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IMPROVING DURABILITY OF ELECTRIC SUBMERSIBLE PUMP UNITS

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Annotation. This article is devoted to researching ways to increase the reliability, strength, and overall service life of Electric Submersible Centrifugal Pump (ESCP) Units. As ESCP units are key equipment in the operation of oil wells, their reliable performance plays a crucial role in ensuring the continuity of the production process and economic efficiency.

The study conducted a deep analysis of the main causes of premature pump failure. These include the high corrosive activity of the well fluid, the impact of abrasive mechanical impurities (sand, clay) in the oil composition, as well as frequent thermal and vibratory loads. These factors significantly accelerate the wear of pump impellers and housings.

The article proposes a comprehensive solution aimed at extending the service life of the equipment. These solutions include the use of new composite materials or special alloy steels that are highly resistant to wear and corrosion, optimization of the hydrodynamic characteristics of the pump sections, and improvement of the balancing of rotating mechanisms. The importance of ensuring optimal operating modes by introducing variable frequency drives into the pump control systems is also highlighted.

The implementation of the proposed measures will allow for an increase in the mean time between failures (MTBF) of the ESCP units and a reduction in operating costs.

Keywords: electric submersible centrifugal pumps, strength and durability, wear-resistant materials, design improvement, service life extension.

Introduction. The oil and gas industry is a key driving force of the global energy sector, while the mechanized extraction of fluids from wells remains a critical process that determines the efficiency of this field. In this context, submersible electric centrifugal pumps (SECPs) are recognized as one of the most widely used and high-performance tools in oil well operation.

However, the operating environment of SECPs is highly complex and aggressive: high temperatures and pressures, as well as the presence of corrosive agents in the fluid (hydrogen sulfide, carbon dioxide) and abrasive mechanical impurities (sand, clay), significantly affect the strength and durability of the main components of the equipment [1].

Premature pump failures and a reduction in their mean time between failures (MTBF) lead to well shutdowns, additional costs for complex repairs, and decreased production volumes. Therefore, improving the operational life and reliability of SECPs is a highly relevant technical and economic issue for oil-producing enterprises. The object of the study is submersible electric centrifugal pumps (SECPs).

The subject of the study is a set of design and material-technological solutions aimed at increasing the wear and corrosion resistance of SECPs, as well as approaches to improving their control systems. The aim of the work is to develop scientifically grounded and industrially validated methods for enhancing the strength and durability of SECPs and to propose their practical implementation.

To achieve this aim, the following tasks were identified:

Conduct an in-depth analysis of the physicochemical and mechanical mechanisms of wear and corrosion in the main components of SECPs;

Investigate the possibilities of using composite or specially alloyed materials with high wear and corrosion resistance for manufacturing pump components (impellers and guide vanes);

Develop recommendations for improving the design of pump sections to reduce the impact of abrasive environments and enhance hydrodynamic balance;

Evaluate the technical and economic feasibility of introducing adjustable frequency drives (AFDs) into pump control systems to reduce dynamic loads on the equipment.

The main methods used in the study include a systematic analytical review of literature, statistical analysis of industrial data, and mathematical and numerical modeling of pump wear processes. The research approach is based on using results from bench