. Levin, A. M., Butusov, A. A. SCADA-sistemy: printsipy postroyeniya, arkhitektura i primeneniye. SPb.: Piter, 2017.
3. Paramonov, V. V. Avtomatizatsiya tekhnologicheskikh protsessov v neftegazovoy promyshlennosti. Moskva: Nedra, 2016.
4. Tekhnicheskoye posobiye. «SCADA-sistemy: struktura, funktsii, printsipy raboty». Brestskiy gosudarstvennyy tekhnicheskiy universitet, 2021.
5. (PDF: Obshchiye ponyatiya i struktura SCADA-sistem)
6. Galkin, V. P. ASU TP kompressornykh stantsiy. Moskva: Mashinostroyeniye, 2013.
7. Metodicheskiye materialy po distsipline «SCADA-sistemy i ASU TP». Sankt-Peterburgskiy politekhnicheskiy universitet Petra Velikogo, 2020.
8. Boyer, S. A. SCADA: Supervisory Control and Data Acquisition. 4th Edition. ISA, 2010.
9. Stouffer, K., Falco, J., Scarfone, K. Guide to Industrial Control Systems (ICS) Security. NIST Special Publication 800-82, Revision 2, 2015.
10. McMillan, G. K. Process/Industrial Instruments and Controls Handbook. McGraw-Hill Education, 2011.
11. Deshpande, P. B. Industrial Process Control Systems: A Survey of SCADA, DCS and PLC Systems. Sigma Research Press, 2014.
12. Pakanati, R. SCADA Systems in Oil and Gas Industry. IEEE Conference Publications, 2018.
13. R. Munz, B. Jones. Remote Monitoring and Control of Compressors Using SCADA Systems. Proceedings of the International Compressor Engineering Conference, Purdue University, 2016.
14. Белов, А. В. Промышленные системы управления и диспетчеризации (SCADA). Москва: Горячая линия – Телеком, 2019.
15. Иванов, И. А., Соколов, В. Н. Автоматизация и управление технологическими процессами в нефтегазовой промышленности. Москва: Инфра-Инженерия, 2018.
16. Шмелёв, А. Н. Основы построения АСУ ТП нефтегазовых объектов. Санкт-Петербург: Лань, 2017.
17. IEC 60870-5 / IEC 60870-6 (TASE.2). Telecontrol equipment and systems — International Electrotechnical Commission, latest edition.
18. IEC 62443. Industrial communication networks – Network and system security. International Electrotechnical Commission, 2018–2022.
19. API Recommended Practice 1165. SCADA Displays for Pipeline Operations. American Petroleum Institute, 2017.

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

20. API Recommended Practice 554. Process Control Systems for Petroleum, Petrochemical, and Natural Gas Industries. American Petroleum Institute, 2014.

NEFT-QAZ SƏNAYESİNDƏ SCADA SİSTEMLƏRİ VASİTƏSİLƏ KOMPRESSOR VƏ NASOS SİSTEMLƏRİNİN İDARƏ OLUNMASI

Cavidə Dəmirova[1], Vaqif Salmanov[2]
[1]Fəlsəfə Doktoru Dosent, Azərbaycan Dövlət Neft və Sənaye Universiteti. Email: cavida.damirova@asoiu.edu.az
[2]Magistr, İnformasiya Texnologiyaları və İdarəetmə Fakültəsi, Azərbaycan Dövlət Neft və Sənaye Universiteti
Email: salmanovvaqif12@gmail.com

XÜLASƏ

Məqalədə neft-qaz sənayesində nasos və kompressor sistemlərinin SCADA sistemləri vasitəsilə idarə olunmasının texniki və funksional aspektləri araşdırılır. SCADA sistemlərinin texnoloji məlumatların real vaxt rejimində toplanması, ötürülməsi və emalı, eləcə də müxtəlif mürəkkəblik dərəcəsinə və ərazi üzrə paylanmış obyektlərdə avadanlıqların məsafədən və mərkəzləşdirilmiş şəkildə idarə olunması imkanları ətraflı təhlil edilir. Xüsusi diqqət SCADA sistemlərinin sənaye təhlükəsizliyinin təmin edilməsində, enerji səmərəliliyinin artırılmasında və nasos-kompressor qurğularının istismar etibarlılığının yüksəldilməsində roluna yönəldilir. İşdə SCADA sistemlərinin əsas arxitektura səviyyələri, onların ilkin ölçü çeviriciləri, sensorlar və icraedici mexanizmlərlə qarşılıqlı əlaqə prinsipləri, həmçinin proqramlaşdırılan məntiqi kontrollerlər və yuxarı səviyyəli sistemlərlə inteqrasiya məsələləri təqdim olunur. Avadanlıqların texniki diaqnostikası və proqnozlaşdırılan texniki xidməti funksiyaları ayrıca nəzərdən keçirilir. Bu funksiyalar istismar parametrlərinin və onların dəyişmə tendensiyalarının təhlilinə əsaslanaraq potensial nasazlıqların vaxtında aşkar edilməsinə və qəza hallarının qarşısının alınmasına imkan yaradır. Aparılmış təhlil göstərir ki, SCADA sistemlərinin tətbiqi istehsal proseslərinin fasiləsizliyinin təmin olunmasına, istismar və texnoloji risklərin azaldılmasına, həmçinin nasos və kompressor aqreqatlarının iş rejimlərinin optimallaşdırılmasına şərait yaradır. SCADA sistemlərinin istifadəsi neft-qaz müəssisələrinin rəqəmsallaşmasının mühüm elementi kimi qiymətləndirilir və idarəetmənin səmərəliliyinin artırılmasına, xərclərin azaldılmasına və sahənin dayanıqlı inkişafının təmin edilməsinə yönəlmişdir.
Açar sözlər: SCADA sistemləri, sənaye avtomatlaşdırılması, nasos sistemləri, kompressor qurğuları, neft-qaz sənayesi, məsafədən idarəetmə, enerji səmərəliliyi.

УПРАВЛЕНИЕ КОМПРЕССОРНЫМИ И НАСОСНЫМИ СИСТЕМАМИ В НЕФТЕГАЗОВОЙ ПРОМЫШЛЕННОСТИ С ПОМОЩЬЮ SCADA-СИСТЕМ

Джавида Демирова[1], Вагиф Салманов[2]
[1]Доктор философии, доцент, Азербайджанский государственный нефтегазовый университет.
Email: cavida.damirova@asoiu.edu.az
[2]Магистр, факультет информационных технологий и управления, Азербайджанский государственный нефтегазовый университет
Email: salmanovvagif12@gmail.com

РЕЗЮМЕ

В статье рассматриваются технические и функциональные аспекты управления насосными и компрессорными системами в нефтегазовой промышленности с помощью SCADA-систем. Подробно анализируются возможности SCADA-систем по сбору, передаче и обработке технологических данных в режиме реального времени, а также по дистанционному и централизованному управлению оборудованием на объектах различной сложности, расположенных на территории. Особое внимание уделяется роли SCADA-систем в обеспечении промышленной безопасности, повышении энергоэффективности и увеличении эксплуатационной надежности насосно-компрессорных установок. В статье представлены основные архитектурные уровни SCADA-систем, принципы их взаимодействия с первичными преобразователями, датчиками и исполнительными механизмами, а также вопросы интеграции с программируемыми логическими контроллерами и системами более высокого уровня. Отдельно рассматриваются функции технической диагностики оборудования и прогнозирующего технического обслуживания. Эти функции позволяют своевременно выявлять потенциальные неисправности и предотвращать аварии на основе анализа рабочих параметров и тенденций их изменения. Анализ показывает, что применение SCADA-систем создает условия для обеспечения непрерывности производственных процессов, снижения эксплуатационных и технологических рисков, а также оптимизации режимов работы насосно-компрессорных установок. Использование SCADA-систем рассматривается как важный элемент цифровизации нефтегазовых предприятий и направлено на повышение эффективности управления, снижение затрат и обеспечение устойчивого развития отрасли.

Ключевые слова: SCADA-системы, промышленная автоматизация, насосные системы, компрессорные установки, нефтегазовая промышленность, дистанционное управление, энергоэффективность.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
228-235

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-26

VOLUME 33 (08) ISSUE 02 2026

COMPOSITION AND TECHNOLOGY FOR SELECTIVE ISOLATION OF WATER FLOW IN PRODUCTION WELLS

Malik Abdullayev[1], Samira Mansurova[2], Fahmin Azizli[3]
[1,2]Associate Professor, Department of Petroleum Engineering, Azerbaijan State Oil and Industry University, Azerbaijan. E-mail:[1]malik.abdullayev.52@mail.ru, https://orcid.org/0000-0002-1383-6240, [2] mansur_s74@mail.ru https://orcid.org/0000-0002-1383-6240 ,
[3]PhD student, Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: fahmin99@mail.ru

ABSTRACT

The article attempts to develop a new composition and technology using hel-forming substances for the isolation of reservoir waters. For this purpose, known technologies were investigated and numerous experiments were conducted to develop a new composition. In laboratory experiments, experiments were conducted to prevent the flow of water into production wells using liquid glass (sodium silicate) and citric acid, which are currently used for various purposes in the oil industry. It was determined by experiments that the high-viscosity hel-like substance formed by the precipitation of minerals in the reservoir waters when the components meet each other in the water channels is converted into a solid substance under the influence of the second component, which is insoluble in water. The application technology of the found composition was also developed by determining the sequence of injection of the components into the wellbore zone of the reservoir through experiments.
Keywords: well production, liquefaction, liquid glass, citric acid, water isolation, composition.

Introduction.
It is known from mining practice that at a certain stage of oil well exploitation, the amount of water in the well product increases, that is, the process of well waterlogging occurs. In this case, in cases where the productive layers consist of unstable and poorly cemented rocks, in the initial moments of waterlogging, along with the intensive increase in water in the well product, sand is also observed. As a result of such an event, the oil production of the wells decreases, and the time between repairs (TAM) in these wells decreases. Such a picture brings to the agenda the relevance of conducting selective isolation works in waterlogged wells. Despite the existence of many technologies in this direction, due to the different nature of both rocks and hydrocarbons and water in the pores of the rock, it leads to the conclusion that the application of these technologies in all variants will not be effective, which has been confirmed in practice. Taking this into account, the article examines known works in this direction and attempts are made to develop new effective compositions and technologies.
In production wells, the increase in the degree of waterlogging of the well product is likely to occur due to the following reasons:

- due to the flow of both produced water and water injected into the formation to compress the oil in the formation from high-permeability formations to production wells;
- due to the flow of bottom waters into production wells;
- Due to the flow of "extraneous" water from behind the pipe as a result of insufficient sealing of the operating pipeline.

Problem statement.

From a physicochemical point of view, the formation of a water-repellent composition by forming a solidifying mass within the layer is divided into three large groups: solidifying, precipitate-forming, and gel-forming. Some reagents belong to both of these groups: precipitate-forming and gel-forming, e.g. acids, acrylic polymers.

- It is noted that the role of the hardening catalyst can be played by an alkali, for example, sodium carbonate, and in some cases hydrochloric acid.
- The water-isolating groups used in oil fields are mainly composed of polymers, and their water-isolating mechanism is based on the interaction of chemical reagents with the formation fluids and rocks. This creates the basis for the injection of sediment-forming polymers into the water-saturated areas of the formation.

In [2, 7, 9], the development of a new composition that is insoluble in water and soluble in oil with the aim of isolating production wells operating in liquefied oil layers from water pressure was demonstrated by using various chemical compounds. It was proposed to use this oil-based reagent to prevent water flow into production wells by injecting it into the wellbore zone. The essence of the work is that the oil-based reagent for increasing the oil yield of the layers and isolating water flow into production wells consists of two parts: a petroleum-based emulsion and an oxidizer, where, as the first part, the petroleum-based emulsion contains 25-30% lower alcohols and heavy commodity oil, and as the second part, chromic acid as an oxidizer, is prepared in a volume that will ensure penetration to the calculated depth of the wellbore zone of the layer in a ratio of 2:1 and is injected into the wellbore zone.

A gel-forming solution has been used to isolate water flow from porous layers into the well [1, 3-6]. As a result of the conducted studies [6], it was determined that when a solution containing 5.1-5.2% liquid glass (Na_2SiO_3) and 5.2-5.3% hydrogen chloride (HCl) is injected into the wellbore zone, the composition polymerizes and gel is obtained. According to the developed technology, 10% solutions of both components of the gel-forming composition (GEC) are mixed with each other in a volume calculated for the operation in the selected well.

However, studies have shown that the composition applied to the layer in this way, although in the form of a gel, is in the form of a solution and its stability in the layer is poor.

In many studies, it is reported that the goal is achieved by injecting high-viscosity solutions that can form sediment in those channels and form a hel, and over time, harden there and turn into a solid mass, in order to isolate the water flow into the well, closing the channels through which water moves in the formation [1, 8].

Methodology and research results.

The article attempts to develop a new composition and technology using helium-forming substances for the isolation of formed waters. For this purpose, numerous experiments were conducted to eliminate the shortcomings of known technologies. In laboratory experiments,

experiments were conducted with compositions consisting of liquid glass (sodium silicate) and hydrochloric acid [6], as well as compositions consisting of liquid glass and chromic acid [3], which are currently used for various purposes in the oil industry, and a new, more efficient and safe composition and a new, more efficient application technology were developed. Experiments have shown that at high concentrations of the components, when they meet each other, a solid substance with a high solubility in the form of helium is obtained, which is insoluble in water.

The development of hel-forming compounds for the purpose of isolating the flow of produced water into production wells has always been in the focus of attention of experts in the field. By increasing the hardening properties of the hel formed in the pores of the formation, it is possible to improve the quality of water isolation works. Otherwise, if, despite the ability of hel-forming substances to penetrate into the pores of the rock, they do not harden in the pores, such isolation works cannot be effective. Thus, as a basic condition, it is important that such substances, as tamponage materials, have a certain level of mechanical strength. Because, if this is not the case, the adhesion (adhesive properties) of these materials with the formation rocks will be weak and due to the difference in formation and wellbore pressures, they may be squeezed out of the formation and into the well, which will make the isolation works less effective (sometimes ineffective).

The effect of water-isolating reagents on the permeability of the bottomhole zone of the formation should be selective, that is, the formation of a sol by the isolating solution should occur only in the pores of the formation through which water flows, in which case, when the flow stops, the volume of water flowing into the well may decrease, while the volume of oil may increase (at least remain constant).

Considering the cases where, after the water-blocking agents proposed in the above-mentioned works are injected into the wellbore zone of the formation, the period of dissolution of the injected composition in oil will continue indefinitely [2, 7, 9] or the pores containing water cannot be completely closed by sediment [3, 4, 5], laboratory studies have been conducted to find a new water-blocking composition capable of completely closing only the water channels.

It is known that liquid glass forms a precipitate when it comes into contact with formation waters. However, it is also known that these precipitates are in the form of a slurry. It is also known from our experiments and literature sources that it is possible to achieve the goal by using an acid (in our case, citric acid) to solidify such slurry-like solutions in formation conditions. Using these properties, experiments were conducted at different concentrations of components for water isolation. The results of the numerous experiments conducted are given in the table.

First, in the laboratory, aqueous solutions of liquid glass of various concentrations are prepared, mixed with formation waters of various compositions, and then citric acid of various concentrations is added to it. How the resulting solution behaves (solidifies) at different temperatures is observed (table).

Since the 9th of the compositions shown in the table is more efficient (it tends to harden quickly), experiments were conducted using it in a linear layer model, and significant results were obtained for the purpose of isolating water flow.

The following research was conducted to investigate the effect of a composition consisting of citric acid and liquid glass on the permeability of a highly permeable porous medium.

^{3}) consisting of quartz sand in a linear reservoir model , it was fully saturated with formation water, and its permeability was determined and found to be 30.12 μm ^{2} . Then, a composition

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

consisting of composition 9 shown in the table was applied to the porous medium in an amount of 25% of the pore volume (aqueous solution of liquid glass). When this composition meets formation water in the model, it begins to form a precipitate and close the pores. At this time, when an aqueous solution of citric acid of various concentrations is applied, the composition immediately begins to solidify. After applying these solutions, both sides of the model were closed and kept for 24 hours, after this period, water was injected into the medium from the inlet of the model and the permeability of the porous medium to water was determined again. In this case, it was found that the permeability of the porous medium decreased to 0.07 μm^{2}.

Table 1. The state of the composition (heline) obtained from the mixture of liquid glass prepared with different concentrations, layered water and citric acid of different concentrations:

Experience No.-	Liquid glass aqueous solution, cm ^{3}			Solution of citric acid with mineral water, cm ^{3}			Condition of the received composition
	5%	10%	15%	5%	10%	15%	
1	10			20			A white solution was obtained in the form of jelly.
2	10				20		A white, curd-like precipitate has formed, with water on top.
3	10					20	The same incident was repeated, but with more water.
4		10		20			It gradually started to harden, there is a mass that has not hardened on it
5		10			20		It began to harden relatively quickly, there is uncured mass on it
6		10				20	It quickly hardened, forming a solid gel with water on it.
7			10	20			A white solution was obtained in the form of a solid jelly.
8			10		20		It begins to solidify rapidly, a solid gel has formed at the bottom of the flask, and there is a white solution like jelly on it.
9			10			20	It starts to harden immediately, over time the entire solution hardens

As can be seen, by applying a composition consisting of an aqueous solution of liquid glass and citric acid to the layer model, it is possible to drastically reduce the permeability of the porous medium (from 30.12 μm^{2} to 0.07 μm^{2}).

The results of laboratory experiments conducted in this direction are given in the table. It should be noted that the strength and adhesion of the gels obtained in the experiments were also checked by the effect of a water jet on them. It was observed that the mass obtained in the form of a jelly obtained from low-concentration mixtures (e.g. 5% components) easily disintegrated even under a weak water jet, while the gel obtained in the proposed composition (experiment 9 in the table) did not disintegrate, dissolve, or detach from the surface even under a strong water jet.

Experiments in the second direction were also conducted in various variants. For this purpose, a layer model was used.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

After creating a porous medium (335 cm ^{3}) consisting of quartz sand in a linear layer model , the model was fully saturated with water and its permeability was determined (28.03 μm ^{2}). Then, a composition consisting of the composition in experiment 9 shown in the table was applied to the porous medium in an amount of 25% of the pore volume (15% liquid glass + 15% citric acid). Since this composition immediately sets, in order to facilitate its application to the model and ensure its immediate solidification in the porous medium, after the liquid glass, the first component of the composition, was applied to the porous medium, a buffer liquid of 3-4% of the total composition was applied (commodity oil was used as a buffer liquid), and then citric acid was applied. That is, first, “liquid glass” was injected into the model (28 cm ^{3}), followed by 7 cm ^{3} of buffer fluid (commodity oil) , and then “citric acid” (56 cm ^{3}). After these solutions were injected, both sides of the model (inlet and outlet) were closed and kept for 24 hours , after which time water was injected into the medium from the inlet of the model, and its permeability to water was determined again. In this case , it was found that the permeability of the porous medium decreased to 0.06 μm 2 .

it is possible to drastically reduce the permeability of the porous medium (from 28.03 μm2 to 0.06 μm2) by separately injecting a composition consisting of liquid glass, commodity oil, and citric acid into the reservoir model with a buffer fluid (commodity oil) and leaving it inactive for 24 hours

Laboratory studies were conducted to isolate water in a porous medium containing residual oil using a composition consisting of "15% liquid glass" and "15% citric acid" as follows:

The reservoir model was filled with quartz sand, creating a porous medium and determining its volume (315.6 cm ^{3}). Then, the porous medium formed in the reservoir model was fully saturated with water, and the permeability of the model to water was determined (28.5 μm ^{2}). Then, the water in the model was displaced with oil, creating an initial oil saturation in the porous medium (243 cm ^{3}). Then, the process of displacing oil with water was carried out in the model. The process was continued until clean water emerged from the model outlet, and in this case, it was possible to displace 57% of the oil (138.5 cm ^{3}) with water.

Then, the composition of the ingredients from experiment 9 shown in the table was applied to the model in the following sequence:

“15% liquid glass” - 26.3 cm ^{3}

Buffer fluid (commodity oil) - 7 cm ^{3}

"15% citric acid" - 52.6 cm ^{3}

These reagents are injected into the model. After the model is kept closed for a while, it is reconnected to the water line through the inlet. In this case, it was possible to squeeze 14.9% of the residual oil with water. We re-determined the permeability of the porous medium after the oil squeeze was completed. In this case, it was determined that the permeability decreased to 4.75 μm ^{2} . This means a 6-fold decrease in permeability compared to the previous value.

The sharp difference in the results of these two experiments (although the isolating composition was the same) aroused our interest. For this purpose, after preparing a linear reservoir model again, the entire process was carried out analogously, only the sequence of application of the isolating components to the model was changed. That is, first 15% citric acid was applied to the model, then buffer liquid - commodity oil, and then 15% liquid glass, the model was kept closed for 24 hours, and after this period, the permeability to water was determined again. The result was quite different from the previous experiment. Thus, in the last experiment, the ratio of permeabilities was expressed as a two-digit number: the permeability to water decreased by 14 times. The reason for this can be explained by the fact that when the surface of the reservoir rock is free from oil components, the solidification of liquid glass-citric acid compounds becomes faster and more durable. The presence of oil components on the rock surface has a negative effect on both the solidification of the composition and the stability of its solidification. Therefore, it is imperative to take this result into account when conducting mining activities. This indicates that the technology for applying water isolation should be carried out according to the specified scheme.

Thus, as a result of the research conducted, it was determined that:

- A new composition has been developed to isolate water flow from formations to production wells: this composition consists of 15% citric acid and 15% liquid glass;
- The technology for applying the newly discovered composition: initially, acid is injected into the wellbore zone, followed by a buffer fluid consisting of commodity oil, followed by liquid glass and again commodity oil as a pressure fluid;
- The proposed technology is proposed for the selective isolation of water flows in production wells.
- The economic benefit is taken as the increase in isolated water and oil production from the well.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Abdullayev MQ, Garayev RQ, Hajiyev AK “Oil-based reagent for increasing oil yield of reservoirs and isolating water flow to production wells”. Patent -№2015/0064, 2015, 05.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

2. Abdullayev MG, Mahmudov QM, Garayev RG "New composition and technology for preventing water flow from formations to production wells" «Azerbaijan Oil Economy», April 2016, No. 4
3. Salavatov T.Sh., Aliyev YM, Kazimov Sh.P. et al. "On the effectiveness of methods for isolating water flow into wells". Azerbaijan Oil Economy , No. 1, 2011, pp. 20-25.
4. Abdullayev MG "Reagent on Oil Basis to Increase Oil Recovery and isolation of Water Breakthrough into Oil Producing Wells". Journal of Petroleum & Petrochemical Engineering. Volume 2 Issue 5, August 2018, p.1-9

HASİLAT QUYULARINA SU AXINININ SELEKTİV TƏCRİDİ ÜÇÜN TƏRKİB VƏ TEXNOLOGİYA

Malik Abdullayev[1], Samirə Mansurova[2] , Fəhmin Əzizli[3]
[1,2]Dosent, "Neft-qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universitetinin, Azərbaycan.
E-mail: [1]malik.abdullayev.52@mail.ru, https://orcid.org/0000-0002-1383-6240, [2]mansur_s74@mail.ru
https://orcid.org/0000-0002-1383-6240,
[3]Doktorant, Azərbaycan Dövlət Neft və Sənaye Universitetinin, Azərbaycan. E-mail: fahmin99@mail.ru

XÜLASƏ

Məqalədə lay sularının təcridi üçün hel əmələ gətirən maddələrdən istifadə etməklə yeni tərkib və texnologiyanın işlənməsinə cəhd göstərilmişdir. Bu məqsədlə məlum texnologiyalar araşdırılaraq yeni tərkibin işlənməsi üçün çoxsaylı təcrübələr aparılmışdır. Laboratoriya təcrübələrində hal-hazırda neft sənayesində müxtəlif məqsədlərlə istifadə olunan maye şüşə (natrium silikat) və limon turşusundan istifadə edilərək hasilat quyularına su axınının qarşısının alınması üçün təcrübələr aparılmışdır. Təcrübələrlə müəyyən olunmuşdur ki, komponentlərin layın su olan kanallarında bir-biri ilə görüşməsindən lay sularının tərkibində olan mineralların çökərək əmələ gətirdiyi yüksək özülülüklü hel şəklində maddə ikinci komponentin təsiri ilə bərk maddəyə çevrilir ki, bu da suda həll olunmur. Komponentlərin layın quyudibi zonasına vurulması ardıcıllığını təcrübələrlə müəyyənləşdirərək, tapılmış tərkibin tətbiq texnologiyası da işlənmişdir.
Açar sözlər: quyu hasilatı, sulaşma, maye şüşə, limon turşusu, su təcridi, tərkib.

СОСТАВ И ТЕХНОЛОГИЯ ДЛЯ СЕЛЕКТИВНОЙ ИЗОЛЯЦИИ ВОДОПРИТОКОВ К ДОБЫВАЮЩИХ СКВАЖИН

Малик Абдуллаев[1], Самира Мансурова[2], Фахмин Азизли[3]
[1,2] Досент кафедры, "Нефте-газовой инженерии" Азербайджанской Государственной Университет Нефти и Промышленности, Азербайджан. E-mail: [1]malik.abdullayev.52@mail.ru, https://orcid.org/0000-0002-1383-6240, E-mail: [2]mansur_s74@mail.ru https://orcid.org/0000-0002-1383-6240
[3]Докторант, Азербайджанской Государственной Университет Нефти и Промышленности, Азербайджан. E-mail: fahmin99@mail.ru

РЕЗЮМЕ

В данной статье предпринята попытка разработать новый состав и технологию использования гелеобразующих веществ для изоляции пластовых вод. Для этого были исследованы известные технологии и проведены многочисленные эксперименты по разработке нового состава. В лабораторных экспериментах были проведены эксперименты по предотвращению притока воды в добывающие скважины с использованием жидкого стекла (силиката натрия) и лимонной кислоты, которые в настоящее время используются для различных целей в нефтяной промышленности. Экспериментально установлено, что высоковязкое гелеобразное вещество, образующееся при осаждении минералов, содержащихся в пластовых водах, от встречи компонентов в водных каналах пласта, под воздействием второй компонент, превращается твердую вещества, который не растворяется в воде. Также путем экспериментов определяя последовательности закачки компонентов в призабойную зону скважины, разработана технология применения найденного состава.

Ключевые слова: продукция скважин, обводненность, жидкое стекло, лимонная кислота, водоизоляция, состав.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

236-247

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-27

VOLUME 33 (08) ISSUE 02 2026

AUTOMATION OF QUALITY CONTROL AND DIAGNOSTICS IN THE METAL INDUSTRY

Javida Damirova[1], Narmin Aliyeva[2]
[1]PhD in engineering, Associate Professor, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: cavida.damirova@asoiu.edu.az
[2]Master's degree student, Department of Electronics and Automation, Azerbaijan State Oil and Industry University, Email: nermin.eliyeva142@gmail.com

ABSTRACT

This article examines the role of quality control and technical diagnostics processes in ensuring product quality in the metal industry, as well as the scientific and technological foundations of their automated and integrated application. It is substantiated that quality control systems act as a complex management mechanism covering all stages of production, ensuring not only regulatory compliance of the product, but also long-term operational reliability.
It is shown that destructive and non-destructive testing methods are mutually complementary in assessing the technical condition of metal products. Although destructive tests allow for an accurate analysis of the mechanical and physical properties of the material, non-destructive testing (NDT) methods provide for the detection of surface and internal defects without violating the structural integrity of the product. The widespread application of visual inspection, liquid penetrant, magnetic powder, ultrasonic, radiological and induction current methods in the metal industry is explained by their high informativeness and the possibility of integration into the production process.
The integration of quality control and technical diagnostics processes is presented as a modern approach aimed at ensuring safety and reliability throughout the entire life cycle of the product. Diagnostic systems based on sensor technologies, real-time data collection, and analytical processing allow for early prediction of potential failures and timely implementation of preventive measures.
As a result, the organization of quality control and technical diagnostics within an automated and unified system is considered a scientifically and technologically justified perspective for optimizing production processes in the metal industry, minimizing the human factor and increasing the operational reliability of products. This approach plays an important role in ensuring sustainable development in accordance with the concepts of industry 4.0 and smart manufacturing.
Keywords: metal industry, quality control, non-destructive testing (NDT), technical diagnostics, automated systems, sensor technologies, industry 4.0, smart manufacturing.

Introduction

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

In modern industrial production, ensuring product quality is considered one of the key indicators of economic competitiveness, technological reliability, and compliance with safety standards. Particularly in strategic sectors such as the metal industry, quality control systems have become an integral part of the production process. The technical condition of metal structures and components directly affects their service life, mechanical strength, and operational safety. Therefore, the correct selection and systematic implementation of control and testing methods used in this field are of particular importance.

The purpose of quality control in the metal industry is not only to confirm that products meet established standards, but also to ensure their reliability and durability during operation. For this purpose, various technical inspection and testing methods are applied both during the production stage and throughout the operational period. Quality management systems (such as ISO 9001, ISO 14001, etc.) require the implementation of control at every stage of the production process, early detection of defects, and minimization of production losses.

In recent years, non-destructive testing (NDT) methods have been widely applied in industrial enterprises to ensure the structural integrity of products and improve technological reliability. These methods allow the detection of internal and surface defects in materials without damaging their integrity. The application of NDT methods is not limited to the inspection of finished products; they also play an important role in optimizing the production process and effectively organizing subsequent stages of technical diagnostics.

The scientific organization of quality control processes in the metal industry, the standardization of applied testing methods, and the reliable analysis of results are among the main factors ensuring the sustainability of production. In this regard, the integration of NDT methods with technical diagnostics processes can be considered one of the modern approaches that ensure the safe and long-term operation of metal structures.

Purpose and importance of quality control

In the metal industry, the quality control process is a multi-stage and systematic field of activity that ensures the compliance of a product's technical parameters with established standards. The primary objective of this process is to guarantee the reliability, safety, and long-term operational capability of manufactured metal products. Quality control also contributes to the efficient use of production resources, the reduction of production costs, and the improvement of a product's competitiveness in the market.

The main tasks of quality control include the evaluation of the physical, mechanical, and chemical properties of products, the detection of technological deviations occurring during the production process, and the elimination of these deviations. In the metal industry, such control is carried out at several stages: during the acceptance of raw materials, at different phases of production, and at the final inspection stage of the finished product. This approach is based on the principle of the "quality chain," meaning that all factors affecting product quality are monitored and managed from the beginning to the end of the production process.

One of the most important aspects of quality control is the early detection of defects and the identification of their causes. If a defect is detected at the final stage of production, it may result in significant losses in terms of both time and financial resources. Therefore, the objective of the control system is not only to identify the presence of a defect but also to analyze its root cause in order to prevent similar issues in the future.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

The quality control system also serves as a key mechanism for ensuring compliance with international and national standards. For example, the ISO 9001 quality management standard promotes a process-oriented approach, continuous improvement, and increased customer satisfaction within enterprises. ISO 17025, on the other hand, establishes the technical requirements necessary to ensure the accuracy of measurements and testing in laboratories. Operating in accordance with these standards allows enterprises to achieve both internal efficiency and international recognition.

In the metal industry, product quality plays an important role not only during production but also throughout the operational period. The durability of structural elements, welded joints, pipelines, and pressure-operated systems directly depends on the level of initial quality control. Therefore, in modern approaches, quality control is viewed not merely as a set of testing and measurement procedures, but as a comprehensive management system with predictive and analytical capabilities.

Thus, quality control plays a decisive role in ensuring technological stability in production, product reliability, and safe operation in the metal industry. The proper organization of this process, the standardization of testing methods, and the scientific analysis of results are essential conditions for the sustainable development of modern industrial enterprises.

Control methods used in the metal industry

In the metal industry, the quality control process is primarily based on measuring, inspecting, and evaluating the technical parameters of a product or structure. For this purpose, various testing methods are used, which are classified according to their application principle into **destructive** and **non-destructive** methods. Both approaches play an important role in determining product quality indicators and complement each other.

1. Destructive Testing Methods

Destructive testing methods involve tests in which a part of the material or component is physically damaged or completely destroyed during the examination process. These methods allow the mechanical, chemical, and thermal properties of materials to be determined with high accuracy. The results obtained from destructive tests are generally used to confirm the compliance of products with technical standards and to assess the quality of raw materials used in the production process.

Destructive testing methods include:

- **Tensile (pulling) test** – determines the strength limit, elongation capability, and elasticity modulus of the material;
- **Compression and bending tests** – examine the resistance of components to plastic and elastic deformation;
- **Hardness measurement** – performed using methods such as Brinell, Rockwell, or Vickers;

Impact resistance test – evaluates the material's energy absorption capability using Charpy or Izod methods;

- **Metallographic analysis** – analyzes the microstructure and internal defects of materials at a microscopic level.

These tests are usually carried out under laboratory conditions, and damage to the sample is unavoidable. Therefore, destructive methods are mainly used at the initial stages of production or in experimental studies of new materials.

2. Non-Destructive Testing Methods

Non-destructive testing methods (**NDT**) allow the detection of internal and surface defects in products without damaging their structural integrity. The main principle of these methods is based on identifying defects indirectly by utilizing the physical properties of materials, such as magnetic, acoustic, optical, and radiation characteristics.

NDT methods are among the most widely used techniques in the modern metal industry. They are applied not only for the inspection of finished products but also for monitoring production processes and performing technical diagnostics. With the help of these methods, hidden defects such as pores, cracks, and deformations in structures, welded joints, pipelines, and other critical elements can be detected at an early stage.

Common NDT methods include **visual inspection, liquid penetrant testing, magnetic particle testing, ultrasonic testing, radiographic testing, and eddy current testing.** Each method has its own technological principle, application area, and level of accuracy. In modern industrial enterprises, NDT techniques are often implemented through automated or robotic systems, which reduce the influence of human factors and increase the reliability of results.

Both destructive and non-destructive methods are integral elements of a comprehensive quality control system. While destructive testing makes it possible to scientifically determine the fundamental properties of materials, non-destructive testing enables the evaluation of the actual condition of products and their operational safety in real production environments. The combined application of these two approaches ensures that quality control processes are carried out in a more comprehensive and reliable manner.

Most commonly used NDT methods

1. Visual Testing (VT)

Visual testing is considered the simplest and most fundamental form of non-destructive testing in the metal industry. This method is based on the direct observation of the surface of a material or structure in order to detect defects. During visual inspection, surface defects such as cracks, pores, corrosion traces, irregularities in weld seams, and other visible imperfections can be identified.

The inspection process is usually carried out under well-illuminated conditions. In addition to direct visual observation, magnifying optical devices, endoscopes, or borescopes are used when higher precision is required. This method is widely applied both at the initial inspection stage and as a preparatory step before other NDT methods. Visual testing is one of the fundamental stages of quality control because, in many cases, surface defects may indicate underlying internal structural problems.

2. Liquid Penetrant Testing (PT)

The liquid penetrant method is used to detect very fine surface cracks that are difficult to observe with the naked eye on metal and non-metal surfaces. This technique is based on the capillary properties of the surface. The process consists of several stages. First, the surface is thoroughly cleaned from oil, dust, and oxide layers. Then a special colored or fluorescent penetrant liquid is applied to the surface and left for a certain period of time. If cracks or pores are present, the liquid penetrates into these openings.

Afterwards, the excess penetrant is removed and a white powder layer called a **developer** is applied. The developer draws the penetrant trapped in the cracks back to the surface, making the defects visible as clear indications. Liquid penetrant testing can be performed manually or using

VOLUME 33 (08) ISSUE 02 2026

automated systems. This method is widely used in the inspection of weld seams, castings, and machined components.

3. Magnetic Particle Testing (MT)

Magnetic particle testing is applied only to ferromagnetic materials, such as magnetizable steel and iron-based alloys. The principle of this method is based on the behavior of magnetic flux within a magnetized material. When the material is subjected to a magnetic field, magnetic flux lines are formed within it. If a defect such as a crack or pore exists, the distribution of the magnetic field is disturbed and a phenomenon known as **magnetic flux leakage** occurs.

During the inspection, after the material is magnetized, a special suspension containing fine iron particles (in dry powder or liquid form) is applied to its surface. The particles accumulate in areas where the magnetic flux leaks, forming visible lines that indicate the location of cracks or near-surface defects. This method is widely used for inspecting weld seams, gears, shafts, and pressure-bearing components.

4. Ultrasonic Testing (UT)

Ultrasonic testing detects internal defects in metals based on the transmission and reflection of sound waves. In this method, high-frequency ultrasonic waves (usually within the range of 1–10 MHz) are introduced into the material. If the material contains voids, pores, cracks, or foreign inclusions, the ultrasonic waves are reflected from these discontinuities and recorded as signals on the instrument's display.

This method allows the determination of the depth, size, and approximate shape of defects. During ultrasonic inspection, parameters such as frequency, angle, and wave type are selected according to the properties of the material being tested. Modern ultrasonic testing equipment is equipped with both analog and digital displays and allows data storage and analysis using computer systems. Ultrasonic testing is considered one of the most reliable methods for inspecting welds, pipelines, aircraft components, and other critical structural elements.

5. Radiographic Testing (RT)

Radiographic testing operates on the principle of visualizing the internal structure of metals using **X-rays or gamma rays**. Radiation emitted from a source passes through the material and reaches a film or electronic detector placed behind it. If there are density differences or defects within the material, the penetration of radiation changes, and these variations appear on the image as darker or lighter areas.

One of the main advantages of radiographic testing is that it provides a visual representation of the internal structure of the material and produces permanent records that can be archived as evidence. In modern technology, traditional X-ray films are often replaced by digital detectors, allowing immediate visualization on screens and automated analysis through software. Radiographic testing is commonly used for thick and critical structures, welded joints, and cast components.

6. Eddy Current Testing (ET)

Eddy current testing is used for electrically conductive materials, especially metals such as aluminum, copper, and steel. This method is based on the principle of electromagnetic induction. During the inspection, an alternating magnetic field is generated by a probe, which induces circulating electrical currents (eddy currents) within the metal surface. If defects are present, the flow of these currents is disturbed, and the change is detected by the measuring instrument.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

This technique is mainly applied for evaluating the condition of thin metal layers, pipes, wires, and coatings. Eddy current testing has very high sensitivity and can be performed without direct contact with the surface. In automated systems, this method is widely used for real-time monitoring, particularly in mass production processes.

Integration of quality control and diagnostic systems

In the modern metal industry, quality control is no longer limited to detecting defects during the production stage. Even after the completion of the manufacturing process, continuous monitoring and forecasting of the technical condition of products are required. For this purpose, technical diagnostic systems are applied as important tools for evaluating the condition of products during their operational life, determining their remaining service life, and identifying potential failures in advance.

Quality control and diagnostics are considered two complementary but functionally different areas in terms of objectives and application stages. Quality control ensures that the technical parameters of a product comply with established standards during the production stage—from the acceptance of raw materials to the final assembly. Diagnostics, on the other hand, evaluates the actual condition of products or systems that are already in operation and aims to predict possible failures in advance. The integration of these two stages ensures safety, reliability, and economic efficiency throughout the entire life cycle of the product.

The process of technical diagnostics is generally based on non-destructive testing (NDT) methods, sensor technologies, and analytical data processing. For example, continuous monitoring of ultrasonic, magnetic, and vibration signals allows early detection of micro-fatigue and deformation occurring within materials. In this way, diagnostic systems enable the identification of potential defects before they develop into actual failures and allow preventive measures to be taken in a timely manner.

In recent years, integrated quality and diagnostic systems (Integrated Quality and Diagnostic Systems – IQDS) have been increasingly implemented in industrial enterprises. In these systems, non-destructive testing methods, sensor networks, and artificial intelligence-based analytical tools operate together to collect and analyze data in real time during both production and operational stages. Within such systems, the quality control module verifies the initial condition of the product, while the diagnostic module monitors its behavior throughout its operational life.

The integrated approach is particularly widely used in complex metal structures, pipelines, and energy and transportation infrastructures. In these fields, simultaneous monitoring of quality and technical condition helps minimize the risk of accidents, reduce operational costs, and optimize maintenance schedules.

Thus, the integration of quality control and technical diagnostic systems represents one of the key modern scientific and technological approaches for ensuring reliability in the metal industry. This approach prevents gaps in the monitoring of production processes, enables continuous control of structural integrity throughout the entire life cycle of products, and supports the transition toward the concept of **smart manufacturing**.

Automated implementation of quality control and diagnostics

In modern industrial production, the effectiveness of quality control and technical diagnostics processes is ensured only when they are carried out together and in an integrated manner. In

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

traditional approaches, these processes were usually performed independently at different stages—during production and during the operational period—through physical inspection methods. However, such methods were often inefficient in terms of time and labor, and the dependence on human factors reduced the reliability of the results.
In recent years, industrial enterprises have increasingly implemented automated quality control and diagnostic systems to address these challenges. The main objective of such systems is to minimize manual inspection processes and perform all monitoring and verification stages through digital technologies. This approach not only improves resource efficiency but also enables the collection and analysis of quality data in real time.
The foundation of automated systems consists of sensor networks, data acquisition modules, data processing and analysis platforms, and artificial intelligence-based decision-making algorithms. These components operate in an interconnected manner, enabling both production-stage quality control and operational-stage technical diagnostics within a unified system.
For example, in automated monitoring of welding processes, ultrasonic and thermographic sensors track weld quality and structural temperature distribution in real time. At the same time, the data obtained from these sensors are transmitted to the diagnostic module, which analyzes and predicts the resistance of the weld to potential micro-cracks that may develop in the future. As a result, the system does not only verify the quality of the finished product but also performs diagnostic analysis to ensure its long-term operational reliability.
One of the key advantages of automated integrated systems is the presence of adaptive control mechanisms. Based on data received from sensors and NDT equipment, these mechanisms automatically regulate production parameters such as temperature, pressure, welding speed, and other technological variables. In this way, the system not only detects defects but also actively reduces the risk of their occurrence.
The design of such a system generally includes the following stages:
- Data collection stage – real-time recording of process parameters using integrated sensors;
- Pre-processing and filtering stage – elimination of noise and random anomalies in the collected data;
- Analytical and diagnostic analysis stage – prediction of potential failures using artificial intelligence and machine learning models;
- Transmission of results to the control system – generation of automatic adjustment signals through decision-making algorithms.
This approach forms the basis of the Smart Quality Management concept in the metal industry. In this framework, quality control and diagnostic systems transition from traditional physical inspection methods to digital and automated technologies. As a result, human intervention is minimized, objectivity increases, operational costs decrease, and product quality indicators remain stable.
Thus, the automated joint implementation of quality control and diagnostics represents one of the main directions of technological modernization and digital transformation in the metal industry. Through this integration, production processes become more flexible, precise, and predictable.

Proposed automated control and diagnostic system

The scientific foundations and industrial practices discussed above indicate that, in the metal industry, effective implementation of both quality control and technical diagnostics requires their

integration within a unified automated system. Such an approach not only ensures that products comply with standards during the production stage but also improves their reliability and operational safety throughout their service life.
According to the proposed concept, the automated control and diagnostic system can be designed in such a way that the quality indicators of metal materials are monitored in real time through multiple sensors. Each sensor would be responsible for measuring a specific physical or structural parameter, such as density, hardness, magnetic permeability, surface defects, or internal voids.
The system would operate according to the following principle:
1. First stage – automatic quality assessment.
The metal sample or structural element passes through sensor modules, where its mechanical and physical properties are measured in real time. The collected data are transmitted to the system's control module and compared with predefined standard parameters.
- If the parameters fall within the acceptable range, the product is assigned a "qualified" status and transferred to the next stage of production.
- If the indicators deviate from the standard, the system automatically initiates the diagnostic stage.
2. Second stage – technical diagnostics and cause analysis.
At this stage, the system activates additional sensors and analytical modules to determine the cause of the detected nonconformity. For example, ultrasonic or magnetic resonance sensors can be used to determine the depth of internal cracks and pores, while thermographic analysis can detect irregularities in temperature distribution.
3. Third stage – transmission of results to the decision-making system.
The system processes all measurement results and classifies the condition of the product as "accepted," "requires reprocessing," or "rejected." At the same time, this information is transmitted to the production management system, enabling automatic correction of process parameters.
For the effective operation of such a system, the main components include:
- Sensor modules: mechanical, acoustic, optical, and electromagnetic measurement sensors;
- Data acquisition and control unit: an industrial control device such as a PLC or a microcontroller-based module;
- Data analysis and decision-making algorithms: software based on artificial intelligence or adaptive logic;
- User interface: a display or SCADA platform for visualization of results and remote monitoring of the process.
The main advantage of the proposed system is its ability to perform continuous control and diagnostic functions without human intervention. As a result, objective data on product quality are collected, the causes of defects are identified immediately, and production stability is ensured.
Testing and further development of such a system can be carried out in future research stages, particularly through industrial PLC-based models. Thus, the proposed concept offers a realistic scientific and practical perspective for the development of intelligent control and diagnostic technologies in the metal industry.

Conclusion

In the metal industry, product quality and operational reliability are of decisive importance for ensuring production sustainability and compliance with safety standards. The conducted scientific analysis and theoretical research demonstrate that quality control and technical diagnostics processes achieve maximum effectiveness only when implemented together in a systematic manner.

Modern approaches involve the consistent and purposeful application of both destructive and non-destructive testing methods, enabling the detection of both surface and internal defects in products. Non-destructive methods—such as visual inspection, liquid penetrant testing, magnetic particle testing, ultrasonic testing, radiographic testing, and eddy current testing—are particularly effective for evaluating the condition of products in real time during production and throughout their operational life. Systematic analysis of the results obtained from these methods makes it possible to establish a scientifically grounded decision-making mechanism that ensures product quality and technical reliability.

The proposed concept of an automated control and diagnostic system represents a promising approach for the integrated management of quality control and diagnostics in the metal industry at future research and implementation stages. The system evaluates all metal parameters in real time using sensors, automatically confirms products that meet quality standards, and activates the diagnostic stage when any deviation is detected. Such integration increases production efficiency, minimizes human involvement, and ensures the safe operation of products.

In conclusion, the integration of quality control and diagnostic processes in the metal industry, their implementation within automated systems, and the future development of PLC-based real models provide a scientifically and technologically grounded perspective for optimizing industrial processes, reducing accident risks, and improving product reliability. This approach represents an essential and relevant direction for the modernization of metal production from both scientific and practical perspectives.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Broday, E. E. (2022). The evolution of quality: From inspection to Quality 4.0. International Journal of Quality and Service Sciences.
2. Eldred, J. R. (2020). Inspection and control processes in the Quality 4.0 environment. Quality Magazine, 59(6).
3. Gür, C. H. (2023). The impact of Industry 4.0 and 5.0 approaches on production chains and the role of non-destructive testing. MTM 2023 International Conference Proceedings.
4. Inspenet Editorial Team. (2024). Automated non-destructive testing in the era of Industry 4.0: The transition to NDT 4.0. Inspenet Magazine.
5. Jaber, A., Karganroudi, S. S., Aminzadeh, A., & Taheri, H. (2022). Smart geometric non-destructive testing: Modern inspection methods and challenges. Materials, 15(20), 7187.
6. Lario, J. (2025). Zero-defect and waste-free manufacturing concept using non-destructive testing technologies. Additive Manufacturing & Automation Review, 9(2), 29.
7. Lario, J., & Mateo, M. (2024). Zero-defect manufacturing models for evaluating the efficiency of investment in quality assurance. International Journal of Production Research, 62(10).
8. Liang, X., & Lu, H. (2024). Research on improving the stability of non-destructive testing of agricultural product quality. Foods, 13(23), 3917.
9. Mineo, C., & Javadi, Y. (2022). Robotic non-destructive testing methods and industrial applications. Sensors, 22(19), 7654.
10. Raj, B., Jayakumar, T., & Banerjee, P. K. (2022). Advances in non-destructive testing (NDE 2020 conference proceedings). Springer, Lecture Notes in Mechanical Engineering.
11. Reis, P., Fernandes, J., & Silva, L. (2024). Automatic fault detection in non-destructive testing: An artificial intelligence-based acoustic and thermal analysis approach. Journal of Failure Analysis and Prevention, 24, 2210–2220.
12. Shaloo, M., Klein, T., Huber, N., & Reitinger, B. (2022). Overview of modern NDT technologies for defect detection: Applications in welding and additive manufacturing processes. Materials, 15(10), 3697.
13. Straat, M., Koster, K., Goet, N., & Bunte, K. (2022). An Industry 4.0 case study: Real-time quality control and machine learning based on sensor data. arXiv Preprint 2206.05818.
14. Wang, Y., & Zhao, L. (2020). Quality inspection and management in water engineering projects using non-destructive testing methods. Journal of World Architecture, 7(2).
15. Yılmaz, B., Jasiuniene, E., Bui, H. K., & Berthiau, G. (2020). Quality assessment of joints using advanced non-destructive testing (NDT) and data fusion methods. Sensors, 20(18), 5127.

METAL SƏNAYESİNDƏ KEYFİYYƏTƏ NƏZARƏT VƏ DİAQNOSTİKANIN AVTOMATLAŞDIRILMASI

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Cavidə Dəmirova[1], Nərmin Əliyeva[2]
[1]T.ü.f.d., dosent, "Elektronika və Avtomatika" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti,
Email: cavida.damirova@asoiu.edu.az
[2]Magistr, "Elektronika və Avtomatika" kafedrası , Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: nermin.eliyeva142@gmail.com

XÜLASƏ

Bu məqalədə metal sənayesində məhsul keyfiyyətinin təmin olunmasında keyfiyyətə nəzarət və texniki diaqnostika proseslərinin rolu, eləcə də bu proseslərin avtomatlaşdırılmış və inteqrasiya olunmuş şəkildə tətbiqinin elmi və texnoloji əsasları araşdırılır. Keyfiyyətə nəzarət sistemlərinin istehsalın bütün mərhələlərini əhatə edən kompleks idarəetmə mexanizmi kimi çıxış etdiyi, məhsulun yalnız normativ uyğunluğunu deyil, eyni zamanda uzunmüddətli istismar etibarlılığını təmin etdiyi əsaslandırılır.

Metal məmulatlarının texniki vəziyyətinin qiymətləndirilməsində destruktiv və zədələmədən sınaq üsullarının qarşılıqlı tamamlayıcı xarakter daşıdığı göstərilir. Destruktiv sınaqlar materialın mexaniki və fiziki xüsusiyyətlərinin dəqiq təhlilinə imkan versə də, zədələmədən sınaq (NDT) metodları məhsulun struktur bütövlüyünü pozmadan səthi və daxili qüsurların aşkar edilməsini təmin edir. Vizual yoxlama, maye penetrant, maqnit toz, ultrasəs, radioloji və induksiya cərəyanı üsullarının metal sənayesində geniş tətbiqi onların yüksək informativliyi və istehsal prosesinə inteqrasiya imkanları ilə izah olunur

Keyfiyyətə nəzarət və texniki diaqnostika proseslərinin inteqrasiyası məhsulun bütün həyat dövrü ərzində təhlükəsizlik və etibarlılığın təmin edilməsinə yönəlmiş müasir yanaşma kimi təqdim edilir. Sensor texnologiyalarına, real vaxt rejimində məlumat toplanmasına və analitik emala əsaslanan diaqnostika sistemləri potensial nasazlıqların erkən mərhələdə proqnozlaşdırılmasına və profilaktik tədbirlərin vaxtında görülməsinə imkan yaradır.

Nəticədə, keyfiyyətə nəzarət və texniki diaqnostikanın avtomatlaşdırılmış və vahid sistem çərçivəsində təşkili metal sənayesində istehsal proseslərinin optimallaşdırılması, insan amilinin minimuma endirilməsi və məhsulun istismar etibarlılığının yüksəldilməsi üçün elmi-texnoloji baxımdan əsaslandırılmış perspektiv kimi qiymətləndirilir. Bu yanaşma sənaye 4.0 və ağıllı istehsal konsepsiyalarına uyğun olaraq davamlı inkişafın təmin edilməsində mühüm rol oynayır.

Açar sözlər: metal sənayesi, keyfiyyətə nəzarət, zədələmədən sınaq (NDT), texniki diaqnostika, avtomatlaşdırılmış sistemlər, sensor texnologiyaları, sənaye 4.0, ağıllı istehsal.

АВТОМАТИЗАЦИЯ КОНТРОЛЯ КАЧЕСТВА И ДИАГНОСТИКИ В МЕТАЛЛУРГИЧЕСКОЙ ПРОМЫШЛЕННОСТИ

Джавида Дамирова[1], Нармин Алиева[2]
[1]К.т.н., доцент, кафедра электроники и автоматизации, Азербайджанский государственный университет нефти и промышленности, Email: cavida.damirova@asoiu.edu.az
[2]Магистрант, кафедра электроники и автоматизации, Азербайджанский государственный университет нефти и промышленности, Email: nermin.eliyeva142@gmail.com

РЕЗЮМЕ

В данной статье рассматривается роль процессов контроля качества и технической диагностики в обеспечении качества продукции в металлургической промышленности, а также научно-технические основы их автоматизированного и интегрированного применения. Обосновывается, что системы контроля качества действуют как комплексный механизм управления, охватывающий все этапы производства, обеспечивая не только соответствие продукции нормативным требованиям, но и долгосрочную эксплуатационную надежность.

Показано, что разрушающие и неразрушающие методы контроля взаимно дополняют друг друга при оценке технического состояния металлических изделий. Хотя разрушающие методы позволяют точно анализировать механические и физические свойства материала, неразрушающие методы контроля (НК) обеспечивают обнаружение поверхностных и внутренних дефектов без нарушения структурной целостности изделия. Широкое применение методов визуального контроля, капиллярной дефектоскопии, магнитопорошковой дефектоскопии, ультразвуковой, радиологической и индукционной дефектоскопии в металлургической промышленности объясняется их высокой информативностью и возможностью интеграции в производственный процесс.

Интеграция процессов контроля качества и технической диагностики представлена как современный подход, направленный на обеспечение безопасности и надежности на протяжении всего жизненного цикла продукта. Диагностические системы, основанные на сенсорных технологиях, сборе данных в режиме реального времени и аналитической обработке, позволяют заблаговременно прогнозировать потенциальные отказы и своевременно внедрять профилактические меры.

В результате организация контроля качества и технической диагностики в рамках автоматизированной и унифицированной системы рассматривается как научно и технологически обоснованная перспектива оптимизации производственных процессов в металлургической промышленности, минимизации человеческого фактора и повышения эксплуатационной надежности продукции. Такой подход играет важную роль в обеспечении устойчивого развития в соответствии с концепциями индустрии 4.0 и интеллектуального производства.

Ключевые слова: металлургическая промышленность, контроль качества, неразрушающий контроль (НК), техническая диагностика, автоматизированные системы, сенсорные технологии, индустрия 4.0, интеллектуальное производство.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

248-265

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-28

VOLUME 33 (08) ISSUE 02 2026

IMPROVEMENT OF THE METHODOLOGY FOR CALCULATING SPRINGS USED IN PUMP CIRCULATION SYSTEM EQUIPMENT

Tahir Süleymanov[1], Tamerlan Mursalli[2]
[1]Dos, Azerbaijan State Oil and Industry University, Department of Mechanics. E-mail: tahir_suleymanov@list.ru
[2]Master's Student, Azerbaijan State Oil and Industry University, Department of Mechanics.
E-mail: tamerlan378@gmail.com

ABSTRACT

Springs represent one of the fundamental mechanical elements widely applied in transmission mechanisms and industrial equipment. Rapid technological progress in computer and mobile industries has encouraged manufacturers to develop compact and highly efficient spring systems. Modern computer-aided design tools enable engineers to perform detailed modeling and decision-making processes by combining geometric and metadata information. The primary objective of this study is to develop a software-based approach for the design and analysis of springs commonly used in pump circulation system equipment. Within the research framework, a specialized program for the design of helical spring systems has been created. After entering the required initial parameters, the software automatically performs complex engineering calculations and generates a comprehensive report containing all essential mechanical and geometric characteristics of the spring. The operational performance and efficiency of the spring system are also evaluated. The developed program determines the required wire parameters and key structural properties, and its reliability has been validated using experimental data available in open scientific sources.
Keywords: Helical spring, calculation system, software, computer-aided design.

Introduction

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.L_S

$$L_s = n' \cdot d$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.L_a

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$L_a = n' \cdot d + \delta_{max1} + 0{,}15\delta_{max}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

δ_{max}The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$0{,}15\delta_{max}$The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$L_a = n' \cdot d + \delta_{max1} + (n' - 1) \cdot 1mm$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system. The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$C = \frac{D}{d}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$K = \frac{W}{\delta}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
δThe purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

$$P = \frac{L_a}{n' - 1}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\frac{L_a - L_S}{n'}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$n'' = n + 1$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.$L_a L_a$

$L_a > 4D$The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.τt

$$T = w \cdot \frac{D}{2} = \frac{\pi}{16 \cdot \tau_1 \cdot d_3}$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.τd

$$\tau_d = \frac{W}{(\pi \cdot d) : 4} = \frac{4W}{\pi d^2}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.τ

$$\tau = \tau_t + \tau_d = \frac{8 \cdot W \cdot D}{\pi \cdot d_3 + \frac{4W}{\pi \cdot d^2}}$$

$$\tau = \frac{8 \cdot W \cdot D}{\pi \cdot d_3 \cdot (1 + \frac{d}{2D})}$$

$$\tau = \frac{K_S \cdot (8 \cdot W \cdot D)}{\pi \cdot d_3}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

K_SThe purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$K_S = 1 + \frac{1}{2C}$$

$$K = \frac{4C - 1}{(4C - 4) + \frac{0.615}{C}}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\tau = \frac{K_S \cdot (8 \cdot W \cdot D)}{\pi \cdot d_3}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\tau = \frac{K \cdot (8 \cdot W \cdot D)}{\pi \cdot d_3}$$

$$C = \frac{D}{d} \rightarrow \tau = \frac{K \cdot (8 \cdot W \cdot D)}{\pi \cdot d^2}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.
The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.$K_s K_s$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.$K_S K_C$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

K_SThe purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.K_C

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system. The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.$\pi \cdot D \cdot n$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.δ

$$\delta = \frac{\theta \cdot D}{2}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

θThe purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\frac{T}{J} = \frac{2\tau}{D} = \frac{G \cdot \theta}{l}$$

$$\theta = \frac{T \cdot l}{J \cdot G}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$J = \frac{\pi d^4}{32}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\theta = \frac{T \cdot l}{J \cdot G} = \frac{\left(\frac{W \cdot D}{2} \cdot \pi \cdot D \cdot n\right)}{\frac{\pi}{32} \cdot d^4 \cdot G}$$

$$\theta = \frac{16 \cdot n \cdot G \cdot D^2}{G \cdot D^4}$$

θThe purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$\delta = \frac{16 \cdot n \cdot W \cdot D^2}{G \cdot D^4} \cdot \frac{D}{2} = \frac{18 \cdot n \cdot W \cdot D^3}{G \cdot D^4}$$

$$\delta = \frac{8 \cdot n \cdot W \cdot C^3}{G \cdot D}$$

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

$$K = \frac{G \cdot d}{8 \cdot n \cdot C^3}$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

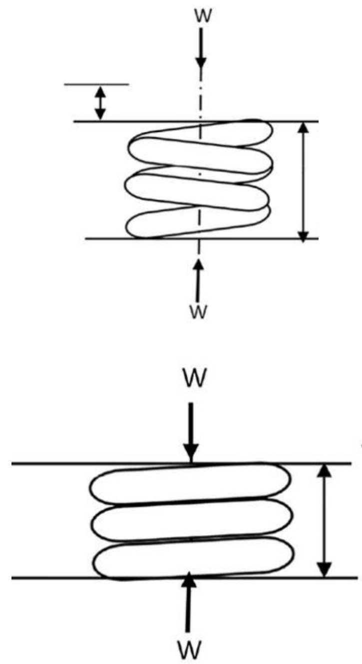


Figure 1: Compressed state of the spring.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

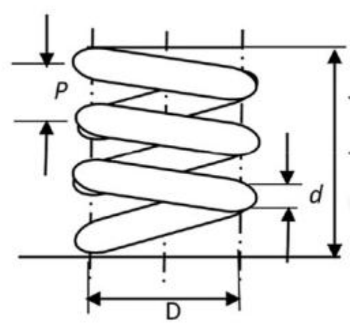


Figure 2: Uncompressed (free) state of the spring.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

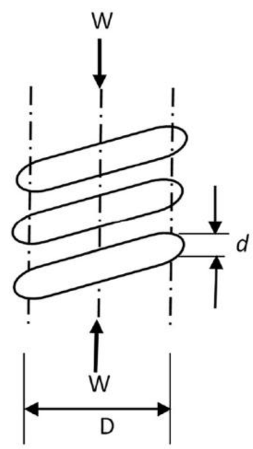


Figure 3: Helical spring.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

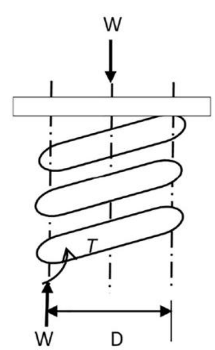


Figure 4: Effect of load on the helical spring.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

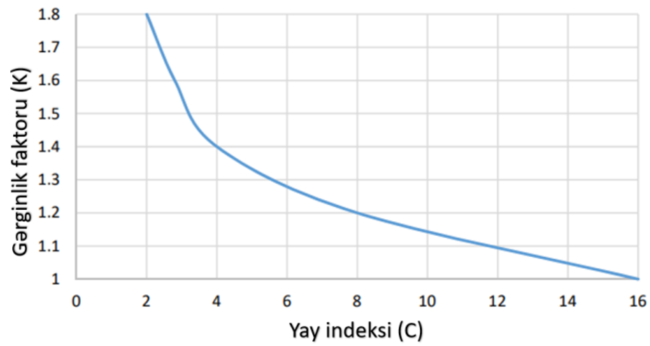


Figure 5: Graph of spring index dependence on stress factor.

The purpose of this research is to improve the calculation methodology for springs used in pump circulation systems by eliminating existing theoretical and practical limitations and applying computer-based design tools. The proposed methodology enables more accurate determination of stress, stiffness, and curvature-related parameters, thereby enhancing operational reliability and efficiency of the system.

Discussion of results

The developed computer-based system enables rapid and accurate design and analysis of springs applied in pump circulation equipment. Compared with traditional manual calculations, the proposed system significantly reduces computational time while simultaneously considering multiple design variables. By modifying parameters such as material properties, wire diameter, geometric dimensions, and loading conditions, various design alternatives can be efficiently evaluated. In pump circulation systems, springs contribute to vibration reduction, load distribution, and increased equipment service life. The implemented software determines optimal geometric and mechanical parameters by accounting for these operational factors. The Visual Basic-based interface allows convenient data input and graphical presentation of results. Obtained results indicate that optimized spring parameters, including wire diameter, number of coils, free length, and stiffness, ensure reliable operation and minimize failure risks under high loading conditions. Furthermore, the system allows rapid comparison of alternative configurations, providing engineers with effective decision-making support for system optimization.

Conclusion

1) The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

2) The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

3) The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

4) The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

The optimization of the spring calculation methodology has been successfully achieved. Complex and time-consuming manual calculations traditionally applied in pump circulation systems have been replaced by a computer-based approach, significantly reducing analysis time while improving accuracy. The developed software enables systematic and precise determination of essential spring parameters such as wire diameter, mean diameter, number of active coils, free length, spring constant, and maximum shear stress. This ensures safe and reliable operation of pump system equipment. Additionally, rapid evaluation of parameter variations allows analysis of alternative operating conditions and scientifically justified spring selection. The user interface developed on the Visual Basic platform simplifies data processing, accelerates engineering decision-making, reduces human error, and enhances overall design efficiency.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. J. M. Munoz-Guijosa, G. F. Zapico, J. de la Peña, and J. Echávarri, “Using FRPs in elastic regime for the storage and handling of mechanical energy and power: application in spiral springs,” Compos. Structures, vol. 213, pp. 317–27, 2019
2. X. Qimin, L. Liwei, and X. Qili, “The optimal design and simulation of helical spring based on particle swarm algorithm and MATLAB,” Wseas Trans. Circuits Syst., vol. 8, no. 1, pp. 84–93, 2009.
3. D. Besnea, D. Rizescu, C. Rizescu, E. Dinu, V. Constantin, and E. Moraru, “Additive technologies and materials for realization of elastic elements,” in Proceedings of the International Conference of Mechatronics and Cyber-MixMechatronics–2018 2. Springer International Publishing, 2019, pp. 62–70.
4. J. Doane, Machine Analysis with Computer Applications for Mechanical Engineers. John Wiley & Sons, 2015.
5. R. Carrese, A. Sóbester, H. Winarto, and X. Li, “Swarm heuristic for identifying preferred solutions in surrogate-based multi8 International Review of Applied Sciences and Engineering Unauthenticated | Downloaded 03/07/24 12:52 PM UTC objective engineering design,” Aiaa J., vol. 49, no. 7, pp. 1437–49, 2011.
6. X. Qimin, L. Liwei, and X. Qili, “Study on particle swarm algorithm and its application in mechanical design based on MATLAB,” in Proceedings of the 3rd WSEAS International Conference on Computer Engineering and Applications, 2009, pp. 182–5.
7. M. Gzal, M. Groper, and O. Gendelman, “Analytical, experimental and finite element analysis of elliptical cross-section helical spring with small helix angle under static load,” Int. J. Mech. Sci., vol. 130, pp. 476–86, 2017.
8. S. A. Kaoua, K. Taibi, K. Taibi, K. Azouaoui, and M. Azzaz, “Numerical modelling of twin helical spring under tensile loading,” Appl. Math. Model., vol. 35, no. 3, pp. 1378–87, 2011.
9. Y. Peng, S. Wang, J. Zhou, and S. Lei, “Structural design, numerical simulation and control system of a machine tool for stranded wire helical springs,” J. Manuf. Syst., vol. 31, no. 1, pp. 34–41, 2012.
10. F. M. Filotto and G. Kress, “Nonlinear planar model for helical structures,” Comput. Struct., vol. 224, 2019, Art no. 106111.
11. H. Pawar and D. Desale, “Optimization of three wheeler front suspension coil spring,” Proced. Manuf., vol. 20, pp. 428–33, 2018.
12. K. Hase, H. Togawa, S. Kobayashi, and G. Obinata, “Parametric modeling of sports prostheses based on the flat spring design formulas,” J. Biomechanical Sci. Eng., vol. 15, no. 1, pp. 19–00446– 19-00446, 2020.
13. S. Navaneethasanthakumar, N. G. R. Ebenezer, M. P. Prabakaran, and K. V. Kumar, “Labview based optimal design of a helical compression spring and analysis using ANSYS”

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

NASOS DÖVRAN SISTEMI AVADANLIQLARINDA İŞLƏDİLƏN YAYLARIN HESABLANMASI METODİKASININ TƏKMİLLƏŞDİRİLMƏSİ

Tahir Süleymanov[1], Tamerlan Mürsəlli[2]
[1]Dos, Azerbaijan State Oil and Industry University, Department of Mechanics. E-mail: tahir_suleymanov@list.ru
[2]Master's Student, Azerbaijan State Oil and Industry University, Department of Mechanics.
E-mail: tamerlan378@gmail.com

XÜLASƏ

Yaylar ötürmə mexanizmlərində istifadə olunan ən əsas mexaniki elementlərdən biridir; kompüter və mobil texnologiyalar sənayesinin sürətli inkişafı isə yay istehsalçılarını sənayeni daha da təkmilləşdirməyə və çox kiçik ölçülü yayların istehsalına yönəltmişdir. Mexaniki detalların layihələndirilməsi üçün istifadə olunan kompüter dəstəkli dizayn proqramlarının əksəriyyəti bu detalların dizaynını mümkün edən funksiyalara malikdir və bu proqramlar müxtəlif qərarvermə mexanizmlərini özündə birləşdirir; həmin qərarların qəbul edilməsi üçün isə həm həndəsi məlumatların koordinatlarına, həm də metadata məlumatlarına ehtiyac duyulur. Bu məqalənin əsas məqsədi, nasos dövran sistemi avadanlıalqında geniş istifadə olunan ən mühüm elementlərdən biri olan yayların layihələndirilməsi və təhlili üçün proqram təminatının hazırlanmasıdır; tədqiqat çərçivəsində spiralvari yay sisteminin dizaynına yönəlmiş xüsusi proqram təminatı işlənib hazırlanmışdır. İstifadəçi sistemə ilkin məlumatları daxil etdikdən sonra proqram daxilində bir sıra mürəkkəb mühəndislik hesablamaları avtomatik şəkildə yerinə yetirilir və nəticədə yay üçün bütün mühəndis ölçülərini əhatə edən ətraflı hesabat təqdim olunur, eyni zamanda yay sisteminin iş qabiliyyəti və səmərəliliyi yoxlanılır. Proqram təminatının çıxış nəticələri yay telinin tələb olunan parametrlərini, o cümlədən əsas konstruktiv ölçüləri və mexaniki xüsusiyyətləri göstərir; hazırlanmış proqram açıq elmi mənbələrdə verilmiş sınaq məlumatları əsasında yoxlanılmış və nəticədə yay telinin tələb olunan parametrləri uğurla əldə edilmişdir.
Açar sözlər: Spiralvari yay, hesablama sistemi, proqram təminatı, komputer dəstəkli layihələndirmə

УСОВЕРШЕНСТВОВАНИЕ МЕТОДИКИ РАСЧЕТА ПРУЖИН, ИСПОЛЬЗУЕМЫХ В ОБОРУДОВАНИИ НАСОСНЫХ ЦИРКУЛЯЦИОННЫХ СИСТЕМ

Тахир Сулейманов[1], Тамерлан Мурселли[2]
[1]Доцент, Азербайджанский государственный университет нефти и промышленности, Кафедра Механики.
E-mail: tahir_suleymanov@list.ru
[2]Студент магистратуры, Азербайджанский государственный университет нефти и промышленности, Кафедра Механики. E-mail: tamerlan378@gmail.com

РЕЗЮМЕ

Пружины являются одним из основных механических элементов, используемых в передающих механизмах; быстрый рост индустрии компьютерных и мобильных технологий направил производителей пружин на дальнейшее совершенствование производства и изготовление пружин очень малых размеров. Большинство программ компьютерного проектирования, используемых для конструирования механических деталей, обладают функциями, позволяющими создавать такие детали, и включают различные механизмы принятия решений; для принятия этих решений требуется как информация о координатах геометрических данных, так и метаданные. Основная цель данной статьи — разработка программного обеспечения для проектирования и анализа пружин, являющихся одним из наиболее важных элементов, широко используемых в оборудовании насосных циркуляционных систем; в рамках исследования было разработано специализированное программное обеспечение, ориентированное на проектирование спиральной пружинной системы. После ввода пользователем исходных данных программа автоматически выполняет ряд сложных инженерных расчетов и предоставляет подробный отчет, охватывающий все инженерные размеры пружины, одновременно проверяя работоспособность и эффективность системы пружины. Результаты работы программного обеспечения отображают требуемые параметры пружинной проволоки, включая основные конструктивные размеры и механические характеристики; разработанная программа была проверена на основе экспериментальных данных, опубликованных в открытых научных источниках, и в результате требуемые параметры пружинной проволоки были успешно получены.

Ключевые слова: Спиральная пружина, система расчета, программное обеспечение, проектирование с поддержкой компьютера.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
266-273

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-29

VOLUME 33 (08) ISSUE 02 2026

IMPROVING THE OPERATION OF DEVICES USED IN PREPARING GASES FOR TRANSPORTATION

Abdulagha Gurbanov[1], Elparast Hasanov[2]
[1]Doctor of Philosophy (Technical), "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: qabdulaga@mail.ru
[2]Master's Degree Student, "Department of Oil and Gas Transportation and Storage", "Azerbaijan State Oil and Industry University", Azerbaijan. E-mail: elparasthesenov@gmail.com

ABSTRACT

Preparing gases for transportation is one of the most critical stages of the technological chain of the gas industry. At this stage, mechanical impurities, water vapor, hydrogen sulfide, carbon dioxide and other unwanted components are separated from the gas, and the gas is brought to the appropriate pressure and temperature parameters. Technological obsolescence of existing equipment, high energy consumption and increased maintenance costs necessitate finding new solutions in this area.

The article analyzes the current operating modes of separators, drying units, compressor stations and filtration systems used in gas transportation preparation systems, and explores modern approaches aimed at improving their technical and economic indicators. Detailed information is provided on the application of hybrid separation technologies, integration of digital control systems, addition of energy recovery modules to devices and application of predictive maintenance methodology.

The research results show that modern sensor technologies, artificial intelligence-based control algorithms and modular design approaches have the potential to increase the performance of facilities by 25-40% and reduce energy consumption by 15-30%. The article also proposes optimal solutions that can be applied to the development of Azerbaijani gas transportation infrastructure and provides relevant examples from international practice.

As a result, it was determined that the comprehensive modernization of gas preparation facilities for transportation allows for a reduction in production costs, an increase in energy efficiency, and an increase in the overall safety level of gas transportation systems.

Keywords: gas transportation, separation, drying unit, compressor station, filtration, digital control, energy efficiency, maintenance, hybrid technology, gas preparation.

Introduction

The delivery of natural gas from the production site to the consumer requires the sequential implementation of complex technological processes. The stage of preparing gases for transportation is the initial link in this technological chain and directly determines the effectiveness of all subsequent processes. Natural gas extracted from the well in its original form

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

is not suitable for transportation: the water vapor it contains causes the formation of hydrates in the pipeline, and hydrogen sulfide causes corrosion of metals. Mechanical particles corrode compressor equipment, and heavy hydrocarbons condense during transportation, reducing the permeability of pipelines.
The increasingly strong requirements of the global gas industry to reduce energy intensity, minimize emissions, and optimize operating costs have made technological modernization of gas preparation equipment an important issue. In Azerbaijan, the expansion of the gas transportation network operated by SOCAR, as well as the improvement of the operation of facilities in the context of the implementation of the Southern Gas Corridor project, are of strategic importance.
Over the past decade, the rapid development of digital technologies, modular construction approaches, and new material technologies has created the basis for radical progress in this area. However, an analysis of the scientific and technical literature shows that research that takes into account the complex improvement of facilities, especially in Azerbaijani conditions, still remains insufficient. The article presents a comprehensive approach aimed at filling this gap.

Purpose of the work

The main objective of the study is to assess the current technological status of the facilities used in the preparation of gases for transportation, to identify modern solutions that increase the efficiency of their work, and to formulate justified recommendations for practical application. To achieve this goal, the following tasks have been set:
– identification of the current technological limitations of separation, drying, filtration and compression facilities;
– conducting a comparative analysis of hybrid separation technologies and their effectiveness with traditional systems;
– assessment of the technical and economic effect of digital control systems on facilities;
– study of the possibilities of integrating energy recovery and efficiency improvement technologies into facilities;
– investigation of the compatibility of the predictive maintenance methodology with existing systems.

Methods

During the study, methodological approaches were applied in several key areas to improve the operation of gas preparation facilities for transportation.

Technological innovations in separation devices.

Traditional vertical and horizontal separators have been the basis of gas preparation processes for many years. However, the main technological limitation of these devices is that the efficiency of the separation process is highly dependent on the gas flow rate, composition and operating parameters. In cases of load fluctuations, the efficiency drops sharply.
Modern hybrid separation technologies are based on the combined use of centrifugal force, coalescence and magnetic fields. Vortex separators use spiral flow mechanics: the gas-liquid mixture enters the cylindrical chamber in a tangential direction, as a result of centrifugal force, heavier components accumulate along the walls, and the gas exits from the central zone. This

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

approach allows the same efficiency to be achieved with devices 3-5 times smaller in size compared to traditional gravity separation.

Electrostatic coalescence technologies accelerate the coalescence of small water droplets into larger fractions. The polarization of water droplets by a high-voltage electric field (5-20 kV/cm) increases their attraction to each other. As a result, the coalescence rate increases by 10-15 times and the separator volume requirement decreases. The efficiency of this technology reaches 85-95%, especially in the separation of high-viscosity emulsions. The modular construction principle is an important advantage of modern separation systems. Standard modules (vessel, internal structures, sensor blocks) are manufactured in the factory and only assembled on site. This approach reduces construction time by 40%, improves quality control and facilitates future capacity expansion.

Optimization of drying equipment performance

Gas drying is carried out using three main technologies: liquid absorption with glycerin, drying with solid adsorbents and low-temperature condensation methods. Each has its own application area, advantages and disadvantages.

Precise regulation of the amount of stripping gas is a key parameter in the optimization of triethylene glycol-based drying processes. Unlike the traditional Stahl column, the modern Drizo process realizes the efficient use of boiler steam with recycled products. The introduction of regenerative structures under vacuum during triethylene glycol regeneration increases the glycol concentration from 99.6% to 99.99%. This means the potential to lower the point from -45°C to -70°C.

Porous membrane technologies are considered to be the direction that determines the future of drying processes. Polyimide, silocation carbide or carbon-based membranes have selective permeability to water vapor under certain temperature-pressure conditions. Membrane drying modules, which have no moving parts, reduce maintenance costs by 60-70%, and energy consumption is 30% lower than adsorption processes. However, the application of this technology on an industrial scale remains limited.

Two-stage combined drying schemes are increasingly being used: in the first stage, 90-95% of water is separated from the gas by Triethylene glycol absorption, and in the second stage, a deeper solid adsorbent drying is applied. This scheme also optimizes the costs of both technologies together and reduces energy consumption by 20-25% as a group.

Increasing energy efficiency in compressor stations

Compressor stations are the most energy-consuming element of the gas transmission infrastructure. The compression stage accounts for 60-70% of the total gas transmission costs. Therefore, improving the efficiency of these units is a priority issue from both economic and environmental points of view.

Variable speed drives are one of the technical solutions with the fastest payback for increasing energy efficiency in compressor stations. The operating mode of the compressor rarely corresponds to the standard (nominal) speed: the variability of gas flow, inlet pressure and temperature usually causes the compressor to operate in partial load modes, which reduces efficiency. The use of variable speed drives in this case reduces energy consumption by 15-25%.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

For example, in the practice of the European Union, the application of variable speed drives in compressor stations shows an average annual saving of 18%.
Heat recovery systems play an important role in increasing the fuel efficiency of compressor stations. Drive gas turbines usually have a thermal efficiency of 25-30%, the remaining heat is lost with exhaust gases. The use of recuperative heat exchangers, which recover some of this heat, can reduce fuel gas consumption by 10-15%. Thermoelectric generators can convert exhaust heat into electrical energy on a small scale to power sensor systems.
Reducing methane leakage from compressor stations is important from both an environmental and economic perspective. Advanced bellows seal technologies reduce methane leakage by 98-99% compared to traditional oil seal systems. A complete seal modernization, combined with laser-based leak detection (LDAR) programs, can reduce annual methane losses at a compressor station by 70-80%.

Application of digital control systems.
The digitalization of gas processing facilities is the most transformative change in this area. Unlike traditional SCADA systems, modern digital twin technologies create a complete virtual model of the facility, correlate real-time measurements with this model, and make recommendations for process optimization.
Data analytics platforms use machine learning algorithms to process large amounts of data collected from facilities to detect operational anomalies early. Vibration analyzers, acoustic emission sensors, and infrared cameras allow for early detection of wear in compressor bearings, hydrate deposits in separators, and contamination on heat exchange surfaces. In the United States, Burlington Resources has reduced unplanned shutdowns by 62% after implementing this technology.
Process optimization algorithms dynamically calculate the optimal operating point of the facility using real-time measurements. For example, the Model Predictive Control (MPC) algorithm that automates the TEG drying process optimizes glycol circulation, evaporator temperature, and stripping gas consumption simultaneously. As a result, TEG consumption is reduced by 15% and gas consumption by 12%.
Cloud-based management platforms enable centralized monitoring and control of multiple units. Equipment manufacturers are now offering remote monitoring services on a subscription basis. This approach allows small companies to operate efficiently without the capital investment of specialist personnel.

Modernization of filtration systems
Filtration devices separate liquid particles, aerosols, mechanical impurities and heavy hydrocarbon fractions from gases. The main problem of existing systems is the need for frequent replacement of filter elements, high differential pressure loss and low filtration efficiency.
Nanofibrous filtration materials have significant advantages over traditional glass-fiber elements. Electrospun fibers with a diameter of 100-500 nm have a high specific surface area. These materials allow them to capture aerosols of 0.1 microns with an efficiency of up to 99.97%, while the differential pressure loss is 40% lower. Nanofibrous elements also increase the loading capacity: 1.5-2 times more impurities are captured per m² of surface.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Self-cleaning filtration systems use wave-pulse technology. Short-term high-intensity air pulses blow through the filter elements in the opposite direction, regenerating them without requiring manual labor. These systems increase the service life of filter elements by 3-4 times, reducing overall maintenance costs by 50-60%.

Conclusıons

Based on the research conducted to improve the operation of devices used in preparing gases for transportation, the following results were obtained:

1. Hybrid separation technologies — a combination of vortex, centrifugal and electrostatic coalescence methods — provide 30-45% higher liquid-gas separation efficiency compared to traditional gravity separators, while significantly improving the dimensional and mass characteristics of the devices. Modular constructive approaches, in addition to shortening the construction period by 40%, increase the long-term capacity flexibility of the system.
2. Two-stage combined schemes for optimizing the gas drying process (TEG absorption + solid adsorbent drying) reduce total energy consumption by 20-25%, while the application of vacuum regeneration technology allows increasing the glycol concentration to 99.99% and lowering the dew point to -70°C. Membrane technologies are identified as a promising direction for the future.
3. The introduction of variable speed drives (VSD) in compressor stations reduces energy consumption by 15-25%, heat recovery systems allow reducing fuel costs by 10-15%, and full-strength (dry gas seal) modernization dramatically improves environmental performance by reducing methane leaks by 98-99%.
4. The integration of digital twin technologies, Model Predictive Control algorithms and machine learning-based anomaly detection systems reduces unplanned downtime in units by 60-65%, increases process efficiency by 10-18% and significantly improves the quality of operator decisions.
5. Various technological innovations — nanofiber filtration materials, self-cleaning filtration systems, digital control platforms and energy recovery modules — when combined within a single comprehensive approach create a synergistic effect: the total energy consumption of units is reduced by 25-35%, maintenance costs by 40-50%, and emissions by 30-40%. The phased modernization of Azerbaijan's gas transportation infrastructure with these technologies is recommended as a strategic priority.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Babayev H.A., Guliyev R.S. "Increasing the efficiency of separation processes in gas transportation systems". Scientific Works of ASOIU. Baku, 2023, No. 2, pp. 41-49.
2. Karimov T.N., Alizade S.M. "Optimization of the triethylene glycol process with vacuum regeneration technology". Journal of Oil and Gas Engineering. Baku, 2022, No. 3, pp. 55-63.
3. Nasirov F.G., Rahimov M.E. "Application of variable speed drives and energy efficiency in compressor stations". Energy and Automation. Baku, 2023, No. 1, pp. 28-35.
4. Khalilov B.O. "Prospects for the application of digital twin technology in gas preparation facilities". SOCAR Proceedings. Baku, 2022, No. 4, pp. 77-85.
5. Panahov T.M., Iskenderov E.A. "Application of nanofibrous filtration materials in the gas industry". Journal of Chemical Technology. Baku, 2023, No. 2, pp. 14-22.
6. Arnold K., Stewart M. "Surface Production Operations: Design of Oil-Handling Systems and Facilities". Gulf Professional Publishing, 3rd Edition, 2021, 672 p.
7. Kidney AJ, Parrish WR, McCartney DG. "Fundamentals of Natural Gas Processing". CRC Press, 3rd Edition, 2019, 432 p.
8. Manning FS, Thompson RE. "Oilfield Processing of Petroleum: Natural Gas". PennWell Corp, 2020, Vol. 1, 349 p.
9. Botros K.K., Jonker R. "Dynamic simulation of gas transmission systems for optimization of compressor station performance". International Journal of Pressure Vessels and Piping, 2022, Vol. 196, pp. 1-12.
10. Hashemi S.A., Naderi-Boldaji M. "Membrane technology for natural gas dehydration: A review". Journal of Natural Gas Science and Engineering, 2021, Vol. 89, 103894.
11. Mokhatab S., Poe W.A. "Handbook of Natural Gas Transmission and Processing". Gulf Professional Publishing, 4th Edition, 2022, 838 p.
12. Seader JD, Henley EJ, Roper DK. "Separation Process Principles: Chemical and Biochemical Operations". John Wiley & Sons, 3rd Edition, 2020, 848 p.

QAZLARIN NƏQLƏ HAZIRLANMASINDA İSTİFADƏ OLUNAN QURĞULARIN İŞİNİN TƏKMİLLƏŞDİRİLMƏSİ

Əbdülağa Qurbanov[1], Elpərəst Həsənov[2]
[1]Texnika üzrə fəlsəfə doktoru, "Neftin-Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: qabdulaga@mail.ru

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

[2]Magistr, "Neftin Qazın Nəqli və Saxlanması kafedrası", "Azərbaycan Dövlət Neft və Sənaye Universiteti", Azərbaycan. E-mail: elparasthesenov@gmail.com

XÜLASƏ

Qazların nəqlə hazırlanması prosesi qaz sənayesinin texnoloji zəncirinin ən kritik mərhələlərindən birini təşkil edir. Bu mərhələdə qazdan mexaniki qarışıqların, su buxarının, hidrogen sulfidinin, karbon qazının və digər qeyri-istənilən komponentlərin ayrılması, qazın müvafiq təzyiq və temperatur parametrlərinə çatdırılması həyata keçirilir. Mövcud avadanlıqların texnoloji cəhətdən köhnəlməsi, enerji istehlakının yüksəkliyi və texniki xidmət xərclərinin artması bu sahədə yeni həllərin tapılmasını zəruri edir.
Məqalədə qazların nəqlə hazırlanması sistemlərində istifadə olunan separatorların, quruducu qurğuların, kompressor stansiyalarının və filtrasiya sistemlərinin mövcud işləmə rejimlərinin təhlili aparılmış, onların texniki-iqtisadi göstəricilərinin yaxşılaşdırılmasına yönəlmiş müasir yanaşmalar araşdırılmışdır. Hibrid separasiya texnologiyalarının tətbiqi, rəqəmsal idarəetmə sistemlərinin inteqrasiyası, enerji bərpası modulllarının qurğulara əlavə edilməsi və proqnozlaşdırıcı texniki xidmət metodologiyasının tətbiqi barədə ətraflı məlumat verilmişdir.
Tədqiqat nəticəsində müəyyən edilmişdir ki, müasir sensor texnologiyaları, süni intellekt əsaslı idarəetmə alqoritmləri və modular konstruktiv yanaşmalar qurğuların performansını 25-40% artırmağa, enerji istehlakını isə 15-30% azaltmağa potensial imkan yaradır. Məqalədə həmçinin Azərbaycan qaz nəqli infrastrukturunun inkişafına tətbiq oluna biləcək optimal həllər təklif edilmiş, beynəlxalq praktikadan müvafiq nümunələr gətirilmişdir.
Nəticə etibarilə müəyyən edilmişdir ki, qazın nəqlə hazırlanması qurğularının kompleks şəkildə modernləşdirilməsi istehsalat xərclərinin azalmasına, enerji səmərəliliyinin yüksəlməsinə və qaz nəqli sistemlərinin ümumi təhlükəsizlik səviyyəsinin artmasına imkan yaradır
Açar sözlər: qaz nəqli, separasiya, qurutma qurğusu, kompressor stansiyası, filtrasiya, rəqəmsal idarəetmə, enerji səmərəliliyi, texniki xidmət, hibrid texnologiya, qaz hazırlığı

УЛУЧШЕНИЕ РАБОТЫ УСТРОЙСТВ, ИСПОЛЬЗУЕМЫХ ДЛЯ ПОДГОТОВКИ ГАЗОВ К ТРАНСПОРТИРОВКЕ

Абдулага Гурбанов[1], Эльпараст Хасанов[2]
[1]Доктор философии (техническая специальность), "Кафедра транспорта и хранения нефти и газа", "Азербайджанский Государственный Университет Нефти и Промышленности", Азербайджан.
E-mail: qabdulaga@mail.ru
[2]Магистрант, "Кафедра транспорта и хранения нефти и газа", "Азербайджанский Государственный Университет Нефти и Промышленности", Азербайджан. E-mail: elparasthesenov@gmail.com

РЕЗЮМЕ

Процесс подготовки газов к транспортировке является одним из наиболее важных этапов технологической цепочки газовой промышленности. На этом этапе из газа отделяются механические примеси, водяной пар, сероводород, диоксид углерода и другие нежелательные компоненты, а газ доводится до соответствующих параметров давления и температуры. Технологическое устаревание существующего оборудования, высокое

энергопотребление и увеличение затрат на техническое обслуживание обусловливают необходимость поиска новых решений в этой области.
В статье анализируются современные режимы работы сепараторов, осушительных установок, компрессорных станций и фильтрационных систем, используемых в системах подготовки газов к транспортировке, и рассматриваются современные подходы, направленные на улучшение их технико-экономических показателей. Представлена подробная информация о применении гибридных технологий разделения, интеграции цифровых систем управления, добавлении модулей рекуперации энергии к устройствам и применении методологии прогнозирующего технического обслуживания.
Результаты исследования показали, что современные сенсорные технологии, алгоритмы управления на основе искусственного интеллекта и модульные подходы к проектированию имеют потенциал для повышения производительности установок на 25-40% и снижения энергопотребления на 15-30%. В статье также предлагаются оптимальные решения, которые могут быть применены к развитию азербайджанской газотранспортной инфраструктуры, и приводятся соответствующие примеры из международной практики.
В результате было установлено, что комплексная модернизация газоподготовительных установок позволяет снизить производственные затраты, повысить энергоэффективность и общий уровень безопасности газотранспортных систем.
Ключевые слова: газотранспорт, сепарация, осушительная установка, компрессорная станция, фильтрация, цифровое управление, энергоэффективность, техническое обслуживание, гибридные технологии, газоподготовка.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

274-281

Publication history
Article received: 11.02.2026
Article accepted: 25.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-30

OIL AND ANNULAR GAS GATHERING AND TRANSPORTATION IN WELLS OPERATED BY SUCKER ROD PUMPING SYSTEMS

Sardar Bayramov[1], Nihad Aliyev[2]
[1]Doctor of Technical Sciences, Professor, "Oil and Gas Transportation and Storage" Department, Azerbaijan State Oil and Industry University. E-mail: petrotech@asoiu.az
[2]Master's Degree Student, Faculty of Oil and Gas Production, Azerbaijan State Oil and Industry University.
E-mail: nihad.aliyev@ufaz.az

ABSTRACT

The Sucker rod pumping systems are extensively applied in the oil production in mature oil fields with decreasing reservoir pressure. When great pressure powering causes the oil to release a part of the petroleum gas accumulates in the annular space. Expansion of the annular gas pressure enhances the bottom-hole pressure, lowers effective drawdown in the reservoir and drives the dynamic level of the fluids towards the pump intake. These effect deteriorate the conditions in pump intakes, and results in free gasses to penetrate the pump, creating interference in gasses and highly declined volumetric efficiency. This paper examines the theoretical accumulation, collection, and transportation of oil and annular gas in wells which are pumped using sucker rods. The findings indicate that there are enhancement in annular gas pressure control and integrated arrangement of gathering and transportation systems to enhance production stability and minimize gas-related losses.

Keywords: sucker rod pump, annular gas, oil production, related petroleum gas, gas interference, the volumetric efficiency, dynamic fluid level, gathering and transportation systems.

Introduction

In most of the mature oil fields with falling reservoir pressure, sucker rod pumping systems are conducted. When making the oil, the oil releases associated petroleum gas that ends up compromising the annular space. The resulting rise in annular gases pressure causes bottom-hole pressure to increase, reservoir drawdown decreases and moves the dynamic fluid level to the pump intake.

Declining pump submergence will result in the freeing of gas in the pump which will result in gas interruptions and lose of volumetric efficiency and will interfere with the total functioning of the pump. These conditions occur most in wells that have high ratios of gas to oil. The presence of annular accumulated gases also raises the pressure in wellheads leading to adverse effects on the surface gathering and transportation systems.

Hence, the annular gas may be regarded as a factors of effects on downhole pump performance as well as surface facilities on a system level. This paper examines the process of oil and annular gas build-up, accumulation, and transport in the suckers rod pumped wells so as to know the solutions

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

capable of enhancing stability of the production process and lessening the losses associated with gases.

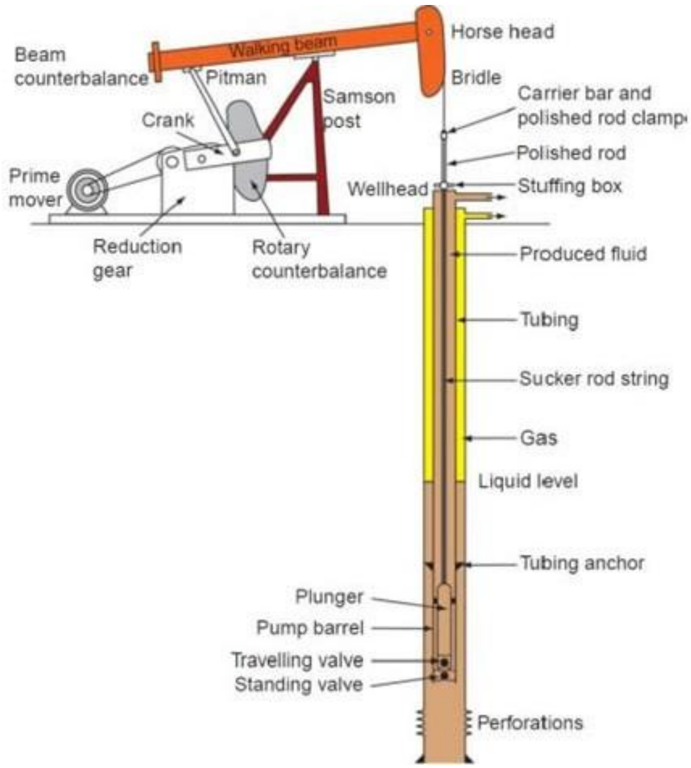


Figure 1: Typical configuration of a sucker rod pump.

Literature Review

Past research has shown that discharge of related petroleum gas as the reservoir pressure decreases is one of the determinants that inhibit the efficacy of the sucker rod pumping system. Gas build up in annular space raises annular and bottom-hole pressure, decreases effective reservoir drawdown, and moves the dynamic fluid level to the pump intake [4,9].

Experimental and field research confirms that free gas in the pump cylinder leads to a huge drop in volumetric efficiency because of gas compression in the plunger stroke. Losses in efficiency of up to 40-60 percent have been experienced in wells whose operating conditions are unfavorable as well as a high degree of instability in the operation of pumps and escalation in mechanical demands on the rod string [2,7].

A number of engineering remedies to eliminate gas interference have also been suggested which include optimization of pump setting depth, down hole gas separators installation, and forced annular gas extraction. Downhole gas separators can operate at moderate flow of gas but have high flow rate as they exhibit less efficiency because of their minimal cross-sectional area [1,6]. Forced annular gas recovery has been proven to show significant effect that is positive in high pressure wells linked to the high pressure gathering systems, which enhance the pump intake conditions as well as oil production [5].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The recent publications note that not only does a downhole equipments accumulation in an annular vortex lead to negative effects on the equipment but surface gathering and transportation systems, as well. High backpressure results in flowline instability and inseparated further production losses [3,8]. Thus, universal solutions that will always look at the operation of the annular gas, the functioning of a pump, and the facilities at the surface are deemed as the best solution [4,9].

Problem Statement and Research Methodology

Sucker rod pumped wells as they are run deeper and greener with varying amounts of gas tend to be unstable in production and less efficient. The fact that associated petroleum gas is accumulated in the annular space causes higher annular pressure, lower effective drawdown of the reservoir, and results in a displacement of the dynamic fluid level to the pump intake, which enhances the likelihood of gas interference [6,8].

Field practice is that the measures used to reduce gas-related complications are often imposed in isolation and fail to consider the interaction of the annular gas behavior, the operation of the pump and surface gathering systems. Consequently, the efficiency of this kind of actions is low and fails to guarantee the stable long-term enhancement of production performance [3,9]. The annular gas formation must be viewed as the system-level issue that impacts the downhole and surface aspects of oil production.

This study aims at examining the process of accumulating, collecting, and transporting oil and annular gas through wells which are operated by sucker rod pump systems and to review engineering solutions that enhance stability in production and efficiency of the activities. The target of the study is the oil production procedure in sucker rod pumped well, and the topic of the study is the behavior of the annular gas and its effects on the performance of the pump and collection systems [1,5].

The methodology used in research is engineering analysis of multiphase flow of the wellbore, the characteristics used in operating the sucker rod pumps, and common oil and gas collection plans. Effects of annular pressure, dynamic behavior of the fluid the level between the pumps and modifications in pump functionality are evaluated with simplified analytical relationships when working conditions are steady-state [2,7].

Oil and Annular Gas Gathering and Transportation Systems

With wells where the sucker rod pumping systems are used, oil is transported to the surface via the tubing with a large part of the free gas entering the annular space. In advantageous circumstances, the annulus serves as a gravity type separator with gases ascending and liquid descending beneath the pump intake. The quality of this mechanism is determined by the depth of pump setting and annular flow area [4,6].

Produced fluids at the wellhead are discharged into surface gathering systems that allow the separation of oil and gas and their transportation. The annular gas usually passes into gas collection lines or gas use systems via the casing head. Rich annular pressure will raise the pressure behind the head which may cause loss in separator efficiency and flow destabilisation in a collecting pipeline [1,8].

Surface gathering systems can either be designed as single flowline or centre systems that service a number of wells. The lack of separation capacity and the improperly designed gas outlets in

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

wells with high gas to oil ratios cause the pressure fluctuation, liquid carryover, and high hydraulic losses [3,7]. These impacts have adverse effects on stability in production and reliability of operations.

To increase the efficiency of the collection and transportation process in the circumstances of annular gas accumulations, the coordination of the work of the downhole equipment and the facilities presented on the surface will be needed. The use of measures like controlled annular gas bleeding, lowering backpressure of the gathering system, and optimization of the operating conditions of the separators are known to give rise to more stable regimes of flow, decrease in the losses occurring due to gases [2,5].

Calculation methodology

order to determine the impact of annular gas accumulation on the performance of sucker rods pumps and gathering efficiency, simplified engineering calculation process is used. The analysis is based on the steady-state operation of well and it is possible to estimate the effect of annular pressure on dynamic fluid level, pump submergence and volumetric efficiency [7,9].

Pump volumetric efficiency will be used as the determination of the actual liquid production divided by an imaginary pump capacity. Compressible gas in the presence of free gas at the pump intake occupies part of the pump cylinder volume, and it reduces effective liquid displacement, and decreases effectiveness [2, 4]. In case of gas interference conditions, the volumetric efficiency can reduce to 0.40-0.60.

The accumulation of annular gas raises the pressure in bottom of the hole and can therefore be described as accumulated bottom-hole pressure which is the summation of wellhead pressure, liquid column hydrostatic pressure and the extra pressure of annular gas that is generated. Increased annular pressure means that the level of the liquid column above the pump inlet will be lower, and it means that the pump submergence will be reduced [1,6].

Comparative calculations of the base, as well as the improved operating conditions are carried out to determine the effectiveness of annular gas control. The variations in the annular pressure are employed in estimating the change in the pump efficiency and rate of liquid production; therefore, offering a quantitative means of assessing gas management practices [3,8].

Development of Measures to Improve Gathering and Transportation Efficiency

To increase performance of sucker rod pumped wells operating in the conditions of annular gas accumulation, the complex of downhole operations with surface ones is needed to decrease annular pressure and maintain conditions of stable pumping intake. Maximization of the depth of pump setting enhances natural separation in the well bore using natural grains and minimizes the chances of free gas entering the pump [5,7].

To restrict entry of gases into the pump intake downhole gas separators and gas anchors are being widely employed. They can be used to effectively increase the volumetric efficiency of a well during moderate in terms of gas content, but they become less efficient at high flow rates because of geometry [1,6]. The choice of the separator type and operating conditions is then imperative.

One of the measures that are highly effective in the wells that are linked with the high-pressure gathering systems is forced extraction of annular gas at the wellhead. The decreasing annular pressure increases the dynamic fluid height, enhances submergence of the pump, and stabilizes production [3,9]. Experimental uses In region of control, experimental uses exhibit that controlled gas recovery not only lessens the fluctuations in pressure in surface flowlines, but it additionally diminishes their occurrence [2,8].

Further enhancements can be done through optimization of surface gathering and transportation systems. Relieving backpressure of flowlines, augmenting separator capacity, and maintaining a steady gas discharge condition can reduce the hydraulic losses and enhance the reliability of the system, in general [4,5]. The combination of all these measures is the most beneficial in terms of stability and efficiency in production.

Calculation Results and Analysis

Relative computations indicate that the accumulation of annular gas has a great impact with a negative effect on the sucker rod pump operation and collection efficiency. The base operating condition of high annular pressure, low pump submergence causes a fear of interference with the gases and high volumetric efficiency reduction, which reduces the rates of liquid production [6,8].

Upon the introduction of the annular gas control tools such as forced extraction of gas and optimization of the gathering conditions, the pressure decreases in the annulus, and the dynamic fluid level increases. This enhances the state of pump intake as well as boosting volumetric efficiency which results in a visible increment in liquid and oil production [2,5]. The estimations made by the engineers show that under supportive conditions, production boosts of a number of tons of oil per day in a single well can be realized [1,9].

Mechanical stability of pumping system is also enhanced due to low annular pressure. A reduced cyclic load variation in the rod string caused by lower gas compression within the pump cylinder helps to increase service life of equipment and lowers the maintenance rate [3,7]. Areas of surface stabilization of flow regimes are generated by lower wellhead pressure in gathering pipelines and better performance of separators [4,8].

The findings establish that the presence of annular gas build-ups influences the downhole and top aspects of the production system. Successful enhancement is possible only when the management of annular gas is considered an engineering activity comprising of pump optimization and reasonable structure of gathering and transportation systems [5,6].

Conclusion

The discussion ensures that a high concentration of the associated petroleum gas in the annular space poses a serious de-performing effect on wells when using the sucker rod type of pumping. Higher annular gas pressure increases the bottom-hole pressure and decreases effective drawdown in the reservoir and the dynamic fluid level moves closer to the pump intake resulting in gas interference and loss in pump volumetric efficiency [4,7].

The engineering analysis demonstrates that a lack of control over the annular gas buildup may decrease the efficiency of pumps by up to 4060 percent, whereas the competent management of annular gas may significantly enhance the pump intake conditions and the regular character of production [1,6]. Annular pressure reduction follows to enhance liquid rates of production, maintenance to the mechanical operation of the pumping system, and decrease in cyclic loads on the rod string [3,8].

The findings prove that solitary technical interventions can offer a low impact. Only a complex strategy that ensures an optimal of the setting depth of pumps, the implementation of gas separation, the active extraction of the annular gas, and the reasonable construction of surface collection and transportation systems contribute to sustainable improvement [2,5,9]. This will decrease the losses associated with gas and will enhance the efficiency and reliability of wells being pumped by a sucker rod.

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Takach, N. E., & Lea, J. F. (1991). Gas separators and gas anchors for rod pumps. SPE Production Engineering, Society of Petroleum Engineers.
2. Fakher, S., Khlaifat, A., Hossain, M. E., & Nameer, H. (2021). A comprehensive review of sucker rod pumps' components, diagnostics, mathematical models, and common failures. Journal of Petroleum Exploration and Production Technology, 11, 3815–3839.
3. McCoy, J. N., Lea, J. F., & Boland, M. R. (2013). Evaluation and performance of packer-type gas separators with sucker rod pumps. SPE Artificial Lift Conference and Exhibition, SPE-164510-MS.
4. Allison, A. P. (2018). Solving gas interference issues with sucker rod pumps in mature oil fields. SPE Artificial Lift Conference and Exhibition – Americas, SPE-190936-MS.
5. Artyukhov, A. V., Isaev, A. A., Drozdov, A. N., & Gorbyleva, Y. A. (2022). Rod string load variation during annular gas extraction. Energies, 15(14), 5045.
6. Lea, J. F., Nickens, H. V., & Wells, M. R. (2008). Gas well deliquification. Gulf Publishing Company.
7. Takach, N. E. (2015). Artificial lift methods for mature oil fields. Journal of Petroleum Technology, 67(6), 72–77.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

8. Guo, B., Lyons, W. C., & Ghalambor, A. (2007). Petroleum production engineering: A computer-assisted approach. Elsevier.
9. American Petroleum Institute. (2010). API Specification 11B: Specification for sucker rods, polished rods and liners (27th ed.). API Publishing.

NASOS ÇUBUĞU SİSTEMLƏRİ İLƏ İŞLƏDİLƏN QUYULARDA NEFT VƏ HALQAVARİ QAZIN TOPLANMASI VƏ NƏQLİ

Sərdar Bayramov[1], Nihad Əliyev[2]
[1]Texnika elmləri doktoru, professor, "Neftin və Qazın Nəqli və Saxlanması" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti. E-mail: petrotech@asoiu.az
[2]Magistr tələbəsi, Neft və Qaz İstehsalı Fakültəsi, Azərbaycan Dövlət Neft və Sənaye Universiteti. E-mail: nihad.aliyev@ufaz.az

XÜLASƏ

Ştanqlı nasos qurğuları lay təzyiqi azalmış neft yataqlarında geniş istifadə olunur. İstismar zamanı neftlə birlikdə poput neft qazı hasil edilir və bu qazın bir hissəsi boru arxası fəzada toplanır. Boru arxası qaz təzyiqinin artması quyu dibi təzyiqini yüksəldir, səmərəli lay axınını azaldır və dinamik səviyyəni nasosun qəbuluna yaxınlaşdırır. Bu isə sərbəst qazın nasosa daxil olmasına və ştanqlı nasosların həcm əmsalının azalmasına səbəb olur. Məqalədə ştanqlı nasoslarla istismar olunan quyularda neftin və boru arxası qazın yığılması, toplanması və nəqli prosesləri təhlil edilir. Nəticələr göstərir ki, boru arxası qazın idarə olunması və düzgün seçilmiş toplama–nəql sistemləri hasilatın sabitliyini artırır və qazla bağlı itkiləri azaldır.
Açar sözlər: ştanqlı nasos, boru arxası qaz, neft hasilatı, poput neft qazı, qaz müdaxiləsi, həcm əmsalı, dinamik səviyyə, toplama və nəql sistemləri.

СБОР И ТРАНСПОРТИРОВКА НЕФТИ И КОЛЬЦЕВОГО ГАЗА В СКВАЖИНАХ С СИСТЕМАМИ ШТОКОВОГО НАСОСА

Сардар Байрамов[1], Нихад Алиев[2]
[1]Доктор технических наук, профессор, кафедра «Транспортировка и хранение нефти и газа», Азербайджанский государственный университет нефти и промышленности. E-mail: petrotech@asoiu.az
[2]Магистрант, факультет добычи нефти и газа, Азербайджанский государственный университет нефти и промышленности. E-mail: nihad.aliyev@ufaz.az

РЕЗЮМЕ

Снижение давления в пласте является распространенным явлением в нефтяных скважинах, которые эксплуатируются с использованием штанговых насосных установок. Часть сопутствующего нефтяного газа отделяется от нефти во время добычи и накапливается в кольцевом пространстве. Повышение давления газа в кольцевом пространстве приводит к повышению давления на дне скважины, снижению эффективного расхода и сдвигу динамического уровня вверх по направлению к входу насоса. Это приводит к попаданию

свободного газа в насос, что снижает объемную эффективность насоса. В статье обсуждаются процессы накопления нефти, сбора и транспортировки в скважинах, эксплуатируемых с помощью штанговых насосов. Доказано, что управление газом в трубах и разумная организация систем сбора и транспортировки обеспечивают большую стабильность добычи, а также снижают потери при эксплуатации.
Ключевые слова: штанговый насос, затрубный газ, добыча нефти, попутный нефтяной газ, газовая интерференция, объёмная эффективность, динамический уровень, системы сбора и транспорта.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

282-286

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-31

POLYMER TECHNOLOGIES FOR ENHANCING OIL RECOVERY: APPLICATION OF WATER INJECTION TECHNOLOGIES BASED ON PRE-CROSSLINKED POLYACRYLAMIDE PARTICLES TO ENHANCE OIL RECOVERY

Fahmin Azizli
Doctoral student, Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: fahmin99@mail.ru

ABSTRACT

Most of the existing oil fields are in the final stage of their exploitation and are characterized by high waterlogging levels and heterogeneity of the layers. In these conditions, the optimization of secondary and tertiary oil recovery technologies applied to increase the oil recovery coefficient is of particular relevance. The article comparatively analyzes the traditional polymer waterlogging technology, which is widely used to increase the oil recovery coefficient, and an alternative water injection method based on pre-crosslinked polyacrylamide (QPA) particles. The rheological properties of partially hydrolyzed polyacrylamides (QPA), the influence of the composition and temperature of the produced water on the polymer behavior, as well as the crosslinking mechanisms of polymers, are studied in detail. The results of international and domestic production experiments show that QPA-based technologies demonstrate more stable rheological properties at high temperatures and salinity and can be more effective in increasing oil production. The article evaluates the advantages of QPA technology, application risks and prospects for Russian oil fields on a scientific basis .
Keywords: oil recovery coefficient, polymer dilution, polyacrylamide, QHPA, QPA, cross-linked polymers, reservoir acceptance profile.

Introduction.

Nowadays, a significant part of the world's oil fields are in the final stages of exploitation. These fields are characterized by high water content, heterogeneity of the layers and difficult-to-recover form of residual oil reserves. In such conditions, technologies applied to increase the oil recovery factor (ERF) remain one of the main scientific and technical problems of the oil industry.

One of the most widely used NFA methods is polymer fluidization. This technology allows the involvement of low-permeability zones saturated with oil by reducing the mobility of water in the formation and redistributing the seepage flow. However, classic polymer fluidization based on water-soluble polyacrylamides has a number of technological and rheological limitations.

In recent years, in order to overcome these shortcomings, water injection technologies based on pre-crosslinked polyacrylamide particles (QPA) have been widely studied and successfully applied in a number of countries. The aim of the article is to comparatively analyze the scientific

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

and technical characteristics of traditional polymer water injection and QPA-based technologies and assess their application prospects.

Traditional Polymer Watering Technology.

Classical polymer watering technology involves injecting a polymer solution equal to 0.3–0.5 volumes of the pore space of the formation. The process usually lasts for a long time (a year or more), and the water injection stage is carried out after the polymer injection.

The main function of the polymer solution is to increase the viscosity of water, thereby reducing its mobility relative to oil. As a result, instead of moving rapidly through high-permeability channels, water is directed to low-permeability and oil-saturated zones. This can lead to an increase in the oil recovery coefficient by 5–30%. The most widely used polymer is partially hydrolyzed polyacrylamide (PHP). Its degree of hydrolysis usually varies in the range of 25–35%. The degree of hydrolysis is one of the main parameters that determines the viscosity of the aqueous solution of the polymer and its sensitivity to ions.

At low hydrolysis rates, the polymer solution does not develop sufficient viscosity, while at high hydrolysis rates, sensitivity to salts in the formation water increases. In particular, polyvalent cations (Ca^{2+} , Mg^{2+}) can cause coagulation by forming intramolecular and intermolecular crosslinks between the polymer chains. QHPA solutions exhibit pseudoplastic and thixotropic behavior. Viscosity decreases with increasing shear rate or increases after a certain critical threshold. This unstable rheological behavior can lead to difficult-to-predict results under formation conditions.

In addition, the rapid degradation of water-soluble polyacrylamides under high temperature and high salinity conditions is one of the main disadvantages of classical polymer hydration.

Technologies Based on Pre-Crosslinked Polymer Particles (QPA).

QPA technology is based on the injection of pre-crosslinked polyacrylamide particles into the formation in the form of an aqueous suspension. These particles swell in water, but do not completely dissolve, and provide flow redistribution by partially blocking high-permeability channels in the formation.

The behavior of QPA particles in the layer is explained by several mechanisms:

- particle deformation and passage through narrow pores;
- particle fragmentation and movement along the layer;
- getting stuck in high permeability zones, creating selective blockage.

Laboratory tests show that swollen QPA particles can pass through pores 15–25% of their diameter. QPA-based polymers maintain their rheological properties more stable at high temperatures (up to 140°C) and in highly mineralized reservoir waters. This makes them more reliable than water-soluble polyacrylamides.

Industrial Applications and International Experience.

China, the United States, and Canada are among the leading countries in the application of QPA technology. By 2013, more than 4,000 well operations using QPA technology had been carried out.

As a result of the applications carried out in the Pucheng and Xinbei fields, waterlogging in production wells was significantly reduced and daily oil production increased by 1.5 times. In the Daqing fields, an additional 113 tons of oil were produced for every ton of polymer.
Technologies based on reagents such as "Temposcreen", "Retin-10", and "Polikar" have been applied in Russia and the CIS countries and positive results have been achieved.

Comparative Analysis of Technologies and Conclusion.
The analysis shows that although traditional polymer fluidization technology is simple and relatively inexpensive, it has a limited application due to rheological instability and high sensitivity to reservoir conditions.
QPA technology and :

- high temperature and to salinity is durable ;
- more low reagent volume demand does ;
- layer acceptance profile effective alignment provide does .

However, in the application of QPA particle size correct selection and the Kern tests carrying out important condition as remains .
Conducted research and analyses shows that in advance cross related polyacrylamide to particles based on QPA technology oil extraction coefficient increase for promising and efficient International approach experience this technology high effectiveness proof Russia and other similar geological QPA technology in suitable fields application for wide scientific research of their work carrying out It is appropriate.

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

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

Acknowledgments
The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

1. Abdullayev MQ, Garayev RQ, Hajiyev AK "Oil-based reagent for increasing oil yield of reservoirs and isolating water flow to production wells". Patent -№2015/0064, 2015, 05.
2. Abdullayev MG, Mahmudov QM, Garayev RG "New composition and technology for preventing water flow from formations to production wells" «Azerbaijan Oil Economy», April 2016, No. 4
3. Salavatov T.Sh., Aliyev YM, Kazimov Sh.P. et al. "On the effectiveness of methods for isolating water flow into wells". Azerbaijan Oil Economy , No. 1, 2011, pp. 20-25.
4. Abdullayev MG "Reagent on Oil Basis to Increase Oil Recovery and isolation of Water Breakthrough into Oil Producing Wells". Journal of Petroleum & Petrochemical Engineering. Volume 2 Issue 5, August 2018, p.1-9

NEFTÇIXARMA ƏMSALININ ARTIRILMASI ÜÇÜN POLİMER TEXNOLOGİYALARI: ƏVVƏLCƏDƏN ÇARPAZ ƏLAQƏLİ POLİAKRİLAMİD HİSSƏCİKLƏRİNƏ ƏSASLANAN SUVURMA TEXNOLOGİYALARININ NEFTÇIXARMA ƏMSALININ ARTIRILMASINDA TƏTBİQİ

Fəhmin Əzizli
Doktorant, Azərbaycan Dövlət Neft və Sənaye Universitetinin, Azərbaycan. E-mail: fahmin99@mail.ru

XÜLASƏ

Mövcud neft yataqlarının əksəriyyəti istismarının son mərhələsində olmaqla, yüksək sulaşma səviyyəsi və layların heterogenliyi ilə xarakterizə olunur. Bu şəraitdə neftçıxarma əmsalının artırılması üçün tətbiq olunan ikincili və üçüncülü neftçıxarma texnologiyalarının optimallaşdırılması xüsusi aktuallıq kəsb edir. Məqalədə neftçıxarma əmsalının artırılması məqsədilə geniş tətbiq olunan ənənəvi polimerli sulaşdırma texnologiyası və əvvəlcədən çarpaz əlaqəli poliakrilamid (QPA) hissəciklərinə əsaslanan alternativ suvurma üsulu müqayisəli şəkildə təhlil edilmişdir. Qismən hidroliz olunmuş poliakrilamidlərin (QHPA) reoloji xüsusiyyətləri, lay suyunun tərkibinin və temperaturun polimer davranışına təsiri, eləcə də polimerlərin çarpaz əlaqələnmə mexanizmləri ətraflı araşdırılmışdır. Beynəlxalq və yerli istehsalat təcrübələrinin nəticələri göstərir ki, QPA əsaslı texnologiyalar yüksək temperatur və duzluluq şəraitində daha sabit reoloji xüsusiyyətlər nümayiş etdirir və neft hasilatının artırılmasında daha səmərəli ola bilər. Məqalədə QPA texnologiyasının üstünlükləri, tətbiq riskləri və Rusiya neft yataqları üçün perspektivləri elmi əsaslarla qiymətləndirilmişdir.
Açar sözlər: neftçıxarma əmsalı, polimerli sulaşdırma, poliakrilamid, QHPA, QPA, çarpaz əlaqəli polimerlər, layın qəbuletmə profili.

ПОЛИМЕРНЫЕ ТЕХНОЛОГИИ ДЛЯ ПОВЫШЕНИЯ НЕФТЕОТДАЧИ: ПРИМЕНЕНИЕ ТЕХНОЛОГИЙ ЗАКАЧКИ ВОДЫ НА ОСНОВЕ ПРЕДВАРИТЕЛЬНО СШИТЫХ ЧАСТИЦ ПОЛИАКРИЛАМИДА ДЛЯ ПОВЫШЕНИЯ НЕФТЕОТДАЧИ.

Фахмин Азизли

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Докторант, Азербайджанской Государственной Университет Нефти и Промышленности, Азербайджан.
E-mail: fahmin99@mail.ru

РЕЗЮМЕ

Большинство существующих нефтяных месторождений находятся на заключительных стадиях эксплуатации и характеризуются высоким уровнем обводнения и неоднородностью пластов. В этих условиях оптимизация технологий вторичной и третичной нефтедобычи, применяемых для повышения коэффициента нефтеизвлечения, приобретает особую актуальность. В статье проводится сравнительный анализ традиционной технологии полимерного обводнения, широко используемой для повышения коэффициента нефтеизвлечения, и альтернативного метода закачки воды на основе предварительно сшитых частиц полиакриламида (ППА). Подробно изучены реологические свойства частично гидролизованных полиакриламидов (ППА), влияние состава и температуры добываемой воды на поведение полимера, а также механизмы сшивания полимеров. Результаты международных и отечественных производственных экспериментов показывают, что технологии на основе ППА демонстрируют более стабильные реологические свойства при высоких температурах и солености и могут быть более эффективными в повышении нефтедобычи. В статье на научной основе оцениваются преимущества технологии ППА, риски применения и перспективы для российских нефтяных месторождений.

Ключевые слова: коэффициент нефтеизвлечения, разбавление полимером, полиакриламид, QHPA, QPA, сшитые полимеры, профиль приемлемости пласта.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

287-296

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-32

VOLUME 33 (08) ISSUE 02 2026

CHARACTERISTICS OF COMBUSTION PROCESSES IN GASOLINE ENGINES

Elvira Huseynova[1], Eljan Najafli[2]
[1]Doctor of Chemical Sciences, Professor, Department of Petrochemical Technology and Industrial Ecology, Azerbaijan State Oil and Industry University, Email: elvira_huseynova@mail.ru
[2]Master's Degree Student, Faculty of Chemical Technology, Azerbaijan State Oil and Industry, Email: nacaflielcan@gmail.com

ABSTRACT

Due to population growth, the demand for machinery and energy has risen across various sectors, including transportation, agriculture, power generation, and heavy industry.

Diesel engines are widely used because they provide high power at a lower cost than similar engines. Current research focuses on improving efficiency, cutting fuel consumption, and reducing emissions, especially due to limited fossil fuels and stricter environmental regulations. As a result, attention is increasing on advanced fuel systems and alternative fuels to enhance performance and lower environmental impact.

The development of the spark-ignition engine represented a major breakthrough in the advancement of internal combustion technology, significantly influencing the design and operation of modern power units. Its introduction made it possible to achieve controlled combustion of the air–fuel mixture, leading to improved reliability, smoother operation, and broader practical applications in transportation and industry.

Over the past few decades, gasoline engines have undergone substantial technological improvements, driven by the demand for higher efficiency, enhanced performance, and lower environmental impact. Innovations such as advanced fuel injection systems, electronic engine management, and optimized combustion strategies have greatly increased their power output and fuel economy while reducing emissions.

Combustion in gasoline engines is a rapid, premixed burning of fuel and air, marked by distinct heat release, pressure variations, and flame spread affected by injection timing, engine load, and mixture uniformity.

Keywords: Gasoline, internal combustion engine, combustion process, detonation, anti-detonation properties.

Introduction

Gasolines are liquid petroleum fuels intended for use in piston internal combustion engines with forced ignition (spark ignition). Depending on their purpose, they are divided into automotive and aviation types.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Despite differences in operating conditions, automotive and aviation gasolines are mainly characterized by common quality indicators that determine their physico-chemical and performance properties.
The operating conditions of gasolines are determined by:

- The operating conditions of automotive equipment (on land, in the air, in summer, in winter, on plains, in mountainous areas, in southern regions, in the North, etc.);
- The characteristics of the engine working process.

The operating cycle of a spark-ignition engine (Fig.1), like all internal combustion engines, consists of the processes of fuel evaporation, mixture formation, ignition, and combustion. During fuel combustion, thermal energy is released and converted by the engine into mechanical work. In piston engines with spark ignition, the combustible mixture is formed either in a special device—the carburetor—or directly in the engine cylinder, into which air and fuel are supplied separately. Accordingly, carbureted engines and engines with direct fuel injection are distinguished [1].
The carburetor operates on the principle of ejection, that is, the creation of a vacuum in a narrow section of the duct due to a pressure difference and the conversion of the air's potential energy into kinetic energy. As a result, fuel is drawn in by the air stream.

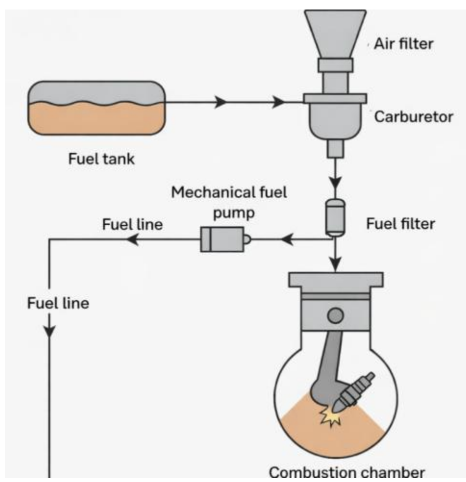


Figure 1: Spark-ignition engine [2].

The evaporation of gasoline and the formation of the combustible mixture occur in the air stream along the path from the carburetor to the cylinder and are completed in the combustion chamber. The air velocity in the carburetor diffuser is 40–150 m/s and is 20–30 times higher than the velocity of the fuel jet.
In the air stream, the fuel jet breaks up into fine droplets with an average diameter of 0.1–0.3 mm. The formed droplets are entrained by the air flow and evaporate intensively. Some of the droplets enter the engine cylinders, where evaporation is completed under the effect of high temperature. Another portion of the droplets, upon leaving the carburetor diffuser, settles on the walls of the intake manifold and forms a film of liquid fuel [3].
The air–fuel vapor flow moves this film in the direction of the engine cylinders. The velocity of movement of the liquid fuel film is 50–60 times lower than the velocity of the air–fuel vapor mixture. Under these conditions, intensive evaporation of fuel from the film surface occurs.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

The formation of a liquid fuel film leads to uneven distribution of the mixture among the engine cylinders, especially under variable operating conditions (Fig. 2).

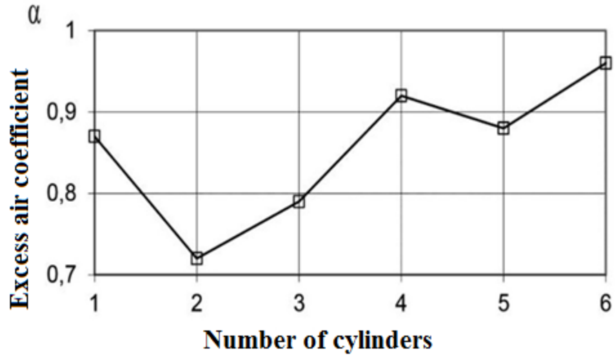


Figure 2: The quantitative unevenness of mixture distribution among the engine cylinders at fully open throttle [4].

The quantitative unevenness of the combustible mixture is characterized by different air–fuel ratio coefficients (α) in the engine cylinders.

Qualitative unevenness is characterized by differences in the content of individual gasoline fractions and additives in the combustible mixture supplied to different engine cylinders. Gasoline is a mixture of various hydrocarbons, so as the lighter fractions evaporate, the liquid film becomes enriched with heavier hydrocarbons. This phenomenon of fuel fractionation occurs during the preparation of the combustible mixture in the intake manifold.

In cylinders receiving a greater proportion of the vapor–air phase, the content of light gasoline fractions will be higher, while in cylinders receiving more of the liquid phase, the content of heavy fractions will be higher. The evaporation of additives contained in gasoline occurs along with the gasoline fractions that have similar volatility to the additive. Uneven distribution of fractions among the cylinders leads to an uneven distribution of additives (Fig. 3).

It has been established that the quality and unevenness of mixture distribution among the cylinders depend on the saturated vapor pressure, fractional composition, latent heat of evaporation, vapor diffusion coefficient, viscosity, surface tension, specific heat, density, as well as the air velocity and temperature, the degree of vacuum in the diffuser, the amount of heat received from the engine, and its operating mode.

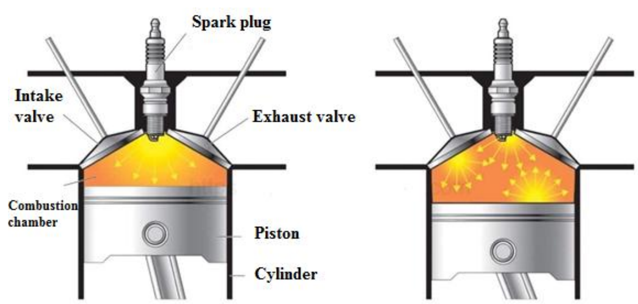


Figure 3: Ignition in a fuel-injected engine [6].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

When forming the fuel–air mixture, the heat required for fuel evaporation is drawn from the air. As a result, the temperature of the air—and consequently of the mixture—can drop enough to cause condensation and subsequent freezing of atmospheric moisture, i.e., carburetor icing occurs. It has been observed that at an air temperature of 7.5 °C, the temperature of the throttle plate drops to −14 °C within 2 minutes. Ice formation is mainly observed on the throttle plate and the inner walls of the carburetor diffuser. Icing intensifies with increasing air humidity.

Ice formation is influenced by the fuel–air ratio, the specific heat and latent heat of evaporation of the fuel, and the air temperature. Evaporation conditions can be improved by heating the intake manifold; however, at elevated temperatures of the fuel–air mixture, the cylinder filling factor decreases, and engine power drops [5].

The ignition and combustion processes in a carbureted engine occur as follows. The fuel–air mixture enters the engine cylinders, where it mixes with the combustion products, is compressed, and then ignited.

When ignited by a spark plug, the mixture in the discharge zone is heated almost instantaneously. The rate of chemical reactions then becomes self-accelerating, culminating in the formation of a flame. Flame propagation can be laminar or turbulent, depending on the nature of the mixture's motion. Cylinder filling occurs at high velocities, creating strong swirling motion. Under these conditions, combustion is turbulent, and the normal flame front propagation speed ranges from 10 to 40 m/s. This speed depends on the crankshaft rotational speed (Fig. 4) and the composition of the fuel–air mixture.

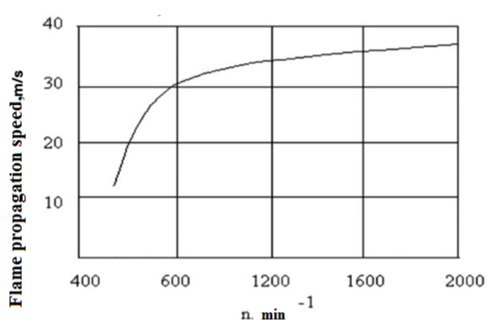


Figure 4: Effect of crankshaft rotational speed on the average flame propagation speed [7].

Increasing the compression ratio and using supercharging lead to a rise in the flame front propagation speed. The maximum flame propagation speed is observed at an air–fuel ratio of α = 0.9.

When the working mixture is enriched, the flame front propagation speed decreases due to a lack of oxygen, while in a lean mixture, it decreases because heat is spent on heating the excess air. It is generally accepted that, under engine conditions, the flammability limits of the fuel–air mixture are 0.4…0.5 < α < 1.3…1.4. From the perspective of mixture formation and fuel combustion processes, it is necessary to ensure a higher temperature of the combustible mixture, which, on the one hand, improves fuel evaporation and, on the other, expands the concentration limits of flammability (Fig. 5).

Expanding the concentration limits of flammability creates the conditions for stable engine operation on lean mixtures.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

To improve mixture homogeneity and effectively solve the problem of mixture uniformity, fuel is injected directly into the engine cylinder or into the intake manifold.

Direct fuel injection into the cylinder ensures reliable ignition and combustion of lean mixtures in gasoline engines by creating a directed swirl of the charge and injecting fuel into the cylinder at such an angle and timing that a region of enriched mixture forms in the area of the spark plug under any engine operating condition. This portion of the charge, ignited by the spark, ensures rapid flame propagation throughout the combustion chamber containing the lean mixture, thereby providing high engine efficiency [9].

Under full-load conditions, a uniform mixture composition close to stoichiometric ($\alpha = 0.9\ldots1.0$) is ensured. Therefore, engines with direct injection and stratified mixture formation exhibit high fuel efficiency and good environmental performance while delivering increased power and torque.

Fuel injection into the intake manifold reduces hydraulic intake losses and increases the volumetric efficiency by creating an inertial supercharging effect. Gasoline is injected in synchronization with the working strokes of each cylinder. The mixture flows in a spiral along the snail-shaped intake channel, forming a vortex. This causes turbulence in the mixture charge, which significantly improves the engine's anti-knock properties.

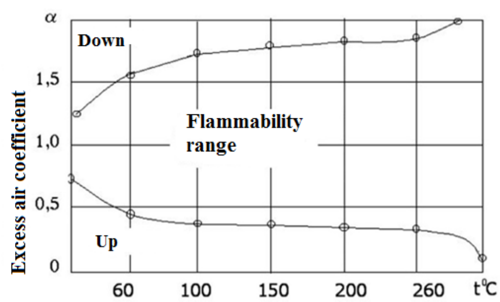


Figure 5: Dependence of the flammability of the fuel–air mixture on temperature at a pressure of P = 0.1 MPa [8].

Vortex processes expand the limits of effective mixture lean operation by 10–15%, increase the optimal values of the air excess ratio (α), and reduce cycle-to-cycle fluctuations in peak pressures when the mixture composition and ignition timing are optimally adjusted.

The "timing" of the combustion process is largely controlled by the ignition timing, i.e., the spark advance angle. If the mixture is ignited too late, combustion may begin during the expansion stroke, which reduces engine power and worsens its fuel efficiency. If the mixture is ignited too early, combustion occurs during the compression stroke, significantly increasing power losses due to the gas pressure acting on the piston as it moves toward the top dead center.

The most advantageous ignition timing is that at which the main phase of combustion is positioned symmetrically around the top dead center on the indicator diagram. For automatic regulation of the ignition timing in modern engines, a centrifugal advance regulator is installed, which adjusts the angle depending on the crankshaft speed, and a vacuum regulator, which changes the angle according to engine load. However, all of this applies to normal combustion. Normal combustion is defined as combustion in which the flame front propagates through the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

combustion chamber as a result of heat transfer by conduction and radiation. During normal fuel combustion in the engine, the flame front propagation speed is relatively low and does not exceed 40–50 m/s.

Under certain engine operating conditions, especially those involving high loads or the use of fuel that does not meet the requirements for normal combustion, detonation combustion may occur.

The process works like this: during the intake and compression strokes, the fuel-air mixture starts small chemical reactions even before ignition, creating highly reactive intermediate compounds. These reactions happen faster and more intensely when temperature and pressure increase, which occurs at higher compression. As the mixture burns, the temperature and pressure in the combustion chamber rise quickly. The last parts of the mixture are exposed to the highest temperature and pressure, causing them to ignite suddenly on their own.

A new flame front forms. At the same time, a new shock wave appears, which, as it moves through the hot, reactive mixture where pre-flame reactions are nearly complete, accelerates its spontaneous ignition. The flame front then spreads at the same speed as the shock waves. This creates a detonation combustion wave, which is the propagation of a shock wave with a flame front at a speed of 1500–2500 m/s. The metallic knocking sound in an engine experiencing detonation is caused by repeated reflections of shock waves off the combustion chamber walls. On the indicator diagram, this appears at the end of combustion as pressure vibrations in the form of a series of damped peaks. Because of the high speed and explosive nature of detonation, part of the fuel and intermediate combustion products are scattered throughout the chamber, mix with combustion products, and do not have time to burn completely.

The main danger of detonation lies in the increased heat transfer from the burned gases to the combustion chamber walls and the piston crown. This is caused by the higher temperatures in the detonation wave and by an increased heat transfer coefficient due to the disruption of the boundary layer of cooler gas [5].

Increased heat transfer to the walls leads to engine overheating and can cause localized damage to the surfaces of the combustion chamber and the piston crown. In addition, operating an engine under detonation conditions, results in increased wear of its components (Fig. 6).

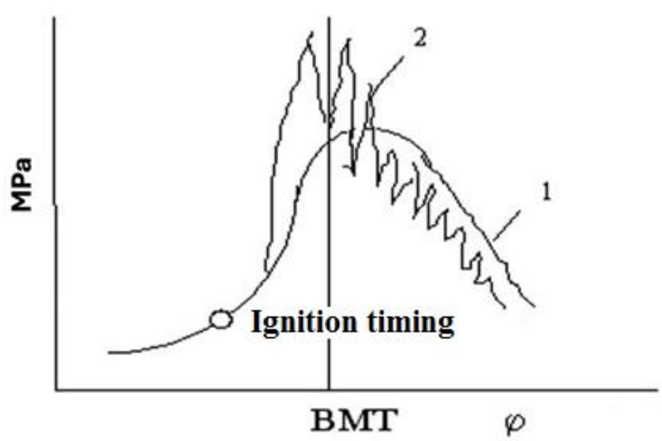


Figure 6: Expanded indicator diagram of a carburetor engine: 1 – normal combustion; 2 – detonation combustion [8].

The main factors affecting the occurrence of detonation include: engine compression ratio, combustion chamber shape, cylinder diameter, piston and cylinder head materials, presence of carbon deposits, ignition timing, crankshaft speed, ambient temperature and humidity, mixture composition, coolant temperature, and so on.

In engines with a high compression ratio, "pre-ignition" can sometimes occur—spontaneous ignition of the working mixture regardless of the spark timing. Sources of pre-ignition are hot objects, such as glowing carbon deposits or overheated parts of the piston-cylinder group [8].

Pre-ignition is fundamentally different from detonation, although the two phenomena are closely related under normal engine operating conditions. After pre-ignition, the mixture burns at normal speeds and may not lead to detonation. While pre-ignition and detonation are often linked and can occur in the engine at the same time, the mechanisms of these processes and the methods for preventing them are significantly different.

Pre-ignition disrupts the normal course of the combustion process, making it uncontrollable. The uncontrolled development of combustion during pre-ignition also causes knocking, engine overheating, and a loss of power [9].

Thus, based on the above, to ensure high efficiency in the use of gasoline in modern engines and to optimize its physico-chemical quality characteristics, the following requirements are set, which can be divided into four areas:

1 – Engine design requirements:

- Have optimal anti-knock properties on both lean and rich mixtures, across various engine operating modes;
- Possess good volatility to ensure easy starting, stable operation, and good engine responsiveness;
- Be compatible with construction materials.

2 – Operational requirements:

- Flow well under different conditions, not form vapor locks, and not produce solid residues at low temperatures;
- Be stable during storage and not form deposits in the fuel system.

3 – Production-related requirements:

- Have a broad raw material and manufacturing base, with well-established technologies.

4 – Environmental safety requirements:

- Be safe to handle;
- Not cause environmental pollution either directly or through combustion products.

Conclusion

The theoretical analysis shows that in gasoline spark-ignition engines, the combustion process is determined by the fuel's ability to vaporize, the homogeneity of the mixture, and the propagation of the flame in a turbulent environment. In fuel-injection systems, the selective vaporization of different fuel fractions and the accumulation of the liquid fuel phase lead to an uneven distribution of the mixture across cylinders, thereby limiting combustion stability. Detonation and pre-ignition are associated with the disruption of the normal flame propagation mechanism under high temperature and pressure conditions, increasing thermal loads on engine components and complicating the control of the engine's operational process. These phenomena can be prevented by precisely optimizing the fuel's anti-detonation properties and ignition parameters. Direct injection systems ensure controlled formation of the mixture in the cylinder, enhance the development of turbulent structures, and increase the thermodynamic efficiency of combustion. As a result, the key requirements for modern gasoline engines are high fuel vaporization capacity, fraction stability, resistance to detonation, and environmental safety.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Samoilov V. O., Stolonogova T. I., Ramazanov D. N., Tyurina E. V., Sultanova M. U., Lavrentyev V. A., Krasnoshtanova S. S., Chernysheva E. A., Kapustin V. M. Tert-butyl ethers of renewable diols as oxygenate additives to motor gasolines. Part II: ethers of ethylene glycol and butanediol-2,3. Petrochemistry, Vol. 63, No. 4, 2023, pp. 545–555.
2. Bozkurt O. D., Yilmaz F., Baglar N., Çelebi S., Uzun A., Compatibility of di- and tri-tert-butyl glycerol ethers with gasoline, Fuel, Vol. 255, 2019, 115767.
3. C.W.M. Noor, R. Mamat, O. Ali, G. Najafi, W.N.D. Mansor, Cyclic variation analysis of palm biodiesel fuel in low compression marine diesel engine, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, Vol. 75 (2), 2020, pp. 43–58.
4. Herrada-Vidales J. A., García-Gonzales J. M., Martínez-Palou R., Guzman-Pantoja J., Integral process for obtaining acetins from crude glycerol and their effect on the octane index, Chemical Engineering Communications, Vol. 207 (2), 2020, pp. 231–241.
5. Herrada-Vidales J. A., García-Gonzales J. M., Martínez-Palou R., Guzman-Pantoja J., Integral process for obtaining acetins from crude glycerol and their effect on the octane index, Chemical Engineering Communications, Vol. 207 (2), 2020, pp. 231–241.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

6. Olson A.L., Tuner M., Verhelst S. A concise review of glycerol derivatives for use as fuel additives. Heliyon, Vol. 9, Issue 1, 2023, e13041.
7. Samoilov V. O., Borisov R. S., Stolonogova T. I., Zarezin D. P., Maximov A. L., Bermeshev M. V., Chernysheva E. A., Kapustin V. M. Glycerol to renewable fuel oxygenates. Part II: Gasoline-blending characteristics of glycerol and glycol derivatives with C–C_4 alkyl(idene) substituents. Fuel, Vol. 280, 2020, 118585.
8. Samoilov V. O., Ramazanov D. N., Nekhaev A. I., Maximov A. L., Bagdasarov L. N., Heterogeneous catalytic conversion of glycerol to oxygenated fuel additives. Fuel, Vol. 172, 2016, pp. 310–319.
9. Yilmaz N., Atmanli A. Experimental assessment of a diesel engine fueled with diesel-biodiesel-1-pentanol blends. Fuel, vol. 191, 2017, pp. 190–197.

ХАРАКТЕРИСТИКИ ПРОЦЕССОВ СГОРАНИЯ В БЕНЗИНОВЫХ ДВИГАТЕЛЯХ

Эльвира Гусейнова[1], Эльджан Наджафли[2]
[1]Доктор химических наук, профессор, кафедра Нефтехимическая технология и промышленная экология, Азербайджанский Государственный Университет Нефти И Промышленности,
Электронная почта: elvira_huseynova@mail.ru
[2]Магистрант факультета Химической технологии, Азербайджанский Государственный Университет Нефти И Промышленности. Электронная почта: nacaflielcan@gmail.com

РЕЗЮМЕ

В связи с ростом населения увеличился спрос на машины и энергию в различных отраслях, включая транспорт, сельское хозяйство, производство электроэнергии и тяжёлую промышленность.
Дизельные двигатели широко применяются, поскольку обеспечивают высокую мощность при более низкой стоимости по сравнению с аналогичными двигателями. Современные исследования направлены на повышение эффективности, снижение расхода топлива и уменьшение выбросов, особенно с учётом ограниченности ископаемых ресурсов и ужесточения экологических норм. В результате всё больше внимания уделяется разработке усовершенствованных топливных систем и альтернативных видов топлива для повышения производительности и снижения воздействия на окружающую среду.
Разработка двигателя с искровым зажиганием стала важным прорывом в развитии технологий двигателей внутреннего сгорания, существенно повлияв на конструкцию и работу современных силовых установок. Его внедрение позволило обеспечить управляемое сгорание топливовоздушной смеси, что привело к повышению надёжности, более плавной работе и расширению практического применения в транспорте и промышленности.
За последние десятилетия бензиновые двигатели претерпели значительные технологические усовершенствования, обусловленные требованиями к более высокой эффективности, улучшенным эксплуатационным характеристикам и снижению негативного воздействия на окружающую среду. Такие инновации, как современные системы впрыска топлива, электронное управление двигателем и оптимизированные стратегии сгорания, существенно повысили их мощность и экономичность при одновременном снижении выбросов.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Сгорание в бензиновых двигателях представляет собой быстрое предварительно перемешанное горение топлива и воздуха, характеризующееся определённой скоростью тепловыделения, изменениями давления и распространением пламени, зависящими от момента впрыска, нагрузки двигателя и однородности смеси.
Ключевые слова: бензин, двигатель внутреннего сгорания, процесс сгорания, детонация, антидетонационные свойства.

BENZİN MÜHƏRRİKLƏRİNDƏ YANMA PROSESLƏRİNİN XÜSUSİYYƏTLƏRİ

Elvira Hüseynova[1], Elcan Nəcəfli[2]
[1] Kimya elmləri doktoru, professor, Neft-kimya texnologiyası və sənaye ekologiyası kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Email: elvira_huseynova@mail.ru
[2]Magistr, Kimya Texnologiya Fakultəsi, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: nacaflielcan@gmail.com

XÜLASƏ

Əhalinin artması ilə əlaqədar olaraq nəqliyyat, kənd təsərrüfatı, elektrik enerjisinin istehsalı və ağır sənaye daxil olmaqla müxtəlif sahələrdə maşın və enerjiyə tələbat artmışdır.
Dizel mühərrikləri oxşar mühərriklərlə müqayisədə daha aşağı maya dəyəri ilə yüksək güc təmin etdiyinə görə geniş tətbiq olunur. Müasir tədqiqatlar, yanacaqların məhdudluğu və ekoloji normaların sərtləşməsini nəzərə alınaraq, səmərəliliyin artırılmasına, yanacaq sərfinin azaldılmasına və emissiyaların minimuma endirilməsinə yönəldilmişdir. Nəticədə məhsuldarlığın yüksəldilməsi və ətraf mühitə təsirin azaldılması məqsədilə təkmilləşdirilmiş yanacaq sistemlərinin və alternativ yanacaq növlərinin hazırlanmasına daha çox diqqət yetirilir.
Qığılcım alışdırmalı mühərrikin yaradılması daxiliyanma mühərrikləri texnologiyasının inkişafında mühüm irəliləyiş olmuş, müasir güc qurğularının konstruksiyasına və iş prinsipinə əhəmiyyətli təsir göstərmişdir. Onun tətbiqi yanacaq-hava qarışığının idarə olunan yanmasını təmin etmiş, bu da etibarlılığın artmasına, daha sabit iş rejiminə və nəqliyyatla sənayedə daha geniş istifadəyə şərait yaratmışdır.
Son onilliklər ərzində benzin mühərrikləri daha yüksək səmərəlilik, yaxşılaşdırılmış istismar göstəriciləri və ətraf mühitə mənfi təsirin azaldılması tələbləri ilə əlaqədar əhəmiyyətli texnoloji təkmilləşmələrə məruz qalmışdır. Müasir yanacaq püskürtmə sistemləri, elektron idarəetmə və optimallaşdırılmış yanma strategiyaları onların gücünü və yanacaq qənaətliliyini əhəmiyyətli dərəcədə artırmış, eyni zamanda emissiyaları azaltmışdır.
Benzin mühərriklərində yanma yanacaq və havanın əvvəlcədən qarışdırılmış şəkildə sürətli yanması ilə xarakterizə olunur və istilik ayrılma sürəti, təzyiq dəyişmələri, həmçinin püskürtmə anı, mühərrik yükü və qarışığın homogenliyindən asılı olan alovun yayılması ilə səciyyələnir.
Açar sözlər: benzin, daxiliyanma mühərriki, yanma prosesi, detonasiya, antidetonasiya xassələri.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

297-305

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-33

CONDITIONS FOR THE ACCUMULATION OF WATER AND CONDENSATE AT THE BUTTONHOLE OF GAS AND GAS-CONDENSATE WELLS AND ITS IMPACT ON THE OPERATING REGIME

Gulbahar Mammadova[1], Nəzir Fərzəliyev[2]
[1]Ph.D. in Engineering, Docent, Azerbaijan State Oil and Industry University (ASOIU), "Department of Oil and Gas Engineering", Azerbaijan. E-mail: gulbahar.mammadova@mail.ru
[2]Master student: Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan
E-mail: nezirferzeliyev919@gmail.com

ABSTRACT

This paper identifies the conditions for the accumulation of water and condensate at the buttonhole of gas and gas-condensate wells and evaluates the effect of the resulting liquid column on the operating regime. In gas-condensate wells operating under depletion conditions, reservoir pressure gradually falls below the dew-point pressure. Under these conditions, two-phase flow develops in the well, leading to operational complications. The accumulation of liquid at the buttonhole creates resistance to flow, causing the well production rate to decline and eventually reach zero. Water entering the well together with condensate is generally not lifted to the surface but accumulates in the wellbore, forming a liquid column. Water loading of gas and gas-condensate wells reduces production rates, creates various operational difficulties in the wellbore, increases the volume of separated liquids, and provides favorable conditions for the formation of crystalline hydrates. Surface and downhole equipment are also subjected to corrosion and other adverse effects. An analysis of the causes of water loading in affected wells shows that wells may be watered by their own formation waters. In such cases, wells can be operated in a water-free production regime, enabling the selection of effective methods to control water loading. Methods for investigating well water loading are presented. One of these methods is the hydro chemical analysis of formation water composition, in which the chloride ion content is determined. For this purpose, water samples are taken from separators, and the chloride ion concentration, water salinity, and water volume are measured. The study demonstrates the possibility of lifting liquids using the energy of the gas in the well with the aid of surfactants, as well as through the application of new equipment and technologies.
Keywords: gas-condensate wells, depletion regime, well water loading, settled water, water salinity, liquid column, surfactants, gas–liquid mixture, well production rate, stimulation method.

As gas production declines due to the depletion of a gas-condensate reservoir, the conditions for lifting liquids to the surface deteriorate, leading to continuous accumulation of liquid at the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

buttonhole. On the other hand, operating experience of gas-condensate wells shows that when the volume of liquid inflowing from the reservoir into the well exceeds the volume produced to the surface, liquid accumulates at the buttonhole, creating resistance to flow, and as a result the well production rate decreases and eventually drops to zero.
According to the expression proposed in [5], when the well production rate (Q) exceeds the minimum rate required for condensate removal (Q_2), condensate should not accumulate at the buttonhole. However, in some wells, under the condition $Q > Q_2$, such liquid accumulation still occurs, leading to well shut-in. In such cases, water is present in the gas–condensate system flowing into the well. It should be noted that the water entering the well together with condensate is generally not lifted to the surface and instead accumulates in the wellbore, whereas the condensate is produced under the condition $Q_2 < Q$.
It is indicated in [1] that although the water content in the production of a number of oil wells operated by the flowing (natural flow) method is insignificant, water may accumulate at the bottom of these wells. In well fluid samples taken at a depth 300 m above the perforations, water content of up to 80% was detected. Above this interval, the amount of free water in the gas–oil system decreases to 1–2%. It is noted that the reason for water accumulation is the low velocity of the gas–oil mixture along the wellbore.
In [2,3], studies of wells at the fiel "Oil Dashes" d have shown that although the water content in well production is very low (0.03–0.04%), the water content in downhole samples taken above the perforations is excessively high. This indicates that, unlike condensate, the lifting of water from the buttonhole to the surface follows a different mechanism.
The majority of gas and gas-condensate reservoirs are produced under under-saturated or elastically under-saturated conditions. In these production regimes, gas displaces water from the reservoir toward the wellbore, so that the gas–water contact line approaches the buttonhole following a certain pattern. The productive formation and its permeability vary both across the thickness of the formation and across the field. Therefore, the productive formation consists of heterogeneous (non-uniform) rocks.
Well water loading occurs in the following cases:
1. When a well penetrates a productive formation consisting of small layers with different properties, formation waters seep through the highly permeable layers to the buttonhole, causing the well to become watered.
2. If the productive formation contains bottom waters, water cones form in the near-wellbore zone during production, which leads to well water loading.
3. It is known that after the productive formation is opened by gas production, the last string, i.e., the production casing, is lowered into the well and the annular space behind it is cemented with cement slurry. Technical and protective casings placed in the well are also cemented [4].
If cementing is of poor quality, water from the formations above the productive layer can enter the wellbore through the cement sheath, leading to well water loading [6].
Water loading of gas and gas-condensate wells reduces their production, creates various operational difficulties in the wellbore, increases the volume of separated liquids, and provides favorable conditions for the formation of crystalline hydrates. Surface and downhole equipment are also subjected to corrosion and other adverse effects.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

An analysis of the causes of water loading in wells has shown that wells can be watered by their own formation waters. For example, if the productive formation consists of multiple layers, some of these layers may be water-bearing. In such cases, these layers should be perforated.
The formation of water cones in the near-wellbore zone depends on the anisotropy of the formation and the well production rate. In this case, wells are operated under a water-free production regime [7].
As a result of poor-quality cementing, formation water from the layer itself, overlying layers, or underlying layers can enter the wellbore. To prevent this, the well is subjected to major workover, which stops the inflow of water into the wellbore.
During well operation, two stages are observed when water loading occurs:
1.Initial stage of water loading: At this stage, the water seeping into the wellbore is lifted to the surface along with the gas.
2. Final stage of water loading: At this stage, the water seeping into the wellbore accumulates at the buttonhole, forming a liquid column.
At this stage, the volume of water accumulated at the buttonhole per unit time is:

$$\Delta q_{su} = Q_{s\ddot{u}z} - Q_{su.\c{c}.}$$

$Q_{s\ddot{u}z}$ - Production of water seeping from the formation to the wellbore

$Q_{su.\c{c}.}$ - Production of water lifted to the surface with gas from the wellbore

Δq_{su} - The water remaining at the buttonhole gradually increases, and the well production is completely shut off.
As in the first stage, a liquid column forms at the buttonhole. New concepts are used to characterize the water loading process. The water loading coefficient of a well is defined as:

$$K_{sul} = \frac{\sum_1^n h_{sul}}{\sum_1^n h_i} \tag{1.1}$$

h_i -thickness of a fully watered layer,

m – tnumber of fully watered layers

$\sum_1^n h_{sul}$ - Thickness of the fully watered layer

$\sum_1^n h_i$ - total thickness of the productive formation,

n – total number of layers.

When K_{sul} =1the well is considered fully watered and $\sum_1^n h_{sul} = \sum_1^n h_i$

When K<1 $\prec \sum_1^n h_{sul} \prec \sum_1^n h_i$ the well is considered partially watered.

Wells are usually operated until they become fully watered.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

To ensure normal operation of watered wells, the source of water inflow, water production rate, and the type (composition) of water are first determined. Studying these parameters allows monitoring of the formation and well water loading. It also enables the selection of effective methods to control water loading.

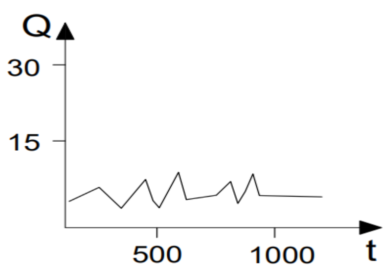
Well water loading is monitored using the following research methods:

- Geophysical research method
- Gas–hydrodynamic research method
- Hydro chemical research method
- Thermodynamic research method

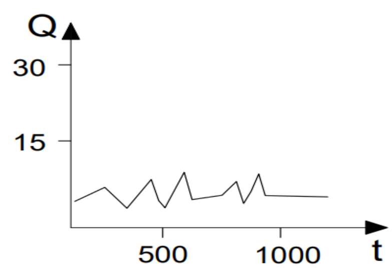
One of the most widely used methods to determine the source of water inflow is the radiometric method.

It is known that, compared to gas-bearing formations, water- and oil-bearing formations differ in porosity, water saturation, and density. Therefore, gamma radiation in water- and oil-bearing formations is higher than in gas-bearing formations.

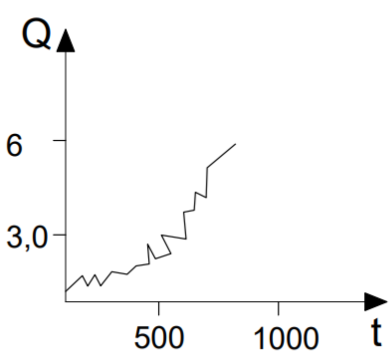
Recently, the hydro chemical research method for studying the composition of formation water has become widespread. In this method, the content of chloride ions is determined. It is known that the concentration of chloride ions and the salinity in condensed water are much lower compared to formation waters. The water content in the gas must also be continuously monitored. For this purpose, water samples are taken from separators, and the chloride ion concentration, water salinity, and water volume are determined.



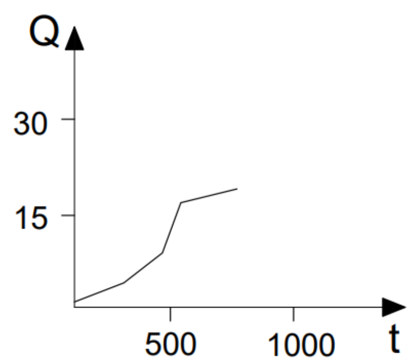
A) in condensed water



b) when water is irregularly



v) when foreign water enters the wellbore



d) when the well becomes watered

produced from the wellbore

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Figure 1.1: Diagnostic curves of water salinity over time.

When the gas contains condensed water, the water salinity reaches a maximum of 1 g/L and changes very little over time (Fig. 1.1a). When water enters the bottomhole intermittently, its salinity varies with time (Fig. 1.1b). When water from an upper or lower formation enters the bottomhole, salinity increases over time (photo. 1.1c). When the well becomes watered, the water salinity suddenly increases over time (photo. 1.1d).
Thus, knowing the time-dependent changes in water salinity and the compositions of formation water and condensed water, the water volume can be calculated using the following formula:

$$Q^{/} = q_1 \frac{M_3 - M_2}{M_1 - M_3} \tag{1.2}$$

q_1 - The amount of water vapor transferred to the liquid:

$$q_1 = [q(P_1) - q(P_2)], \text{ kq/1000 m}^3$$

$[q(P_1)]$ - Water content in the gas (under reservoir conditions),
$[q(P_2)]$ - Water content in the gas (at buttonhole conditions),
M_1, M_2, M_3 – Salinity of formation water, condensed water, and their mixture, kg/1000 m³,
$Q^{/}$ - The amount of water required to raise the salinity from M_2 to M_3.
Total volume of liquid entering the wellbore:

$$\Sigma Q = (Q^{/} + q_1)Q = Qq_1(1 + \frac{M_3 - M_2}{M_1 - M_3}) \tag{1.3}$$

Q - Gas production, thousand m³/day.

Methods used for lifting settled water and condensate in the wellbore
At the final stage of gas and gas-condensate reservoir development, the energy of the gas flow is insufficient to lift the liquid (formation water and condensate) accumulated in the wellbore. In general, to lift the liquid, the diameter of the tubing is adjusted, plunger lifts are used, and finally, pumping methods are applied. In some cases, to remove liquid from the bottomhole, gas and gas-condensate wells are converted to gas-lift operation, where gas is injected into the annular space from the wellhead [8].
To foam the liquid accumulated in the wellbore, surfactants (foam-forming agents) can be used. When foam is generated using surfactants, the density of the gas–liquid mixture at the gas–liquid interface decreases. This helps lift the liquid using the energy of the gas in the well.
The hydrodynamic basis of all methods used to remove liquid from the bottomhole is the mechanism of gas–liquid flow movement and the movement of foamed systems in vertical tubing–casing strings, which is enhanced with the help of new equipment and technologies. With the application of new technologies, it is possible to calculate the operating mode of a gas-lift system and, using known formulas, determine the regime of watered gas and gas-condensate wells [9].

Conclusions and recommendations

1. Since the calculated production rates in the paper differ significantly from the actual well production, using these values to determine the minimum production rate required to remove condensate accumulated at the bottomhole is not appropriate.
2. The conducted studies show that it is possible to determine the minimum gas production rate necessary to lift condensate from the wellbore.
3. When the pressure distribution in the wellbore, P = P(H), is linear, no water or condensate accumulates at the bottomhole. Otherwise, if the linearity is broken, liquid accumulates at the bottomhole.
4. Condensate is lifted from the wellbore when the gas flow velocity in the tubing is v = 3–6 m/s. Accumulated condensate in the wellbore is lifted at lower velocities compared to water.
5. Knowing the bottomhole and wellhead pressures, the height of the water column in the wellbore of an operating gas-condensate well has been determined.
6. To remove liquid from the bottomhole of gas-condensate wells, the diameter and length of the lift tubing have been determined.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Mirzadzhanzade, A.Kh., Kovalev, A.G., et al. (1967). Razrabotka gazokondensatnykh mestorozhdeniy [Development of Gas Condensate Fields]. Moscow: Nedra, pp. 355-356.
2. Vezirov, R.R., Aleskerov, S.S., et al. (1963). K opredeleniyu minimal'nogo debita gaza, neobkhodimogo dlya pod"yema zhidkogo kondensata s zaboya skvazhiny [On the

determination of the minimum gas flow rate required to lift liquid condensate from the bottom of the well]. ANKh (Azerbaijan Oil Industry), No. 6.
3. Korotaev, Yu.P. (1958). Vliyanie zhidkosti na dvizhenie gaza po vertikal'nym trubam [Influence of liquid on gas movement through vertical pipes]. Proceedings of VNIIGaz, Vol. 2/10, Gostoptekhizdat.
4. Zotov, G.A., Aliev, Z.S. (1980). Instruktsiya po kompleksnomu issledovaniyu gazovykh i gazokondensatnykh plastov i skvazhin [Instructions for the comprehensive study of gas and gas condensate reservoirs and wells]. Moscow: Nedra, pp. 116-147.
5. Sayakhov, F.L., Shagiev, R.G., et al. (1989). Gidrodinamicheskie aspekty ostanovki gazovykh skvazhin pri nalichii zhidkoy vodnoy fazy v usloviyakh kraynego severa [Hydrodynamic aspects of shutting down gas wells in the presence of a liquid water phase in Far North conditions]. Neft i Gaz, p. 93.
6. Salavatov, T.Sh., Mustafaev, A.A., Dadashzade, M.A., Mamedova, E.V. (2013). Sovmestnaya rabota skvazhiny i plasta pri gazliftnoy ekspluatatsii skvazhin [Combined operation of well and reservoir during gas lift exploitation]. Neftepromyslovoye Delo, No. 1, pp. 28-30.
7. Salavatov, T.S., Dadaszade, M.A., Aliyev, I.N. (2017). Yatagin sulasmasi zamani hidro-dinamiki hesablamalar [Hydrodynamic calculations during field watering]. Azerbaijan Oil Industry (Azərbaycan Neft Təsərrüfatı), No. 12, pp. 17-20.
8. Mamedova, G.G. (2022). Meropriyatiya po likvidatsii skopleniya zhidkosti na zaboye gazokondensatnykh skvazhin s primeneniyem novogo oborudovaniya i tekhnologiy [Measures to eliminate liquid accumulation at the bottom of gas condensate wells using new equipment and technologies]. IV All-Russian Scientific-Practical Conference, Makhachkala, pp. 66-71.
9. Mamedova, G.G. (2017). Sposoby likvidatsii stolba zhidkostey, nakopivshikhsya na zaboye gazokondensatnykh skvazhin [Methods for eliminating the column of liquids accumulated at the bottom of gas condensate wells]. Oborudovanie i tekhnologiya dlya neftegazovogo kompleksa - VNIIOENG, No. 2, pp. 48-50.

УСЛОВИЯ НАКОПЛЕНИЯ ВОДЫ И КОНДЕНСАТА НА ЗАБОЕ ГАЗОВЫХ И ГАЗОКОНДЕНСАТНЫХ СКВАЖИН И ИХ ВЛИЯНИЕ НА РЕЖИМ ЭКСПЛУАТАЦИИ

Гюльбахар Маммадова[1], Ферзильев Нэзир[2]
[1]Кандидат технических наук, доцент Азербайджанского Государственного Нефте и Промышленность Университета (АГНПУ), кафедра нефтегазовой инженерии, Азербайджан,
E-mail: gulbahar.mammadova@mail.ru
[2]Магистрант: Азербайджанский Государственный Нефте и Промышленность Университет (АГНПУ), Азербайджан. E-mail: nezirferzeliyev919@gmail.com

РЕЗЮМЕ

В статье определены условия накопления воды и конденсата на забое газовых и газоконденсатных скважин и влияние образующегося столба жидкости на режим эксплуатации. В газоконденсатных скважинах, работающих в режиме истощения, пластовое давление постепенно снижается ниже давления насыщения. В результате в скважине возникает двухфазный поток и начинаются осложнения в процессе эксплуатации.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Накопление жидкости на забое скважины создает противодействие движению флюида, вследствие чего дебит скважины снижается вплоть до нуля. Вода, поступающая в скважину вместе с конденсатом, как правило, не выносится на поверхность, а накапливается в стволе скважины, образуя столб жидкости. Обводнение газовых и газоконденсатных скважин приводит к снижению их дебита, возникновению ряда эксплуатационных осложнений в стволе скважины, увеличению объема сепарируемой жидкости, созданию благоприятных условий для образования кристаллогидратов. Происходит коррозия наземного и подземного оборудования и другие негативные последствия. На основе анализа причин обводнения скважин установлено, что скважины могут обводняться собственными пластовыми водами. В этом случае скважины эксплуатируются в безводном режиме добычи, что позволяет обеспечить выбор эффективных методов борьбы с обводнением. Выбраны методы исследования причин обводнения скважин. Одним из таких методов является гидрохимическое исследование состава пластовой воды, при котором определяется содержание хлорид-ионов. С этой целью из сепараторов отбираются пробы воды, по которым определяются содержание хлорид-ионов, солёность воды и её количество. Показана возможность подъема жидкости за счет энергии газа в скважине с использованием поверхностно-активных веществ, а также применения новой техники и технологий.
Ключевые слова: газоконденсатные скважины, режим истощения, обводнение скважин, осевшая вода, солёность воды, столб жидкости, поверхностно-активные вещества, газожидкостная смесь, дебит скважины, методы воздействия.

QAZ VƏ QAZKONDENSAT QUYULARINDA SU VƏ KONDENSATIN QUYU DİBİNDƏ YIĞILMA ŞƏRAİTİ VƏ ONUN İSTİSMAR REJİMİNƏ TƏSİRİ

Gülbahar Məmmədova[1], Nəzir Fərzəliyev[2]
[1]Texnika elmləri üzrə fəlsəfə doktoru, dosent, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), "Neft - qaz mühəndisliyi" kafedrası", Azərbaycan, E-mail: gulbahar.mammadova@mail.ru
[2]Magistr tələbəsi: Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), Azərbaycan.
E-mail: nezirferzeliyev919@gmail.com

XÜLASƏ

Məqalədə qaz və qazkondensat quyularında su və kondensatın quyu dibində yığılma şəraiti və yaranmış maye sütununun istismar rejiminə təsiri müəyyən edilmişdir. Tükənmə rejimində olan qazkondensat quyularında lay təzyiqi yavaş -yavaş doyma təzyiqindən aşağı düsur. Bu zaman quyuda iki fazalı axın yaranır. Quyularda mürəkkəbləşmələr başlayır. Quyu dibində maye yığılaraq hərəkətə əks təsir yaratdığından quyunun hasilatı azalaraq sıfra bərabər olur. Kondensatla birlikdə quyuya gələn su bir qayda olaraq yer üzərinə çıxarılmayaraq, quyu gövdəsinə yığılıb maye sütunu yaradır. Qaz və qaz-kondensat quyularının sulaşması quyuların hasilatını azaldır, quyu gövdəsində bir sıra çətinliklər yaradır, separasiya olunan maye həcmi artır, kristal hidratların əmələ gəlməsi üçün əlverişli şərait yaranır. Yerüstü və yeraltı avadanlıqlar korroziyaya uğrayır və s. Sulaşmış quyuların sulaşma səbəblərini təhlil edərək, müəyyən olunmuşdur ki, quyular öz lay suları ilə sulaşa bilərlər. Bu halda quyular susuz hasilat rejimində istismar olunurlar, sulaşmaya qarşı səmərəli mübarizə üsulunun seçilməsi də təmin edilir.

Quyuların sulaşmasına qarşı aparılan tədqiqat üsulları seçilmişdir. Bu üsullardan biri lay suyunun tərkibinin hidro-kimyəvi tədqiqat üsulu ilə öyrənilməsidir. Bu üsulda xlor ionlarının miqdarı təyin olunur. Bu məqsədlə separatorlardan su nümunələri götürülür və xlor ionlarının miqdarı, suyun duzluğu və suyun miqdarı təyin olunur. Səthi aktiv maddələrin, tətbiq edilən yeni texnika və texnologiyaların köməyi ilə quyudakı qazın enerjisi hesabına mayenin qaldırılmasının mümkünlüyü göstərilmişdir.

Açar sözlər: qaz-kondensat quyuları, tükənmə rejimi, quyuların sulaşması, çökmüş su, suyun duzluluğu, maye sütunu, səthi-aktiv maddələr, qaz-maye qarışığı, quyu hasilatı, təsir üsulları.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

306-314

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-34

DETERMINATION OF HYDROCARBON LOSSES IN THE GAS-LIQUID MIXTURE COLLECTION AND TRANSPORTATION SYSTEM

Gulbahar Mammadova[1], Faiq Qurbanov[2]
[1]Ph.D.in Engineering, Docent Azerbaijan State Oil and Industry University (ASOİU), "Department of Oil and Gas Engineering", Azerbaijan. E-mail: gulbahar.mammadova@mail.ru
[2]Master student, Azerbaijan State Oil and Industry University (ASOİU), Azerbaijan.
E-mail: hasanfaiq001@gmail.com

ABSTRACT

The article addresses the issue of determining hydrocarbon losses in the system for collecting and preparing a gas–liquid mixture for transportation. At present, the main objective of the oil and gas industry is the maximum development of hydrocarbon reserves in fields. It is well known that hydrocarbon production is mainly carried out using the natural energy of the reservoir. Therefore, the reserves of a field should be understood as a combination of its hydrocarbon and energy resources. In other words, during the production process, efforts should be made not only to extract the maximum possible amount of hydrocarbons, but also to utilize the reservoir energy as efficiently as possible.In a period when the major share of global energy demand is met by hydrocarbon resources, hydrocarbon losses have become one of the global problems of mankind. Within the limits of modern scientific and technological progress, it is impossible to carry out hydrocarbon production and processing processes without losses. In order to minimize these losses, it is necessary to identify their causes. For this reason, an analysis of the system for collection, preparation, and transportation of products from the Bulla- sea gas-condensate field, as well as the operation of gas separation units, makes it possible to determine the amount of condensate carried over with sales gas. Due to the lack of facilities for collecting and transporting low-pressure gas, the gas is flared, and the entrainment of a certain amount of oil with the gas flow from the final separators leads to these losses. During the inspection of the above-mentioned facilities, it was determined that these losses occur as a result of the unsatisfactory condition of the technical means used for the separation of heavy hydrocarbons produced together with gas. When crude oil is stored in the tanks of gathering stations and during their filling and emptying operations, valuable light hydrocarbon fractions, generally used as motor fuel (gasoline), are lost due to evaporation. At certain pressures and temperatures, during tank filling and emptying, so-called "large breathing" losses occur: during filling, the vapor–air mixture is expelled from the tank ("exhalation"), and during emptying, atmospheric air enters the tank ("inhalation"). Based on this, calculations of losses occurring in the tank farm of the Dashgil DNOU are performed, and the volume of light hydrocarbon vapors released from the tanks is determined. In order to reduce losses of heavy components, it is considered expedient to transport gas condensate in a saturated

state at a pressure of 20 atm from the Dashgil coastal facilities to the Azerbaijan Gas Processing Plant.
Keywords: gas–liquid mixture, hydrocarbon losses, temperature, pressure, crude oil, separation, vapor phase, air–vapor mixture, gathering station, volume of hydrocarbon vapors, tank farm.

It is well known that during the development of gas-condensate fields, the composition of the gas-condensate system continuously changes until depletion. For this reason, the maximum condensation pressure determined at the initial stage of field development may not be sufficient in later periods to ensure optimal conditions for condensate separation from gas in separators. Low gas temperatures in gas pipelines further enrich the gas with water vapor and heavy hydrocarbons. In general, within oil and gas production areas, the transportation of gas and liquid through the same pipeline is considered economically efficient, as it significantly reduces metal consumption. Despite several additional challenges, the combined transportation method also substantially reduces the energy demand associated with pumping stations. Moreover, during the transportation of two-phase gas–liquid mixtures, the presence of a liquid phase in the flow decreases the operational efficiency of the pipeline. In most cases, long-distance transportation of two-phase mixtures (including oil and gas, gas and condensate, including liquefied phases) is limited and, in some cases, impossible.

An analysis of the system for collection, preparation, and transportation of products from the Bulla-deniz gas-condensate field, as well as the operation of gas separation units, made it possible to determine the amount of condensate carried over with sales gas. The maximum achievable condensate recovery from raw gas was determined with sufficient accuracy based on both calculations and experimental laboratory studies. As a result of thermodynamic calculations of gas and gas-condensate flows at various technological nodes, phase transformations were carried out in accordance with a three-stage gas separation system (TB-100 → GPM → Dashgil gas gathering station). Thermo-hydrodynamic calculations were performed according to a three-stage separation scheme: Stage I — high pressure, Stage II — medium pressure, and Stage III — low pressure.

In the high-pressure separation system, pressure varies within the range of 1.5–3.5 MPa and temperature within 27–30 °C; in the medium-pressure separation system, pressure ranges from 1.0 to 1.1 MPa and temperature is about 20 °C; finally, in the low-pressure separation system, pressure varies within 0.5–0.6 MPa and temperature within 11–14 °C. In accordance with the TB-100 (S_1) → GPM-1,2 (S_2) → Dashgil gas gathering station (S_3), gas separation is carried out in three stages. Liquid condensate separated from gas in separators S_1, S_2, and S_3 is directed to the medium-pressure gas-hydrodynamic line.

In this system, the pressure variation range is from 1.1–1.0 MPa to 0.6–0.5 MPa, with the corresponding temperature changing from 20 °C to 11–14 °C. After heating, the liquid separated at the first-stage separator undergoes three-stage separation. Gas exiting separators S' and S'', as well as separators P', P'_1, and P'_2, is transported to Ali-Bayramli at a pressure of 0.4–0.5 MPa with a daily flow rate of 600,000 m^3.

In mines, oil reservoirs are metal containers of various volumes used for the collection, short-term storage, and measurement of crude and commercial oil. A group of reservoirs located within a certain area is referred to as a tank farm.

Let us consider the losses of light fractions of oil and measures to combat them.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Losses due to large "breathing":
When crude oil is stored in the reservoirs of a gathering station and during its filling and emptying, evaporation occurs, resulting in the loss of valuable light hydrocarbon fractions, generally used as fuel or gasoline. These fractions are high-octane hydrocarbons and act as anti-knock agents. Oil loss in a reservoir occurs due to evaporation under the following conditions:
During filling and emptying of the reservoir, large "breathing" occurs — during filling, the vapor–air mixture exits the reservoir ("exhalation"), and during emptying, atmospheric air enters the reservoir ("inhalation").
When the surrounding air temperature changes, small "breathing" occurs — when the air heats up, the vapor–air mixture exits the reservoir into the atmosphere ("exhalation"), and when the air cools, atmospheric air enters the reservoir ("inhalation").

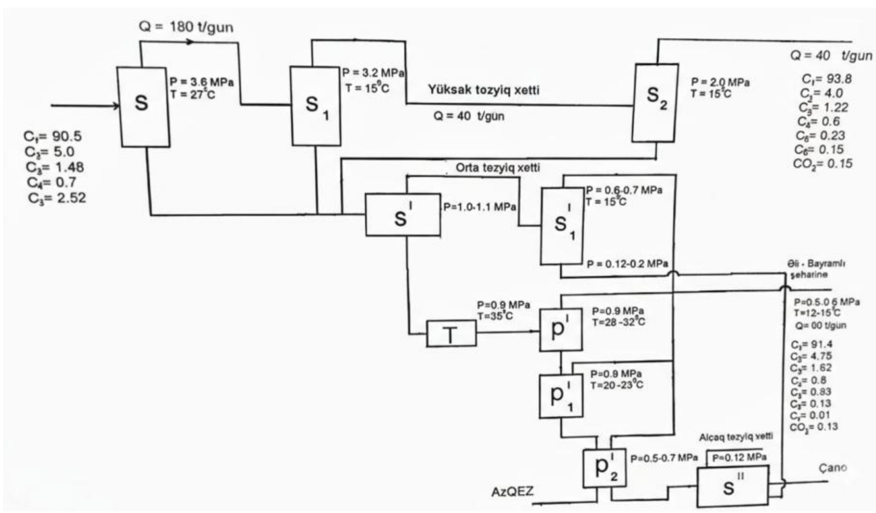


Figure 1: Model of Product Gathering and Transportation at the "Bulla-deniz" Field.

Since the vapor pressure of crude oil vapors is lower than that of the atmosphere, there is always an air–vapor phase at the top of the reservoir. The molar concentration of these vapors depends on the temperature of the crude oil surface layer. The molar concentration of any component in the vapor phase equals the ratio of its partial pressure to the total pressure of the mixture. Here, total pressure refers to atmospheric pressure, and partial pressure refers to the vapor pressure of saturated crude oil. For example, if the vapor pressure of saturated crude oil is 0.15 atm, the molar composition of the air–vapor mixture will be 0.15 for vapor and 0.85 for air.
The determination of the vapor pressure of saturated crude oil is based on this principle. After measuring the amount of air in the vapor–air mixture of the reservoir using an Ors-Fischer apparatus, the vapor pressure of saturated crude oil at the temperature of the upper layer of oil is determined. If crude oil is stored in a single reservoir, or if the reservoirs of a gathering station are isolated from each other, losses due to large "breathing" are inevitable.
When filling the reservoir with oil, a vapor–air mixture is expelled; when emptying, atmospheric air enters. Installing tight caps and breather valves in reservoirs does not reduce losses caused by large "breathing." As is known, the pressure in the reservoir should not exceed 40 mmHg, and the vacuum pressure should not exceed 30 mmHg. This pressure is low enough that it does not

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

practically prevent gas escape. To prevent the release of vapor–air mixtures from the reservoir to the atmosphere and the ingress of atmospheric air, the gathering station operations must be properly organized.

The most effective measure to reduce losses caused by large "breathing" is to interconnect the air–vapor phases of reservoirs and correctly schedule filling and emptying operations. The number of interconnected reservoirs should not be less than three. During the operation of a tank farm, depending on the sequence of filling and emptying, the air–vapor mixture transfers from one reservoir to another.

For fire safety, flame arrestors must be installed in the interconnecting pipelines. If the use of the gathering station's tank farm — that is, the sequence of filling and emptying oil — is not properly organized, the light hydrocarbon fraction in the vapor phase of crude oil will always be lost due to large "breathing."

To calculate losses caused by large "breathing," the following symbols are accepted:

V — total volume of the reservoir (excluding residuals), m^3;

Q — vapor pressure of saturated crude oil, atm;

P_1 — initial pressure in the reservoir at the start of filling, atm; this minimum pressure is regulated by a vacuum valve, $P_1 < 1$ atm;

P_2 — allowable maximum pressure in the reservoir, atm; maintained by a pressure relief valve;

M_b — molecular weight of the vapors (usually taken as pentane).

In an emptied reservoir, the pressure is P_1; in this case, the entire reservoir volume is filled with an air–vapor mixture. To calculate losses caused by large "breathing," the following formula is used:

$$G_b = 0{,}045 V_p \frac{P_1 - Q}{P_2 - Q} Q M_b \quad (1)$$

Losses due to small "breathing":

Losses caused by small "breathing" occur when the reservoir is heated, resulting in the escape of the air–vapor mixture into the atmosphere, and when cooled, atmospheric air enters the reservoir.

Calculation of losses due to small "breathing":

V_b — average volume of the air–vapor space in the reservoirs of the gathering station, m^3;

T_{day} — average daytime temperature, °C;

T_{night} — average nighttime temperature, °C;

Y_{day} — molar concentration of hydrocarbon vapors at the average daytime temperature;

Y_{night} — molar concentration of hydrocarbon vapors at the average nighttime temperature.

To calculate the losses due to small "breathing," it is assumed that the temperature difference T_{day} T_{night} is constant. As a result, the following formula is obtained:

$$V_b = V\left\{1 - \left[\left(1 - y_{day}\right)\frac{273 + T_d}{273 + T_{day}} + y_d\right]\right\} \quad m^3 \quad (2)$$

A report is compiled on the losses occurring in the reservoir at the Dashgil GPM. Specifically, losses in the reservoirs of the Dashgil oil and gas gathering station are calculated as follows:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

First, let us calculate the “inhalation” and “exhalation” losses for two RVS-5000 m³ crude oil reservoirs at this station:

The average daily volume of the vapor phase is 5000 m³. During the autumn-winter months, the average daytime temperature is 16 °C, and the average nighttime temperature is 8 °C. Atmospheric pressure is assumed, and the vapor pressure of saturated crude oil at 16 °C is Y_{day} = 0.3 atm, while at 8 °C it is Y_{night} = 0.14 atm.

During a single “breathing” event, when the reservoir cools from 16 °C to 8 °C, the volume of air entering the reservoir is determined using formula (1).

$$V_b = V\left\{1-\left[\left(1-y_{day}\right)\frac{273+T_d}{273+T_{day}}+y_d\right]\right\} = 5000\left\{1-\left[(1-0.3)\frac{273+8}{273+16}+14\right]\right\}$$
$$= 5000\left\{1-\left[0.7\frac{281}{289}+0.14\right]\right\} = 5000(1-0.82) = 900\ m^3 \quad (3)$$

During “inhalation,” two RVS-5000 m³ crude oil reservoirs will receive a total of 2 × 900 = 1800 m³ of air. The volume of air leaving the reservoir during “exhalation” is calculated as follows:

When the air in the reservoir warms from the nighttime temperature of 8 °C to the daytime temperature of 16 °C, the following volume of air will exit the reservoir.

$$V_b = V\left\{\left[\left(1-y_{night}\right)\frac{273+T_d}{273+T_{day}}+y_{day}\right]-1\right\} = 5000\left\{\left[(1-0.14)\frac{273+16}{273+8}+0.3\right]-1\right\}$$
$$= 5000\left\{\left[0.86\frac{289}{281}+0.3\right]-1\right\} = 5000(1.184-1) = 920.5\ m^3 \quad (4)$$

Since there are two RVS-5000 type crude oil reservoirs at the field, this volume will be 2 × 920.5 = 1841 m³.

Let us calculate the volume of light hydrocarbon vapors leaving one RVS-5000 reservoir during “exhalation.”

$$V_b = V_{n.v}\frac{Y_{day}}{1-Y_{day}} = 920.5\frac{0.3}{0.7} = 920.5\cdot 0.43 = 394.5\ m^3 \quad (5)$$

For two RVS-5000 reservoirs, this volume will be 2 × 394.5 = 789 m³. Assuming that these vapors consist of pentane and hexane, the volume of liquid gasoline will be:

$$V_{gasoline} = 394.5:194 = 2.033\ m^3 \quad (6)$$

Assuming that the total volume of oil in the two RVS-5000 reservoirs is 10,000 m³, the losses due to evaporation during a single “breathing” event will be as follows:

$$d = \frac{2.033\cdot 100}{10000} = 0.02033\% \quad (7)$$

Thus, the reason for such significant condensate losses carried away with the gas is the low operational efficiency of the existing gas separation units, meaning that these units are outdated and do not meet modern requirements. To eliminate this deficiency, new filter-separators with high condensate retention capacity should be applied in the gas–condensate transportation and preparation system. At the same time, to prevent hydrocarbon losses in the reservoirs, the breather valves should be connected to a vacuum line.

Conclusions and recommendations

1.The article examined the losses of gas condensate in a high-pressure pipeline. For the high-pressure line, the pressure varies from 3.0–3.2 MPa to 2.0–2.1 MPa, and the temperature ranges from 27–35 °C to 12–15 °C.

2.The sources of hydrocarbon losses occurring during crude oil storage and during the filling and emptying of reservoirs due to large and small “breathing” are described.

3.At the Dashgil Oil and Gas Gathering Station, there are four reservoirs for collecting oil and gas–condensate from the Bulla-deniz field and oil from the Alat-deniz field. According to the calculations, during a single “exhalation,” the volume of light hydrocarbon vapors leaving two RVS-5000 reservoirs is $V_1 = 789$ m³.

4.Whenever possible, it is recommended to replace outdated equipment with new units.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Mirzadzhanzade, A.Kh., Iskendeyrov, M.A., Abdullayev, M.A., Agayev, R.G., Aliyev, S.M., Amirov, A.C., Gasimov, A.F. (2010). Neft va qaz yataqlarinin istismari va ishlanilmasi [Operation and Development of Oil and Gas Fields]. Baku.
2. Rasulov, A.M. (2008). Tabbii qazlarin yigilmasi, naqla hazirlanmasi va istifadasi [Collection, preparation for transport, and use of natural gases]. Baku: SOCAR Scientific Research Institute (ETI).
3. Mammadov, K.M., Musayev, Z.S., Mursalov, A.A., Mammadova, V.V. (2009). Neft yigilan naql edan muhandis qurgulari va avadanliqlari [Engineering structures and equipment for oil collection and transportation]. Baku, p. 214.
4. Zotova, G.A., Alieva, Z.S. (1980). Instruktsiya po kompleksnomu issledovaniyu gazovykh i gazokondensatnykh plastov skvazhin [Instructions for the comprehensive study of gas and gas condensate reservoirs and wells]. Moscow: Nedra, pp. 98-107.
5. Smith, J.M., Van Ness, H.C., Abbott, M.M. (2001). Introduction to Chemical Engineering Thermodynamics, 6th ed. in SI Unit, McGraw Hill, New York, pp. 314-351.
6. Ismayilov, Q.Q., Ismayilova, F.B., Iskendeyrov, E.Kh. (2017). Neftqazchixarmada multifazali texnologiyalar [Multiphase technologies in oil and gas production]. Baku: Elm, 350 p.
7. Ismayilov, Q.Q. (2003). Neft va neft mahsullarinin ardicil naqli. Dars vasaiti [Sequential transportation of oil and oil products. Textbook]. Baku, 125 p.
8. Mammadova, G.G. (2022). Negative features of gas condensation deposits development and ways to eliminate them. Scientific Proceedings of the Scientific Research Institute "Geotechnological Problems of Oil, Gas and Chemistry," No. 1, pp. 19-24, ISSN 2218-5054.
9. Shanshool, J., Habobi, N., Kareem, S. (2011). Volumetric Behavior of Mixtures of Different Oil Stock. Petroleum & Coal Journal, 53 (3), August 2011, pp. 223-228.
10. Bunchuk, B.A. (1977). Transport i khranenie nefti, nefteproduktov i gaza [Transport and storage of oil, oil products and gas]. Moscow: Nedra, 366 p.

ОПРЕДЕЛЕНИЕ ПОТЕРЬ УГЛЕВОДОРОДОВ В СИСТЕМЕ СБОРА И ПОДГОТОВКИ ГАЗОЖИДКОСТНОЙ СМЕСИ К ТРАНСПОРТИРОВКЕ

Гюльбахар Маммадова[1], Фаиг Гурванов[2]
[1]Кандидат технических наук, Доцент, Азербайджанский Государственный Университет Нефти и Промышленности (АГУНП), Кафедра нефтегазовой инженерии, Азербайджан.
E-mail: gulbahar.mammadova@mail.ru
[2]Студент магистратуры, Азербайджанский Государственный Университет Нефти и Промышленности (АГУНП), Азербайджан. E-mail: hasanfaiq001@gmail.com

РЕЗЮМЕ

В статье рассмотрен вопрос определения потерь углеводородов в системе сбора и подготовки газожидкостной смеси к транспортировке. В настоящее время основной целью нефтегазовой промышленности является максимальное освоение углеводородных запасов месторождений. Известно, что добыча углеводородов в основном осуществляется за счёт собственной энергии пласта. Поэтому под запасами месторождения следует понимать совокупность его углеводородных и энергетических ресурсов. Иными словами, в процессе эксплуатации необходимо стремиться не только к извлечению максимально возможного количества углеводородов, но и к наиболее полному использованию энергии месторождения. В условиях, когда основная часть мировых потребностей в энергии удовлетворяется за счёт углеводородных ресурсов, потери углеводородов превратились в одну из глобальных проблем человечества. В рамках современных научно-технических возможностей невозможно осуществлять процессы добычи и переработки углеводородов полностью без потерь. Для их максимального сокращения необходимо знать причины их возникновения. В связи с этим анализ системы сбора, подготовки и транспортировки продукции газоконденсатного месторождения Булла-дениз, а также работы газосепарационных установок, позволяет определить количество конденсата, уносимого с товарным газом. Ввиду отсутствия возможностей для сбора и транспортировки газа низкого давления, газ сжигается на факеле, а вынос определённого количества нефти с потоком газа из последних сепараторов приводит к данным потерям. В ходе обследования указанных объектов установлено, что данные потери обусловлены неудовлетворительным состоянием технических средств, используемых для выделения тяжёлых углеводородов, добываемых совместно с газом. При хранении сырой нефти в резервуарах пунктов сбора, а также в процессе их наполнения и опорожнения, в результате испарения теряется ценная лёгкая углеводородная фракция, используемая в целом как моторное топливо (бензин). При определённых давлениях и температурах в процессе опорожнения и заполнения резервуаров происходят так называемые «большие дыхания»: при заполнении — выход паро-воздушной смеси из резервуара («выдох»), при опорожнении — поступление атмосферного воздуха в резервуар («вдох»). На этой основе производится расчёт потерь, происходящих в резервуарном парке Дашгильского ДНУ, и определяется объём лёгких углеводородных паров, выходящих из резервуаров.С целью снижения потерь тяжёлых компонентов целесообразно направлять газоконденсат в насыщенном состоянии при давлении 20 атм с береговых сооружений Дашгиля на Азербайджанский газоперерабатывающий завод.

Ключевые слова: газожидкостная смесь, потери углеводородов, температура, давление, сырая нефть, сепарация, паровая фаза, паро-воздушная смесь, пункт сбора, объём углеводородных паров, резервуарный парк.

QAZ-MAYE QARIŞIĞININ YIĞIM VƏ NƏQLƏ HAZIRLANMASI SİSTEMİNDƏ KARBOHİDROGEN İTKİLƏRİNİN MÜƏYYƏN OLUNMASI

Gülbahar Məmmədova[1], Faiq Qurbanov[2]

[1]Texnika elmləri üzrə fəlsəfə doktoru, Dosent, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU),"Neft-qaz mühəndisliyi", Azərbaycan. E-mail: gulbahar.mammadova@mail.ru

[2]Magistr tələbəsi, "Neft-qaz mühəndisliyi" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: hasanfaiq001@gmail.com

XÜLASƏ

Məqalədə qaz-maye qarışığının yığım və nəqlə hazırlanması sistemində karbohidrogen itkilərinin müəyyən olunması məsələsinə baxılmışdır. Hal-hazırda neft-qaz sənayesinin əsas məqsədi yataqlarda olan karbohidrogen ehtiyatlarının maksimum istismar edilməsidir. Məlumdur ki, karbohidrogenlərin əldə olunması əsasən layın öz enerjisi hesabına həyata keçirilir. Bu səbəbdən yatağın ehtiyatı dedikdə onun karbohidrogen və enerji ehtiyatı birlikdə nəzərdə tutulmalıdır. Yəni istismar prosesində yataqdan mümkün qədər çox karbohidrogen əldə olunması ilə yanaşı yatağın enerjisinin mümkün qədər çox istiadə edilməsinə çalışılmalıdır.Dünyada enerji tələbatının əsas hissəsinin karbohidrogen ehtiyatları hesabına ödənildiyi bir dövrdə karbohidrogen itkiləri bəşəriyyətin qlobal problemlərindən birinə çevrilmişdir. Müasir elmi texniki tərəqinin imkanları daxilində karbohidrogen hasilatı və emalı proseslərini itkisiz aparmaq mümkün deyildir. İtkilərin mümkün qədər aradan qaldırılması üçün onların yaranma səbəblərini bilmək lazımdır. Bu səbəblərdən də Bulla-dəniz qaz-kondensat yatağının məhsulunun yığılması, hazırlanması və nəqli sisteminin və qazın separasiya qurğularının işləməsinin təhlili əmtəə qazı ilə aparılan kondensatin miqdarını təyin etməyə imkan verir. Aşağı təzyiqli qazın yığılması və nəqli üçün imkanlar olmamasına görə qaz məşələ atılır və son separatorlardan qaz axını ilə müəyyən miqdarda neftin aparılması bu itkiləri yaradır.Qeyd edilən obyektlərin yoxlanılması zamanı müəyyən olunmuşdur ki, qazla birlikdə hasil edilən ağır karbohidrogenlərin ayrılmasında istifadə olunan texniki vasitələrin qeyri qənaətbəxş olmasına görə bu itkilərə yol verilir. Xam nefti yığım məntəqəsinin rezervuarlarında saxladıqda və onun doldurub-boşaldılması zamanı buxarlanması nəticəsində, bütövlükdə yanacaq-benzin kimi istifadə olunan qiymətli yüngül karbohidrogen fraksiyasından istifadə olunur. Müəyyən təzyiq və temperaturlarda rezervuarın boşaldılması və doldurulması zamanı böyük “nəfəsalma”sı nəticəsində- doldurma zamanı buxar-hava qarışığının rezervuardan xaric olması – “nəfəsvermə”, nefti rezervuardan boşaltdıqda isa atmosferdən havanı rezervuara daxil olması - «nəfəsalma» kimi qebul edilir. Bununla da Daşgil DNYM-də rezervuarında baş verən itkilərin hesabatı aparılır və rezervuarından çıxan yüngül karbohidrogen buxarlarının həcmi hesablanır: Ağır komponentlərin itkilərini azaltmaq üçün Daşgil Sahil qurğularında qaz-kondensat doymuş halda 20 atm-də Azərbaycan Qaz Emal zavoduna yönəltmək məqsədə uyğun hesab olunur.

Açar sözlər: qaz-maye qarışığı, karbohidrogen itkiləri, temperatur, təzyiq, xam neft, separasiya, buxar fazası, hava-buxar qarışığı, yığım məntəqəsi,karbohidrogen buxarın həcmi, rezervuar parkı.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

315-321

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-35

VOLUME 33 (08) ISSUE 02 2026

ANALYSIS OF THE DEVELOPMENT PROCESS IN MULTILAYER OIL FIELDS

Kanan Guliyev[1], Zamig Mirzadzhanov[2]
[1]Master, Azerbaijan State Oil and Industry University, Azerbaijan, kquliyev128@gmail.com
[2]Oil and Gas Engineering, Department of oil and gas engineering, Azerbaijan Oil and Industry University, teacher, Azerbaijan, zamiq.mirzacanov@asoiu.edu.az

ABSTRACT

The presented article examines the main features and technological approaches of the development process of multilayer oil fields. As is known, the efficient development of multilayer structured fields in the modern oil production industry is one of the most complex issues from an economic and technical point of view. In multilayer fields, the correct selection of the development strategy according to the individual properties, pressure regimes and reservoir of each productive horizon is important for maximizing oil production. When analyzing the development process, parameters such as the interaction of layers, hydraulic connection, filtration properties and the state of the wellbore zone should be taken into account. The article discusses various development methods applied in multilayer systems, their advantages and limitations.

A significant part of oil production in Azerbaijan and in the world is obtained from multi-layered structural fields. This type of fields consists of several productive horizons, each of which has different geological and physical characteristics. The process of developing multi-layered fields is more complex than that of single-layered fields. The main problem here is the presence of hydraulic communication between the layers, different permeability and porosity indicators, different pressure and temperature conditions. The interaction of layers plays an important role in choosing a development strategy, and the application of the right technological solution significantly increases the overall oil yield.

Keywords: multilayered reservoir, development process, productive layer, hydraulic connection, oil production, wellbore zone, pressure, filtration, reservoir properties.

INTRODUCTION

The main goal of the analysis of the development process in multilayer oil fields is to determine the optimal technological parameters that ensure maximum oil production from each productive horizon. For this purpose, the following work is carried out:

- Study and characterization of the geological-physical properties of productive layers
- Assessment of the interaction between layers and hydraulic connections
- Analysis of the compliance of development methods with the properties of the layers
- Monitoring the technical condition and operating modes of wells

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

- Planning technological measures to increase oil yield

Development in multilayer systems is not limited only to oil production, but also includes issues of ensuring long-term operation of wells, environmental safety and economic efficiency. The choice of a strategy for individual or joint development of layers depends on the characteristics of the field, technical capabilities and economic indicators.

The main methods used in the development of multilayer oil fields are divided into two categories according to the nature of the development of the layers: joint development and separate development of the layers.

Layer co-processing method.

In the joint development method, several productive layers are exploited simultaneously through one well. This approach is technically simpler and reduces the cost of thickening. When applying the method, the fluid produced from all layers enters the well as a common flow and is raised to the surface. When applying the joint development method, the wellbore is perforated to cover all productive intervals. Each layer supplies fluid to the wellbore in accordance with its natural energy potential. During this process, a natural energy balance is created between the layers - layers with high pressure and good collector properties provide more fluid, while weak layers provide relatively less fluid.

The main conditions for joint development:

Pressure compatibility: The reservoir pressures of the layers should be close to each other. If the pressure difference between the layers is more than 2-3 MPa, the high-pressure layer can squeeze out the others, minimizing their participation. Experience shows that joint development gives effective results when the pressure difference is in the range of 15-20%.

Similarity of collectors: It is more expedient to jointly develop layers with similar porosity and permeability indicators. If the permeability difference is more than 3-5 times, the layer with high permeability becomes the main fluid source, and the low-permeable layers are practically not involved in the work.

Physicochemical properties of the fluid: The density, viscosity and chemical composition of the oil produced from different layers should be similar. Otherwise, precipitation of asphaltene-resinous substances, paraffin crystallization or the formation of emulsions may occur during mixing in the wellbore. The difference in oil viscosity should not exceed 2-3 times.

Hydraulic isolation: There must be a reliable layer of clay or dense rocks between the layers so that direct hydraulic communication between the layers does not occur. Otherwise, gas or water may pass from the high-pressure layer to the low-pressure layer, which reduces the total production.

Water section compatibility: The degree of hydration of the layers must be close. If one layer is fully hydrated and the other is not, the water section increases sharply in joint development and the economic efficiency of the well decreases. The water section difference should not exceed 20-25%.

The joint development method has a number of significant technical and economic advantages:

Economic efficiency: A significant reduction in well drilling costs is the main advantage of the method. Instead of drilling a separate well for each layer, developing several layers with one well provides 40-60% savings at the investment stage. When joint development is applied in a three-layer field, the number of wells is reduced by 3 times.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Infrastructure optimization: Fewer wells mean fewer pipelines, smaller rig sites, and a simplified collection system. This is especially important in offshore or mountainous areas. Equipment maintenance and repair are also easier.
Simplicity of operation: Since maintenance personnel have to monitor fewer wells, the operation process is simplified and human resources are saved. One operator can service 2-3 times more wells in a joint development than in an individual development.
Fast start-up: Since the number of wells is small, the process of field start-up and commissioning is accelerated. This allows for a faster return on initial investments.
Energy efficiency: Since more product is produced from a single well, energy consumption per ton of product is reduced. The advantage is especially clear when electricity consumption is calculated per well.
Minimization of environmental impact: Fewer wells mean less land disturbance, less wastewater, and a smaller ecological footprint. This is important to meet the requirements of modern environmental standards.

Separate layer processing method.
The method of separate development of layers is a complex technological approach that ensures the independent and isolated exploitation of each productive horizon in the exploitation of multilayer oil fields. The main principle of this method is that each layer is isolated by separate technical means and exploited in optimal modes corresponding to its individual parameters. Separate development of layers is the most effective, but at the same time the most capital-intensive method for obtaining maximum oil yield in multilayer systems.
The application of the method requires special equipment: packer systems, two- or multi-row devices, selective perforation tools. Advantages of separate development of layers: separate control of each layer, full participation of weak layers, individual regulation of pressure regimes and maximization of production. The main disadvantages are high technical complexity, excess financial costs and complexity of the exploitation process.
There are various technical schemes and equipment for organizing separate development of layers. Each option has its own characteristics and areas of application.
Development through separate wells: The simplest and most classic option is to drill a separate development well for each productive layer. In this case, each well perforates only one layer, and the product produced from that layer is brought to the surface by an independent system. If there are three productive layers in the field, the number of wells increases three times.
The technique of this approach is simple: each well is equipped with a fountain, gas lift or pumps. The pump-compressor pipes, devices and collection systems of the wells are completely independent. The production, water cross-section, gas factor and other parameters of each layer are easily measured and controlled.
However, the main disadvantage of this method is a sharp increase in the cost of thickening. It is technically difficult or impossible to place a large number of wells on offshore platforms or in limited areas. Therefore, more compact solutions are sought in modern practice.
Isolation with packer systems
The main technical element of the separate development of layers is the correct placement and selection of packers. The packer is a mechanism that seals the annular space between the wellbore and the production pipeline in the well and isolates the layers from each other.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Selective perforation technology.
In the separate development of layers, the perforation of each layer must be precisely planned. Selective perforation means perforating only a certain interval and not touching other layers.
Staged perforation: In the initial stage, the uppermost layer is perforated and put into operation. Then the next layer is opened and the first layer is isolated using a packer. This process continues until all layers are put into operation. The staged approach allows each layer to be put into operation at the optimal time.
Corrosion and cement control: The quality of the cement stone should be checked between the perforated intervals to prevent contact between the layers.
Perforation density and geometry: The optimal perforation hole density (number of perforation holes per meter) and the angular location of the perforation holes are selected for each layer. Sparse perforation is applied in high-permeability layers, and dense perforation is applied in weak layers. This minimizes damage to the wellbore zone and maximizes production.

Hybrid approach to layer processing.
In practice, it is often practiced to treat layers with similar properties together in groups, and layers with different parameters separately. This hybrid approach provides a technical and economic balance, increasing overall efficiency.

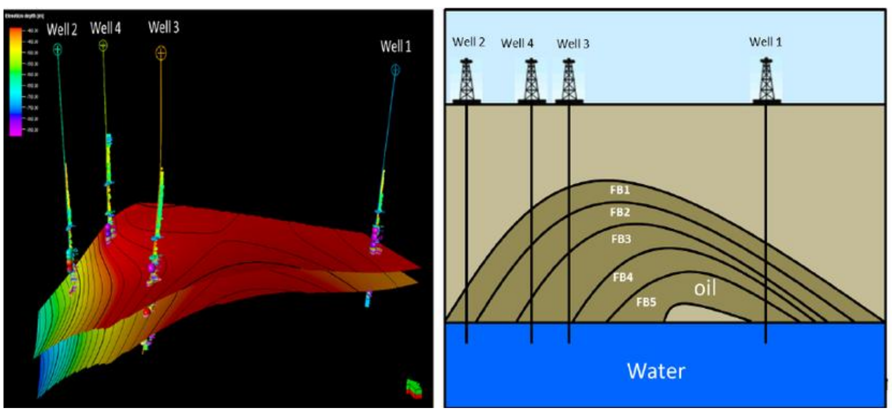


Figure 1: 3D view of a multilayer reservoir structure pierced by four wells.

Methods for increasing processing efficiency.
Various technological measures are applied to increase oil production in multilayered fields:
Artificial reservoir pressure maintenance: Recovery of reservoir energy by injecting water or gas. The application of artificial reservoir pressure maintenance in multilayered systems requires consideration of the absorption capacity of each layer.
Chemical methods: Improving filtration conditions by injecting surfactants, polymers, and alkalis. These methods are especially effective in low-permeability layers.
Physical methods: Changing the rheological properties of oil and increasing productivity through thermal, electromagnetic, or acoustic effects.
Horizontal and multistage wells: Modern thickening technologies ensure maximum contact of layers and increased production.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Hydroautomatic systems: Real-time monitoring of bottomhole pressure and temperature, automatic adjustment of operating modes.

Conclusion

1. The application of the layer-by-layer method in the development of multilayer oil fields provides significant technological and economic advantages, but requires accurate study of the individual properties of each layer (permeability, porosity, fluid composition).
2. Research results show that during the application of the general development mode in multilayer systems, intra-layer and interlayer interference processes can lead to a 15-25% decrease in productivity, which reflects the importance of effective isolation measures.
3. The complex application of hydrodynamic modeling and geological-technological research allows you to select the optimal development scheme in multilayer fields, increase well productivity and improve the accuracy of oil production forecasting.
4. The most common problems in the development of multilayer fields - early water ingress, interlayer crossflow, formation of uneven drainage zones - can be eliminated or minimized using modern monitoring systems and selective impact technologies.
5. The application of modern mechanical and chemical methods (smart completion, selective perforation, gel technologies) for reservoir level productivity management has the potential to increase the oil yield of the field by 8-12%.
6. For the efficient development of multilayer oil fields, it is necessary to prioritize the reservoirs based on the integration of geological, geophysical and technological data and prepare an individual development strategy for each reservoir.

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

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

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

REFERENCES

1. Ahmedov, T.A., Guliyev, V.Q. (2020). Choxlayli neft yataqlarinin ishlenma sistemleri [Development systems of multilayer oil fields]. Scientific Works of ADNSU (ASOİU), Baku, No. 2, pp. 45-52.
2. Mammadov, M.A. (2019). Neft yataqlarinin geoloji-fiziki xarakteristikalarinin oyrenilmesi [Study of geological and physical characteristics of oil fields]. Neft-Qaz (Oil-Gas) Journal, Baku, No. 4, pp. 23-29.
3. Ismayilov, Q.Sh., Hasanov, R.N. (2021). Laylar arasi hidravlik alaqanin qiymatlandirilmasi metodlari [Methods for evaluating hydraulic communication between layers]. Problems of Energetics, Baku, No. 3, pp. 67-74.
4. Azizov, I.M. (2020). Neft yataqlarinda suni lay tazyiqinin saxlanilmasi texnologiyalari [Technologies for maintaining artificial reservoir pressure in oil fields]. ADNSU (ASOİU) News, Baku, No. 1, pp. 89-96.
5. Mukhametzyanov, R.N., Andreev, V.E. (2018). Razrabotka mnogoplastovykh mestorozhdeniy nefti [Development of multilayer oil fields]. Moscow: Nedra, 342 p.
6. Li, K., Horne, R.N. (2019). Analysis of pressure interference in multilayer reservoirs. SPE Journal, Vol. 24, pp. 1567-1582.
7. Aziz, K., Settari, A. (2018). Petroleum Reservoir Simulation. Applied Science Publishers.

АНАЛИЗ ПРОЦЕССА РАЗВИТИЯ МНОГОСЛОЙНЫХ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ

Канан Гулиев[1], Замиг Мирзажанов[2]
[1]Магистрант, Департамент нефтегазовой инженерии, Азербайджанский государственный университет нефти и промышленности, Азербайджанагистр, kquliyev128@gmail.com
[2]Нефтегазовая инженерия, Департамент нефтегазовой инженерии, Азербайджанский государственный университет нефти и промышленности, преподаватель, Азербайджан, zamiq.mirzacanov@asoiu.edu.az

РЕЗЮМЕ

В представленной статье рассматриваются основные особенности и технологические подходы к разработке многослойных нефтяных месторождений. Как известно, эффективная разработка многослойных структурированных месторождений в современной нефтедобывающей промышленности является одним из наиболее сложных вопросов с экономико-технической точки зрения. В многослойных месторождениях правильный выбор стратегии разработки в соответствии с индивидуальными свойствами, режимами давления и коллектором каждого продуктивного горизонта важен для максимизации добычи нефти. При анализе процесса разработки следует учитывать такие параметры, как взаимодействие слоев, гидравлическая связь, фильтрационные свойства и состояние зоны ствола скважины. В статье рассматриваются различные методы разработки, применяемые в многослойных системах, их преимущества и ограничения.
Значительная часть добычи нефти в Азербайджане и в мире приходится на многослойные структурированные месторождения. Этот тип месторождений состоит из нескольких

продуктивных горизонтов, каждый из которых имеет различные геологические и физические характеристики. Процесс разработки многослойных месторождений сложнее, чем однослойных. Основная проблема здесь заключается в наличии гидравлической связи между слоями, различных показателях проницаемости и пористости, различных условиях давления и температуры. Взаимодействие пластов играет важную роль в выборе стратегии разработки, а применение правильного технологического решения значительно увеличивает общую нефтеотдачу.
Ключевые слова: многослойный пласт, процесс разработки, продуктивный пласт, гидравлическая связь, добыча нефти, зона ствола скважины, давление, фильтрация, свойства пласта.

ÇOXLAYLI NEFT YATAQLARINDA İŞLƏNMƏ PROSESİNİN TƏHLİLİ

Kənan Quliyev[1], Zamiq Mirzəcanov[2]
[1]Magistrant, Neft-qaz mühəndisliyi, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, kquliyev128@gmail.com
[2]Neft-qaz mühəndisliyi, Neft-qaz mühəndisliyi departmenti, , Azərbaycan Dövlət Neft və Sənaye Universiteti, müəllim, Azərbaycan, zamiq.mirzacanov@asoiu.edu.az

XÜLASƏ

Bu məqalədə çoxlaylı neft yataqlarının işlənməsinin əsas xüsusiyyətləri və texnoloji yanaşmaları araşdırılır. Müasir neft sənayesində çoxlaylı strukturlaşdırılmış yataqların səmərəli işlənməsi iqtisadi və texniki baxımdan ən çətin məsələlərdən biri kimi tanınır. Çoxlaylı yataqlarda neft hasilatını maksimum dərəcədə artırmaq üçün hər bir məhsuldar üfüqün fərdi xüsusiyyətlərinə, təzyiq rejimlərinə və lay şəraitinə əsaslanan işlənmə strategiyasının düzgün seçilməsi vacibdir. İşlənmə prosesini təhlil edərkən lay qarşılıqlı təsirləri, hidravlik əlaqə, filtrasiya xüsusiyyətləri və quyu şəraiti kimi parametrlər nəzərə alınmalıdır. Məqalədə çoxlaylı sistemlərdə istifadə olunan müxtəlif işlənmə metodları, onların üstünlükləri və məhdudiyyətləri müzakirə olunur.
Çoxlaylı strukturlaşdırılmış yataqlar Azərbaycanda və dünyada neft hasilatının əhəmiyyətli bir hissəsini təşkil edir. Bu tip yataqlar hər biri fərqli geoloji və fiziki xüsusiyyətlərə malik bir neçə məhsuldar üfüqdən ibarətdir. Çoxlaylı yataqların işlənməsi təklaylı yataqlardan daha mürəkkəbdir. Burada əsas çətinliklər laylar arasında hidravlik əlaqənin mövcudluğu, müxtəlif keçiricilik və məsaməlilik parametrləri, eləcə də müxtəlif təzyiq və temperatur şəraiti daxildir. Lay qarşılıqlı təsiri işlənmə strategiyasının seçilməsində əsas rol oynayır və düzgün texnoloji həllin tətbiqi ümumi neft hasilatını əhəmiyyətli dərəcədə artırır.
Açar sözlər: çoxlaylı yataq, işlənmə prosesi, məhsuldar lay, hidravlik əlaqə, neft hasilatı, quyudibi zona, təzyiq, süzülmə, kollektorun xassələri.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

332-330

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-36

VOLUME 33 (08) ISSUE 02 2026

CREATION OF AN INNOVATIVE MODEL BY APPLYING A DOUBLE-ROW PLANETARY GEARBOX TO THE OUTPUT SHAFT OF THE PUMPJACK

Vali Fataliyev[1], Bilal Gulmammadov[2]
[1]Associate Professor, Azerbaijan State University of Oil and Industry, Doctor of Philosophy in Engineering.
[2]Master, Azerbaijan State Oil and Industry University.
Email: vali.fataliyev@asoiu.edu.az[1], gulmemmedov.bilal@gmail.com[2]

ABSTRACT

In this study, the application of a planetary gear transmission mechanism in the gearbox of a pumpjack is proposed. The main objective of the proposed approach is to reduce the overall dimensions compared to existing conventional gearboxes, while simultaneously increasing the transmission ratio, thereby improving the overall technical and technological performance of the system.

Traditional pumpjack gearboxes are mainly based on cylindrical or bevel gear transmissions. To achieve high transmission ratios in such gearboxes, the use of multiple gear stages is required, which leads to an increase in the gearbox size and mass, as well as higher mechanical losses. As a result, the demand for installation space increases, and vibration and noise levels rise during operation.

The application of a planetary transmission mechanism makes it possible to eliminate these disadvantages. From a structural point of view, planetary gearboxes consist of a central sun gear, planet gears, and a ring gear, which enables the transmission of torque simultaneously through multiple gear meshes. This feature ensures a uniform load distribution among the gears and significantly increases both the load-carrying capacity and the mechanical reliability of the gearbox.

One of the main advantages of planetary transmissions is the ability to achieve high transmission ratios with relatively small overall dimensions. By using a single- or two-stage planetary system, it is possible to obtain the same or even higher transmission ratios compared to traditional multi-stage cylindrical gearboxes. This allows the size of the pumpjack gearbox to be reduced, its weight to be lowered, and material consumption to be minimized.

The reduction in overall dimensions also has a positive impact on the overall structure of the pumpjack. A more compact gearbox reduces loads on the frame, simplifies installation and maintenance processes, and enables more accurate balancing of the unit. This factor is particularly important for continuous and stable operation in deep and low-permeability oil reservoirs.

The application of a planetary gearbox in a pumpjack also ensures more efficient utilization of the torque transmitted from the electric motor to the crank mechanism. As a result of the increased

transmission ratio, a high torque is achieved at a low rotational speed, allowing the rod pumping unit to operate stably under heavy loads. At the same time, the reduction of mechanical losses contributes to energy savings and a decrease in operating costs.
Thus, the application of a planetary transmission mechanism in the pumpjack gearbox provides significant advantages, including reduced overall dimensions, increased transmission ratio, enhanced load-carrying capacity, and improved operational reliability. This demonstrates that pumpjacks equipped with planetary gearboxes represent a promising technical solution for improving oil production efficiency in modern oil fields, especially in low-permeability reservoirs.
Keywords: planetary transmission, transmission ratio, overall dimensions, mechanical transmission systems.

Introduction

In the modern era, the development of new machines and mechanisms is carried out in the direction of increasing their load-carrying capacity and motion speed, simplifying control, ensuring safety, and harmonizing the techno sphere, biosphere, and human activity.
As the technical characteristics of oil-field equipment improve, most of them become heavier and structurally more complex. This increases the demand for lifting machines with higher load capacity for the assembly and disassembly of such structures.
The KP-25 MG type trailer-mounted crane currently used in the installation of drilling equipment is no longer capable of lifting and transporting drilling pumps and other heavy equipment weighing more than 25 tons as a single unit. Therefore, the development of a new trailer-mounted crane with a load capacity of 40 tons has become a necessary engineering task.
The winch mechanism of the trailer-mounted crane utilizes a planetary gear transmission widely applied in engineering practice. These transmissions are distinguished by their compactness, coaxial arrangement of shafts, high transmission ratio, and other advantages [3;4;19;22;30;39;41;52].
Planetary transmissions are widely used in various fields of engineering, including general mechanical engineering, shipbuilding, lifting and conveying machinery, instrument engineering, mining equipment, aircraft manufacturing, machine tool construction, automobile, tractor and tank transmissions, friction planetary drives, variators, and rocket technology [19;41].
Significant contributions to the development of new planetary gear constructions have been made by many researchers and engineers. In addition, fundamental theoretical studies on planetary gear systems have played an important role in the advancement of mechanical systems.
Although the mechanics and calculation methods of planetary transmissions have been thoroughly studied in existing literature, the problem of structural optimization has not been fully resolved from a modern engineering perspective. Determination of the main parameters using traditional methods often results in low operational efficiency and high metal consumption of planetary reducers, which increases their production cost.
Therefore, optimization of the planetary gear construction and, on this basis, the development of a new trailer-mounted crane with higher lifting capacity for drilling equipment installation is a current and significant scientific and technical task.

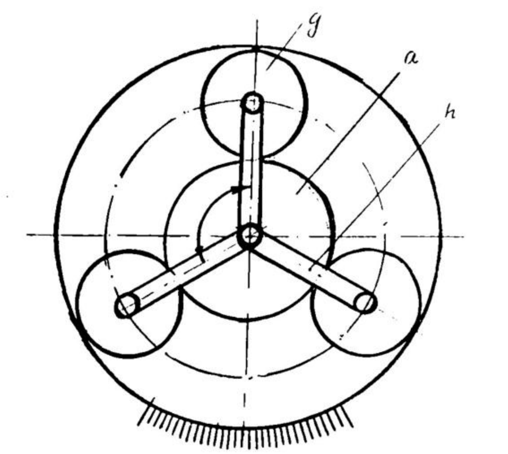
Relevance

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

In modern oil fields, particularly in low-permeability reservoirs, the operation of sucker-rod pumping units exposes pump jack gearboxes to high mechanical loads, continuously varying torque, and long-term operating conditions.
Gear reducers (Figure 1) designed on the basis of conventional cylindrical and bevel gear transmissions require multi-stage configurations in order to achieve high transmission ratios. As a result, the overall dimensions and mass of these gearboxes increase, while mechanical losses, vibration levels, and noise emissions also rise.
This negatively affects the reliability, energy efficiency, and service life of the equipment.

Figure 1: Gear Reducer.

Increasing load-carrying capacity while simultaneously reducing mechanical losses emerges as a significant engineering challenge. Since existing gearbox designs are unable to fully satisfy these requirements at the same time, the implementation of alternative transmission mechanisms becomes necessary.
In this context, the technical justification for the application of a planetary gear transmission in the pump jack gearbox, as well as the investigation of its influence on transmission ratio, overall dimensions, load-carrying capacity, and operational reliability, is identified as an important scientific and engineering task.



ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

Figure 2: Planetary Gear Transmission.

The main objective of this research is to improve the structural and technological characteristics of the gearbox through the implementation of a planetary transmission system (Figure 2), thereby increasing the overall operational efficiency of the pump jack unit.

- To analyze the technical characteristics and shortcomings of existing gearbox designs used in pump jack systems.
- To investigate the feasibility of implementing a planetary gear transmission mechanism in pump jack gearboxes.
- To evaluate the effect of planetary transmission on the transmission ratio and overall dimensions of the gearbox.
- To determine the load-carrying capacity and mechanical reliability of the planetary gearbox.
- To examine the potential for reducing mechanical losses and improving energy efficiency.
- To assess the impact of the proposed structural solution on the overall operational performance of the pump jack unit.

The solution to the stated problem is based on eliminating the existing structural deficiencies of the pump jack gearbox and improving its technical and technological performance through the implementation of a planetary gear transmission mechanism. For this purpose, both theoretical analysis and constructive design approaches are applied in an integrated manner throughout the research process.

At the initial stage, the operating principles, structural configurations, and operational characteristics of conventional cylindrical and bevel gear reducers widely used in pump jack systems are analyzed. It is determined that achieving high transmission ratios in these systems requires multi-stage gear arrangements, which leads to increased overall dimensions and mass of the gearbox, higher mechanical losses, and elevated vibration and noise levels. Furthermore, uneven load distribution in gear pairs negatively affects gearbox reliability and service life.

In the next stage, the structural configuration and operating principle of the planetary gear transmission mechanism are investigated. The transmission of torque through multiple simultaneous gear engagements between the sun gear, planetary gears, and ring gear is evaluated. This characteristic enables more uniform load distribution among gear elements, reduces contact stress, and consequently increases the load-carrying capacity of the gearbox.

One of the key stages of the solution involves the development of a structural scheme for a planetary gearbox adapted to the operating regime of the pump jack unit. At this stage, the number of planetary stages is determined according to the required overall transmission ratio, the input and output torque values are calculated, and the primary geometric parameters of the gear pairs are selected. During these calculations, both mechanical efficiency and long-term operational reliability are taken into consideration.

Since the implementation of a planetary transmission allows reduction of the gearbox dimensions and mass, the proposed planetary gearbox is comparatively analyzed against conventional gearbox designs. The comparative evaluation demonstrates that a planetary-based gearbox provides the same transmission ratio within a more compact configuration. This leads to reduced structural loads on the pump jack frame and simplifies installation and maintenance procedures.

Within the framework of the proposed solution, the integration of the planetary gearbox with the crank-slider mechanism of the pump jack is also considered. This integration ensures more

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

efficient utilization of the torque transmitted from the electric motor. Achieving a high transmission ratio enables the generation of high torque at low rotational speeds, which ensures stable operation of the sucker-rod pumping system under heavy and fluctuating load conditions.
At the same time, the application of planetary transmission contributes to reduced mechanical losses and improved energy efficiency. Decreased friction and reduced additional loading in gear elements result in lower electrical energy consumption and reduced operating costs. This represents a significant advantage, particularly for long-term continuous operation in low-permeability oil fields.
Thus, the solution to the stated problem ensures comprehensive improvement of the structural and technological characteristics of the gearbox through the implementation of a planetary gear transmission mechanism, leading to enhanced reliability and operational efficiency of the pump jack system.
A key advantage of the planetary transmission compared to conventional cylindrical gear systems is its ability to provide a higher transmission ratio within a more compact structural configuration.
The purpose of the comparison is to demonstrate which gearbox configuration can provide a higher transmission ratio within the same dimensional (size) limitation.

- Electric motor speed:

$n_1 = 1500\ \text{rpm}$

- Required output speed:

$n_2 \approx 15\ \text{rpm}$

- Required overall transmission ratio:

$i_{required} = \frac{n_1}{n_2} = \frac{1500}{15} = 100$

- Dimensional constraint:

$D_{max} \leq 500mm$

In a conventional spur gear reducer, the transmission ratio per stage typically ranges between 4 and 6.

$$i_1 = 5, i_2 = 5, i_3 = 4$$
$$i_{total} = 5 \times 5 \times 4 = 100$$

Number of teeth:

$$Z_p = 20, Z_g = 100$$

Pitch diameter:

$$d_g = m \times Z_g = 5 \times 100 = 500mm$$

For a simple planetary gear system:

$$i = 1 + \frac{Z_r}{Z_s}$$

Stage 1:

$$Z_r = 90, Z_s = 18$$
$$i_1 = 1 + \frac{90}{18} = 6$$

Stage 2:

$$Z_r = 100, Z_s = 20$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

$$i_2 = 1 + \frac{100}{20} = 6$$

Stage 2:

$$Z_r = 44, Z_s = 22$$

$$i_3 = 1 + \frac{44}{22} = 3$$

Ring gear diameter:

$$d_r = m \times Z_r = 5 \times 100 = 500mm$$

In the planetary configuration, gears are arranged coaxially and torque is distributed among multiple planets:

$$F_{t,planet} \approx \frac{F_t}{N_p}$$

If:

$$N_p = 3$$

Each planet carries approximately one-third of the total tangential load.

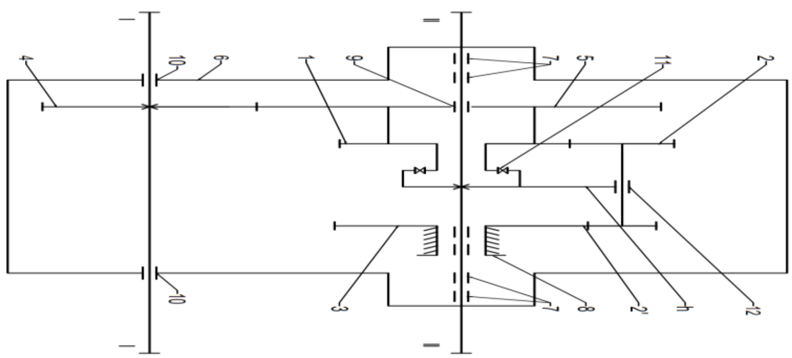


Figure 3: Application of the Planetary Gear Transmission.

Conclusion

As a result of the conducted research, it has been determined that the application of a planetary gear transmission mechanism in the pump jack gearbox contributes to a reduction in overall dimensions, an increase in transmission ratio, and an improvement in operational reliability.
From this perspective, the implementation of planetary gearbox-based pump jack systems in low-permeability oil fields is considered technically justified and practically advantageous.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. API Specification 11E. Specification for Pumping Units. American Petroleum Institute, Washington, DC, USA, 2018.
2. API Specification 11B. Specification for Sucker Rods. American Petroleum Institute, Washington, DC, USA, 2017.
3. Norton, R. L. Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines. McGraw-Hill Education, New York, 2019.
4. Shigley, J. E., Mischke, C. R., Budynas, R. G. Mechanical Engineering Design. McGraw-Hill, New York, 2015.
5. Dudley, D. W. Handbook of Practical Gear Design and Manufacture. CRC Press, Boca Raton, 2012.

MANCANAQ DƏZGAHININ REDUKTORUNUN ÇIXIŞ VALINA İKİ CƏRGƏLİ PLANETAR REDUKTORU TƏTBİQ ETMƏKLƏ İNNOVATİV MODELİN YARADILMASI

Vəli Fətəliyev[1], Bilal Gulməmmədov[2]

[1]Dosent, Azərbaycan Dövlət Neft və Sənaye Universiteti, texnika üzrə fəlsəfə doktoru.
[2]Magistr, Azərbaycan Dövlət Neft və Sənaye Universiteti.
Email: vali.fataliyev@asoiu.edu.az[1], gulmemmedov.bilal@gmail.com[2]

XÜLASƏ

Bu tədqiqatda mancanaq dəzgahının reduktorunda planetar dişli ötürmə mexanizminin tətbiqi təklif olunur. Təklif edilən yanaşmanın əsas məqsədi mövcud ənənəvi reduktorlarla müqayisədə qabarit ölçülərin azaldılması və eyni zamanda reduktorun ötürmə ədədinin artırılması yolu ilə sistemin ümumi texniki və texnoloji göstəricilərinin yaxşılaşdırılmasıdır.

Ənənəvi mancanaq dəzgahı reduktorları əsasən silindrik və ya konik dişli ötürmələr əsasında qurulur. Bu tip reduktorlarda yüksək ötürmə ədədlərinin əldə edilməsi üçün bir neçə pilləli ötürmə tələb olunur ki, bu da reduktorun ölçülərinin böyüməsinə, kütləsinin artmasına və mexaniki itkilərin yüksəlməsinə səbəb olur. Nəticədə həm quraşdırma sahəsinə olan tələbat artır, həm də istismar zamanı vibrasiya və səs səviyyəsi yüksəlir.
Planetar ötürmə mexanizminin tətbiqi bu problemlərin aradan qaldırılmasına imkan verir. Planetar reduktorlar konstruktiv baxımdan mərkəzi günəş dişlisi, planet dişliləri və halqa dişlisindən ibarət olub, fırlanma momentinin eyni vaxtda bir neçə dişli vasitəsilə ötürülməsini təmin edir. Bu xüsusiyyət yüklərin dişlilər arasında bərabər paylanmasına şərait yaradır və reduktorun həm yükdaşıma qabiliyyətini, həm də mexaniki etibarlılığını əhəmiyyətli dərəcədə artırır.
Planetar ötürmənin əsas üstünlüklərindən biri yüksək ötürmə ədədlərinin nisbətən kiçik qabarit ölçülərdə əldə edilməsidir. Bir və ya iki pilləli planetar sistem vasitəsilə ənənəvi çoxpilləli silindrik reduktorlarla müqayisədə eyni və ya daha yüksək ötürmə nisbətinə nail olmaq mümkündür. Bu isə mancanaq dəzgahının reduktorunun ölçülərinin kiçildilməsinə, çəkisinin azalmasına və metal sərfinin minimuma endirilməsinə imkan verir.
Qabarit ölçülərin azalması mancanaq dəzgahının ümumi konstruksiyasına da müsbət təsir göstərir. Daha yığcam reduktor konstruksiyası çərçivəyə düşən yükləri azaldır, montaj və texniki xidmət proseslərini sadələşdirir, həmçinin qurğunun balanslaşdırılmasını daha dəqiq şəkildə həyata keçirməyə şərait yaradır. Bu amil xüsusilə dərin və aşağı keçiriciliyə malik neft yataqlarında fasiləsiz və stabil istismar baxımından mühüm əhəmiyyət kəsb edir.
Planetar reduktorun mancanaq dəzgahında tətbiqi eyni zamanda elektrik mühərrikindən krank mexanizminə ötürülən fırlanma momentinin daha səmərəli istifadəsini təmin edir. Yüksək ötürmə ədədinin əldə edilməsi nəticəsində aşağı fırlanma sürətində yüksək moment təmin olunur ki, bu da ştanqlı quyu nasosunun ağır yüklər altında daha stabil işləməsinə imkan yaradır. Bununla yanaşı, mexaniki itkilərin azalması elektrik enerjisinə qənaət olunmasına və istismar xərclərinin aşağı salınmasına səbəb olur.
Nəticə etibarilə, mancanaq dəzgahının reduktorunda planetar ötürmə mexanizminin tətbiqi qabarit ölçülərin azaldılması, ötürmə ədədinin artırılması, yükdaşıma qabiliyyətinin yüksəldilməsi və istismar etibarlılığının artırılması kimi mühüm üstünlüklər yaradır. Bu isə planetar reduktorlu mancanaq dəzgahlarının müasir neft yataqlarında, xüsusilə aşağı keçiriciliyə malik laylarda hasilatın səmərəliliyinin artırılması üçün perspektivli texniki həll olduğunu göstərir.
Açar sözlər: planetar ötürmə, ötürmə ədədi, qabarit ölçülər, mexaniki ötürmə sistemləri.

СОЗДАНИЕ ИННОВАЦИОННОЙ МОДЕЛИ ПУТЕМ ПРИМЕНЕНИЯ ДВУХРЯДНОГО ПЛАНЕТАРНОГО РЕДУКТОРА НА ВЫХОДНОМ ВАЛУ СТАНКА-КАЧАЛКИ

Вели Фаталиев[1], Билал Гюльмамедов[2]
[1]Доцент, Азербайджанский государственный университет нефти и промышленности, доктор философии по технике.
[2]Магистр, Азербайджанский государственный университет нефти и промышленности.
Email: vali.fataliyev@asoiu.edu.az[1], gulmemmedov.bilal@gmail.com[2]

РЕЗЮМЕ

В данном исследовании предлагается применение планетарного зубчатого передаточного механизма в редукторе станка-качалки. Основной целью предлагаемого подхода является уменьшение габаритных размеров по сравнению с существующими традиционными редукторами, а также увеличение передаточного числа редуктора, что в целом способствует улучшению технических и технологических показателей системы.
Традиционные редукторы станков-качалок в основном строятся на основе цилиндрических или конических зубчатых передач. Для получения высоких передаточных чисел в таких редукторах требуется использование многопередаточных ступеней, что приводит к увеличению габаритов и массы редуктора, а также к росту механических потерь. В результате возрастает потребность в монтажном пространстве, а в процессе эксплуатации увеличиваются уровни вибрации и шума.
Применение планетарного передаточного механизма позволяет устранить указанные недостатки. С конструктивной точки зрения планетарные редукторы состоят из центральной солнечной шестерни, планетарных шестерен и кольцевой шестерни, что обеспечивает передачу крутящего момента одновременно через несколько зубчатых зацеплений. Данная особенность способствует равномерному распределению нагрузок между шестернями и существенно повышает как грузоподъемность редуктора, так и его механическую надежность.
Одним из основных преимуществ планетарной передачи является возможность получения высоких передаточных чисел при относительно малых габаритных размерах. С помощью одно- или двухступенчатой планетарной системы можно достичь такого же или более высокого передаточного отношения по сравнению с традиционными многозвенными цилиндрическими редукторами. Это позволяет уменьшить размеры редуктора станка-качалки, снизить его массу и минимизировать расход металла.
Сокращение габаритных размеров оказывает положительное влияние и на общую конструкцию станка-качалки. Более компактный редуктор снижает нагрузки на раму, упрощает процессы монтажа и технического обслуживания, а также обеспечивает более точную балансировку установки. Данный фактор имеет особое значение для непрерывной и стабильной эксплуатации оборудования на глубоких и низкопроницаемых нефтяных месторождениях.
Таким образом, применение планетарного передаточного механизма в редукторе станка-качалки обеспечивает такие существенные преимущества, как уменьшение габаритных размеров, увеличение передаточного числа, повышение грузоподъемности и рост эксплуатационной надежности. Это свидетельствует о том, что станки-качалки с планетарными редукторами являются перспективным техническим решением для повышения эффективности добычи нефти на современных месторождениях, особенно в пластах с низкой проницаемостью.
Ключевые слова: планетарная передача, передаточное число, габаритные размеры, механические передаточные системы.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

331-338

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-37

VOLUME 33 (08) ISSUE 02 2026

DEVELOPMENT OF A RAM-TYPE BLOWOUT PREVENTER USED FOR SEALING THE WELLHEAD

Veli Fataliyev[1], Murad Aliyev[2]
[1]Associate Professor, Candidate of Technical Sciences, Department "Mechanics", Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: veli.feteliyev@aztu.edu.az
[2]Faculty of Oil Mechanical Engineering, undergraduate, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: blessedjedik27@mail.ru

ABSTRACT

Operational safety during drilling and workover of oil and gas wells largely depends on the reliability of blowout prevention equipment. Ram-type blowout preventers play a key role in this system, as they are responsible for sealing the wellhead and containing formation fluids during emergency situations. Field experience shows that the performance of ram preventers is strongly influenced by the design of the rams, which are subjected to severe wear and loss of sealing capability under high pressure and cyclic loading conditions.

This paper explores possible ways to improve the design of ram elements in ram-type blowout preventers with the aim of extending their service life and maintaining stable sealing performance. Typical shortcomings of existing ram designs are analyzed, and the need for design modifications to enhance the interaction between the rams and the elements being sealed is substantiated. The proposed solutions help reduce contact stresses, limit wear of sealing surfaces, and improve the overall reliability of blowout preventer operation.

The results obtained can be applied in the development and upgrading of ram-type blowout preventers used in the oil and gas industry.

Keywords: ram-type blowout preventer, ram element, well control safety, sealing performance, wear resistance, operational reliability.

Introduction

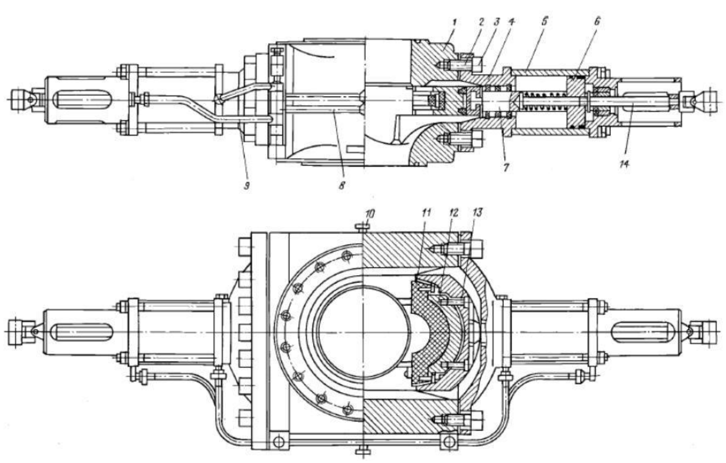
The development of the oil and gas industry is closely linked to increasingly stringent requirements for industrial and environmental safety during drilling, well completion, and major well interventions. Among the critical components of blowout prevention equipment, designed to prevent uncontrolled release of formation fluids, are ram-type blowout preventers (BOPs). Their reliable operation largely determines personnel safety, equipment integrity, and the overall stability of the technological process.

Historically, ram-type BOPs became widely adopted due to deeper drilling, higher formation pressures, and the increasing complexity of geotechnical conditions in field development. Early ram BOP designs were relatively simple and focused primarily on mechanically sealing the wellbore. With the advancement of drilling techniques and well operation technologies, BOP

designs became more sophisticated; however, the fundamental operational principles of the rams remained largely unchanged for an extended period.
Operational experience indicates that the rams themselves represent the most heavily loaded and vulnerable component of a ram-type BOP. During service, they are subjected to substantial contact stresses, high pressures, abrasive particles, and temperature fluctuations. These factors contribute to accelerated wear of the working surfaces, reduced sealing performance, and consequently, a decrease in the overall service life of the assembly. Under modern requirements for the reliability of blowout prevention systems, these limitations become especially critical.
Currently, improvements in ram-type BOPs are primarily focused on increasing the strength of the housing, as well as enhancing control and automation systems, whereas optimization of the ram design itself receives comparatively less attention. Yet, the structural characteristics of the rams significantly influence the effectiveness of wellbore sealing and the stability of BOP operation in emergency scenarios.
Therefore, a relevant scientific and technical objective is the development and substantiation of design improvements for ram elements in ram-type BOPs aimed at enhancing wear resistance, sealing integrity, and operational reliability. Addressing this task will contribute to higher safety standards during drilling and well intervention operations, as well as an extended service life of blowout prevention equipment overall.

1. Main Section

Ram-type blowout preventers are widely employed as integral components of well control equipment during drilling, well completion, and major well interventions in the oil and gas industry. Among various design configurations, hydraulically actuated ram BOPs have gained particular prominence, as they ensure reliable sealing of the wellbore in both emergency and routine operational situations. In this study, the focus is on a hydraulically operated ram-type blowout preventer manufactured by JSC "VZBT," which is utilized on drilling rigs and during well servicing operations.
The design of the studied BOP consists of the housing, ram assemblies, hydraulic drive cylinders, sealing systems, and control elements. Its operational principle is based on converting the energy of the hydraulic fluid into linear motion of the rams, which move toward each other to close and seal the wellbore.



ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Figure 1: Hydraulically operated ram-type blowout preventer by JSC VZBT. 1 – housing; 2 – rubber gaskets; 3 – bolts; 4 – hinged covers; 5 – hydraulic cylinder; 6 – piston; 7 – rod; 8 – manifold; 9 – pipeline; 10 – steam lines; 11 – rubber ram seals; 12 – replaceable inserts; 13 – ram body; 14 – locking screw.

The performance and reliability of a ram-type blowout preventer are largely determined by the design characteristics of its rams, as they directly bear the formation fluid pressure and ensure the sealing integrity of the wellbore.

Various types of rams are used in ram-type BOPs, including pipe rams, universal rams, and blind rams. In this study, particular attention is given to the blind ram, which is designed to completely seal the wellbore in the absence of a drill string or casing. Blind rams operate under the most demanding conditions, as they are subjected to the full wellbore pressure and experience significant contact stresses in the sealing zone.

Operational data from JSC "VZBT" indicate that during extended service, blind rams undergo intensive wear of both the working and sealing surfaces. The main causes of this wear include high specific loads, uneven contact stress distribution, and the presence of abrasive particles in drilling and formation fluids. These factors reduce the sealing effectiveness and increase the likelihood of BOP failure.

Furthermore, the current design of blind rams features rigid contact with the BOP housing. Under conditions of misalignment or uneven loading, this can create localized zones of elevated pressure, adversely affecting the service life of sealing elements and necessitating frequent maintenance or ram replacement.

Consequently, modernization of the blind ram design in the hydraulically operated ram-type BOP by JSC "VZBT" appears desirable. Key improvement directions include optimizing the ram's shape and dimensions, enhancing its contact interface with the BOP housing, and increasing the wear resistance and durability of sealing surfaces. Implementing these measures is expected to improve BOP reliability and ensure more stable wellbore sealing under various operational conditions.

The flow of working fluid within pipelines and connecting components generates a combination of forces acting on the pipeline system elements. The primary load arises from the internal fluid pressure, which is transmitted to the pipeline material, couplings, transitional components, and other system elements. These pressures induce stress states in the metal or other structural materials, which, if exceeding the design limits, may lead to residual deformations, microcrack development, and subsequent equipment damage.

In addition to acting on the pipe wall, the fluid pressure generates an axial force along the pipeline. This force is transmitted to connection elements, including threaded joints, flanged interfaces, welded joints, and sealing components, creating additional stress at the contact points. Insufficient strength or suboptimal design parameters of these connections increases the risk of leakage, loosening, and operational anomalies.

Elevated local stresses occur in sections where the pipeline geometry changes. At diameter transitions, flow parameters are redistributed, resulting in variations of velocity and pressure and increasing loads on transitional components. Similar phenomena are observed at pipeline bends, where changes in flow direction produce transverse forces acting on pipe walls and supporting structures. Flow kinematics also play a significant role: higher velocities amplify dynamic forces,

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

intensify vibrations, and accelerate equipment wear. These factors must be considered when assessing pipeline strength and estimating service life.

2. Research Objective

The primary objective of this study is to examine the design features and operational performance of the hydraulically operated ram-type blowout preventer manufactured by JSC "VZBT," and to identify potential directions for its modernization. Particular focus is placed on the blind ram, which is designed to fully seal the wellbore in the absence of a drill string or casing. The blind ram experiences the highest operational loads, as it must withstand the maximum formation fluid pressure while maintaining effective sealing even under extreme operating conditions.

Operational experience has shown that blind rams are subject to significant wear of both the working and sealing surfaces. The main factors contributing to reduced service life include high specific loads on the ram material, uneven distribution of contact stresses, and the presence of abrasive particles in drilling mud and formation fluids. Additionally, the rigid contact of the ram with the BOP housing, particularly under misalignment or uneven loading, generates localized zones of elevated pressure, which negatively impacts the durability of sealing elements.

Therefore, the objectives of modernizing the blind ram design are:

- To enhance the wear resistance and durability of the blind ram;
- To optimize the shape and geometry of the working surface for more uniform load distribution;
- To improve the contact interface with the BOP housing to reduce stress concentrations;
- To ensure more stable wellbore sealing under various operational scenarios, including emergency situations.

Implementation of these measures will not only extend the service life of the BOP but also reduce the frequency of maintenance interventions, thereby improving the overall reliability of blowout prevention equipment during drilling and well intervention operations.

3. Methodology

To achieve the stated objectives, a comprehensive engineering analysis methodology was applied, incorporating both theoretical calculations and evaluation of operational factors. The research approach was structured around the following directions:

3.1. Calculation of Forces and Stresses in the Pipeline System

The flow of working fluid within pipelines and connecting components generates a combination of forces acting on all elements of the system. The primary load is caused by the internal pressure of the fluid, which is transmitted to the pipe material, couplings, transitional components, and sealing elements. Under the influence of this pressure, circumferential (hoop) stresses develop, tending to expand the pipe diameter. The key parameter for assessing the strength of the pipe wall is determined using the following formula:

$$\sigma = \frac{P \cdot D}{2 \cdot t}$$

here:

- σ — stress in the pipe wall,
- P — working fluid pressure,
- D — internal pipe diameter,

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

- t — pipe wall thickness.

In addition, the fluid pressure generates axial forces along the pipeline, which act on threaded joints, flanged connections, and welded seams. In sections with diameter transitions, these axial forces are distributed unevenly, resulting in localized stress concentrations and non-uniform load transfer.

$$F = P \cdot (A_1 - A_2)$$

Where A_1 and A_2 are the cross-sectional areas of the larger and smaller diameters, respectively. This approach allows for consideration of the "extrusion" effect on connection components, which is critical when the equipment operates under high pressure.

3.2. Consideration of Dynamic Effects

When the working fluid flows at high velocity, an additional dynamic load arises due to the flow's kinetic energy. This manifests as impulsive and vibrational forces, which accelerate the wear of pipeline components and the BOP's sealing elements. The dynamic pressure is calculated using the following expression:

$$P_{д} = \frac{\rho v^2}{2}$$

Where ρ — fluid density, and v — flow velocity. This calculation is particularly important for gases or high-velocity flows, whereas for slow-moving liquids and crude oil, its effect can typically be considered negligible.

3.3. Analysis of Formation Pressure Impact on Rams

During well blowout conditions, formation pressure can significantly exceed the nominal operating pressure. This pressure is distributed over the internal surfaces of the rams, generating directed forces that can cause displacement, misalignment, and elevated stresses in the locking assemblies. The rounded design of the internal surface of the blind ram allows these loads to be redistributed: part of the pressure acts radially, while part is directed axially, producing a self-tightening effect on the seals.

The closing force of the rams under these conditions is calculated using the following formula:

$$F_{сбл} = P \cdot A \cdot \sin(\alpha)$$

Where A— area of the ram's rounded surface, and α— the angle of the tangent to the working surface. This calculation enables the assessment of the effectiveness of self-sealing and overall tightness.

3.4. Strength Calculation of the Blind Ram

The blind ram is treated as a thick-walled component. The maximum stresses are determined based on the characteristic radius of curvature and the minimum wall thickness as follows:

$$\sigma = \frac{P \cdot R}{t}$$

The strength verification is performed according to the following criterion:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

$$\sigma \leq \frac{\sigma_T}{n}$$

Where σ_t— steel yield strength, $n = 1.5 \div 2.5$— safety factor.

3.5. Methodology Conclusions

- 0.4 of the wellbore diameter (roughly 140–150 mm), which helps reduce local stress concentrations and improve sealing performance.

Analysis of these parameters demonstrates that implementing a rounded profile for the working surfaces is a structurally justified solution, enabling more uniform distribution of contact stresses and utilizing the fluid pressure energy to enhance sealing efficiency.

Conclusion

The conducted study demonstrated that, under a formation pressure of approximately 70 MPa, rams with a rounded internal surface geometry develop a self-tightening effect due to the redistribution of the working fluid pressure. This phenomenon enhances the sealing of the wellhead, reducing leakage during emergency operating conditions.

Implementing this surface geometry reduces the load on the actuating mechanisms of the blowout prevention equipment, lowers contact zone stresses, and increases the operational lifespan of sealing elements.

The proposed design solution is recommended for consideration in the development of new blowout preventers as well as the modernization of existing units, with the aim of improving operational reliability and elevating industrial safety standards in oil and gas wells.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

REFERENCES

1. American Petroleum Institute. API RP 53: Blowout Prevention Equipment Systems for Drilling Wells. Washington, DC: API, 2018.
2. American Petroleum Institute. API Specification 16A: Specification for Drill-through Equipment. Washington, DC: API, 2019.
3. Belenky, B. Z. Sealing Technology in Mechanical Systems. Moscow: Mashinostroenie, 2009.
4. Chen, W. F., Han, D. J. Plasticity for Structural Engineers. New York: Springer, 2007.
5. Dushin, V. I., Popov, V. I. Hydraulic Drives and Fluid Power Systems. Moscow: Energoatomizdat, 2010.
6. Fomin, V. A. Engineering Strength of Materials. Moscow: Mashinostroenie, 2012.
7. Munson, B. R., Young, D. F., Okiishi, T. H., Huebsch, W. W. Fundamentals of Fluid Mechanics. 8th ed. Hoboken: Wiley, 2017.
8. Schlumberger. Oilfield Glossary: Blowout Preventers (BOPs). Houston: Schlumberger, 2020.
9. Shakhnovich, M. I. Machine Elements: Design and Reliability. Moscow: Mashinostroenie, 2011.
10. Streeter, V. L., Wylie, E. B., Bedford, K. W. Fluid Mechanics. New York: McGraw-Hill, 2016.
11. White, F. M. Fluid Mechanics. 8th ed. New York: McGraw-Hill, 2016.
12. Vakhrushev, V. N. Design of Machine Elements. Moscow: Mashinostroenie, 2013.

QUYU AĞZINI KİPLƏNDİRMƏK ÜÇÜN İSTİFADƏ OLUNAN PLAŞKALI PREVENTORUN İŞLƏNMƏSİ

Vəli Fətəliyev[1], Murad Əliyev[2]
[1]Dosent, texnika elmləri namizədi, "Mexanika" kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, E-mail: veli.feteliyev@aztu.edu.az
[2]"Neft-Mexanika" fakultəsi, Magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan, E-mail: blessedjedik27@mail.ru

XÜLASƏ

Neft və qaz quyularının qazılması və əsaslı təmiri zamanı işlərin təhlükəsizliyi böyük dərəcədə fontana qarşı avadanlığın etibarlılığından asılıdır. Bu sistemdə əsas rolu plaşkalı preventorlar oynayır, çünki fövqəladə hallarda quyu ağzının bağlanmasını və lay flüidlərinin saxlanmasını məhz onlar təmin edir. İstismar təcrübəsi göstərir ki, plaşkalı preventorların səmərəliliyi plaşkaların konstruktiv xüsusiyyətlərindən ciddi şəkildə asılıdır və yüksək təzyiq və dövri yüklənmələr şəraitində onlar intensiv aşınmaya və hermetikliyin zəifləməsinə məruz qalır.
Məqalədə plaşkalı preventorlarda istifadə olunan plaşka elementlərinin konstruksiyasının təkmilləşdirilməsi istiqamətləri araşdırılır. Bu təkmilləşdirmələr onların istismar müddətinin uzadılmasına və hermetikliyin stabil saxlanmasına yönəldilmişdir. Mövcud plaşka konstruksiyalarının tipik çatışmazlıqları təhlil edilir və plaşkaların bağlanan elementlərlə qarşılıqlı təsirinin yaxşılaşdırılması üçün konstruktiv dəyişikliklərin zəruriliyi əsaslandırılır. Təklif olunan

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

hələr kontakt gərginliklərini azaltmağa, sıxlaşdırıcı səthlərin aşınmasını minimuma endirməyə və preventorun ümumi etibarlılığını artırmağa imkan verir. Əldə olunan nəticələr neft-qaz sənayesində tətbiq olunan plaşkalı preventorların layihələndirilməsi və modernləşdirilməsi zamanı istifadə oluna bilər.

Açar sözlər: plaşkalı preventor, plaşka elementi, quyu təhlükəsizliyinin təmin olunması, hermetikliyin saxlanması, aşınmaya davamlılıq, istismar etibarlılığı.

РАЗРАБОТКА ПЛАШЕЧНОГО ПРЕВЕНТОРА ИСПОЛЬЗУЕМОГО ДЛЯ ГЕРМЕТИЗАЦИИ УСТЬЯ СКВАЖИНЫ

[1]Вяли Фаталиев, Мурад Алиев[2]
[1]Доцент, кандидат технических наук "Кафедра механики", Азербайджанский технический университет, Азербайджан. E-mail: veli.feteliyev@aztu.edu.az
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: blessedjedik27@mail.ru

РЕЗЮМЕ

Безопасность работ при бурении и капитальном ремонте нефтегазовых скважин в значительной степени определяется надежностью противовыбросового оборудования. Существенную роль в его составе играют плашечные превенторы, обеспечивающие перекрытие устья скважины и удержание пластовых флюидов при возникновении нештатных ситуаций. Эксплуатационный опыт показывает, что эффективность работы плашечных превенторов во многом зависит от конструктивных особенностей плашек, которые в условиях высоких давлений и циклических нагрузок подвержены интенсивному износу и потере герметичности.

В статье рассматриваются направления усовершенствования конструкции плашек плашечных превенторов, ориентированные на повышение ресурса их работы и стабильности герметизирующих свойств. Проанализированы характерные недостатки применяемых конструкций плашек и обоснована необходимость внесения изменений, направленных на улучшение взаимодействия плашек с перекрываемыми элементами. Предложенные решения позволяют снизить контактные напряжения, уменьшить износ уплотняющих поверхностей и повысить общую надежность работы превентора.

Полученные результаты могут быть использованы при разработке и модернизации плашечных превенторов, применяемых в нефтегазовой промышленности.

Ключевые слова: плашечный превентор, плашка, противовыбросовая безопасность, герметизация, износ, надежность.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

339-345

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-38

MATHEMATICAL MODEL OF VIBRATING SIEVE TECHNOLOGICAL PROCESSES

Tahir Suleymanov[1], Aybeniz Amirova[2], Elnara Salimova[3]
[1]Associate Professor , Azerbaijan State Oil and Industry University, Department of Mechanics, Candidate of Technical Sciences. tahir_suleymanov@list.ru
[2]Laboratory Assistant, Azerbaijan State Oil and Industry University, Department of Mechanics. ayka59@mail.ru
[3]Laboratory Assistant, Azerbaijan State University of Oil and Industry Department of Mechanics. elnare.selimova.1980@gmail.com

ABSTRACT

It is assumed that the technological process of vibrating screens should have a mathematical description. A mathematical description is understood to mean mathematical dependencies that link the mechanical parameters of the movement of the working body of the vibrating screen with the main quality indicators of the technological process. At the same time, inelastic resistance and the perfect elasticity of the vibrating screen's support springs are not taken into account. This assumption is approximately correct in the case of steel coil springs. However, if rubber or cork gaskets are used, the damping is significant and can no longer be ignored. In this work, without taking into account free vibrations, we obtain the so-called steady state of forced vibrations, determined by the corresponding equation.
Keywords: Vibrating screens, technological process, vibration, coil springs, centrifugal force, elastic support, dynamic coefficient, natural frequency.

The vibrational principle of the technological process must have a mathematical description. A mathematical description refers to mathematical dependencies that link the mechanical parameters of the vibrating screen's working body with the main quality indicators of the technological process [1, 2,3].
It is assumed that there is no inelastic resistance and that the support springs of the vibrating screen are perfectly elastic. This assumption is approximately correct in the case of steel coil springs. However, if rubber or cork gaskets are used (incidentally, they cannot be used in vibrating screens), the damping is significant and cannot be ignored. In the case of such imperfect elasticity, it can be assumed that the resistance force consists of two parts: an elastic force proportional to the compression (and elongation) of the spring, and a damping force proportional to the velocity/4.5/.
During operation, vibrating screens with some imbalance transmit periodic force disturbances to their body, which can cause unwanted vibrations in the foundations, fatigue phenomena in the nodes, and noise. To reduce these harmful effects, (other) elastic springs are used in the supports. Let a body with weight P (Fig. 1) represent a vibrating screen and F denote the centrifugal force

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

arising from rotational imbalance (from the effects of imbalance rotation). Then, at any angular velocity ω, the centrifugal force is equal to $F\omega^2$. Counting the angles as shown in the figure, we obtain the vertical and horizontal components of the disturbing force, equal to $F\omega^2 \cos\omega t$ and $F\omega^2 \sin\omega t$, respectively. Thus, we obtain a vibration system consisting of a vibrating screen body on vertical springs. To determine the variable vertical force transmitted to the body (foundation) of the vibrating screen, it is necessary to study the oscillations of the body under the action of the disturbing force $F\omega^2 \sin\omega t$.

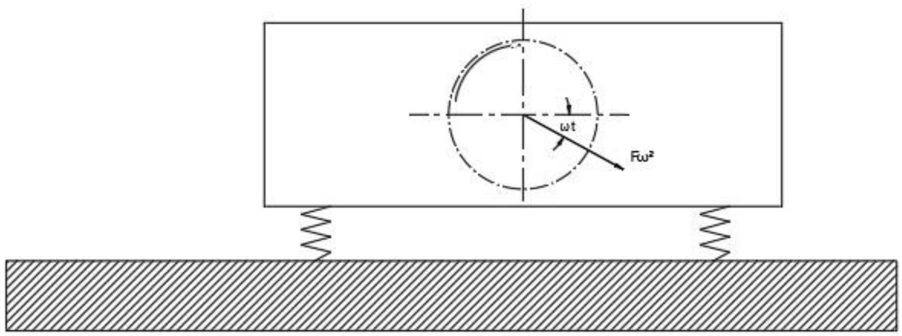


Figure 1: Vibrating screens with elastic supports.

If the vibrating screen is rigidly attached to a rigid foundation, then the full centrifugal force will be transmitted to the foundation [6,7,8].

Consider a case where, in addition to the weight force and the elastic force of the spring, a periodic disturbing force $F\omega^2 \sin\omega t$ acts on the vibrating screen. The period of this force is equal $\tau_1 = \frac{2\pi}{\omega}$ to, and its frequency is $f_1 = \frac{\omega}{2\pi}$. This results in the following differential equation of motion:

$$\frac{P}{g}\ddot{x} = P - (P - kx) + F\omega^2 \sin\omega t \tag{1}$$

or by entering the designations

$$q = \frac{F\omega^2 g}{P}, \quad P^2 = \frac{kg}{P}, \tag{2}$$

we have

$$\ddot{x} + P^2 x = q \sin\omega t \tag{3}$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

A particular solution to this equation can be obtained by assuming that is x proportional to $sin\omega t$ i.e.

$$x = A sin\omega t \tag{4}$$

where $A -$ is a constant whose value must satisfy equation (3).
Substituting (4) into this equation, we find

$$A = \frac{q}{P^2 - \omega^2}$$

Then the desired particular solution is

$$x = \frac{q\, sin\omega t}{P^2 - \omega^2} \tag{5}$$

Adding to this particular solution, the solution for free oscillations, we obtain

$$x = C_1 cos(Pt) + C_2 sin(Pt) + \frac{q\, sin\omega t}{P^2 - \omega^2} \tag{6}$$

This expression contains two integration constants and represents the general solution (1). As can be seen, this solution consists of two parts: the first two terms represent free oscillations, and the third term, which depends on the disturbing force, represents the forced oscillations of the vibrating screen. These latter oscillations have the same period $\tau_1 = \frac{2\pi}{\omega}$ as the disturbing force.

Using the accepted notation for q and ignoring free oscillations, we obtain the so-called steady state of forced oscillations, defined by the equation

$$x = \frac{F_p^2}{k} \frac{\frac{\omega^2}{P^2}}{1 - \frac{\omega^2}{P^2}} sin\omega t \tag{7}$$

From this, it can be seen that the amplitude of forced oscillations is equal to the absolute value of the expression

$$\frac{F_{P^2}}{k} = \frac{\frac{\omega^2}{P^2}}{1 - \frac{\omega^2}{P^2}} \cdot \tag{8}$$

here $k -$ spring stiffness coefficient, i.e., the force capable of causing vertical displacement of the vibrating screen;

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

$P-$ natural frequency of angular oscillations.
As can be seen, for this value of the ratio, the $\frac{F_p^2}{k}$ amplitude of forced oscillations depends only on the ratio $\frac{\omega}{P}$. The dependence of the absolute values of the second factor in expression (8) on the values is $\frac{\omega}{P}$ shown in Fig. 2. At large values $\frac{\omega}{P}$ of , these values tend to unity, and the absolute value of expression (2) tends to $\frac{F_p^2}{k}$. Knowing the amplitude of forced vibrations of a vibrating screen with weight p and multiplying it by the stiffness coefficient k , we find the maximum variable force that the springs will transmit to the foundation/9,10/.
Recalling that $F\omega^2$ there is a maximum vertical disturbing force corresponding to the case of a vibrating screen rigidly attached to the foundation, it can be concluded from (8) that elastic springs reduce the force transmitted to the body (to the foundation) only if the absolute value of the difference is greater than one, i.e., if $\omega > \sqrt{2}P$. When ω is significantly greater than P, i.e., when the vibrating screen is mounted on very flexible springs, expression (8) numerically approaches the value $\frac{F_p^2}{k}$, and due to the elasticity of the springs, there is a decrease in the vertical force relative to $\frac{P^2}{\omega^2}$. From this it can be seen that in order to reduce the disturbing force transmitted to the body (to the foundation), the vibrating screen must be mounted on flexible springs so that the natural frequency of the vibrating screen with a weight P is small compared to the number of revolutions per second of the vibrating screen/11/.
Consider the following example: A vibrating screen weighing $P = 450$ kg, vibrating at 1000 rpm, is supported by four coil springs made of steel wire with a diameter of $D = 1{,}2$ cm. The average diameter of the spring is $d = 10$ cm and the number of coils is $n = 10$. We determine the maximum vertical disturbing force transmitted to the frame (foundation) if the centrifugal force from the imbalance is $F = 0{,}45$ kg at an angular velocity of I rad/sec.

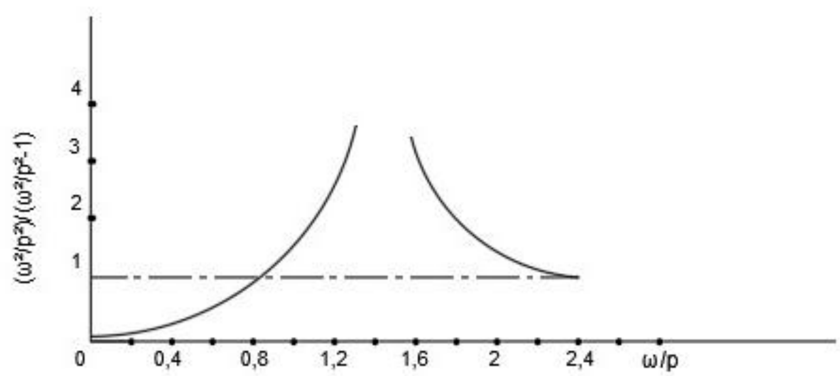


Figure 2: Change in the dynamic coefficient.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

We solve this problem using the following sequence. The static deflection of the springs under the weight of the vibrating screen is equal to

$$\delta_{cm} = \frac{2 \cdot n \cdot D^2 \cdot P}{d^4 \cdot G} = \frac{2 \cdot 10 \cdot 10^3 \cdot 450}{1{,}2^4 \cdot 0{,}8 \cdot 10^6} = 5{,}43 \text{ см.}$$

We determine the stiffness coefficient $k = 450 : 5{,}43 = 83$ kg/cm. The square of the angular frequency of free vibrations is $P^2 = \frac{g}{\delta_{cm}} = 181$ sec^2. Using expression (4), we obtain the maximum force transmitted to the frame:

$$0{,}45 \frac{(60\pi)^2}{\frac{(60\pi)^2}{181} - 1} = 82 \text{ кг}$$

Thus, without changing the technological processes, by rationally selecting the design characteristics of various elements of the vibrating screen, it is possible to minimize the force transmitted through the spring supports to the frame. This is useful primarily for increasing the durability of the support assemblies and working elements of the vibrating screen.

Conclusions

1. Studies show that the correct choice of technological process, along with other operating parameters, significantly affects the strength properties of key components.

2. The collection and analysis of field data on the operation of vibrating screens show that the strength properties of key components, namely elastic elements, directly depend on the vibration mode parameters.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Bykovsky, I.I. Fundamentals of Vibration Technology Theory. Moscow, Mashinostroenie, 1979, 363 p.
2. Bauman, V.A., Bykovsky, I.I. Vibration Machines and Processes in Construction. Moscow: Higher School, 1977, 255 p.
3. Blekhman I.I., Dzhanalidze G.Yu. Vibration Movement. Moscow: Nauka, 1964, 410 p.
4. Vibration Machines in Construction and Production of Building Materials (Reference Book). Moscow: Mashinostroenie, 1970, 548 p.
5. Lavenel E.E. Synthesis of optimal vibrating machines. Riga, Zinatne, 1970, 250 p.
6. Golovin M.V., Dobik A.A., Kortunov A.V., Mishchenko V.I. Modern trends in the development of vibrating screens for cleaning drilling fluids. Drilling and Oil, No. 03 (March), 2014, pp. 45-53.
7. Drilling Fluids Processing Handbook. Burlington, MA: Elsevier Inc., 2005, 666 p.
8. US Patent No. 6513664B1, 04.02.2003.
9. Russian Federation Patent No. 2356648C2, IPC B07B1/40, B07B1/42, published 27.05.2009.
10. Kichkar Yu.E., Kichkar I.Yu. Mathematical model of the specific throughput capacity of a vibrating screen network. Scientific and Technical Journal, Construction of Oil and Gas Wells on Land and at Sea, June 2021, No. 6/342, pp. 23-25.
11. Mishchenko V.I., Kortunov A.V. Preparation, purification, and degassing of drilling fluids, Krasnodar: Art. Press, 2008, 336 pp.

TİTRƏYƏN ƏLƏKLƏRİN TEXNOLOJİ PROSESLƏRİNİN RİYAZİ MODELİ

Tahir Süleymanov[1], Aybəniz Əmirova[2], Elnarə Səlimova[3]
[1]Azərbaycan Dövlət Neft və Sənaye Universiteti, Mexanika kafedrası, texnika elmləri namizədi, dosent.
[2]Azərbaycan Dövlət Neft və Sənaye Universiteti, Mexanika kafedrası, laborant.
[3]Azərbaycan Dövlət Neft və Sənaye Universiteti Mexanika kafedrası, laborant.

XÜLASƏ

Güman edilir ki, vibrasiyalı qurğu riyazi modelə malik olmalıdır. Bu riyazi model vibrasiya qurğusunun işçi orqanının mexaniki parametrlərini əsas prosesin keyfiyyət göstəriciləri ilə birləşdirən riyazi əlaqələrə aiddir. Bu, titrəyən qurğunun dayaqda yayların müqavimətini və ideal elastikliyini nəzərə almır. Bu fərziyyə polad yaylar üçün təxminən doğrudur. Bununla belə yastıqlar istifadə edilərsə, sönmə əhəmiyyətli olur və proses dayana bilər. Bu məqalədə, sərbəst vibrasiyalara məhəl qoymadan, müvafiq tənliklə müəyyən edilmiş məcburi vibrasiyaların sabit vəziyyətinə baxılır.

Açar sözlər: Titrəyən qurğular, texnoloji proses, vibrasiya, yaylar, mərkəzdənqaçma qüvvəsi, elastik dayaq, dinamik əmsal, məxsusi tezlik.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ ВИБРАЦИОННОГО СИТА

Тахир Сулейманов[1], Айбениз Амирова[2], Эльнара Салимова[3]
[1]Азербайджанский государственный нефтегазовый университет, факультет механики, кандидат технических наук, доцент. tahir_suleymanov@list.ru
[2]Азербайджанский государственный нефтегазовый университет, факультет механики, лаборант. ayka59@mail.ru
[3]Азербайджанский государственный нефтегазовый университет, факультет механики, лаборант. elnare.selimova.1980@gmail.com

РЕЗЮМЕ

Предполагается, что технологический процесс вибрационного сито должен иметь математическое описание. Под математическим описанием понимаются математические зависимости, связывающие механические параметры движения рабочего тела вибрационного сито с основными показателями качества технологического процесса. При этом не учитывается неупругое сопротивление и идеальная упругость пружин опоры вибрационного сито. Это предположение приблизительно верно в случае стальных винтовых пружин. Однако, если используются резиновые или пробковые прокладки, демпфирование становится значительным и им уже нельзя пренебрегать. В данной работе, не учитывая свободные колебания, мы получаем так называемое стационарное состояние вынужденных колебаний, определяемое соответствующим уравнением.
Ключевые слова: Вибрационные сито, технологический процесс, вибрация, винтовые пружины, центробежная сила, упругая опора, динамический коэффициент, собственная частота.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

346-356

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-39

CALCULATION OF TRIBOLOGICAL WEAR OF MANIFOLD GATE VALVES

Veli Fataliyev[1], Shahin Garayev[2]
[1]Associate Professor, Ph.D. in Engineering, Department of Mechanics, Azerbaijan Technical University, Azerbaijan.E-mail: veli.feteliyev@aztu.edu.az
[2]Master's Student, Faculty of Oil and Gas Mechanical Engineering, Azerbaijan State University of Oil and Industry, Azerbaijan.E-mail: qarayevayxan783@gmail.com

ABSTRACT

This research paper examines manifold gate valves used in oil and gas equipment and analyzes their interaction mechanisms under conditions of high contact stresses and abrasive exposure of the working medium. A review of existing design solutions is conducted from the standpoint of tribological processes, including friction, wear, and the distribution of contact stresses at mating surfaces.

An assessment of currently applied methodologies for calculating tribological wear is carried out, identifying their advantages and limitations. Based on fundamental tribological principles and the results of analytical calculations, an improved approach to evaluating the wear resistance of manifold valve components is proposed, taking into account the condition of the surface layer and the application of advanced surface hardening technologies.

Special attention is given to the use of hard-alloy coatings and nanostructured coatings as effective means of enhancing wear resistance, reducing the coefficient of friction, and extending the service life of working surfaces. The results of wear calculations for valve components are presented, along with a comparative analysis of the operational performance of the baseline and modernized designs. The effectiveness of the proposed calculation methods and their positive impact when implemented in manifold gate valve design are summarized.

Keywords: manifold gate valve; tribology; tribological wear; nanocoating; hard-alloy coatings; coefficient of friction; contact stresses; surface hardening; oil and gas equipment.

Introduction

Manifold gate valves represent a critical component of oil and gas equipment, ensuring reliable regulation of working fluid flow under conditions of high pressure, variable mechanical loads, and aggressive operating environments. The operational reliability and service life of these units are largely determined by the condition of their contacting surfaces, which are continuously subjected to frictional interaction and wear.

During operation, mechanical contact occurs between the gate, seats, and sealing elements, resulting in progressive degradation of sealing integrity, increased actuation force requirements, and a reduction in overall equipment lifespan. The wear rate within the gate–seat contact zone

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

depends on the magnitude of contact stresses, the mechanical and tribological properties of the materials involved, as well as the extent of relative motion between interacting surfaces.

Modern oil and gas production facilities operate under increasingly demanding conditions, characterized by elevated working pressures, more complex compositions of transported media, and stricter safety and reliability standards. Under such circumstances, tribological wear of manifold gate valve components becomes a matter of significant engineering concern. The presence of abrasive particles in the working fluid, cyclic loading regimes, and unfavorable lubrication conditions considerably intensify surface degradation processes, potentially leading to premature equipment failure.

A quantitative assessment of wear in the working contact surfaces may be performed using Archard's wear law, according to which the volume of removed material is expressed as:

$$V = \frac{k \cdot (F_n \cdot L)}{H}$$

here

k — wear coefficient characterizing the tribological behavior of the material pair;

F_n — normal force pressing the gate against the seat;

L — total sliding distance of relative motion;

H — hardness of the softer material within the contact pair.

Despite the availability of various design modifications of gate valves and the extensive operational experience accumulated in the oil and gas industry, the problem of quantitative tribological wear assessment remains insufficiently developed. Existing wear prediction approaches are often of an approximate nature and do not fully reflect the actual service conditions of manifold gate valves. In particular, they inadequately account for the specific features of contact interaction, the real distribution of contact stresses, and the mechanical and physical properties of mating surfaces.

Under practical operating conditions, the normal contact force within the "gate–seat" pair is primarily determined by the pressure of the working medium. This force can be represented by the following relationship:

$$F_n = p \cdot A_c$$

p — pressure of the working medium; A_c — effective contact area between the gate and the seat.

In cyclic operation of the valve, the cumulative friction path is governed by the number of opening and closing cycles performed during service. The total sliding distance can therefore be determined as a function of the operating cycle count:

$$L = s \cdot N$$

s — gate displacement during a single operating cycle; N — number of operating cycles.

In view of the above considerations, the objective of the present study is to perform a quantitative evaluation of tribological wear in manifold gate valves, taking into account their design characteristics and actual service conditions. To accomplish this objective, the paper provides an analysis of the tribological mechanisms occurring within valve components, examines the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

principal factors governing wear intensity, and conducts a durability assessment of the contacting surfaces.
The linear wear of the working surfaces of the gate and the seat is determined using the following relationship:

$$h = \frac{V}{A_c}$$

By substituting the fundamental relationships into the base wear equation, the final analytical expression for the tribological wear of the "gate–seat" contact pair can be obtained as follows:

$$h(N) = \frac{k \cdot (p \cdot s \cdot N)}{H}$$

To evaluate the stress–strain state within the contact region, Hertzian contact theory is applied. According to this approach, the maximum contact stress is determined by the following expression:

$$\sigma_{max} = \sqrt{\frac{6 \cdot F_n \cdot E'}{\pi \cdot b^2}}$$

here E'— equivalent (reduced) elastic modulus of the materials forming the contact pair; b—

characteristic width of the contact zone.
The derived analytical relationships make it possible to assess the influence of operating pressure, material properties, and service conditions on wear intensity. They also enable the determination of the permissible number of operating cycles and provide a technical basis for improving the design of manifold gate valves. Such an approach supports the enhancement of reliability, extension of service life, and overall improvement of operational efficiency.

Research objective
The ongoing advancement of the oil and gas industry is accompanied by a steady increase in operating pressures, higher throughput capacities of technological systems, and progressively more severe service conditions for pipeline valves. Under such circumstances, manifold gate valves perform a crucial function in ensuring safe and reliable flow control during the production, transportation, and processing of hydrocarbons.
The operational reliability of these valves is largely governed by the condition of their contact assemblies, particularly the "gate–seat" interface, which is exposed to significant tribological loading throughout service. Continuous frictional interaction, combined with high contact stresses, leads to gradual degradation of sealing performance and mechanical integrity.
The aim of the present study is to develop and substantiate a computational methodology for evaluating the tribological wear of manifold gate valves. The proposed approach is based on an analysis of frictional processes and contact mechanics within the "gate–seat" pair, taking into account valve design characteristics as well as actual operating conditions. The ultimate objective

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

is to enhance reliability, extend service life, and improve the overall operational efficiency of oil and gas equipment.

Friction and wear phenomena occurring within the contact zone of manifold gate valves directly affect the sealing integrity of the shut-off element, the magnitude of the actuation force, the stability of operational characteristics, and the overall service life of the equipment. The presence of abrasive particles in the transported medium, exposure to elevated contact stresses, cyclic operating conditions, and insufficient lubrication significantly accelerate surface degradation. These factors may result in premature component failure and potentially lead to hazardous operating situations. Consequently, the issue of tribological wear in manifold gate valves possesses substantial scientific and practical relevance.

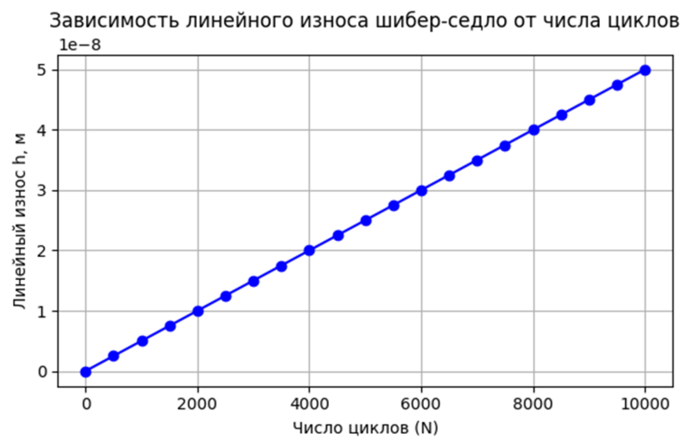


Figure 1: Dependence of linear wear of the gate–seat pair on the number of operating cycles.

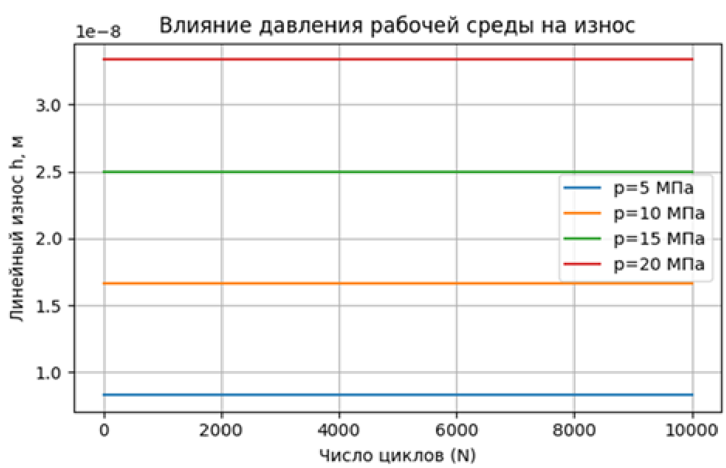


Figure 2: Influence of operating pressure on the linear wear of the gate–seat contact pair.

Despite the wide variety of existing valve designs and the extensive operational experience accumulated in the oil and gas sector, the quantitative assessment of tribological wear remains insufficiently structured and theoretically substantiated. In practice, service life estimations are often based on empirical data and simplified assumptions that do not adequately consider the influence of geometric parameters, loading regimes, or the physical and mechanical properties of contacting materials. Such limitations may lead either to excessive safety factors or to underestimation of actual wear, both of which negatively impact economic performance and operational reliability.

With increasingly stringent industrial safety standards and growing demands for resource efficiency, there is a clear need for scientifically grounded calculation methodologies capable of predicting wear of manifold gate valve components at the design and modernization stages. In this context, the application of tribological principles and contact mechanics theory becomes especially important for developing analytical models that realistically describe the working conditions of the "gate–seat" interface, including load distribution patterns, contact stresses, and cumulative sliding distance.

Accordingly, the principal objective of the present research is to develop, refine, and substantiate a computational methodology for determining tribological wear in manifold gate valves. The proposed approach is based on a detailed analysis of frictional processes and contact interaction within the "gate–seat" pair, taking into account valve design features, material properties, and actual service conditions.

Achievement of this objective involves the formulation of an integrated framework for evaluating wear resistance, combining classical and modern tribological models, including Archard's wear law and Hertzian contact theory. A specific task of the study is the adaptation of these theoretical models to the operating conditions of manifold gate valves, which are characterized by high pressures, cyclic mechanical loading, and exposure to aggressive working media.

An additional objective is to establish a quantitative relationship between the primary operational parameters of manifold gate valves—namely working pressure, number of opening–closing cycles, magnitude of relative gate displacement, and the physical and mechanical characteristics of materials—and the intensity of tribological wear. This approach enables the transition from qualitative reliability assessment to quantitative service life prediction.

Particular attention is devoted to analyzing how specific design solutions influence tribological behavior. Within the framework of the study, possibilities for reducing wear intensity are examined, including optimization of contact area, redistribution of contact stresses, and the application of wear-resistant materials and protective coatings. In this respect, the calculation of tribological wear is considered not only as an evaluation tool but also as an instrument for constructive improvement of valve design.

Furthermore, the research aims to establish wear-based operability criteria for manifold gate valves, enabling determination of the permissible limit of material degradation within the contact pair and the corresponding allowable number of operating cycles. This provides a rational basis for defining maintenance intervals and enhancing overall equipment reliability.

Thus, the objective of the present study is comprehensive in nature and is directed toward solving a scientific and practical problem: improving the reliability and durability of manifold gate valves through the development and implementation of analytical wear assessment methods. The realization of this objective forms a scientific foundation for the design and modernization of manifold gate valves with enhanced operational characteristics and contributes to increasing the efficiency and safety of oil and gas equipment as a whole.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Applied methodology

In the course of the calculations, it was necessary to take into account that blowout valve gate valves represent among the most critical and heavily loaded components of oil and gas equipment. During operation, these valves are subjected to high working pressures, significant frictional forces, and axial loads, which contribute to accelerated wear and may lead to loss of sealing integrity and reduced overall reliability of the assembly.

It is well known that an increase in friction forces within the shut-off and sealing assembly, as well as in threaded connections, adversely affects valve operability, increases the required torque on the handwheel, and negatively impacts the performance of the blowout equipment as a whole. Therefore, the analysis of operational factors was aimed at solving the following tasks: determining the forces acting on the main valve components during opening and closing; evaluating the stress state of valve parts; calculating the torque required for valve operation; and establishing conditions for maintaining sealing performance. Variations in forces acting on the valve components were determined analytically, taking into account working pressure, geometric dimensions of the parts, and friction in the contact zones. To isolate the influence of secondary factors, it was assumed that all other structural elements were in proper condition, free of additional defects or wear.

The forces acting on the spindle were calculated for the most heavily loaded operating condition, namely the moment of complete valve closure. In this scenario, the total axial force on the spindle was taken as the sum of friction forces between the gate and seat, friction in the stuffing box assembly, and the force generated by the working fluid pressure. The resulting values were then used to compute stresses in the spindle, the threaded connection, and the driving nut.

The strength of threaded components was evaluated by calculating the stress on the spindle and driving nut threads under compression, bending, and shear. The analysis was performed for the most loaded thread, taking into account a load distribution non-uniformity factor. The obtained stress values were compared with allowable limits defined by the mechanical properties of the materials.

The gate was analyzed using the theory of thick plates. Deflections as well as radial and circumferential stresses induced by working pressure were determined. Based on these calculations, the stiffness of the gate and its ability to ensure uniform contact pressure distribution along the sealing surface were assessed. For ensuring valve tightness, the shut-off and sealing assembly, comprising the gate, seat, and disc spring, was calculated. Contact pressures on the sealing surfaces were established such that the minimum pressure required for sealing was exceeded while ensuring that the maximum pressure did not exceed limits defined by material strength and wear resistance.

The torque on the valve handwheel was calculated as the sum of frictional moments in the spindle threads, support assembly, and stuffing box. These torque values enabled evaluation of manual operability and determination of rational parameters for the actuating mechanism.

Thus, the applied methodology is based on a sequential determination of loads, stresses, and contact pressures in the main valve components, followed by verification of strength, stiffness, and sealing conditions. This approach allows for an objective assessment of the operability and reliability of blowout valve gate valves under specified operational conditions.

Proposal for Cleaning and Strengthening Manifold Valve Springs

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

During the operation of manifold gate valves, spring elements are exposed to contaminants, corrosive media, and wear products, which adversely affect their elastic properties, reduce operational performance, and may lead to premature component failure.
To enhance the reliability and service life of the springs, the use of electrochemical polishing (electropolishing) is proposed as a method for surface cleaning and finishing. Electropolishing effectively removes oxide layers, micro-contaminants, and surface defects, while reducing surface roughness. This process contributes to lower stress concentrations and improved fatigue strength of the springs.
Following electropolishing, it is recommended to apply a nanocoating based on nitrides, oxides, or carbon compounds, forming a protective functional layer. Such nanocoatings provide:

- Increased wear resistance and corrosion protection;
- Reduced friction between spring coils and interacting components;
- Stabilization of elastic properties under cyclic loading;
- Extended service life under high-pressure and aggressive operating conditions.

The combined application of electropolishing and nanocoatings allows for a substantial improvement in the operational and tribological performance of manifold valve springs, which in turn enhances the overall reliability and fault-free operation of manifold equipment.

Results and discussion

The analytical study of tribological wear in the shut-off elements of manifold gate valves operating under the transport of formation fluid containing solid inclusions revealed quantitative patterns in wear intensity as a function of operational parameters. The primary influencing factors considered include working pressure, flow velocity, concentration of abrasive particles, hardness of contacting materials, and the coefficient of friction within the contact zone.
Analysis of the obtained dependencies indicated that the dominant wear mechanism affecting the gate and seat surfaces is abrasive-adhesive wear. This mechanism is driven by the combined action of hard particles moving with the flow and elevated contact stresses within the sealing zone. An increase in the concentration of mechanical impurities in the working fluid from 0.5% to 3% results in more than a threefold rise in wear intensity, highlighting the high sensitivity of the assembly to the abrasive component of the flow.
Stress-strain calculations demonstrated that increasing the working pressure from 10 to 25 MPa leads to a proportional rise in contact stresses at the gate–seat interface. This, in turn, intensifies micro-welding and plastic deformation of surface layers. Consequently, the wear depth increases on average by 40–55%, significantly reducing the safe operational lifespan of the equipment.
Special attention was paid to the effect of material hardness. It was established that the application of overlay coatings and hard-alloy layers with hardness exceeding 58–62 HRC reduces the wear rate by 2–2.5 times compared to conventional structural steels. This confirms the effectiveness of surface hardening in environments with high abrasive content.
The predicted service life of the valve, based on the criterion of allowable wear depth, indicates that under standard operating conditions (working pressure 16 MPa, abrasive concentration approximately 1%, flow velocity 2 m/s), the critical wear state is reached after 18–22 months of continuous operation. Under harsher conditions—higher particle concentration and increased number of opening–closing cycles—the service life decreases to 8–10 months.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

It was also observed that the most intense wear occurs during the initial phase of gate movement, corresponding to the breakdown of the hydrodynamic lubrication film and the onset of boundary friction. This region is critical for maintaining sealing integrity and requires targeted design or technological reinforcement.

Reducing the coefficient of friction through the application of anti-friction coatings and specialized lubricants decreases wear intensity by 25–30%, which positively affects the duration of maintenance intervals.

Conclusion

The conducted study identified the main patterns of tribological wear in the “gate–seat” assembly of manifold gate valves operating under elevated pressures and abrasive conditions of formation fluids. It was determined that the intensity of degradation of the working surfaces primarily depends on the level of contact stresses, the concentration of solid impurities in the transported medium, the microgeometry of the mating surfaces, and the friction regime within the sealing zone.

It was demonstrated that increased surface roughness contributes to higher friction coefficients, localized heat generation, and the activation of the abrasive-adhesive wear mechanism, which predominates under the studied operating conditions. Elevated contact loads and higher solid particle content in the flow significantly accelerate the degradation of surface layers, leading to reduced service life and diminished reliability of the shut-off assembly.

The effectiveness of a comprehensive approach to enhancing valve durability was substantiated, involving final polishing of working surfaces, formation of a protective oxide layer, and the application of nanostructured coatings via PVD on components made from 38ХНЮАЛ steel. Implementation of these technological measures ensures a reduction in the friction coefficient, increased hardness and corrosion resistance of the surface layer, stabilization of tribological properties, and an extended maintenance interval.

The results obtained can be applied in the design, modernization, and material selection for manifold gate valves operating under high pressures and abrasive load conditions. Practical implementation of the proposed solutions is expected to improve the operational reliability and service life of oil and gas equipment.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Karimov, Z. H. Machine Parts and Lifting-and-Transport Machines. Baku: Maarif Publishing House, 2002, 376 p.
2. Fataliyev, V. M. Gear Transmissions: Dynamics and Test Rigs. Textbook for Higher. Technical Institutions. Baku: Maarif Publishing House, 2004, 45 p.
3. Reshetov, D. N. Machine Elements. Moscow: Mashinostroenie Publishing House, 1975, 656 p.
4. Svirshchevsky, Yu. I., Makeychik, N. N. Calculation and Design of Gearboxes and Feed Gear Units. Minsk: Vysheishaya Shkola Publishing House, 1976, 584 p.
5. Karimov, Z. H. Durability of Machine Parts. Textbook for Higher Technical Institutions. Baku: ELM Publishing House, 2009, 113 p.
6. Abdullaev, A. I., Najafov, A. M. Eurasian Patent No. 017053 B1, F16H 1/20, EAPO. Moscow, 2012, Bulletin No. 9, 4 p. Analytical Kinematics of Gear Teeth.
7. Huseynov, R. Q., Fataliyev, V. M. Materials Science (Collection of Laboratory Works). Textbook. Baku, 2022.
8. Aliyev, Alasgar. Dynamics and Strength of Special Mechanisms. Textbook. Baku, 2015.
9. Gradt T., Schneider J. Tribological behavior of coatings in seals and hydraulic systems. Wear, 302(1–2), 2013, pp. 1258–1267.
10. Schiffmann K. I. Tribological behavior of nanostructured coatings for sealing applications. Tribology International, 43(1–2), 2010, pp. 87–94.
11. Musil J. Hard nanocomposite coatings: Thermal stability, oxidation resistance and toughness. Surface and Coatings Technology, 207, 2012, pp. 50–65.
12. Holmberg K., Matthews A. Coatings Tribology: Properties, Mechanisms, Techniques and Applications in Surface Engineering. Elsevier, Amsterdam, 2009.
13. Voevodin A. A., Zabinski J. S. Nanocomposite and nanostructured tribological materials for space and terrestrial applications. Composites Science and Technology, 65(5), 2005, pp. 741–748.
14. Leyland A., Matthews A. Design criteria for wear-resistant nanostructured and glassy-metal coatings. Surface and Coatings Technology, 177–178, 2004, pp. 317–324.

MANİFOLD SİYİRTMƏLƏRİNİN TRİBOLOJİ AŞINMASININ HESABLANMASI

Vəli Fətəliyev[1], Şahin Qarayev[2]
[1]Dosent, texnika üzrə fəlsəfə doktoru, "Mexanika" kafedrası, Azərbaycan Texniki Universiteti, Azərbaycan. E-mail: veli.feteliyev@aztu.edu.az

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

[2]Magistrant, Neft-mexanika fakültəsi, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: qarayevayxan783@gmail.com

XÜLASƏ

Təqdim olunan elmi işdə neft-qaz avadanlıqlarında tətbiq edilən manifold siyirtmələri və onların yüksək kontakt gərginlikləri və işçi mühitin abraziv təsiri şəraitində qarşılıqlı təsir mexanizmləri tədqiq edilmişdir. Mövcud konstruktiv həllər triboloji proseslər — sürtünmə, aşınma və qoşalaşmış səthlərdə kontakt gərginliklərinin paylanması baxımından təhlil edilmişdir.
Triboloji aşınmanın hesablanması üzrə tətbiq olunan mövcud metodikalar qiymətləndirilmiş, onların üstün və məhdud cəhətləri müəyyən edilmişdir. Tribologiyanın nəzəri əsaslarına və aparılmış analitik hesablamaların nəticələrinə əsaslanaraq, manifold siyirtmələrinin elementlərinin aşınmaya davamlılığının qiymətləndirilməsi üçün səthi qatın vəziyyətini və müasir səthi möhkəmləndirmə üsullarını nəzərə alan təkmilləşdirilmiş yanaşma təklif edilmişdir.
Aşınmaya davamlılığın artırılması, sürtünmə əmsalının azaldılması və işçi səthlərin istismar müddətinin uzadılması məqsədilə sərt ərintili örtüklərin və nanostrukturlu örtüklərin tətbiqinə xüsusi diqqət yetirilmişdir. Siyirtmə elementlərinin aşınma hesablamalarının nəticələri təqdim edilmiş, həmçinin baza və modernləşdirilmiş konstruksiyaların istismar göstəricilərinin müqayisəli təhlili aparılmışdır. Təklif olunan hesablama metodlarının tətbiqinin effektivliyi və onların manifold siyirtmələrinin konstruksiyasında tətbiqi zamanı əldə olunan müsbət nəticələr ümumiləşdirilmişdir.
Açar sözlər: manifold siyirtməsi; tribologiya; triboloji aşınma; nanoörtük; sərt ərintili örtüklər; sürtünmə əmsalı; kontakt gərginlikləri; səthin möhkəmləndirilməsi; neft-qaz avadanlıqları.

РАСЧЁТ ТРИБОЛОГИЧЕСКОГО ИЗНОСА ЗАДВИЖЕК МАНИФОЛЬДА

Вяли Фаталиев[1], Шахин Гараев[2]
[1]Доцент, кандидат технических наук “Кафедра механики”, Азербайджанский технический университет, Азербайджан. E-mail: veli.feteliyev@aztu.edu.az
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail:qarayevayxan783@gmail.com

РЕЗЮМЕ

В данной научной работе рассматриваются задвижки манифольда, применяемые в нефтегазовом оборудовании, а также механизмы их взаимодействия в условиях высоких контактных нагрузок и абразивного воздействия рабочей среды. Проведён анализ существующих конструктивных решений задвижек с точки зрения трибологических процессов, включающих трение, износ и распределение контактных напряжений в сопряжённых поверхностях. Выполнена оценка применяемых методик расчёта трибологического износа, выявлены их преимущества и ограничения. На основе теоретических положений трибологии и результатов расчётных исследований предложен усовершенствованный подход к оценке износостойкости элементов задвижек манифольда с учётом влияния состояния поверхностного слоя и применения современных методов поверхностного упрочнения.

Особое внимание уделено использованию твёрдосплавных покрытий и нанопокрытий в качестве эффективных средств повышения износостойкости, снижения коэффициента трения и увеличения эксплуатационного ресурса рабочих поверхностей. Представлены результаты расчёта износа элементов задвижек, а также выполнен сравнительный анализ эксплуатационных показателей базовой и модернизированной конструкций. Обобщены результаты применения предложенных расчётных методов и отмечен их положительный эффект при внедрении в конструкцию задвижек манифольда.
Ключевые слова: задвижка манифольда; трибология; трибологический износ; нанопокрытие; твёрдосплавные покрытия; коэффициент трения; контактные напряжения; поверхностное упрочнение; нефтегазовое оборудование.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

357-367

Publication history
Article received: 12.02.2026
Article accepted: 26.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-40

VOLUME 33 (08) ISSUE 02 2026

OPTIMIZATION OF THICKNESS AND STRUCTURAL–MECHANICAL PROPERTIES OF PLASMA-SPRAYED COATINGS BY LASER REMELTING

Tahir Jabbarov[1], Nərmin Najafzade[2]
[1]Professor, Head of the Department of Materials Science and Processing Technologies, ASOIU.
E-mail: tahir.cabbarov@asoiu.edu.az
[2]Master's Student, Department of Materials Science and Processing Technologies, ASOIU.
E-mail: nnacafzada@gmail.com

ABSTRACT

This paper is devoted to the scientific and technological foundations for improving the structure and performance characteristics of Co–Cr–W-based coatings produced by plasma spraying through laser remelting. The main objective of the study is to evaluate the possibilities of densifying plasma-sprayed coatings—initially characterized by high porosity and heterogeneous microstructure—via laser treatment, optimizing their microstructure, and enhancing their mechanical properties, particularly impact toughness. For this purpose, the optimal coating thickness was theoretically and experimentally justified, the influence of laser processing parameters on porosity was analyzed using statistical methods, and the effect of Ca and Zr microalloying on the structural and mechanical properties was systematically investigated.

Plasma-sprayed Co–Cr–W-based coatings were subjected to laser remelting, and the main technological parameters influencing the effectiveness of this process were identified. The effect of laser beam travel speed (0.83×10^{-3}–5×10^{-3} m/s) and beam diameter (1–5 mm) on porosity was quantitatively evaluated using the Design of Experiments (DOE) methodology. Based on the experimental results, a regression model was developed, and analysis of variance (ANOVA) was performed. Statistical analysis showed that the most significant parameter affecting porosity is the laser beam speed ($p < 0.01$), confirming that heat input and melting–solidification kinetics play a decisive role in coating structure formation. The effect of beam diameter was also observed, though it was found to be less influential than beam speed.

Theoretical calculations and experimental validation determined that the optimal coating thickness for repair and reinforcement applications is 0.7 ± 0.05 mm. Within this range, the coating ensures strong metallurgical bonding with the substrate while minimizing the risk of crack formation and internal stresses during laser processing. Laser remelting significantly reduced the initial high porosity level (36–40%) to 1–3%, indicating substantial densification and enhanced mechanical strength of the coating.

Additionally, the influence of Ca and Zr microalloying on microstructure formation and mechanical properties was investigated. These elements were found to refine the grain structure, homogenize the microstructure, and evenly distribute phases. Consequently, the impact toughness

of the coatings increased 2.0–2.5 times compared to the initial state, indicating improved resistance to dynamic loading and enhanced operational reliability.
The results demonstrate that laser remelting of plasma-sprayed Co–Cr–W-based coatings is an effective technological approach for comprehensive improvement of structural and mechanical properties. The proposed method ensures minimal porosity, microstructure homogenization, and enhanced mechanical performance, highlighting its potential for repairing and reinforcing machine parts subjected to wear, impact, and high mechanical loads.
Keywords: laser remelting, plasma spraying, Co–Cr–W alloy, porosity, impact toughness, microalloying, DOE optimization, restoration, mechanical, strengthening, beam diameter.

Introduction

The service life of machine and mechanism components operating under conditions of wear, intense friction, impact, and variable mechanical loads directly depends on the physical-mechanical and structural properties of their surface layer. In practice, most failures occur not due to the bulk material but as a result of gradual surface layer wear, formation of micro-cracks, and structural degradation. Therefore, in modern mechanical engineering, to increase economic efficiency and conserve resources, surface modification or restoration of components is widely applied instead of their complete replacement [2]. Technologies used in the field of surface engineering not only reduce material consumption but also allow the targeted improvement of the functional properties of components.
One of the promising methods for this purpose is plasma spraying technology. This method is based on the principle of directing molten feedstock material onto the base metal surface at high velocity, where it consolidates. The main advantages of plasma spraying include the ability to form coatings on complex geometries, a wide selection of materials, high productivity, and technological flexibility [1]. In particular, Co–Cr–W-based alloys are distinguished by high wear resistance, thermal stability, and corrosion resistance, which makes coatings based on these materials widely used for surface strengthening of machine components.
However, one of the main drawbacks of coatings obtained by plasma spraying is their high porosity, typically 30–40 %. This porosity is primarily associated with incomplete deformation of molten particles, formation of a layered structure, and the uneven nature of the consolidation process. The presence of pores reduces the effective density of the coating, weakens its mechanical strength and impact resistance, and also limits metallurgical bonding with the substrate. As a result, such coatings can experience early degradation under intensive loading, which restricts their practical application [3,6].
To address these issues, post-processing methods using laser energy, especially laser remelting technology, have attracted significant attention in recent years. This method relies on creating selective melting in the surface layer of the coating due to the high energy density of the laser beam. Rapid subsequent solidification of the melted zone restructures the initial layered and porous structure: most pores are eliminated, and a denser, more homogeneous microstructure is formed [2,4]. Intensive thermal and mass transfer processes occurring in the molten pool, including convective flows and temperature gradients, contribute to the redistribution of phases, optimization of the crystallization process, and strengthening of metallurgical bonding between the coating and the substrate. As a result, the mechanical strength, impact resistance, and wear resistance of the coating are significantly improved.

The effectiveness of the laser remelting process directly depends on the technological parameters used, including the laser beam scanning speed, beam diameter, energy density, and coating thickness. Correct selection of these parameters determines the melt depth, consolidation rate, and ultimately the characteristics of the resulting microstructure. Existing studies have investigated to some extent the effect of laser processing parameters on structural and mechanical properties; however, issues such as theoretically justified selection of coating thickness, statistical modeling and optimization of the interaction of technological parameters, and the influence of microalloying elements on the structural formation mechanism have not been studied systematically [5].

Furthermore, a microalloying approach is of significant importance for the targeted improvement of the coating structure. In particular, active elements such as Ca and Zr can influence the formation of crystallization centers, leading to grain refinement, homogenization of the structure, and improvement of mechanical properties. Studying the mechanism of their combined effect with laser processing is of considerable scientific and practical importance for enhancing the impact toughness and operational reliability of coatings.

2. Materials and methods

2.1. Research materials and coating preparation

The following initial components were used in the study to obtain the alloy material with high-speed consolidation [4]:

- PK-1U cobalt powder, GOST 9721, cobalt content at least 99.35 %, main particle size 5–15 µm;
- Titanium carbide powder (TiC), main particle size 5–15 µm;
- Boron carbide powder (B_4C), TY 6-09-668-76, main particle size 5–15 µm;
- Cobalt boride powder (Co_3B), TU 6-09-03-427-76, main particle size 5–15 µm;
- Co–Cr–W system cobalt alloy powder, main particle size 15–40 µm, chemical composition shown in table 2.1;
- Amorphous boron powder (B-GG), TY 1-92-154-90, main particle size 5–15 µm.

The research object was a powder composition based on the Co–Cr–W system, distinguished by high wear resistance and thermal stability. These composite alloys are characterized by high strength and resistance to oxidation and abrasive wear, making them widely applicable for the restoration and reinforcement of machine components. The coatings were deposited using the plasma spraying method onto substrates made of structural steel. Prior to plasma spraying, the substrate surfaces were cleaned mechanically and abrasively, and surface activation was performed to ensure strong mechanical and metallurgical bonding between the coating and substrate. The required surface roughness for this purpose was maintained in the range Ra = 6–12 µm.

Table 2.1. Chemical composition of Co–Cr–W system powder.

Chemical composition, wt.%				
Co	Cr	W	C	Fe, Ni
balance	24,5	8,8	1,2	≤ 10,5

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

For microalloying studies, Ca and Zr were introduced into the Co–Cr–W matrix as microadditives. The alloys were melted in an induction furnace under protective atmosphere, held in the liquid phase for 3–5 minutes to ensure chemical homogeneity, and then solidified under controlled conditions. The resulting compositions matched the nominal chemical compositions presented earlier. Microalloying aimed to control crystallization, refine structure, and improve mechanical properties.
Plasma spraying produced coatings with thicknesses of 0.6–0.9 mm. Initially, coatings exhibited lamellar structure and high porosity, necessitating subsequent laser treatment.

2.2. Theoretical and experimental justification of coating thickness
Optimal coating thickness determines functional reliability and service life. Minimal thickness was calculated considering functional wear depth, allowance for subsequent mechanical processing, technological margin, and thickness reduction during laser treatment:

$$H=\delta wear+\delta machining+\delta margin+\delta settling$$

here:
- δwear – expected maximum wear depth during operation,
- δmachining – allowance for mechanical processing,
- δmargin – technological margin,
- δsettling – thickness reduction due to densification during laser treatment.

Calculations determined a minimal thickness of 0.6 mm. Considering process variability and laser melt depth, the practical optimal thickness was taken as 0.7 ± 0.05 mm, ensuring structural integrity, reliable metallurgical bonding, and high mechanical performance.

2.3. Laser remelting process and experimental design
Laser remelting densified plasma-sprayed coatings and optimized microstructure. Continuous-wave laser processing caused selective surface melting and rapid resolidification, forming denser, homogeneous structures.
Laser travel speed and beam diameter were the main parameters, affecting heat input, melt pool size, and densification. Parameter ranges used were:
- Laser speed: $0.83\times10^{-3} – 5\times10^{-3}$ m/s
- Beam diameter: 1–5 mm

DOE methodology (full factorial 3×3 design, three repetitions per combination) enabled systematic analysis of individual and interactive effects on porosity.

2.4. Microstructure and mechanical properties Investigation
Metallographic analysis was performed (×200–×400 magnification) to examine grain size, phase distribution, porosity morphology, and coating-substrate interface. Porosity was quantified via optical microscopy and digital image analysis.
Impact toughness was measured using the Charpy method to evaluate the effect of Ca and Zr microalloying. Comparative analysis between microalloyed and non-alloyed coatings was conducted.

2.5. Statistical analysis and modeling

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Experimental results were analyzed using multiple regression to quantify the dependence of porosity on laser parameters. ANOVA was used to evaluate statistical significance (confidence level 95%). The method enabled justification of optimal thickness, optimization of laser parameters, and assessment of microalloying effects on structure and impact toughness.

3. Results and Discussion

3.1. Influence of laser parameters on porosity

Metallographic analysis of the coatings obtained from the initial Co–Cr–W system powder composition by plasma spraying revealed a layered structure and a high level of porosity. Based on digital image analysis, the porosity of the as-sprayed coatings ranged from 36 to 40%, which is associated with the technological characteristics of the plasma spraying process and represents a major factor limiting the mechanical strength of the coating.

Laser remelting experiments, conducted according to the DOE plan described in Section 2.3, demonstrated that the laser beam scanning speed has a decisive effect on the formation of porosity. At the minimum scanning speed (0.83×10^{-3} m/s), porosity sharply decreased to 1–3%. This reduction is explained by the selective melting of the surface layer under laser exposure (local melting of zones due to laser energy) and subsequent rapid solidification, which led to pore closure and densification of the structure.

Increasing the beam speed reduces the duration of heat exposure, weakening the densification effect. At the maximum speed (5×10^{-3} m/s), porosity increased to 16%. This indicates that at higher speeds, the energy supplied is insufficient for complete formation of the melt pool, and pore closure does not fully occur.

Based on the results of the experiments, a multivariate regression analysis was performed, resulting in the following empirical model describing the dependence of porosity on the laser parameters:

$$P=28.6+4.2V-3.8Ed:$$

- P – porosity, %
- V – normalized laser speed
- dEd – energy density parameter

The statistical adequacy of the model was verified using analysis of variance (ANOVA). The results showed that the laser beam scanning speed is the most statistically significant parameter affecting porosity ($p < 0.01$). The coefficient of determination for the model (R^2), which characterizes the degree of fit to the experimental data, was 0.91, confirming a high correspondence between the experimental and predicted results.

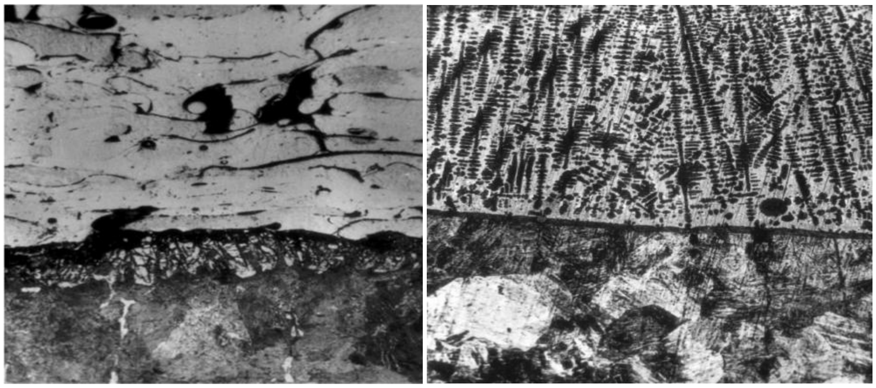
Thus, it was established that optimizing the laser beam scanning speed allows effective control of the coating's porosity.

3.2. Microstructure characteristics

The metallographic analysis described in Section 2.4 showed that significant changes occurred in
The metallographic analysis described in Section 2.4 showed that significant changes occurred in
the coating structure after the laser remelting process. The layered structure characteristic of the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

initial plasma-sprayed coatings disappeared after laser treatment, resulting in a more homogeneous, cast-like structure (Fig. 3.1).



a b

Figure. 3.1: Microstructures of the coatings:
a) Plasma-sprayed Co–Cr–W powder without remelting (×200);
b) Co–Cr–W powder remelted by laser at a laser beam scanning speed of $V_1 = 0.83 \times 10^{-3}$ m/s (×400).

Observations conducted using optical microscopy revealed a dendritic crystallization structure within the coating. It was found that the dendrite arms were predominantly oriented at approximately a 45° angle to the direction of heat flow. This orientation is associated with the directional heat flux and rapid solidification conditions occurring during laser processing.
In the interdendritic regions, the formation of a Co–B-based eutectic phase was observed. This phase positively influenced the densification of the structure, contributing to the filling of microvoids and reducing the risk of potential crack formation.
Microstructural analysis also confirmed that, as a result of laser processing, both the size and the overall area fraction of pores were significantly reduced, which is consistent with the quantitative results obtained from porosity analysis.

3.3. Effect of microalloying on mechanical properties

To evaluate the effect of Ca and Zr microalloying on the mechanical properties of the coatings, impact toughness tests were conducted using the Charpy method (see Section 2.4).
The test results showed that coatings containing 0.3% Zr exhibited a maximum impact toughness of 0.22 kg·m/mm². This value was approximately 2.2 times higher than that of the unalloyed reference samples. Statistical comparison using the Student's t-test confirmed that the observed difference was statistically significant ($p < 0.01$, $\alpha = 0.05$).
The improvement in mechanical properties was associated with the following structural mechanisms:

- Fragmentation of crystalline grains and refinement of the microstructure;
- Modification of the size and morphology of non-metallic inclusions;
- More homogeneous distribution of carbide and boride phases;
- Cleansing of grain boundaries and overall structural homogenization.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

These structural changes enhanced the resistance to crack propagation, thereby increasing the impact resistance of the coatings.

The results of the experimental and statistical studies demonstrated that the laser remelting process effectively modified the structure of Co–Cr–W system coatings obtained by plasma spraying.

Under the influence of the laser beam, localized melting and subsequent rapid crystallization occurred in the surface layer of the coating. This process led to the closure of pores, homogenization of the structure, and the formation of a denser dendritic crystallization pattern.

It was established that the laser beam scanning speed is the primary controlling parameter for structure formation. At low speeds, the prolonged thermal exposure allowed for full development of the melt pool and effective closure of pores. Increasing the speed, however, limited the energy input, weakened the densification effect, and resulted in higher porosity.

Statistical modeling confirmed the quantitative relationship between laser parameters and porosity and demonstrated the high adequacy of the developed model ($R^2 = 0.91$).

Ca and Zr microalloying acted as structure-refining elements, stabilizing the crystallization process, optimizing the distribution of inclusions (Table 3.1), and significantly enhancing the impact toughness of the coating. At the same time, the wear resistance of the coating was maintained, which represents an important practical advantage.

Table 3.1. Chemical composition of coatings with high impact toughness (wt.%).

Alloy No.	C	Si	Mn	Cr	B	V	Al	Cu	Ca	Zr	Co
1	0,7	1,2	0,43	3,1	4,3	0,53	2,0	0,05	0,05	0,3	balance
2	1,0	8,0	1,50	0,08	2,9	1,7	1,0	1,0	0,08	0,2	balance
3	1,23	2,8	2,54	4,54	1,5	3,0	0,05	2,0	0,1	0,1	balance

Thus, the combination of laser cladding and microalloying techniques can be considered an effective technological approach for producing coatings with high density and enhanced mechanical durability.

Conclusions

1. Optimal coating thickness for repair applications was determined as 0.7 ± 0.05 mm.
2. Porosity decreased from 36–40% to 1–3% after laser remelting.
3. Laser travel speed was identified as the most significant technological parameter affecting porosity ($p < 0.01$).
4. The regression model ($R^2 = 0.91$) provided a reliable analytical tool for process optimization.
5. Ca and Zr microalloying increased impact toughness 2.0–2.5 times, associated with grain refinement and homogeneous phase distribution.
6. The combination of laser remelting and microalloying enables high-density, structurally homogeneous, mechanically robust coatings with significant potential for restoration and reinforcement applications.

Declarations

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

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

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Stepanov, M.V., & Trushina, L.N. (2017). On the issue of plasma-sprayed coatings with subsequent remelting. Science Without Borders, (12(17)), 40–45.
2. Kardapolova, M.A., et al. (2005). Influence of the phase composition of powder coatings after laser treatment on residual stresses. In Mechanical Engineering and Technosphere of the XXI Century: Proceedings of the International Scientific and Technical Conference (Vol. 2, pp. 59–63). Donetsk.
3. Devoyno, O.G., et al. (2002). Construction of a thermal model of the laser processing. In Mathematical Models of Physical Processes and Their Properties: Proceedings of the 8th International Conference, June 28–29, 2002 (pp. 61–65). Taganrog.
4. Dorozhkin, N.N., Abramovich, T.M., & Donskikh, S.A. (2004). Some aspects of electro-contact sticking theory of powdery coatings. Acta Technica Napocensis, Series: Machine Construction Materials, (47), 75–79. Technical University of Cluj-Napoca.
5. Dorozhkin, N.N., et al. (2006). Methodology for studying the effect of laser processing parameters on the adhesion strength of Fe–Cr–B–Si adhesive coatings. In Mathematical Models and Algorithms for Simulation of Physical Processes: Proceedings of the International Scientific and Technical Conference (Vol. 1, pp. 44–48). Taganrog.
6. Dorozhkin, N.N., et al. (2004). Influence of laser processing on the densification kinetics of Fe–Cr–B–Si coatings. Engineering Physics Journal, 77(4), 92–95.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

PLAZMA PÜSKÜRTMƏ İLƏ FORMALAŞDIRILMIŞ ÖRTÜKLƏRİN LAZERLƏ ÜSTƏRİTMƏ ÜSULU İLƏ QALINLIQ VƏ STRUKTUR – MEXANİKİ XASSƏLƏRİNİN OPTİMALLAŞDIRILMASI

Tahir Cabbarov[1], Nərmin Nəcəfzadə[2]
[1]Professor,Materialşünaslıq və emal texnologiyaları kafedrasının müdiri,ADNSU.
E-mail:tahir.cabbarov@asoiu.edu.az
[2]Magistr,Materialşünaslıq və emal texnologiyaları kafedrası, ADNSU.
E-mail: nnacafzada@gmail.com

XÜLASƏ

Məqalə plazma püskürtmə texnologiyası ilə formalaşdırılmış Co–Cr–W əsaslı örtüklərin strukturunun və istismar göstəricilərinin lazerlə üstəritmə (laser remelting) prosesi vasitəsilə yaxşılaşdırılmasının elmi və texnoloji əsaslarının araşdırılmasına həsr olunmuşdur. Tədqiqatda ilkin olaraq yüksək məsaməlilik və heterogen mikrostruktur ilə xarakterizə olunan plazma püskürtmə örtüklərinin lazer emalı nəticəsində sıxlaşdırılması, mikrostrukturunun optimallaşdırılması və mexaniki xassələrinin, xüsusilə də zərbə özlülüyünün artırılması imkanları öyrənilmişdir. Bu məqsədlə örtüyün optimal qalınlığının nəzəri və eksperimental əsaslandırılması, lazer emalı parametrlərinin məsaməliliyə təsirinin statistik üsullarla təhlili və Ca ilə Zr mikroəlavələrinin struktur və mexaniki xassələrə təsiri sistemli şəkildə öyrənilmişdir.
Tədqiqat çərçivəsində plazma püskürtmə üsulu ilə alınmış Co–Cr–W əsaslı örtüklərin lazerlə üstəritmə prosesi aparılmış və bu prosesin effektivliyinə təsir edən əsas texnoloji parametrlər müəyyən edilmişdir. Lazer şüasının hərəkət sürətinin ($0,83\times10^{-3}$–5×10^{-3} m/s intervalında) və şüa diametrinin (1–5 mm intervalında) məsaməlilik göstəricisinə təsirini kəmiyyətcə qiymətləndirmək üçün eksperimentlərin planlaşdırılması (Design of Experiments – DOE) metodundan istifadə olunmuşdur. Eksperimental nəticələr əsasında reqressiya modeli qurulmuş və dispersiya təhlili (ANOVA) aparılmışdır. Statistik təhlil göstərmişdir ki, məsaməlilik səviyyəsinin dəyişməsinə ən əhəmiyyətli təsir edən parametr lazer şüasının hərəkət sürətidir ($p < 0,01$), bu isə istilik daxilolmasının və ərimə–bərkimə kinetikasının örtük strukturunun formalaşmasında həlledici rol oynadığını təsdiq etmişdir.. Şüa diametrinin təsiri də müşahidə olunmuş, lakin onun təsir dərəcəsinin şüa sürətinə nisbətən daha az olduğu müəyyən edilmişdir.
Aparılmış nəzəri hesablamalar və eksperimental yoxlamalar nəticəsində bərpa və möhkəmləndirmə tətbiqləri üçün optimal örtük qalınlığının 0,7 ± 0,05 mm olduğu müəyyən edilmişdir. Bu qalınlıq intervalında örtüyün həm əsasla möhkəm metallurji əlaqəsi təmin edilir, həm də lazer emalı zamanı çatların və daxili gərginliklərin yaranma riski minimuma endirilir. Lazer üstəritmə prosesi nəticəsində örtüyün ilkin vəziyyətdə müşahidə olunan yüksək məsaməlilik səviyyəsi (36–40 %) əhəmiyyətli dərəcədə azalaraq 1–3 % intervalına qədər enmişdir. Bu isə örtüyün struktur sıxlığının əhəmiyyətli dərəcədə artdığını və onun mexaniki möhkəmliyinin yüksəldiyini göstərmişdir.
Bundan əlavə, tədqiqatda Ca və Zr mikroəlavələrinin mikrostrukturun formalaşmasına və mexaniki xassələrə təsiri də araşdırılmışdır. Müəyyən edilmişdir ki, bu elementlərin mikrolegirlənməsi kristallaşma prosesinə təsir göstərərək dənə ölçüsünün xırdalanmasına, strukturun daha homogen olmasına və fazaların daha bərabər paylanmasına səbəb olmuşdur. Nəticədə örtüyün zərbə özlülüyü ilkin vəziyyətlə müqayisədə 2,0–2,5 dəfə artmışdır. Bu artım

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

örtüyün dinamik yüklənmələrə qarşı davamlılığının yüksəldiyini və istismar etibarlılığının yaxşılaşdığını göstərmişdir.
Alınmış nəticələr göstərmişdir ki, plazma püskürtmə ilə formalaşdırılmış Co–Cr–W əsaslı örtüklərin lazerlə üstəritmə yolu ilə emalı onların struktur və mexaniki xassələrinin kompleks şəkildə yaxşılaşdırılması üçün yüksək effektiv texnoloji yanaşmadır. Təklif olunan üsul örtüklərin məsaməliliyinin minimuma endirilməsini, strukturun homogenləşdirilməsini və mexaniki dayanıqlığın artırılmasını təmin etmişdir. Bu isə belə örtüklərin yeyilməyə, zərbəyə və yüksək mexaniki yüklənmələrə məruz qalan maşın hissələrinin bərpası və möhkəmləndirilməsi sahəsində geniş tətbiq perspektivlərinə malik olduğunu göstərmişdir.
Açar sözlər: lazerlə üstəritmə, plazma püskürtmə, Co–Cr–W ərintisi, məsaməlilik, zərbə özlülüyü, mikrolegirləmə, DOE optimallaşdırması, bərpa,mexaniki, möhkəmləndirmə, şüa diametri.

ОПТИМИЗАЦИЯ ТОЛЩИНЫ И СТРУКТУРНО-МЕХАНИЧЕСКИХ СВОЙСТВ ПОКРЫТИЙ, СФОРМИРОВАННЫХ ПЛАЗМЕННЫМ НАПЫЛЕНИЕМ, ПУТЕМ ЛАЗЕРНОЙ ДОПОЛНИТЕЛЬНОЙ ОБРАБОТКИ

Тахир Джаббаров[1], Нармин Наджафзаде[2]
[1]Профессор, заведующий кафедрой материаловедения и технологий обработки, АДНГУ.
E-mail: tahir.cabbarov@asoiu.edu.az
[2]Магистр, кафедра материаловедения и технологий обработки, АДНГУ.
E-mail: nnacafzada@gmail.com

РЕЗЮМЕ

Статья посвящена исследованию научных и технологических основ улучшения структуры и эксплуатационных характеристик покрытий на основе Co–Cr–W, сформированных методом плазменного напыления, с помощью процесса лазерного донагрева (laser remelting). В работе изучены возможности уплотнения плазменно-напыленных покрытий, первоначально характеризующихся высокой пористостью и гетерогенной микроструктурой, оптимизации их микроструктуры и повышения механических свойств, в частности ударной вязкости, в результате лазерной обработки. Для этого систематически исследованы теоретическое и экспериментальное обоснование оптимальной толщины покрытия, статистический анализ влияния параметров лазерной обработки на пористость, а также влияние микро-добавок Ca и Zr на структуру и механические свойства.
В рамках исследования был проведен процесс лазерного донагрева покрытий на основе Co–Cr–W, сформированных методом плазменного напыления, и определены основные технологические параметры, влияющие на эффективность процесса. Для количественной оценки влияния скорости движения лазерного луча (в диапазоне $0{,}83\times10^{-3}$–5×10^{-3} м/с) и диаметра луча (в диапазоне 1–5 мм) на показатели пористости использован метод планирования экспериментов (Design of Experiments – DOE). На основании экспериментальных данных построена регрессионная модель и проведен дисперсионный анализ (ANOVA). Статистический анализ показал, что наиболее значимым параметром, влияющим на уровень пористости, является скорость движения лазерного луча ($p < 0{,}01$), что подтверждает решающую роль теплового воздействия и кинетики плавления-

уплотнения в формировании структуры покрытия. Влияние диаметра луча также наблюдалось, однако его эффект оказался менее значимым по сравнению со скоростью движения.

Теоретические расчеты и экспериментальные проверки показали, что для применения в восстановительных и упрочняющих процессах оптимальная толщина покрытия составляет 0,7 ± 0,05 мм. В этом диапазоне толщины обеспечивается прочная металлургическая связь с основанием, а риск образования трещин и внутренних напряжений при лазерной обработке минимален. В результате лазерного донагрева первоначально наблюдавшийся высокий уровень пористости покрытия (36–40 %) значительно снижался до 1–3 %, что свидетельствует о существенном повышении плотности структуры и механической прочности покрытия.

Кроме того, исследовано влияние микро-добавок Ca и Zr на формирование микроструктуры и механические свойства. Установлено, что микро-легирование этими элементами влияет на процесс кристаллизации, приводя к дроблению зерен, более однородной структуре и более равномерному распределению фаз. В результате ударная вязкость покрытия увеличилась в 2,0–2,5 раза по сравнению с исходным состоянием, что свидетельствует о повышении его стойкости к динамическим нагрузкам и улучшении эксплуатационной надежности.

Полученные результаты показали, что лазерная дообработка покрытий на основе Co–Cr–W, сформированных плазменным напылением, является высокоэффективным технологическим подходом для комплексного улучшения их структуры и механических свойств. Предлагаемый метод обеспечивает минимизацию пористости, гомогенизацию структуры и повышение механической прочности, что открывает широкие перспективы применения таких покрытий при восстановлении и упрочнении деталей машин, подвергающихся износу, ударам и высоким механическим нагрузкам.

Ключевые слова: лазерное донагревание, плазменное напыление, сплав Co–Cr–W, пористость, ударная вязкость, микролегирование, оптимизация DOE, восстановление, механические свойства, упрочнение, диаметр луча.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

368-375

Publication history
Article received: 13.02.2026
Article accepted: 27.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-41

METHODS AND APPROACHES FOR EXTRACTION OF RESIDUAL RESERVES FROM HETEROGENEOUS OIL FIELDS

Bunyad Kazymov[1], Ilham Hasanli[2]
[1]Doctor of Technical Sciences, Associate Professor, Azerbaijan State Oil and Industry University (ASOIU), Department of Oil and Gas Engineering, Azerbaijan. E-mail: bunyadkazymov1969@gmail.com
[2]Master's student, Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan. E-mail: ilham.hasanli@mail.ru

ABSTRACT

Extraction of residual oil reserves from heterogeneous deposits is one of the most pressing problems of the oil and gas industry. Due to the depletion of easily extracted stocks, the need for effective methods of extracting residual stocks is constantly increasing. Therefore, in practice, oil and gas production is constantly in the center of attention, both traditional methods of extracting residual reserves taking into account the geological features of heterogeneous deposits, and modern technologies and innovative approaches that allow to increase the efficiency of the development of these reserves during development. Since the study of the characteristics of the distribution of residual reserves in the fields is related to the reasons for their formation, and the reasons, in turn, are related to the heterogeneity of layers, specifying the specifics of the methods and approaches to the extraction of residual reserves from non-homogeneous oil fields has theoretical and practical importance from the point of view of determining the effectiveness of technologies for the development of identified residual reserves during development. Since the theoretical and practical research conducted in this direction is primarily aimed at studying the conditions under which factors depending on the heterogeneous properties of the reservoirs manifest themselves during the field development, the article analyzes the influence of non-homogeneous properties of layers on the features of oil field development, as well as the regularity of the formation of residual reserves and traditional and non-traditional technological methods of extracting residual oil from non-homogeneous oil fields, highlighting the main characteristics and types of stratum heterogeneity. It was determined that a number of technological factors affect the heterogeneity of oil fields due to their structural and reservoir properties in the development process, and as a result, the impact of the heterogeneity of the fields on the development process becomes even more complex due to the influence of these factors, which are also necessary in assessing the efficiency of the applied technologies. As a result, it was noted that the extraction of residual oil reserves from heterogeneous fields is a process that requires a comprehensive approach based on understanding the geological and technological properties of the fields, and the application of modern technologies and development methods can help to significantly increase hydrocarbon production at minimal cost and in accordance with modern environmental sustainability requirements.

Keywords: Oil field, residual reserve, heterogeneous layer, technological methods and approaches, filtration-capacity properties, efficiency

Introduction

The extraction of residual oil reserves from heterogeneous reservoirs is one of the most pressing problems of the oil and gas industry. Considering the depletion of easily recoverable reserves, the need for effective methods for the extraction of residual reserves is steadily increasing. Therefore, in oil and gas production practice, traditional methods for extracting residual reserves from heterogeneous reservoirs, taking into account their geological characteristics, as well as modern technologies and innovative approaches that can increase the efficiency of reservoir sweep, are continuously kept in focus.

At the same time, clarifying the conditions for the formation of residual reserves within a reservoir and the causes leading to this process can be considered among the main efficiency indicators of the applied methods and approaches. In connection with the above, this article clarifies the specific features of methods and approaches for the extraction of residual reserves from heterogeneous oil reservoirs.

Objective

Relevance of the Problem and Related Studies

The modern practice of hydrocarbon reservoir development has necessitated the advancement of the theoretical and practical foundations of oil and gas production on new scientific bases. This requirement primarily manifests itself in the need to make decisions during the development process of hydrocarbon reservoirs characterized by complex geological, physical, and operational properties, where reserves are difficult to recover. In fact, the proportion of hydrocarbon reservoirs with such characteristics among fields currently under development and those newly introduced into development is steadily increasing.

In this regard, along with studying the distribution characteristics of residual reserves in reservoirs, interest in scientific and practical research aimed at their efficient involvement in development continues to expand. These research studies are primarily focused on investigating the conditions under which factors arising from the heterogeneous characteristics of formations manifest themselves during the reservoir development process.

Since the study of the distribution characteristics of residual reserves in reservoirs is related to the causes of their formation, and the efficiency of technologies used to involve these reserves in development is directly associated with these causes, clarifying the specific features of methods and approaches for extracting residual reserves from heterogeneous oil reservoirs is of theoretical and practical significance. Numerous scientific research studies in this field have been published in the literature [1–8].

Methods

Characteristics and Types of Formation Heterogeneity

The heterogeneity of reservoirs in terms of their collector properties may be caused by various factors, including types of sedimentary rocks, facies changes, and the structure of the porous medium. In natural conditions, productive oil and gas formations are rarely homogeneous. If the permeability and porosity of a formation are not the same at different points, the formation is

considered heterogeneous. However, changes in permeability within formations are often so chaotic that large areas of the formation can be considered, on average, equally permeable. There are also formations in which large areas differ significantly in terms of their filtration properties.
Within a reservoir, zones of high permeability may be adjacent to zones of low permeability. Under such conditions, hydrocarbon flows become more complex, creating difficult conditions for efficient oil production.
The following main types of formation heterogeneity are distinguished (Figure 1):
1. Layered heterogeneity (when the formation is divided along its thickness into several layers, each having a constant average permeability but differing from the permeability of adjacent layers). Such formations are called heterogeneous formations along thickness. The boundary separating layers with different permeability is usually considered to be planar. Thus, in the layered heterogeneous formation model, it is assumed that permeability changes only along the thickness of the formation and represents a piecewise constant function of the vertical coordinate.
2. Zonal heterogeneity (when the formation is divided into several zones with different permeability). Within the same zone, permeability is generally uniform; however, it changes sharply at the boundary between two zones.
In geological terms, heterogeneous formations are characterized by broader geological parameters, such as the relative sandiness coefficient, the stratification coefficient, and others. Depending on the scale of manifestation of heterogeneity, micro-heterogeneity and macro-heterogeneity are distinguished. Micro-heterogeneity refers to variations in the properties of rocks belonging to the same lithological type, whereas macro-heterogeneity manifests itself in the alternating occurrence of rocks with different lithological types within a single structural unit.

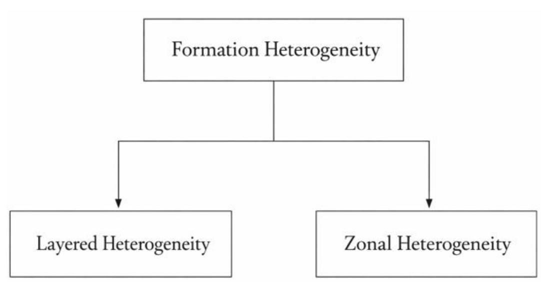


Figure 1: Main types of formation heterogeneity.

The study of reservoir heterogeneity in terms of permeability becomes possible through special investigations, including a complex of geological studies such as seismic sounding and core analysis. The data obtained from this research complex provide an important basis for selecting the optimal development strategy for heterogeneous reservoirs and for applying technologies aimed at extracting residual reserves.

Influence of Formation Heterogeneity on the Patterns of Residual Reserves Formation in Oil Fields

A number of technological factors also influence the heterogeneity of oil reservoirs in terms of their structural and reservoir characteristics during the development process. As a result, the impact of reservoir heterogeneity on the development process acquires a more complex character due to the influence of technological factors. Consequently, we encounter an irregular distribution of residual recoverable reserves within the reservoir. Thus, many technological and geological factors contribute to the formation of residual reserves in oil fields.

Wells that penetrate both high- and low-permeability layers through a single filter generally ensure the flow of production from productive intervals with high filtration properties. The presence of various types of voids within the formation also complicates the process of oil recovery. The formation of oil rims facilitates the water flooding of low-permeability layers, which leads to a decrease in the final oil recovery factor. Uneven reservoir pressure within an oil field characterized by complex geological conditions may be associated with variations in the piezoconductivity of the formation, which in turn leads to variable rates of reserve production. Zones of unrecovered reserves arise due to the formation of linear filtration channels between production wells when the direction of filtration flows changes as a result of uneven pressure variation related to the heterogeneous characteristics of the formation. In all these cases, low-permeability layers remain unaffected, and significant residual reserves accumulate within them.

Residual reserves may also arise due to other technogenic disturbances occurring in the formation. For example, when water is injected into the formation at a temperature lower than the formation temperature, the filtration–capacity properties of the rocks may deteriorate. This may increase the viscosity of the reservoir oil and lead to paraffin crystallization as well as the precipitation of resins and asphaltenes in the porous medium, which results in changes in the composition of both the oil and the porous medium. When injected water mixes with formation water, salt precipitation is frequently observed, which further worsens the filtration–capacity properties of the formations. The localization of residual reserves is important for maintaining existing production levels and for selectively producing residual reserves from reservoir margins with reduced permeability and previously unaccounted oil-saturated intervals. Therefore, special importance is attached to the localization of residual reserves in oil production practice [1–4].

Main Conventional Methods for Extracting Residual Reserves from Heterogeneous Oil Reservoirs

In heterogeneous formations, the following conventional methods are commonly used to effectively extract residual oil reserves [5–7] (Figure 2):

1. Waterflooding method. Water injection into formations is one of the most widely used methods. This approach is applied in various schemes and combinations (for example, by creating barriers, using water-gas mixtures, etc.).

2. Chemical methods. The use of surfactants and other chemical additives can change the surface tension of oil and improve its recovery. For example, special solutions may reduce oil viscosity and increase its mobility in low-permeability formations.

3. Thermal methods. These methods involve the injection of steam or hot water, which increases the thermal energy of the oil and therefore reduces its viscosity. Steam heating is actively used in reservoirs containing high-viscosity oil.

4. Hydraulic fracturing. This method is used to create fractures that increase the overall permeability and the size of the area from which oil can be recovered. It is particularly effective in reservoirs containing low-permeability zones. The hydraulic fracturing process involves injecting fluid into the rock under high pressure, causing fractures to form and increasing the contact area between the rock and the fluids.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

5. Wave stimulation. This method enables the involvement of residual reserves in development by generating artificial waves of different intensities (usually by increasing the permeability of the near wellbore zone).
In addition to these traditionally used methods in the extraction process of reserves from heterogeneous oil fields, various modern technologies and innovative approaches are also employed.

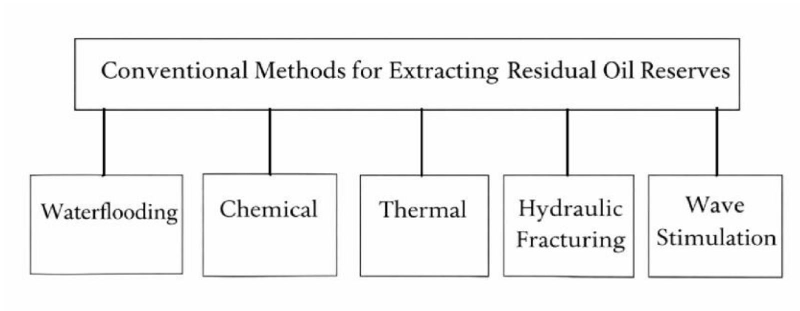


Figure 2: Conventional Main Methods for the Extraction of Residual Oil Reserves.

Innovative Approaches for Enhancing the Recovery Efficiency of Residual Reserves from Heterogeneous Oil Fields

The application of modern technologies and innovative approaches in heterogeneous oil fields plays a key role in improving the efficiency of residual reserve extraction. These include:

- Modeling and flow simulation;
- Data integration;
- Big data analysis;
- Application of nanotechnologies.

Modeling and flow simulation, based on the use of software to create dynamic reservoir models, allow for more accurate planning of residual reserve extraction operations. This contributes to the efficient utilization of reserves and helps manage risks.
3D geological modeling allows detailed study of the heterogeneity of porosity and permeability and optimal well placement, while differential approaches enable the identification of zones with varying filtration-capacity characteristics for the application of individual intensification methods.
Monitoring and analysis systems for large volumes of data can help manage production processes in reservoirs more precisely. The use of such technologies can significantly increase the efficiency of reservoir exploitation.
The application of nanotechnologies is based on the use of nanomaterials to improve oil properties and enhance its mobility within layers, representing a promising direction for reservoir development [8].
On the other hand, it is known that the extraction of residual oil reserves from heterogeneous fields requires significant investment. Nevertheless, the use of modern technologies can substantially reduce costs and increase the profitability of the extraction process. In this context, it is also important to consider environmentally significant issues associated with oil production. It should be noted that modern production methods must comply with sustainable development requirements and minimize negative impacts on the environment.

Thus, the extraction of residual oil reserves from heterogeneous fields is a process that requires a comprehensive approach based on understanding the geological and technological characteristics of reservoirs. The application of modern technologies and production methods can significantly enhance
hydrocarbon recovery at minimal cost and in accordance with contemporary ecological sustainability requirements.

Conclusion

In this article, the heterogeneity characteristics and types of layers were identified, and the impact of layer heterogeneity on reservoir exploitation as well as on the formation patterns of residual reserves was analyzed, along with the conventional and unconventional technological methods for extracting residual oil from heterogeneous fields. It was determined that, due to the structural and reservoir properties of oil fields, several technological factors influence their heterogeneity during exploitation, resulting in a more complex nature of heterogeneity impact on the production process. These factors are essential in evaluating the efficiency of applied technologies. The extraction of residual oil reserves from heterogeneous fields is a process requiring a comprehensive approach based on understanding geological and technological characteristics, and the application of modern technologies and production methods can significantly enhance hydrocarbon recovery at minimal cost and in accordance with contemporary ecological sustainability requirements.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

1. Bondarenko O.A., Grandov D.V., Ruchkin A.A., Smirnov D.S., Ufimceva M.N., Neustroev K.A.Perspektivy primenenija metodov uvelichenija nefteotdachi na zrelom mestorozhdenii v uslovijah vysokoj vyrabotki zapasov. Jekspozicija Neft' Gaz, 2023, № 7 (100), s. 90-95.
2. Shahverdiev A.H. Nekotorye konceptual'nye aspekty sistemnoj optimizacii razrabotki neftjanyh mestorozhdenij // Neftjanoe hozjajstvo. 2017, № 2, s. 58-63.
3. Bogopol'skij A.O., Shahverdiev A.H., Galeev F.H., Chukcheev O.A., Bokserman A.A., Krickij I.R., Lejbin Je.L. Sposob obrabotki prizabojnoj zony skvazhin, vskryvshih neodnorodnyj neftjanoj plast. Patent na izobretenie RU 2103494 C1, 27.01.1998.
4. Kondratiev M., Azarov E. Probabilistic approach as a tool for identifying areas of residual oil reserves. V sbornike: Society of Petroleum Engineers - SPE Russian Petroleum Technology Conference 2017.
5. Pravdina L.V., Litvinova V.A., Kondrat'eva N.M. Himicheskie metody vozdejstvija v tehnologicheskih processah pri neftedobyche. V sbornike: Izbrannye doklady 71-j Universitetskoj nauchno-tehnicheskoj konferencii studentov i molodyh uchenyh. Doklady konferencii. Tomsk, 2025, s. 285-287.
6. Zholdanbaeva D.A., Makedon S.A. Metod gidrorazryva plasta: sushhnost' i osnovnye aspekty primenenija na neftjanyh mestorozhdenijah. V sbornike: Innovacionnye tehnologii v toplivno-jenergeticheskom komplekse. Sbornik trudov VI Mezhdunarodnoj nauchno-prakticheskoj konferencii, posvjashhennoj 80-letiju Pobedy v Velikoj Otechestvennoj vojne. Stavropol', 2025, s. 289-292.
7. Mamedova E.V. Perspektivy ispol'zovanija dioksida ugleroda dlja povyshenija KIN. V sbornike: Rassohinskie chtenija - 2025. Materialy 17-j mezhdunarodnoj konferencii. Uhta, 2025, s. 123-126.
8. Kazakov R.T. Nanotehnologii v dobyche nefti. V sbornike: Nauka. Tehnika. Innovacii. Sbornik statej po materialam XV Vserossijskoj nauchno-prakticheskoj konferencii, posvjashhennoj 80-letiju Pobedy v Velikoj Otechestvennoj vojne i Godu zashhitnika Otechestva. Sankt-Peterburg, 2025, s. 230-234.

QEYRİ-BİRCİNS NEFT YATAQLARINDAN QALIQ EHTİYATLARIN ÇIXARILMASININ ÜSUL VƏ YANAŞMALARI

Bünyad Kazımov[1], İlham Həsənli[2]
[1]Texnika üzrə elmlər doktoru, dosent, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), "Neft-qaz mühəndisliyi" kafedrası, Azərbaycan. E-mail: bunyadkazymov1969@gmail.com
[2]Magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), Azərbaycan. E-mail: ilham.hasanli@mail.ru

XÜLASƏ

Qeyri-bircins yataqlardan qalıq neft ehtiyatlarının çıxarılması neft-qaz sənayesinin ən aktual problemlərindən biridir. Asanlıqla çıxarıla bilən ehtiyatların tükənməsi nəzərə alınmaqla, qalıq ehtiyatların çıxarılması üçün səmərəli üsullara ehtiyac getdikcə daha da artmaqdadır. Ona görə də neftqazçıxarma təcrübəsində qeyri-bircins yataqların geoloji xüsusiyyətləri nəzərə alınmaqla qalıq ehtiyatların çıxarılmasının ənənəvi üsulları, eləcə də həmin ehtiyatların işlənmə ilə əhatə olunma səmərəliliyini artıra biləcək müasir texnologiyalar və innovativ yanaşmalar davamlı olaraq diqqət

mərkəzində saxlanılır. Yataqlar üzrə qalıq ehtiyatların paylanma xüsusiyyətlərinin öyrənilməsi onların formalaşma səbəbləri ilə, bunlar isə, öz növbəsində, layların qeyri-bircinslik xüsusiyyətləri ilə bağlı olduğundan, müəyyən edilmiş qalıq ehtiyatarın işlənməyə cəlb edilməsi texnologiyalarının nə dərəcədə səmərəli olmasının müəyyənləşdirilməsi baxımdan qeyri-bircins neft yataqlarından qalıq ehtiyatların çıxarılmasının üsul və yanaşmalarının məxsusi xüsusiyyətlərinin aydınlaşdırılması nəzəri-təcrübi aktuallıq kəsb edir. Bu istiqamətdə nəzəri-təcrübi əsasda yerinə yetirilmiş tədqiqat işləri, ilk növbədə, layların qeyri-bircins xüsusiyyətlərindən asılı olaraq meydana gələn amillərin yataqların işlənmə prosesində özünü biruzə vermə şəraitlərinin tədqiqinə yönəldiyindən, məqalədə layların qeyri-bircinslik xüsusiyyətləri və növləri ayırd edilməklə, layların qeyri-bircins xüsusiyyətlərinin neft yataqlarının işlənmə, eləcə də qalıq ehtiyatların formalaşma qanunauyğunluqlarına xüsusiyyətlərinə təsiri və qeyri-bircins neft yataqlarından qalıq neftin çıxarılmasının ənənəvi və qeyri-ənənəvi texnoloji üsulları təhlil edilmişdir.

Açar sözlər: Neft yatağı, qalıq ehtiyat, qeyri-bircins lay, texnoloji üsul və yanaşmalar, süzülmə-tutum xassələri, səmərəlilik

МЕТОДЫ И ПОДХОДЫ К ИЗВЛЕЧЕНИЮ ОСТАТОЧНЫХ ЗАПАСОВ ИЗ НЕОДНОРОДНЫХ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ

Буньяд Казымов[1], Ильхам Гасанли[2]
[1]Д.т.н., доцент, кафедра нефтегазовой инженерии, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: bunyadkazymov1969@gmail.com
[2]Магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: ilham.hasanli@mail.ru

РЕЗЮМЕ

Извлечение остаточных запасов нефти из неоднородных месторождений является одной из наиболее актуальных проблем нефтегазовой отрасли. В связи с истощением легко извлекаемых запасов, потребность в эффективных методах извлечения остаточных запасов постоянно возрастает. Поэтому в практике добычи нефти и газа постоянно находятся в центре внимания как традиционные методы извлечения остаточных запасов с учетом геологических особенностей неоднородных месторождений, так и современные технологии и инновационные подходы, позволяющие повысить эффективность освоения этих запасов при разработке. Поскольку проводимые в этом направлении теоретические и практические исследования в первую очередь направлены на изучение условий, при которых в процессе разработки месторождений проявляются факторы, зависящие от неоднородных свойств пластов, в статье анализируется влияние неоднородных свойств пластов на характеристики разработки нефтяных месторождений, а также закономерности формирования остаточных запасов и традиционные и нетрадиционные технологические методы извлечения остаточной нефти из неоднородных нефтяных месторождений, с выделением основных характеристик и типов неоднородности пластов.

Ключевые слова: Нефтяное месторождение, остаточные запасы, неоднородный пласт, технологические методы и подходы, фильтрационно-емкостные свойства, эффективность.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

376-382

Publication history
Article received: 13.02.2026
Article accepted: 27.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-42

THE ROLE OF AUTOMATIC CONTROL SYSTEMS IN COKE PRODUCTION

Kamala Aliyeva[1], Fidan Akhundova[2]
[1]Professor, Department of Instrument engineering, Azerbaijan State Oil and Industry University, 20 Azadlig Avenue, AZ1010, Baku, Azerbaijan, E-mail: kamala.aliyeva@asoiu.edu.az
[2]Master, Department of Instrument engineering, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, E-mail: fidanakhundova03@gmail.com

ABSTRACT

The coke production process is a critical component of the steel manufacturing industry, requiring precision and efficiency in its operations. In recent years, the implementation of automatic control systems (ACS) has revolutionized the way coke plants operate, leading to enhanced productivity, energy efficiency, and product quality. These systems provide real-time monitoring and regulation of key parameters such as temperature, pressure, and material flow, thus optimizing the overall process. This paper explores the integration of automatic control systems in coke production, highlighting their role in optimizing process efficiency, reducing operational costs, and improving product consistency. Furthermore, the challenges faced during implementation and the potential for future advancements in ACS for coke production are also discussed.
Keywords: Coke production, steel manufacturing, automatic control systems (ACS), efficiency, productivity, real-time monitoring, process optimization, energy efficiency, product quality, operational costs, implementation challenges, future advancements.

Introduction

Coke production plays an essential role in the iron and steel industries, where it is used as a reducing agent in blast furnaces. The production of coke involves complex chemical reactions, high temperatures, and precise material handling, making it a highly energy-intensive process. Traditionally, coke production has relied heavily on manual control and human intervention to maintain the stability of the process. However, with the advent of automatic control systems (ACS), the industry has seen significant improvements in efficiency and consistency.

Automatic control systems offer real-time data acquisition and feedback control to regulate crucial parameters such as temperature, pressure, and gas flow rates. These systems help to optimize the coke oven operations by minimizing energy consumption, improving coke quality, and reducing the environmental impact. In this paper, we examine the implementation of ACS in the coke production process, focusing on the key areas of optimization, operational benefits, and challenges associated with their integration.

The optimization of coke production processes through ACS can lead to various improvements, including reduced downtime, enhanced safety, and improved product quality. However, the

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

implementation of these systems is not without its challenges, as it requires significant investment in technology, expertise, and infrastructure. This paper is structured to explore the theoretical background, current practices, and future potential of ACS in coke production.

1. The role of automatic control systems in coke production

Coke production is an intricate process involving multiple stages, including coal preparation, carbonization, and handling of coke by-products. Throughout these stages, various process parameters must be monitored and controlled to ensure the desired product quality and process efficiency. Automatic control systems play a pivotal role in this context by integrating sensors, actuators, and control algorithms to regulate these parameters in real-time.

Components of automatic control systems in coke production

Automatic control systems in coke production typically consist of three main components: sensors, controllers, and actuators. The sensors measure important process variables, such as temperature, pressure, and gas concentrations, and send this data to the controllers. The controllers process the data and compare it with setpoint values to determine if corrective action is required. Actuators, such as valves and fans, are then adjusted to maintain optimal conditions.

For instance, in the coke oven battery, temperature regulation is crucial to prevent overheating or underheating of the coal charge. Sensors placed inside the oven continuously monitor the temperature, and the control system adjusts the fuel injection rate to maintain the desired temperature profile.

Key parameters in coke production

The main parameters monitored and controlled by ACS in coke production include:

Temperature Control: Coke production requires precise temperature control throughout the process. The temperature inside the coke ovens needs to be maintained within a specific range to ensure optimal coal carbonization. Overheating can lead to the formation of undesirable by-products, while underheating results in low-quality coke.

Pressure Regulation: Pressure within the coke oven affects the chemical reactions taking place inside. Proper pressure regulation ensures that gases produced during carbonization are efficiently removed and that the coal is processed at the correct rate.

Gas Flow Control: The control of gas flow is essential to maintain the right chemical composition of the gas and prevent the emission of harmful gases into the environment. ACS helps to regulate the flow of gases, such as coke oven gas, ensuring they meet environmental standards.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

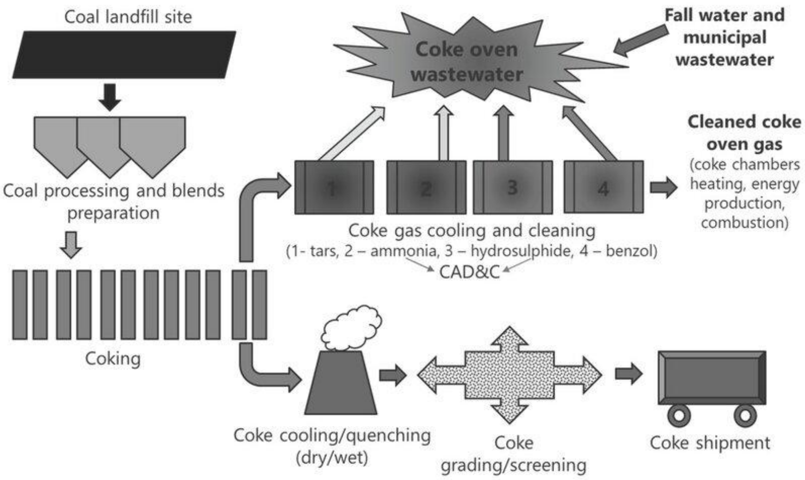


Figure 1: The scheme of coke production at a coke oven plant

Automation in other areas of coke production

In addition to the core process of carbonization, ACS also plays a significant role in other areas of coke production, such as coal handling, oven charging, and coke handling. Automation in these stages contributes to the overall optimization of the plant, reducing manual labor and improving operational safety.

2. Optimization of coke production through automatic control systems

The main goal of implementing automatic control systems in coke production is to optimize the entire production process. Optimization involves reducing energy consumption, minimizing waste, and improving product quality. Through the integration of real-time data and advanced algorithms, ACS can make continuous adjustments to the process to achieve these goals.

Energy efficiency improvements

One of the most significant benefits of ACS in coke production is the improvement in energy efficiency. By accurately controlling the temperature and pressure within the coke ovens, ACS ensures that the energy required for carbonization is used efficiently. For example, excess fuel consumption can be avoided by adjusting fuel injection rates based on real-time temperature data, reducing both operational costs and environmental impact.

Moreover, ACS can optimize the use of by-product gases generated during coke production. These gases, such as coke oven gas, can be recovered and used as fuel for power generation or heating purposes. ACS allows for the efficient management of these gases, ensuring that they are utilized in the most energy-efficient manner.

Improved coke quality

The quality of coke is a critical factor in the efficiency of blast furnaces in steel production. High-quality coke ensures smoother and more efficient iron-making processes. Automatic control systems contribute to improved coke quality by maintaining consistent temperature profiles during carbonization and by adjusting the coal feed rate based on real-time data.

For instance, ACS can monitor the temperature and pressure in the ovens and adjust the fuel flow or air supply to ensure that the coal undergoes the desired level of carbonization. By maintaining

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

these parameters within optimal ranges, ACS helps to produce coke with the correct porosity and strength, which are essential for high-performance blast furnace operations.

Minimizing downtime and reducing maintenance costs

Automatic control systems also contribute to minimizing downtime in coke plants. By continuously monitoring equipment performance and process parameters, ACS can detect potential issues before they lead to system failures. For example, sensors can monitor the wear and tear of mechanical components, such as the coke oven doors and pushing machines. Early detection of problems allows for timely maintenance and repairs, reducing unplanned downtime and preventing costly breakdowns.

Additionally, ACS can optimize the scheduling of maintenance activities by providing data on the condition of equipment, which helps in planning maintenance during periods of low production demand.

3. Challenges in implementing automatic control systems in coke production

While the benefits of automatic control systems in coke production are clear, the implementation of these systems presents several challenges. These challenges must be addressed to ensure the successful integration of ACS into existing production facilities.

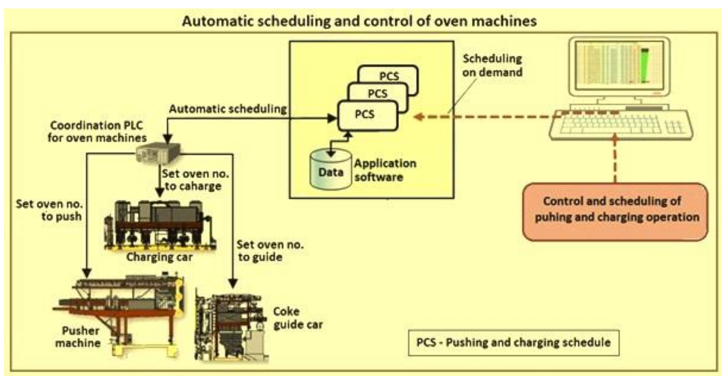


Figure 3: Automatic scheduling and control of oven machines

High initial investment costs

The installation of ACS in coke plants requires significant capital investment. This includes the cost of sensors, controllers, actuators, and the integration of these components into the existing infrastructure. Additionally, specialized software and hardware for data analysis and process optimization must be purchased. For many coke producers, the high upfront costs can be a barrier to adopting these technologies.

However, the long-term benefits of ACS, such as energy savings, reduced operational costs, and improved product quality, often outweigh the initial investment, making the implementation of ACS a cost-effective solution over time.

Complexity of integration

Integrating automatic control systems into existing coke production processes can be a complex task, especially in older plants with legacy equipment. The retrofit process involves modifying or

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

replacing parts of the production system to accommodate new control technologies. This can lead to temporary disruptions in production and may require specialized expertise.

To ensure a smooth integration process, it is essential for coke producers to work closely with system integrators and control engineers who are familiar with the specific needs and constraints of coke production.

Data management and analysis

ACS generates vast amounts of data, which must be analyzed to derive actionable insights. Effective data management and analysis are crucial for optimizing the control system and ensuring that it functions properly. However, managing and interpreting this data can be a challenge, especially if the plant lacks the necessary data analytics tools or expertise.

Investing in advanced data analytics platforms and training personnel to interpret and act on the data is essential for realizing the full potential of ACS.

Conclusion

The implementation of automatic control systems (ACS) in coke production processes has significantly transformed the way coke plants operate. With increasing demand for high-quality coke and the need for energy efficiency in steel manufacturing, automatic control systems have emerged as a critical component in modernizing the coke production process. These systems enable precise regulation of essential process parameters such as temperature, pressure, gas flow, and material handling, thereby optimizing operational efficiency and minimizing human error.

The primary benefits of integrating ACS into coke production include enhanced energy efficiency, improved product consistency, reduced downtime, and lower maintenance costs. By continuously monitoring and adjusting key process variables, ACS ensures that the coke production process runs within optimal conditions, leading to reduced fuel consumption and waste. Moreover, these systems improve the quality of the coke produced, which directly impacts the efficiency of downstream processes like iron and steel production.

However, the integration of ACS into existing coke production facilities is not without its challenges. The high initial investment costs associated with installing sensors, controllers, and actuators, as well as the complexity of retrofitting legacy equipment, are significant hurdles. Additionally, managing and interpreting the vast amounts of data generated by these systems requires specialized tools and expertise. Despite these challenges, the long-term benefits, including operational savings and enhanced process control, make ACS a worthwhile investment for coke producers.

Looking forward, the continued development of advanced control algorithms, artificial intelligence (AI), and machine learning will further enhance the capabilities of ACS. These innovations have the potential to improve the adaptability and predictive capabilities of automatic control systems, enabling even more efficient and sustainable coke production processes. As the industry embraces digital transformation, the role of ACS in coke production will only grow, helping to meet the demands of a rapidly changing global economy.

In conclusion, automatic control systems are poised to revolutionize coke production by enabling real-time process optimization, reducing environmental impact, and ensuring the consistent quality of coke. The future of ACS in coke production holds great promise, with ongoing advancements in technology likely to further enhance their capabilities and effectiveness.

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

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

Acknowledgments
The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Singh, K. (2020). "Automation and Control of the Coke-Making Process." Journal of Process Control, 35(2), 84-99.
2. White, M. J. (2019). "Advanced Control Strategies in Coke Production." Automation in Industry, 42(3), 145-160.
3. Zhang, L., & Li, X. (2018). "Optimization of Coke Oven Control Using Fuzzy Logic and Neural Networks." Control Engineering Practice, 72, 65-77.
4. Liu, X., & Zhang, Y. (2021). "Data-Driven Optimization of Coke Production: Integration of Machine Learning in Automatic Control Systems." Industrial Automation Journal, 56(4), 203-215.
5. Chen, J., & Wang, Q. (2022). "Real-Time Process Monitoring and Control in Coke Plants: Challenges and Solutions." Journal of Automation and Industrial Technology, 39(6), 1120-1132.
6. Smith, A., & Williams, R. (2023). "Energy Optimization in Coke Production: Role of Automatic Control Systems." Energy Management Review, 44(1), 32-45.
7. Gao, F., & Yang, Z. (2020). "Predictive Maintenance and Failure Detection in Coke Production with Automated Systems." Journal of Process Engineering, 61(7), 455-469.

РОЛЬ СИСТЕМ АВТОМАТИЧЕСКОГО УПРАВЛЕНИЯ В ПРОИЗВОДСТВЕ КОКСА

Камала Алиева[1], Фидан Ахундова[2]
[1]Профессор, кафедра приборостроения, Азербайджанский государственный нефтегазовый университет,

проспект Азадлыг, 20, AЗ1010, Баку, Азербайджан, E-mail: kamala.aliyeva@asoiu.edu.az
[2]Магистр, кафедра приборостроения, Азербайджанский государственный нефтегазовый университет, Баку, Азербайджан,E-mail: fidanakhundova03@gmail.com

РЕЗЮМЕ

Процесс производства кокса является критически важным компонентом сталелитейной промышленности, требующим точности и эффективности в своей работе. В последние годы внедрение систем автоматического управления (ССУ) произвело революцию в работе коксовых заводов, что привело к повышению производительности, энергоэффективности и качества продукции. Эти системы обеспечивают мониторинг и регулирование ключевых параметров в режиме реального времени, таких как температура, давление и поток материала, тем самым оптимизируя весь процесс. В данной статье рассматривается интеграция автоматизированных систем управления в производство кокса, подчеркивается их роль в оптимизации эффективности процесса, снижении эксплуатационных затрат и повышении стабильности качества продукции. Кроме того, обсуждаются проблемы, возникающие при внедрении, и потенциал будущих достижений в области автоматизированных систем управления для производства кокса.
Ключевые слова: производство кокса, сталелитейная промышленность, автоматизированные системы управления (АСУ), эффективность, производительность, мониторинг в реальном времени, оптимизация процесса, энергоэффективность, качество продукции, эксплуатационные затраты, проблемы внедрения, будущие достижения.

KOKS İSTEHSALINDA AVTOMATİK İDARƏETMƏ SİSTEMLƏRİNİN ROLU

Kəmalə Əliyeva[1], Fidan Axundova[2]
[1]Professor, Cihazqayırma mühəndisliyi kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azadlıq prospekti 20, AZ1010, Bakı, Azərbaycan, E-poçt: kamala.aliyeva@asoiu.edu.az
[2]Magistr, Cihazqayırma mühəndisliyi kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Bakı, Azərbaycan, E-poçt: fidanakhundova03@gmail.com

XÜLASƏ

Koks istehsalı prosesi polad istehsalı sənayesinin vacib bir hissəsidir və əməliyyatlarında dəqiqlik və səmərəlilik tələb edir. Son illərdə avtomatik idarəetmə sistemlərinin (ACS) tətbiqi koks zavodlarının işləmə tərzində inqilabi dəyişikliklərə səbəb olub və məhsuldarlığın, enerji səmərəliliyinin və məhsul keyfiyyətinin artmasına səbəb olub. Bu sistemlər temperatur, təzyiq və material axını kimi əsas parametrlərin real vaxt rejimində monitorinqini və tənzimlənməsini təmin edir və beləliklə, ümumi prosesi optimallaşdırır. Bu məqalədə koks istehsalında avtomatik idarəetmə sistemlərinin inteqrasiyası araşdırılır, onların proses səmərəliliyinin optimallaşdırılmasında, əməliyyat xərclərinin azaldılmasında və məhsulun ardıcıllığının yaxşılaşdırılmasındakı rolunu vurğulayır. Bundan əlavə, tətbiq zamanı qarşılaşılan çətinliklər və koks istehsalı üçün ACS-də gələcək irəliləyişlər potensialı da müzakirə olunur.
Açar sözlər: Koks istehsalı, polad istehsalı, avtomatik idarəetmə sistemləri (ACS), səmərəlilik, məhsuldarlıq, real vaxt monitorinqi, prosesin optimallaşdırılması, enerji səmərəliliyi, məhsul keyfiyyəti, əməliyyat xərcləri, tətbiq çətinlikləri, gələcək irəliləyişlər.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

383-391

Publication history
Article received: 13.02.2026
Article accepted: 27.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-43

VOLUME 33 (08) ISSUE 02 2026

MAIN CHARACTERISTICS OF WASTEWATER, ITS TREATMENT AND RETURN TO THE ECOSYSTEM

Nazim Mamedov[1], **Ali Gasimov**[2]
[1]Associate professor, Department of Petrochemical Technology and Industrial Ecology, Azerbaijan State Oil and Industry University, PhD in Environmental Protection, Azerbaijan. E-mail: nazimmemedov@gmail.com
[2]Master student, Department of Petrochemical Technology and Industrial Ecology, Azerbaijan State Oil and Industry University, Azerbaijan. E-mail: qasimove2003@gmail.com

ABSTRACT

The article examines the main characteristics of wastewater, their types, pollutants, sources of organic substances in their composition and their effects on wastewater, as well as types and problems of treatment.

Wastewater is considered to be water discharged into the natural environment (ecosystem) after being used for domestic or industrial purposes or as a result of atmospheric precipitation, contaminated with various types of mixtures (mechanical, chemical, biological). These waters require treatment before being discharged into the natural environment to prevent pollution of soil, water bodies and air.

It is known that the contact of wastewater with natural systems, in general, negatively affects the ecosystem, ultimately creating conditions for human health and the destruction of natural biodiversity. Therefore, studying the conditions of their occurrence and the comprehensive impact of their expected negative consequences on the natural environment is considered to be one of the important issues.

The main sources of wastewater are domestic water, industrial water, commercial wastewater, rainwater, and groundwater or surface water entering the sewage system in various ways.

They are distinguished by their physical, chemical and biological properties. Depending on these properties, various pollution characteristics of the natural environment arise. Among these pollutants, organic pollutants, mainly contained in waste generated in connection with human domestic and industrial activities, occupy an important place. For example, pollution with domestic water occupies 60-70% of the pollution with organic substances. In order to reduce the negative impact of wastewater on the environment, as well as to ensure its subsequent return to the ecosystem, the process of cleaning it from pollutants is carried out. Wastewater treatment is the process of removing pollutants from it so that it is safe for discharge into the environment or reuse. The treatment process usually includes several steps, including advanced treatment, primary treatment, secondary treatment, tertiary treatment.

Problems associated with wastewater treatment include the high costs required to construct and operate wastewater treatment plants, the need for qualified operators to operate wastewater

treatment plants, and potential environmental impacts such as the release of harmful pollutants into the air and water.
Keywords: Wastewater, pollutants, ecosystem, wastewater treatment.

Introduction

Wastewater is considered to be water discharged into the natural environment (ecosystem) after being used for domestic or industrial purposes or as a result of atmospheric precipitation, contaminated with various types of mixtures (mechanical, chemical, biological). These waters require treatment before being discharged into the natural environment to prevent pollution of soil, water bodies and air.

It is known that the contact of wastewater with natural systems, in general, negatively affects the ecosystem, ultimately creating conditions for human health and the destruction of natural biodiversity. Therefore, the study of the conditions of their occurrence and the comprehensive impact of their expected negative consequences on the natural environment is considered an important issue. In connection with the above, the article examines the main characteristics of wastewater, their types, pollutants, sources of organic substances in their composition and their effects on wastewater, as well as types and problems of treatment.

Objective

The relevance of the problem and related research

Wastewater, first of all, pollutes water bodies and soil with toxic substances, pathogens and heavy metals, causes the growth of vegetation on the water (eutrophication) and the formation of “dead zones”, destroys aquatic life, creates health risks for humans (poisoning, infections) and worsens air quality through unpleasant odors. This destroys entire ecosystems, makes the soil unsuitable for agriculture and destabilizes wildlife. From this point of view, ensuring the timely identification of these types of wastewater and the implementation of necessary measures for their treatment and return to the ecosystem in a scientifically substantiated form is currently considered one of the issues of scientific and practical research of urgent importance. Proceeding from this urgency, many systematic studies have been carried out to date to study the impact of various wastewaters on the environment. The article is aimed at improving the environmental performance of ballast water treatment systems used in maritime shipping. Particular attention is paid to the selection of sorption materials capable of purifying chemical compounds. The article examines the main criteria for evaluating filter components, such as economic feasibility, sorption activity and environmental safety [1]. The problem of treating industrial wastewater and preparing water for industrial, domestic (farm) and drinking purposes is becoming increasingly important. The discharge of insufficiently purified wastewater into water bodies leads to a deterioration in the quality of their water. The complexity of treatment is associated with the extreme diversity of pollutants in wastewater, the amount and composition of which are constantly changing due to the emergence of new industries and changes in the technology of existing industries [2]. The article explains the problem of classifying violations of the law, expressed in the pollution of water bodies as a result of the discharge of wastewater or other pollutants due to non-compliance with the requirements of treatment facilities by economic entities [3]. The impact of industrial wastewater treatment systems is studied in detail using existing wastewater treatment methods. Physical, chemical and biological water treatment methods demonstrate varying effectiveness in

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

removing pollutants from natural water bodies. Comprehensive monitoring of treated wastewater is carried out using key pollution indicators, including oxygen demand and the concentration of solids in the treated product [4]. The book [5] discusses the operation methods of wastewater treatment plants. The article [6] develops scientifically substantiated proposals for reducing the environmental damage caused by wastewater generated in the oil refining process.

Methods

Wastewater and its types

The main sources of wastewater include:

• Domestic wastewater: This is wastewater generated in households, including water from sanitary facilities (sinks, showers, and toilets), dishwashers, and washing machines. This wastewater typically contains organic matter, nutrients, pathogenic microorganisms (bacteria, viruses), and personal hygiene products.

• Industrial wastewater: This type of wastewater is generated by industrial processes and activities, such as manufacturing, mining, and the food industry. It can contain a wide range of contaminants, including heavy metals, toxic chemicals, solvents, and oils.

• Commercial wastewater: This wastewater is generated in commercial establishments such as restaurants, hotels, hospitals, and office buildings. It is typically a mixture of domestic and industrial wastewater, as well as grease, food residue, and cleaning products.

• Stormwater: This is rainwater or melted snow that runs off impervious surfaces such as roads, parking lots, and roofs. Sediment can carry pollutants such as nutrients, pesticides, and heavy metals into water bodies.

• Infiltration of wastewater: This occurs when groundwater or surface water enters the sewage system through cracks or defects in pipes and manholes. This can contribute to wastewater overflowing treatment plants and reduce the effectiveness of the treatment process.

In addition to these sources, wastewater from landfills and landfills (leakage) and wastewater treatment plant wastewater are also included. Leachate is water that has leached from disposed waste and removed pollutants from it. Its main characteristics: It contains a wide range of pollutants, including heavy metals, organic compounds, and toxic chemicals in high concentrations. It can contaminate groundwater and surface water, posing a risk to human health and the environment. Wastewater is formed as a byproduct of water treatment processes such as coagulation, filtration, and disinfection.

Domestic wastewater can cause eutrophication (excessive enrichment of nutrients) in water bodies, which leads to overgrowth of plants and depletion of oxygen in water bodies, which poses a threat to aquatic ecosystems and human health.

Characteristics and pollutants of wastewater

The properties of wastewater can vary considerably depending on its source. However, common properties include:

• Physical properties: These include temperature, color, turbidity, and suspended solids content.

• Chemical properties: These include pH, dissolved oxygen, biochemical and chemical oxygen demand, nutrients (nitrogen and phosphorus), and heavy metals.

• Biological properties: These include the presence of microorganisms such as bacteria and viruses.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Wastewater contains a variety of pollutants, including organic matter. Organic matter is matter that is produced by living or once-living organisms. This includes, for example, food waste, paper, and human waste.
The biochemical oxygen demand and chemical oxygen demand of wastewater organic matter are measures of the amount of oxygen required to break down organic matter. Chemical oxygen demand is a measure of the total amount of oxygen required to oxidize all organic matter in wastewater.
In addition to organic substances, as mentioned, toxic and pathogenic pollutants are also distinguished as pollutants, depending on their chemical and biological properties.
Toxic pollutants are substances that can have a negative impact on health even at low concentrations. These pollutants include:
• Heavy metals such as lead, mercury and cadmium.
• Pesticides
• Solvents
• Polycyclic aromatic hydrocarbons
• Dioxins
• Furans
Pathogens are microorganisms that can cause disease. These microorganisms include:
• Bacteria such as Escherichia coli and salmonella.
• Viruses such as hepatitis A and norovirus.
• Protozoa such as Lyme disease and cryptosporidiosis.
In addition to these pollutants, synthetic pollutants are also found in wastewater.
The main pollutants of domestic wastewater are:
Organic substances (60-70% of total pollutants):
• Proteins, fats, carbohydrates
• Feces, food waste
• Cellulose (toilet paper)
• Volatile fatty acids
Organic pollutant indicators:
• BOT_5 (5-day biochemical oxygen demand) – 150-400 mg/l
• COT (chemical oxygen demand) – 300-600 mg/l
Minerals (30-40%):
• Sand, clay
• Sodium, potassium and calcium ions
• Chlorides, sulfates
Biological pollutants:
• Bacteria (including pathogens – Escherichia coli, salmonella)
• Viruses (enteroviruses, rotaviruses)
• Protozoa (simple microorganisms)
• Helminth eggs
Synthetic components:
• Surfactants – 5-15 mg/l
• Drug residues
• Microplastics

Sources of organic matter in wastewater and their effects on wastewater

Organic matter in wastewater, as mentioned, comes from a variety of sources, including:

• Human waste: Human waste is the main source of organic matter in wastewater. It contains a variety of organic compounds, including proteins, carbohydrates, and fats.

• Food waste: Food waste is another important source of organic matter in wastewater. This includes, for example, meat, vegetables, and fruits.

• Paper products: Paper products are a significant source of organic matter in wastewater. This includes, for example, toilet paper, paper towels, and cardboard.

• Industrial waste streams: Industrial wastewater can also be a source of organic matter. Depending on the type of industry, it can contain a variety of organic compounds.

Organic matter in wastewater can have a number of negative effects, including:

• Oxygen depletion: Organic matter in wastewater can reduce oxygen levels in water bodies. This can be harmful to aquatic organisms and make it difficult for them to breathe.

• Eutrophication: This is the process by which water bodies become enriched with nutrients, leading to excessive growth of plants. This can block sunlight from reaching aquatic plants and animals, causing them to bloom to harmful levels.

• Pathogens: Organic matter in wastewater can also contain pathogens - microorganisms that can cause disease. These pathogens can pose a threat to human and animal health.

Types and problems of wastewater treatment

Organic matter in wastewater is a serious problem for water quality. As mentioned, organic matter can cause a number of negative effects, including oxygen depletion, eutrophication, and the spread of pathogens. However, organic matter in wastewater can be treated in various ways, which helps to protect water quality and human health.

Wastewater treatment is the process of removing contaminants from wastewater so that it is safe for discharge into the environment or reuse. The treatment process usually involves several steps, including:

• Pretreatment: This step involves filtration and sand removal to remove large particles and debris from the wastewater.

• Primary treatment: This step involves sedimentation to remove settleable solids and organic matter.

• Secondary treatment: This step uses biological processes such as activated sludge or trickling filters to remove dissolved organic matter and nutrients.

• Tertiary treatment: This stage involves additional treatment processes such as filtration, disinfection, and nutrient removal to further improve the quality of wastewater.

After treatment, wastewater is usually discharged into surface water bodies such as rivers or lakes or reused for irrigation, industrial purposes, or groundwater recharge.

Wastewater treatment can be a complex and expensive process. Problems associated with wastewater treatment include:

• High costs for constructing and operating wastewater treatment plants.

• Need for skilled operators to operate wastewater treatment plants.

• Potential environmental impacts such as the release of harmful pollutants into air and water.

Untreated domestic wastewater can have the following environmental impacts:

Water pollution:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

• Oxygen starvation (eutrophication)
• Death of aquatic organisms
• Accumulation of toxins in the food chain
Epidemiological hazards:
• Spread of intestinal infections
• Pollution of soil and groundwater
Corrosion and clogging of sewage systems:
• Formation of oil sludge
• Formation of hydrogen sulfide
Modern wastewater treatment plants for the treatment of domestic wastewater use a multi-stage treatment system:
1. Mechanical treatment
• Cages (retention of large debris)
• Sand chambers (removal of mineral suspended solids)
• Primary settling tanks (sedimentation of suspended solids)
Efficiency of this stage: 30-40% removal of pollutants
2. Biological treatment
• Aeration tanks (oxidation of organic matter with activated sludge)
• Biofilters (filtration through a biofilm medium)
• Membrane bioreactors
Efficiency of this stage: Removal of 85-95% organic matter
3. Final stage of treatment:
• Filtration through sand filters
• Phosphate removal (reagent precipitation)
• Denitrification (nitrogen removal)
4. Disinfection:
• Chlorination
• Ultraviolet irradiation
• Ozonation
The following promising technologies are available based on wastewater treatment:
1. Water reuse (recycling):
• Use of treated wastewater for irrigation
• Industrial water supply
2. Energy production:
• Biogas production from sediment
• Hydrogen technologies
3. Intelligent systems:
• Automatic monitoring of wastewater composition
• Optimization of wastewater treatment plants

Conclusion

The article examines the main characteristics of wastewater, their types, pollutants, sources of organic substances in their composition and their effects on wastewater, as well as types and problems of treatment. It is noted that wastewater pollutes water bodies and soil with toxic substances, pathogens and heavy metals, causes eutrophication and the formation of "dead zones", destroys aquatic life, creates health risks for humans (poisoning, infections) and worsens air quality through unpleasant odors. This destroys entire ecosystems, makes the soil unsuitable for agriculture and destabilizes wildlife. The timely identification of these types of wastewater and the implementation of necessary measures to attract them for treatment and return them to the ecosystem in a scientifically substantiated manner is currently considered one of the issues of scientific and practical research of urgent importance.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests

The authors declare no competing interests.

Funding Source

This research was conducted without support from external funding.

Ethical Standards

The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Cyguta A.N., Golovackaja L.I. Osnovnye trebovanija k podboru komponentov fil'trov v sisteme ochistki ballastnyh vod. V sbornike: Transport. Gorizonty razvitija. Trudy 5-go Mezhdunarodnogo nauchno-promyshlennogo foruma. Nizhnij Novgorod, 2025, c. 137.
2. Sekirina A.P., Rovenskaja I.A. Ochistka stochnyh vod v estestvennyh uslovijah. V sbornike: Saharovskie chtenija - 2025: ekologicheskie problemy XXI veka. Materialy 25-j Mezhdunarodnoj nauchnoj konferencii. V 2-h chastjah. Minsk, 2025, c. 231-234.
3. Rumjancev F.P., Zvereva Ju.N. K teoreticheskomu opredeleniju ponjatija “degradacija vodnyh ob#ektov”. Rossijsko-aziatskij pravovoj zhurnal. 2025, № 3, c. 45-48.
4. Dzhalagonija N.G., Orehova V.I. Ocenka vlijanija ochistnyh sooruzhenij na okruzhaju-shhuju sredu. V sbornike: Upravlenie ob#ektami nedvizhimosti i razvitiem territorij. Materialy VI Nacional'noj nauchno-prakticheskoj konferencii. Saratov, 2025, c. 23-26.
5. Meral R., Cavadzade F. Tullanty sutemizleyici qurghularyn istismary. Baky, 2018, 172 s.

6. Baghyrova N., Sultanova G. Piroliz prosesinin chirkab sularynyn ekstraksiya usulu ile temizlenmesi. Proceedings of Azerbaijan High Technical Educational Institutions. 2021, c. 5, № 1, s. 58-64.

ОСНОВНЫЕ ХАРАКТЕРИСТИКИ СТОЧНЫХ ВОД, ИХ ОЧИСТКА И ВОЗВРАТ В ЭКОСИСТЕМУ

Назим Мамедов[1], Али Касумов[2]

[1]Доцент, кафедра нефтехимической технологии и промышленной экологии, Азербайджанский государственный университет нефти и промышленности, доктор философии по охране окружающей среды, Азербайджан. Э-почта: nazimmemedov@gmail.com

[2]Магистрант, кафедра нефтехимической технологии и промышленной экологии, Азербайджанский государственный университет нефти и промышленности, Азербайджан. Э-почта: qasimove2003@gmail.com

РЕЗЮМЕ

В статье рассматриваются основные характеристики сточных вод, их виды, загрязняющие вещества, источники органических веществ в их составе и их воздействие на сточные воды, а также виды и проблемы очистки. Отмечается, что к сточным водам относятся воды, сбрасываемые в природную среду (экосистему) после использования в бытовых или промышленных целях или в результате атмосферных осадков, загрязненные различными видами смесей (механическими, химическими, биологическими). Эти воды требуют очистки перед сбросом в природную среду для предотвращения загрязнения почвы, водоемов и воздуха. Контакт сточных вод с природными системами, как правило, негативно влияет на экосистему, в конечном итоге создавая условия для здоровья человека и разрушения природного биоразнообразия. Поэтому изучение условий их возникновения и комплексного воздействия ожидаемых негативных последствий на природную среду считается одним из важных вопросов. Основными источниками сточных вод являются бытовые воды, промышленные воды, коммерческие сточные воды, дождевая вода, а также грунтовые или поверхностные воды, поступающие в канализационную систему различными путями.

Для уменьшения негативного воздействия сточных вод на окружающую среду, а также для обеспечения их последующего возвращения в экосистему, проводится процесс очистки сточных вод от загрязняющих веществ. Очистка сточных вод — это процесс удаления загрязняющих веществ из них, чтобы сделать их безопасными для сброса в окружающую среду или повторного использования. Проблемы, связанные с очисткой сточных вод, включают высокую стоимость строительства и эксплуатации очистных сооружений, необходимость в квалифицированных операторах для работы на очистных сооружениях, а также потенциальное воздействие на окружающую среду, такое как выброс вредных загрязняющих веществ в воздух и воду.

Ключевые слова: Сточные воды, загрязняющие вещества, экосистема, очистка сточных вод.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

AXINTI SULARININ ƏSAS XÜSUSİYYƏTLƏRİ, TƏMİZLƏNMƏSİ VƏ EKOSİSTEMƏ QAYTARILMASI

Nazim Məmmədov[1], Əli Qasımov[2]
[1]Dosent, “Neft-kimya texnologiyası və sənaye ekologiyası” kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, ətraf mühitin mühafizəsi üzrə fəlsəfə doktoru, Azərbaycan. E-mail: nazimmemedov@gmail.com
[2]Magistr tələbəsi, “Neft-kimya texnologiyası və sənaye ekologiyası” kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan. E-mail: qasimove2003@gmail.com

XÜLASƏ

Məqalədə axıntı sularının əsas xüsusiyyətləri, onların növləri, çirkləndiriciləri, onların tərkibində olan üzvi maddələrin mənbələri və onların axıntı sularına təsirləri, eləcə də təmizlənmə növləri və problemləri araşdırılır.Qeyd edilir ki, axıntı suları məişət və ya sənaye məqsədləri üçün istifadə edildikdən sonra və ya atmosfer yağıntıları nəticəsində müxtəlif növ qarışıqlarla (mexaniki, kimyəvi, bioloji) çirklənməklə təbii mühitə (ekosistemə) axıdılan sular hesab edilir. Bu sular torpağın, su hövzələrinin və havanın çirklənməsinin qarşısını almaq üçün təbii mühitə axıdılmadan öncə təmizlənməsini tələb edir. Axıntı sularının təbii sistemlərlə təması, ümumilikdə, ekosistemə mənfi təsir etməklə, son nəticədə insan sağlamlığına, təbii biomüxtəlifliyin pozulmasına şərait yaradır. Ona görə də onların müydana gəlmə şəraitlərinin və onların təbii mühitə gözlənilən mənfi nəticələrinin hərtərəfli təsirinin öyrənilməsi mühüm məsələlərdən hesab edilir. Əsas axıntı su mənbələri olaraq məişət suları, sənaye suları, kommersiya tullantı suları, yağıntı suyu, müxtəlif yollarla kanalizasiya sisteminə daxil olan yeraltı və ya səth suları hesab edilir.
Axıntı sularının ətraf mühitə mənfi təsirinin azaldılması, habelə sonradan ekosistemə qaytarılmasının təmin edilməsi üçün onun çirkləndiricilərdən təmizlənməsi prosesi həyata keçirilir. Axıntı sularının təmizlənməsi ətraf mühitə axıdılması və ya təkrar istifadə üçün təhlükəsiz olması üçün onlardan çirkləndiricilərin çıxarılması prosesidir. Axıntı sularının təmizlənməsi ilə bağlı problemlər olaraq, axıntı su təmizləyici qurğuların tikintisi və istismarı üçün yüksək xərclərin tələb edilməsi, axıntı su təmizləyici qurğuların istismarı üçün ixtisaslı operatorlara ehtiyacın olması və zərərli çirkləndiricilərin havaya və suya buraxılması kimi ətraf mühitə potensial təsirlərin olması göstərilir.
Açar sözlər: Axıntı suları, çirkləndiricilər, ekosistem, axıntı sularının təmizlənməsi.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

392-402

Publication history
Article received: 13.02.2026
Article accepted: 27.02.2026
Article published online: 10.03.2026
DOI: 10.36962/ETM33022026-44

SINGLE-FLOW REDUCER WITH AN INNOVATIVE PLANETARY GEAR

Veli Fataliyev[1], Toghrul Alakbarli[2]
[1]Associate Professor, PhD in Technical Sciences, Department of Mechanics, Azerbaijan Technical University, Azerbaijan. E-mail: veli.feteliyev@aztu.edu.az
[2]Faculty of Oil-Mechanical Engineering, Master's Student, Azerbaijan State Oil and Industry University, Azerbaijan.
E-mail: togrul.alekberli@mail.ru

ABSTRACT

The design features of drive gear reducers used in oil and gas equipment are considered, with particular emphasis on the arrangement of planetary gear trains within geared motor units. The influence of the mounting schemes of the central gear and the carrier on system stiffness, load distribution, and dynamic processes is analyzed.
Based on the elastic dynamic model of the system "electric motor — gear mechanism — driven unit" using Lagrange equations, the relationship between the transmission layout, equivalent stiffness, and the conditions for the occurrence of resonance modes has been established. The influence of shaft torsional compliance and the cantilever arrangement of elements on vibrations and meshing conditions is demonstrated.
The feasibility of mounting the central gear and the carrier on bearings relative to the housing, in which the shaft primarily performs a centering function, is substantiated. The effect of this arrangement on the dynamic characteristics of the transmission is shown.
The obtained relationships can be used in the design of planetary reducers for drives of mechanized oil production systems.
Keywords: planetary reducer, layout, mounting, equivalent stiffness, dynamics, resonance, torsional vibrations, geared motor.

Introduction

Gear reducers are widely used in equipment of the oil and gas industry and constitute an integral part of drilling rigs as well as mechanized oil production units. The operation of such assemblies takes place under conditions of increased loads, exposure to aggressive environments, and significant temperature fluctuations, which impose high requirements on the reliability, durability, and operational stability of drive mechanisms.
One of the most common types of equipment used for mechanized oil production is the sucker rod pumping unit, the drive of which is typically implemented through gear reducers of various configurations. In the designs of beam pumping units, both cylindrical and planetary gear reducers are applied to reduce rotational speed and transmit substantial torque.
In recent years, planetary gear systems have been increasingly used in the drives of such installations due to their compactness, high efficiency, and ability to transmit load through parallel

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

power flows via several planet gears. This makes it possible to significantly reduce the overall dimensions of the gearbox compared with conventional cylindrical gear transmissions while maintaining the required transmission characteristics.

However, an analysis of existing motor-gearbox designs shows that in configurations where the central gear is rigidly mounted on the electric motor input shaft and the carrier is cantilevered on the output shaft, additional elastic deformations occur in the system. These deformations are associated with the torsional compliance of the shafts, the cantilever arrangement of elements, and the non-uniform distribution of loads. As a result, oscillations arise, gear meshing conditions deteriorate, and the service life of the unit decreases.

Thus, when planetary gear systems are used as part of motor-gearboxes, it becomes important not only to select the type of gear engagement but also to determine the mounting scheme of the central gear and the carrier relative to the housing and shafts. The layout solution itself has a significant influence on the system dynamics, its stiffness, and its resistance to vibrations.

2. RESEARCH OBJECTIVE

In order to obtain simple planetary mechanisms from satellite systems, three central gears are usually fixed (Fig. 1).

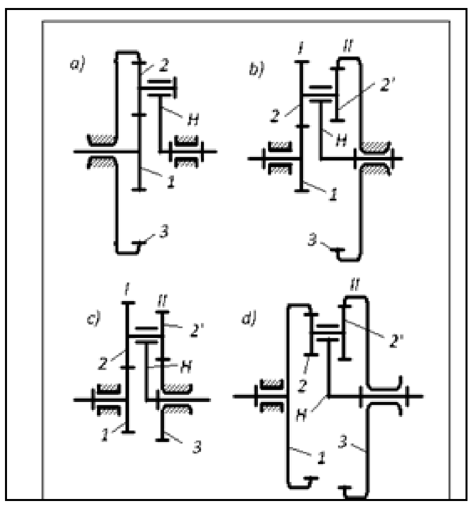


Figure 1: Schemes of simple planetary mechanisms.

As follows from Figure 1, in mechanisms of schemes **c** and **d**, when the carrier **H** is used as the input element, it is possible to obtain very large transmission ratios by selecting an appropriate number of teeth. However, due to the extremely low efficiency (less than 1%), such schemes are not used in power transmissions and can only be applied in low-power mechanisms to obtain transmission ratios of $u_{H1} = 30–100$.

Planetary mechanisms of schemes **a** and **b**, on the contrary, are characterized by high efficiency (96–98%) and are therefore widely used in power transmissions to obtain transmission ratios of $u_{1H} = 3–8$(single-stage scheme) and $u_{1H} = 1.1–10$(two-stage scheme). In these mechanisms, power is transmitted through several parallel load paths via the planet gears, which ensures compactness compared with conventional gear reducers.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Modern motor-gearboxes often represent an integrated unit combining an electric motor and a planetary gear train within a single housing. In such designs, the central gear is connected to the motor rotor, while the carrier is connected to the output shaft extending beyond the housing.
The use of such solutions makes it possible to employ high-speed electric motors. At the same time, the cantilever arrangement of the central gear on the input shaft and the carrier on the output shaft leads to torsional deformations and oscillations. This negatively affects the stiffness of the system, the durability of the components, the smoothness of gear meshing, and the overall efficiency of the transmission.
In the proposed layout, the central gear is mounted movably on the carrier supporting axis, and the transmission of motion is carried out by means of a belt drive or a coupling. In this case, the gear is placed on the input journal, one end of which is supported by the housing through a bearing, while the other end is connected to the carrier housing **H**.

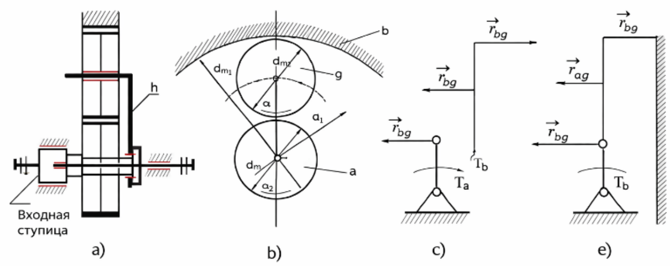


Figure 2: Structure of the innovative device.

The driving element mounted on the central shaft is supported on one side by a ball through a bearing corresponding to the center of the ball. In other words, the input ball is installed concentrically on the central shaft. Through this ball, motion is transmitted from another drive to the central gear (a) without creating torque on shaft (g). The shaft is centered only on the ball, while the ball itself is supported on the housing by its outer diameter. Unlike the traditional Achab transmission, the central gear mounted on the driving shaft is not cantilevered and is therefore not subjected to bending and torsional deformation [3,5]. For this reason, a mathematical model can be applied to the new innovative transmission.
In the proposed planetary gearbox, the ball is supported on the central gear (a) instead of the input shaft and on the central shaft through rolling bearings. This makes it possible to reduce the overall dimensions of the structure, decrease the stiffness of the shaft carrying the ball and the central gear, as well as the shaft on which the driving bar is mounted (C_1, C_3). As a result, the natural rotational frequency of the system decreases (operation outside resonance; see equation (7b)), which increases the durability and service life of the mechanism.
Let us proceed to the dynamic analysis of gear mechanisms with elastic connections. Consider the case when the rotor of an electric motor is connected to the machine actuator through a gear

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

transmission (Fig. 3). The moment of inertia of the rotor is J_m and the torque is T_m; for the actuator these values are J_i and T_i respectively (the masses of the gears and shafts are neglected) [1,2,7,8]. The connections between the rotor and the first gear, as well as between the driving bar of the second gear and the actuator, possess elasticity with stiffness coefficients c_1, c_2, c_3. With absolutely rigid connections, the number of degrees of freedom would be $W = 1$. Taking into account three elastic elements increases the number of degrees of freedom to $H = W + 3 = 4$, which corresponds to the number of generalized coordinates.

As generalized coordinates, we consider the rotation angles of the motor, the central gear, the driving bar, and the actuator — $(\varphi_m, \varphi_a, \varphi_h, \varphi_i)$. Based on this, the equations of motion of the dynamic system can be written in the following form:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \omega_m}\right) - \frac{\partial L}{\partial \varphi_m} = T_m \;; \qquad \frac{d}{dt}\left(\frac{\partial L}{\partial \omega_i}\right) - \frac{\partial L}{\partial \varphi_i} = T_i \;;$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \omega_a}\right) - \frac{\partial L}{\partial \varphi_a} = T_1 \;; \qquad \frac{d}{dt}\left(\frac{\partial L}{\partial \omega_h}\right) - \frac{\partial L}{\partial \varphi_h} = T_3 \;.$$

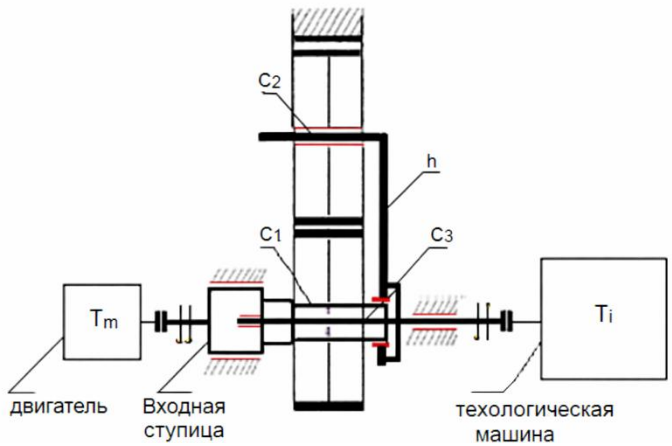


Figure 3: Diagram of the connection between the electric motor rotor and the actuator housing of the technological machine.

Since no external forces act on connections 1), 2), and 3), $T_1 = T_3 = 0$. In accordance with Lagrange's equation, we obtain:

$$L = E - V = \tfrac{1}{2}J_m\omega_m^2 + \tfrac{1}{2}J_i\omega_i^2 - \tfrac{1}{2}c_1(\varphi_m - \varphi_a)^2 - \tfrac{1}{2}c_2(\varphi_a - \varphi_g)^2 - \tfrac{1}{2}c_3(\varphi_h - \varphi_i)^2 \;. \quad (1)$$

The angle φ_g, included in equation (1), depends respectively on the angles φ_a and φ_h. Thus

$$\frac{d\varphi_a}{d\varphi_h} = u_{ah} \;; \qquad \frac{d\varphi_g}{d\varphi_h} = u_{gh} \;. \quad (2)$$

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

In this system, the angles φ_{ah} and φ_{gh} represent the transmission ratios of the corresponding gear engagements. As a rule, for gear transmissions these ratios are assumed to be constant. Based on this, the following expression can be derived from equation (2):

$$\frac{\varphi_a}{\varphi_h} = u_{ah} \ ; \qquad \frac{\varphi_g}{\varphi_h} = u_{gh} \ . \tag{3}$$

Considering equations (2) and (3) and substituting them into equation (1) in the form of the differential expressions given above, we obtain the following expression:

$$J_m \frac{d\omega_m}{dt} - c_1(\varphi_m - \varphi_a) = T_m$$
$$-c_1(\varphi_m - \varphi_a) + c_2(\varphi_h u_{ah} - \varphi_h u_{gh}) \cdot u_{ah} \, ; \tag{4}$$

$$-c_2(\varphi_h u_{ah} - \varphi_h \cdot u_{gh}) u_{gh} + c_3(\varphi_h - \varphi_i) = 0;$$
$$J_m \frac{d\omega_h}{dt} - c_3(\varphi_h - \varphi_i) = T_i \ .$$

From the second and third equations of system (4), we find φ_a and φ_h, and then, by substituting them into the second and fourth equations, we obtain a system of differential equations describing the motion of the considered unit.
Now, let us consider a special case. Suppose that the motor is capable of developing sufficiently high power; in this case, we can assume $\omega_m = \text{const}$. Then $\varphi_m = \omega_m t$, and the equations (5) can be solved independently of each other: from the second equation, φ_i is determined, and then, using the known values of φ_m and φ_i, the torques of the motor T_m and the actuator T_i are calculated from the first equation.
Taking into account φ_m and φ_i from the first equation, the torques required from the motor T_m and the actuator T_i are determined.

$$J_m \frac{d\omega_m}{dt} + \frac{c_1 \cdot c_2 \cdot c_3 \cdot u^2{}_{ah}}{c_1 \cdot c_3 + c_1 \cdot c_2 \cdot u_{gh} + c_2 \cdot c_3 \cdot u_{ah}} \left(\varphi_m - \varphi_{gh} \cdot \varphi_i\right) = T_m;$$

$$J_i \frac{d\omega_i}{dt} + \frac{c_1 \cdot c_2 \cdot c_3 \cdot u_{ah} \cdot u_{gh}}{c_1 \cdot c_3 + c_1 \cdot c_2 \cdot \omega^2{}_{gh} + c_2 \cdot c_3 \cdot \omega^2{}_{ah}} \left(\varphi_m - \varphi_{gh} \cdot \varphi_i\right) = T_i \ . \tag{5}$$

If in the second equation of (5) we factor out φ_{gh}, divide both sides by J_i, and perform the substitution, we obtain:

$$\frac{c_1 \cdot c_2 \cdot c_3 \cdot u^2{}_{gh}}{c_1 \cdot c_3 + c_1 \cdot c_2 \cdot \omega^2{}_{gh} + c_2 \cdot c_3 \cdot \omega^2{}_{ah}} = C_g; \tag{6}$$

$$\frac{C}{J_i} = k^2 \ ; \quad \frac{\varphi_m}{\varphi_{gh}} - \varphi_i = \varphi \ .$$

Here, C_g is the equivalent stiffness coefficient of the system. Since $\frac{d\omega_i}{dt} = \frac{d^2\varphi}{dt^2}$, on this basis we obtain the following equation:

$$\frac{d^2\varphi}{dt^2} + k^2\varphi = -\frac{T_i}{J_i} \quad (7)$$

Here, k is the natural rotational frequency of the system. If internal friction is taken into account, the torque it generates, being proportional to the relative angular velocity, can be expressed as follows:

$$T_s = -\beta\frac{d\varphi}{dt} \; ;$$

$$\frac{T_s}{J_i} = -\frac{\beta}{J_i} \cdot \frac{d\varphi}{dt} \; .$$

By denoting $\frac{\beta}{J_i} = 2n$, we obtain:

$$\frac{d^2\varphi}{dt^2} + 2n\frac{d\varphi}{dt} + k^2\varphi = f(t). \quad (8)$$

Let us assume that the torque T_i is a function of time. Then, by making the substitution $-T_i/J_i = f(t)$, expression (8) can be written in the following form:

$$\frac{d^2\varphi}{dt^2} + 2n\frac{d\varphi}{dt} + k^2\varphi = f(t) \; . \quad (9)$$

The first terms of the resulting expressions describe the motion (oscillations) arising from the system's own initial conditions, while the second terms represent the forced oscillations. Over time, since $e^{-nt} \to 0$, the natural oscillations decay, and the forced oscillations persist. Denoting the amplitude of the forced oscillations by D, we obtain:

$$D = \frac{h}{\sqrt{(p^2 - k^2)^2 + 4n^2p^2}} = \frac{h}{k^2\sqrt{\left(\frac{p^2}{k^2} - 1\right)^2 + \frac{4n^2p^2}{k^2}}} \quad (25)$$

Figure 4. Diagrams showing the dependence of k_{din} on the ratio p/k for several values of n/k[1,2,6].

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

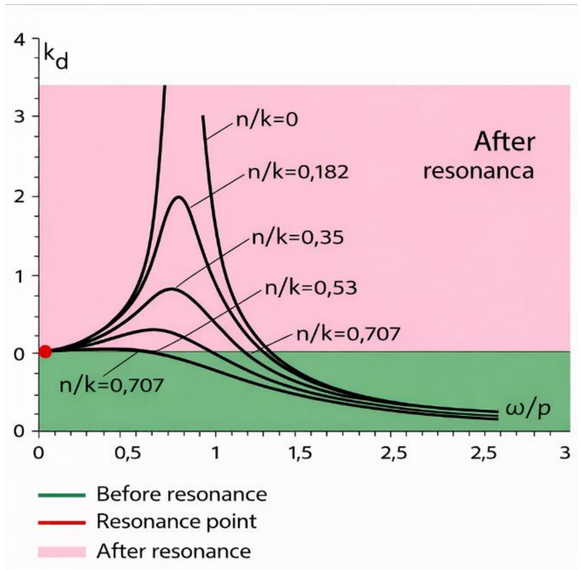


Figure 4: Diagrams of the dependence of k_{din} on the ratio p/k.

Based on equation (18) and the value of n_2, the following conclusion can be drawn:

$$\frac{h}{k^2} = \frac{T_0}{J_i k^2} = \frac{T_0}{J_i c_g / J_i} = \frac{T_0}{c_g}$$

It shows the static deformation of the system under the action of the torque T_0. The ratio of the amplitude of the forced oscillations to the static deformation is called the dynamic factor:

$$k_d = \frac{D}{h/k^2} = \frac{1}{\sqrt{\left(\frac{p^2}{k^2}-1\right)^2 + \frac{4n^2p^2}{k^4}}} \quad (26)$$

As seen from the figure, at $n = 0$and $p/k = 1$, the dynamic factor tends to infinity. This point is called the resonance point. At this point, the value of $n$shifts to the maximum of k_{din}, and when $n/k = 0.707$, it reaches $p/k = 0$. In other words, for values $n/k \leq 0.707$, the condition $k_{\text{din}} < 1$is satisfied.

Points with $p/k < 1$correspond to pre-resonance states, while points with $p/k > 1$correspond to post-resonance states. As can be seen from the diagram, after resonance, with increasing frequency of forced rotations ω, the dynamic factor approaches zero.

Research Methodology

In this study, an operational factor considered was the backlash of the gearbox elements, the increase of which during operation leads to a reduction in efficiency and deterioration of the performance of the oil pumping unit.

The research objectives were:

- To evaluate the influence of backlash magnitude on the stress dynamics in the gearbox components;
- To assess the effect of backlash on the reliability of the mechanism;
- To determine the permissible limit value of backlash.

The change in backlash magnitude was simulated by controlled wear of the splined shafts while keeping the other gearbox elements unchanged, allowing the elimination of external influencing factors.

Experimental studies were conducted under a constant static friction torque of 0.3 N·m and a load of 350 N·m. For each value of backlash, a series of strain gauge measurements were performed on the gear teeth, crank, and bearings. Representative strain diagrams obtained over one rotation of the crank are shown in Fig. 7.

Analysis of the strain diagrams showed that an increase in backlash leads to:

- Growth in vibrations of the gearbox elements;
- Greater unevenness in torque transmission;
- Increased characteristic stresses in components, which accelerates wear and reduces the operational performance of the mechanism.

Methodology Used

To analyze the dynamic characteristics of the planetary gearbox, an elastic dynamic model of the system "electric motor — gear mechanism — actuator" was applied. The generalized coordinates were taken as the rotation angles:

$$\varphi_m, \varphi_a, \varphi_h, \varphi_i$$

here:

- φ_m— rotation angle of the electric motor rotor;
- φ_a— angle of the central gear;
- φ_h— angle of the driving bar (carrier);
- φ_i— angle of the actuator.

The system's energy accounts for the moments of inertia of the rotor and actuator (J_m, J_i) and the elastic deformations of the connections with stiffness coefficients c_1, c_2, c_3:

$$L = E - V = \frac{1}{2}J_m\omega_m^2 + \frac{1}{2}J_i\omega_i^2 - \frac{1}{2}c_1(\varphi_m - \varphi_a)^2 - \frac{1}{2}c_2(\varphi_a - \varphi_h)^2 - \frac{1}{2}c_3(\varphi_h - \varphi_i)^2$$

Using the transmission ratios of the gear engagements (u_{ah}, u_{gh}), a system of differential equations of motion was constructed, accounting for the equivalent system stiffness and damping:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

$$\frac{d^2\varphi}{dt^2} + 2n\frac{d\varphi}{dt} + k^2\varphi = f(t)$$

here:

- k— natural rotational frequency of the system;
- n— damping coefficient;
- $f(t)$— function of the forced torque applied to the actuator.

This methodology allowed for:

- Determining the influence of the mounting scheme of the central gear and carrier on system stiffness and dynamics;
- Identifying conditions for resonance regimes;
- Evaluating the dependence of the amplitude of forced oscillations on equivalent stiffness and damping;
- Predicting the dynamic characteristics and vibration stability of the gearbox under various operating conditions.

Results and Conclusions

The conducted studies showed that the proposed gearbox demonstrates higher efficiency compared to analogs and prototypes due to its design features and the absence of axial loads on the shaft.

Key advantages of the design include:

- Reduction in material consumption by up to 1.5 times;
- Reduction of contact stresses in the gear transmissions by at least 2 times;
- Decrease in the number of shafts by at least 1.5 times;
- Increased lifespan and reliability of the mechanism.

It was established that with an increase in the transmission ratio, the efficiency of the proposed gearbox rises due to the reduction in the number of gears involved in torque transmission.

Considering the stress relaxation effect in structural elements, stress levels decrease by 15–20% compared to prototypes.

Thus, the proposed gear transmission is characterized by compact dimensions, high efficiency, stable transmission ratios, and applicability across a wide range of loads and speeds, confirming its prospective use in drives of oil pumping units.

Declarations

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

Study Limitations

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

Acknowledgments

The author would like to thank for the support of staff and experienced people who participated in this study by sharing their invaluable knowledge and experience. Their cooperation and openness contributed greatly to the depth and richness of the research results.

Competing Interests
The authors declare no competing interests.

Funding Source
This research was conducted without support from external funding.

Ethical Standards
The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

REFERENCES

1. Kengerli A.M. Mashin ve mexanizmler nezereyyesi. Baku: “Turxan” NPB, 2021. – 688 p.
2. Kerimov Z.H. Mashin hisseleri ve yukqaldirici-neqledici mashinlar. Baku: “Maarif”, 2002. – 376 p.
3. Reshetov D.N. Detali mashin. Moscow: Mashinostroenie, 1975. – 656 p.
4. V.M. Fataliyev. Disli charx oturmemeleri, onlarning dinamikasi ve sinag stendlari. Baku: Maarif, 2004. – 45 p.
5. Kerimov Z.H., Fataliyev V.M. Dynamics of planetary reductor. Transactions of the Academy of Sciences of Azerbaijan, №4, 2000.
6. H.B. Qadirov. Nezerei mexanika. Baku State University Press, 1990. – 344 p.
7. Mirzadzhanzade A.Kh., Kerimov Z.G., Kopeykis G.K. Teoriya kolebaniy v neftepromyslovom dele. 2005.
8. Timoshenko S.P. Kolebaniya v inzhenernom dele. Moscow: Mashinostroenie, 1985. – 472 p.
9. Gershun V.V., Golubev A.N. Osnovy mekhaniki mashin. Moscow: Mashinostroenie, 1988. – 512 p.
10. Boresi R.K., Schmidt R.J. Advanced Mechanics of Materials. John Wiley & Sons, 2002. – 768 p.
11. Shigley J.E., Mischke C.R. Mechanical Engineering Design. McGraw-Hill, 2001. – 900 p.

ОДНОПОТОЧНЫЙ РЕДУКТОР С ИННОВАЦИОННОЙ ПЛАНЕТАРНОЙ ПЕРЕДАЧЕЙ

Вели Фаталиев[1], Тогрул Алекберли[2]
[1]Доцент, кандидат технических наук “Кафедра механики”, Азербайджанский технический университет, Азербайджан. E-mail: veli.feteliyev@aztu.edu.az
[2]Нефтемеханический факультет, магистрант, Азербайджанский Государственный Университет Нефти и Промышленности, Азербайджан. E-mail: togrul.alekberli@mail.ru

РЕЗЮМЕ

Рассмотрены конструктивные особенности редукторов приводов нефтегазового оборудования с акцентом на компоновку планетарных передач в составе мотор-редукторов.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Проанализировано влияние схем базирования центрального колеса и водила на жёсткость системы, распределение нагрузок и динамические процессы.
На основе упругой динамической модели системы «электродвигатель — зубчатый механизм — исполнительный орган» с использованием уравнений Лагранжа установлена связь между компоновкой передачи, приведённой жёсткостью и условиями возникновения резонансных режимов. Показано влияние крутильной податливости валов и консольного расположения элементов на вибрации и условия зацепления.
Обоснована целесообразность базирования центрального колеса и водила на подшипниках относительно корпуса, при котором вал выполняет преимущественно центрирующую функцию. Показано влияние такой схемы на динамические характеристики передачи.
Полученные зависимости могут быть использованы при проектировании планетарных редукторов приводов механизированной добычи нефти.
Ключевые слова: планетарный редуктор, компоновка, базирование, приведённая жёсткость, динамика, резонанс, крутильные колебания, мотор-редуктор.

TƏKAXINLI REDUKTOR İNNOVASİYALI PLANETAR ÖTÜRMƏ İLƏ

Vəli Fətəliyev[1], Toğrul Ələkbərli[2]
[1]Dosent, texnika üzrə fəlsəfə doktoru, “Mexanika” kafedrası, Azərbaycan Texniki Universiteti, Azərbaycan.
E-mail: veli.feteliyev@aztu.edu.az
[2]Neft-mexanika fakültəsi, magistrant, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan.
E-mail: togrul.alekberli@mail.ru

XÜLASƏ

Neft-qaz avadanlıqlarının ötürücü reduktorlarının konstruktiv xüsusiyyətləri, xüsusilə motor-reduktorların tərkibində planetar ötürmələrin kompono¬vka sxemləri baxımından araşdırılmışdır. Mərkəzi çarxın və vodilonun bazalaşdırma sxemlərinin sistemin sərtliyinə, yüklərin paylanmasına və dinamik proseslərə təsiri təhlil edilmişdir.
“Laqranj tənlikləri”ndən istifadə etməklə “elektrik mühərriki — dişli mexanizm — icraedici orqan” sisteminin elastik dinamik modeli əsasında ötürmənin kompono¬vkasının, gətirilmiş sərtliyin və rezonans rejimlərinin yaranma şərtlərinin qarşılıqlı əlaqəsi müəyyən edilmişdir. Valların burulma elastikliyinin və elementlərin konsol yerləşməsinin vibrasiyalara və dişlənmə şəraitinə təsiri göstərilmişdir.
Mərkəzi çarxın və vodilonun korpusa nəzərən podşipniklər üzərində bazalaşdırılmasının məqsədəuyğunluğu əsaslandırılmışdır; bu halda val əsasən mərkəzləşdirici funksiya yerinə yetirir. Belə sxemin ötürmənin dinamik xarakteristikalarına təsiri göstərilmişdir.
Alınmış asılılıqlardan mexanikləşdirilmiş neft hasilatı ötürücüləri üçün planetar reduktorların layihələndirilməsində istifadə oluna bilər.
Açar sözlər: planetar reduktor, komponovka, bazalaşdırma, gətirilmiş sərtlik, dinamika, rezonans, burulma rəqsləri, motor-reduktor.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

AIMS AND SCOPE

IRETC MTÜ The Baltic Scientific Journals publishes peer-reviewed, original research and review articles in an open access format. Accepted articles span the full extent of the social and behavioral sciences and the humanities.

IRETC MTÜ The Baltic Scientific Journals seeks to be the world's premier open access outlet for academic research. As such, unlike traditional journals, IRETC MTÜ The Baltic Scientific Journals does not limit content due to page budgets or thematic significance. Rather, IRETC MTÜ The Baltic Scientific Journals evaluates the scientific and research methods of each article for validity and accepts articles solely on the basis of the research. Likewise, by not restricting papers to a narrow discipline, IRETC MTÜ The Baltic Scientific Journals facilitates the discovery of the connections between papers, whether within or between disciplines.

IRETC MTÜ The Baltic Scientific Journals offers authors quick review and decision times; a continuous-publication format; and global distribution for their research via IRETC MTÜ The Baltic Scientific Journals Online. All articles are professionally copyedited and typeset to ensure quality.

Those who should submit to IRETC MTÜ The Baltic Scientific Journals include:

1. Authors who want their articles to receive quality reviews and efficient production, ensuring the quickest publication time.
2. Authors who want their articles to receive free, broad, and global distribution on a powerful, highly discoverable publishing platform.
3. Authors who want their articles branded and marketed by a world-leading social science publisher.
4. Authors who want or need their articles to be open access because of university or government mandates.

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

NGO International Research, Education & Training Center (Estonia, Tallinn) is publishing scientific papers of scientists on Website and in Referred Journals with subjects which are mentioned below:

ISSN: 2613-5817; E-ISSN: 2613-5825; UDC: 0 (0.034);
DOI PREFIX: 10.36962/PIRETC
Proceeding of The International Research Education & Training Center.
https://bsj.esif.net/index.php/piretc

ISSN: 2674-4562, E-ISSN: 2674-4597, UDC: 620.9 (051) (0.034);
DOI PREFIX: 10.36962/ENECO
Proceedings of Energy Economic Research Center. ENECO
https://bsj.esif.net/index.php/peerc

ISSN: 3059-8036 (Online); UDC: 62 (051) (0.034)
DOI PREFIX: 10.36962/PTEI
PTEI-Proceedings of Technical Engineering & Innovations
https://bsj.esif.net/index.php/ptei

ISSN: 2663-8770, E-ISSN: 2733-2055; UDC: 672, 673, 67.01-67.02
DOI PREFIX: 10.36962/ETM
ETM Equipment, Technologies, Materials
https://bsj.esif.net/index.php/etm

ISSN: 2733-2713; E-ISSN: 2733-2721; UDC: 33
DOI PREFIX: 10.36962/SWD
SOCIO WORLD-SOCIAL RESEARCH & BEHAVIORAL SCIENCES
https://bsj.esif.net/index.php/swd

E-ISSN: 2587-4713; UDC: 620.9 (051) (0.034)
DOI PREFIX: 10.36962/ECS
Economics
https://bsj.esif.net/index.php/ecs

Society of Azerbaijanis living in Georgia. NGO. (Georgia, Tbilisi) is publishing scientific papers of scientists on Website and in Referred Journals with subjects which are mentioned below:

ISSN: 2346-8068; E-ISSN: 2346-8181; UDC: 611-618
DOI PREFIX: 10.36962/ALISJMSC
Ambiance in Life-International Scientific Journal in Medicine of Southern Caucasus.
https://scsj.esif.net/index.php/ALISJMSC

Representation of the International Diaspora Center of Azerbaijan in Georgia. NGO (Georgia Tbilisi) is publishing scientific papers of scientists on Website and in Referred Journals with subjects which are mentioned below:

ISSN: 2298-0946, E-ISSN: 1987-6114; UDC: 3/k-144
DOI PREFIX: 10.36962/CESAJSC
The Caucasus-Economic and Social Analysis Journal of Southern Caucasus
https://scsj.esif.net/index.php/CESAJSC

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

Title of the Paper (14 point, Bold, Times New Roman)

First Author's Name[1], Second Author's Name[2] , Third Author's Name[3], …….
[1]Affiliation (Department, Faculty/College, Institution/University)
[2, 3]Affiliation of other authors, if different (Department, Faculty/College, Institution/University)
Corresponding author's email:
(Affiliation1,2,3 Times New Roman, 10)

Article Type: Refer to the section policy of journal for acceptable article types.

ABSTRACT
(Times New Roman, 12)
The manuscript should contain an abstract within 300 words. The manuscript should have a self-contained, citation-free abstract and state briefly the purpose of the research, methodology, key results and major conclusions. Abstract should be in a single paragraph with running sentences. Do not use any subheading or point list within the abstract. Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.
Keywords: Authors are advised to writes 3-5 keywords related to the article, separated by comma. These keywords will be used for indexing purpose.

Introduction (Times New Roman, 12)
Mostly Papers starts with introduction. It contains the brief idea of work, requirement for this research work, problem statement, and Authors contribution towards their research. Sufficient recent reference citation [1] from last 2 years should be included for showing the existing challenges and importance of current work. This section should be succinct, with no subheadings unless unavoidable [2, 3]. State the objectives of the work and provide an adequate background related to your work, avoiding a detailed literature survey or a summary of the results.

Research Methodology (Times New Roman, 12)
This part should contain sufficient detail to reproduce reported data. It can be divided into subsections if several methods are described. Methods already published should be indicated by a reference [4], only relevant modifications should be described. Methodology should be written concisely in detail by maintaining continuity of the texts.

Theory and Calculation (Times New Roman, 12)
A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis. Do not add extensive basic definitions or well-known theories, instead highlight theoretical background and its specific usages in view of your work only.

Mathematical Expressions and Symbols (Times New Roman, 12)

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

Mathematical expressions and symbols should be inserted using **equation tool** of Microsoft word. References may be added for used equations to support its authenticity, e.g. this result has been analysed using Fourier series [5].

$$f(x) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos \frac{n\pi x}{L} + b_n \sin \frac{n\pi x}{L} \right) \quad (1)$$

Results and Discussion (Times New Roman, 12)

This section may each be divided by subheadings or may be combined. A combined Results and Discussion section is often appropriate. This should explore the significance of the results of the work, don't repeat them. Avoid extensive citations and discussion of published literature only, instead discuss recent literature for comparing your work to highlight novelty of the work in view of recent development and challenges in the field.

Preparation of Figures and Tables (Times New Roman, 12)

Authors are supposed to embed all figures and tables at appropriate place within manuscript. Figures and tables should neither be submitted in separate files nor add at the end of manuscript. Figures and Tables should be numbered properly with descriptive title. Each Figure/Table must be explained within the text by referring to corresponding figure/table number. Any unexplained or unnumbered Figure/Table may cause rejection of the paper without being reviewed.

Formatting Tables (Times New Roman, 12)

Table should be prepare using table tool within the Microsoft word and cited consecutively in the text. Every table must have a descriptive title and if numerical measurements are given, the units should be included in the column heading. Formatting requirement has been summarized in the Table 1.

Table 1: Summary of formatting requirement for submitting paper in this journal.
(Times New Roman, 12)

Layout	**Size**	**Margin (Normal)**	Header	Footer	
Single column	A4 (8.27" X 11.69")	Top=1" Bottom=1" Left=1" Right=1"	Do not add anything in the header	So not add anything in the footer	
Font	**Article Title**	**Headings**	**Subheadings**	**Reference list**	**Text**
	Times New Roman, 16 pt, Bold, centred	Times New Roman, 11 pt, Bold, Left aligned	Times New Roman, 10 pt, Bold, Left aligned	Times New Roman, 8 pt, Justified	Garamond, 11 pt, Justified
Line Spacing	1.15	1.15	1.15	1.15	1.15
Page number	We will format and assign page numbers				

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL
VOLUME 33 (08) ISSUE 02 2026

(Times New Roman, 10)

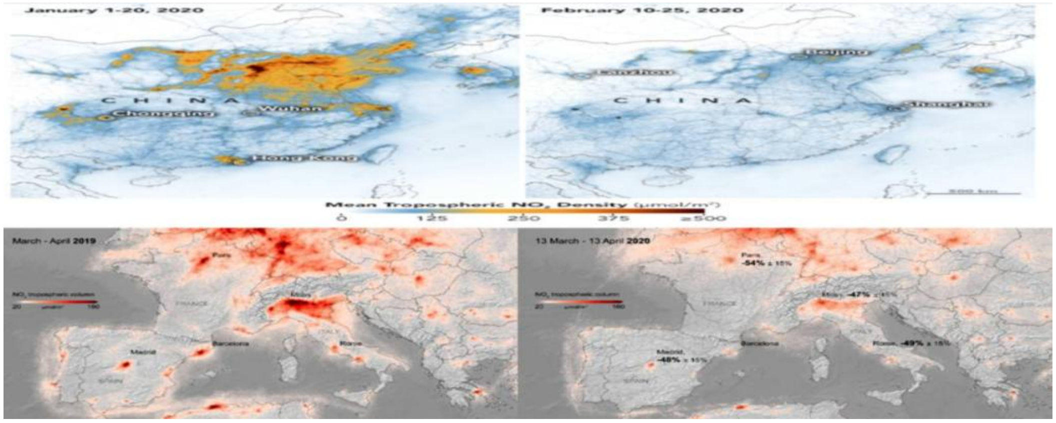


Figure 1: Logo of the AIJR Publisher (Times New Roman, 12)

Formatting Figures (Times New Roman, 12)
All figures should be cited in the paper in a consecutive order, author may be asked to provide separate files of the figure. Figures should be used in bitmap formats (TIFF, GIF, JPEG, etc.) with 300 dpi resolution at least unless the resolution is intentionally set to a lower level for scientific reasons. If a bitmap image has labels, the image and labels should be embedded in separate layer. Figure 1 shows the logo of AIJR Publisher.

Conclusions (Times New Roman, 12)
Each manuscript should contain a conclusion section within 250-450 words which may contain the major outcome of the work, highlighting its importance, limitation, relevance, application and recommendation. Conclusion should be written in continuous manner with running sentences which normally includes main outcome of the research work, its application, limitation and recommendation. Do not use any subheading, citation, references to other part of the manuscript, or point list within the conclusion.

Declarations (Times New Roman, 12)

Study Limitations (Times New Roman, 12)
Provide all possible limitation faced in the study which might significantly affect research outcome, If not applicable write, none.

Acknowledgements (Times New Roman, 12)
All acknowledgments (if any) should be included in a separate section before the references and may include list of peoples who contributed to the work in the manuscript but not listed in the author list.

Funding source (Times New Roman, 12)

Provide funding source, supporting grants with grant number. The name of funding agencies should be written in full, if no funding source exist, write, none.

Competing Interests (Times New Roman, 12)

Declare any potential conflict of interest exist in this publication.

Human and Animal Related Study (Times New Roman, 12)

If the work involves the use of human/animal subjects, each manuscript should contain the following subheadings under the declarations section-

Ethical Approval (Times New Roman, 12)

Provide ethical approval authority name with the reference number. If ethical approval is not required, provide an ethical exemption letter of not required. The author should send scan copy (in pdf) of the ethical approval/exemption letter obtained from IRB/ethical committee or institutional head.

Informed Consent (Times New Roman, 12)

Write a statement of informed consent taken from the participants to publish this research work. The editor may ask to upload scan copy if required.

References (Times New Roman, 12)

Author(s) are responsible for ensuring that the information in each reference is complete and accurate. **Do not use grey literature (unauthentic website, news portal, social media, Wikipedia etc) as reference, only scholarly literature (Journal, online books, proceedings, patents, authentic websites with permanent archival policy) are acceptable references.** Author should include sufficient recent (last 2 years) references in the article. All references must be numbered consecutively and citations of references in the text should be identified using numbers in square brackets (e.g., "as explained by AIJR [1]"; "as discussed in many reports [2]-[6]"). All references should be cited within the text correctly; do not add only list of references without citation within the text. All cited references should be listed after declarations section in the following style-

1. W. S. Author, "Title of paper," Name of Journal in italic, vol. x, no. x, pp. xxx-xxx, Abbrev. Month, year. https://doi.org/10.21467/ajgr
2. Bahishti, "Peer Review; Critical Process of a Scholarly Publication", J. Mod. Mater., vol. 2, no. 1, pp. 1.1-1.2, Oct. 2016. https://doi.org/10.21467/jmm.2.1.1.1-1.2
3. Bahishti, "A New Multidisciplinary Journal; International Annals of Science", Int. Ann. Sci., vol. 1, no. 1, pp. 1.1-1.2, Feb. 2017. https://journals.aijr.in/index.php/ias/article/view/163
4. W. S. Author, "Title of paper," Name of Journal in italic, vol. x, no. x, pp. xxx-xxx, Abbrev. Month, year. Access online on 20 March 2018 at https://www.aijr.in/journal-list/advanced-journal-graduate-research/
5. W. S. Author, "Title of paper," Name of Journal in italic, vol. x, no. x, pp. xxx-xxx, Abbrev. Month, year. Access online on 5 March 2018 at https://www.aijr.in/about/publication-ethics/
6. M. Ahmad, "Importance of Modeling and Simulation of Materials in Research", J. Mod. Sim. Mater., vol. 1, no. 1, pp. 1-2, Jan. 2018. DOI: https://doi.org/10.21467/jmsm.1.1.1-2

Main features of citation style are given as-

- The author name format is, "first name (Initial), middle name (Initial) and last name". This differs from other styles where author's last name is first.
- The title of an article (or chapter, conference paper, patent, etc.) is in quotation marks.
- The title of the book or journal is in italics.
- Online link of the original paper. If any reference is not available online, it should be modified with available online reference

Название статьи (14 пунктов, полужирный шрифт, Times New Roman)

Имя первого автора[1], Имя второго автора[2], Имя третьего автора[3], …….
(Times New Roman, 12)
[1]Принадлежность (кафедра, факультет/колледж, институт/университет)
[2,3]Аффилиация других авторов, если отличается (кафедра, факультет/колледж, институт/университет)
Электронная почта ответственного автора:
(Times New Roman, 10)
Тип статьи: Информацию о допустимых типах статей см. в политике раздела журнала.

АННОТАЦИЯ (Times New Roman, 12)

Рукопись должна содержать аннотацию в пределах 300 слов. Рукопись должна иметь самодостаточный реферат без цитирования и кратко излагать цель исследования, методологию, основные результаты и основные выводы. Аннотация должна быть в одном абзаце с предложениями. Не используйте подзаголовки или список точек в аннотации. Кроме того, следует избегать нестандартных или необычных сокращений, но, если они необходимы, они должны быть определены при их первом упоминании в самом реферате.
Ключевые слова: Авторам рекомендуется указывать 3-5 ключевых слов, относящихся к статье, через запятую. Эти ключевые слова будут использоваться для целей индексации.

Məqalənin adı (14 punkt, Qalın, Times New Roman)

Birinci Müəllifin Adı[1], İkinci Müəllifin Adı[2], Üçüncü Müəllifin Adı[3], (Times New Roman, 12)
[1]Afiliasiya (Departament, Fakültə/Kollec, Müəssisə/Universitet)
[2, 3]Əgər fərqlidirsə, digər müəlliflərin mənsubiyyəti (Departament, Fakültə/Kollec, Müəssisə/Universitet)
Cavabdeh müəllifin e-poçtu:
(Times New Roman, 10)
Məqalə növü: Məqbul məqalə növləri üçün jurnalın bölmə siyasətinə baxın.

XÜLASƏ (Times New Roman, 12)

Əlyazmada 300 sözdən ibarət abstrakt olmalıdır. Əlyazma öz məzmunlu, sitatsız bir referat olmalıdır və tədqiqatın məqsədini, metodologiyasını, əsas nəticələrini və əsas alınmış nəticələri qısa şəkildə ifadə etməlidir. Xülasə davam edən cümlələrlə bir paraqrafda olmalıdır. Xülasədə heç bir alt başlıq və ya nöqtələr siyahısından istifadə etməyin. Bundan əlavə, qeyri-standart və ya qeyri-adi abbreviaturalardan qaçmaq lazımdır, onlara ehtiyac olduqda, onlar xülasədə qeyd edilməklə yerləri təyin olunmalıdır.
Açar sözlər: Müəlliflərə məqaləyə aid 3-5 açar sözü vergüllə ayıraraq yazmaları tövsiyə olunur. Bu açar sözlər indeksləşdirmə məqsədilə istifadə olunacaq.

Complete Detail of Each Author
Provide complete detail of each author in the following format as well as add each author with complete detail during online submission (step 3) in the same order as appears in the manuscript.

First Author's Full Name: (Times New Roman, 12)
Highest Qualification:
Department:
Post/Rank (If a student, provide course name and course year):
Affiliation (College/University/Institute) with postal address:
email id:
ORCID:
Mobile:

Second Author's Full Name: (Times New Roman, 12)
Highest Qualification:
Department:
Post/Rank (If a student, provide course name and course year):
Affiliation (College/University/Institute) with postal address:
email id:
ORCID:
Mobile:

Third Author's Full Name: (Times New Roman, 12)
Highest Qualification:
Department:
Post/Rank (If a student, provide course name and course year):
Affiliation (College/University/Institute) with postal address:
email id:
ORCID:
Mobile:

ISSN: 2663-8770, E-ISSN: 2733-2055
ETM
REFERRED & REVIEWED JOURNAL

VOLUME 33 (08) ISSUE 02 2026

NOTES

JOURNAL INDEXING

ISSN: 2663-8770, E-ISSN: 2733-2055, DOI: 10.36962/ETM UDC: 62-44

©Publisher: IRETC. MTÜ (Estonia, Tallinn), R/C 80550594.
Director and Founder: Seyfulla İsayev (Azerbaijan).
Deputy and Founder: Namig Isazade. PhD in Business Administration. (Azerbaijan).
©Editorial office / Redaksiya: Harju maakond, Kesklinna linnaosa, Vesivärava tn 50-301, 10152, Tallinn, Estonia.
Telephones / Telefonlar: +994 55 241 70 12 (Whatsapp); +994 55 280 70 12.
Website/Veb səhifə: https://bsj.esif.net/; https://bsj.esif.net/index.php/etm
E-mail: sc.mediagroup2017@gmail.com

©Publisher: Azerbaijan State Oil and Industry University. I/C 1400196861 (Azerbaijan).
Rector: Rufat Azizov. PhD, Associate Professor.
Registered address: 20, Azadlig pr., Baku, Azerbaijan, AZ1010.
©Editorial office: 20, Azadlig pr., Baku, Azerbaijan, AZ1010.
©Typography: Azerbaijan State Oil and Industry University İ/C 1400196861 (Azerbaijan).
Registered address: 20, Azadlig pr., Baku, Azerbaijan, AZ 1010.

ISSN: 2663-8770, E-ISSN: 2733-2055, DOI: 10.36962/ETM

EQUIPMENT TECHNOLOGIES MATERIALS

AVADANLIQLAR, TEXNOLOGİYALAR, MATERİALLAR

VOLUME 33 (08) ISSUE 02 2026

CİLD 33 (08) BURAXILIŞ 02 2026









http://emtasoiu.com/index.php/en/archives

http://bsj.esif.net/index.php/etm

9 772663 877008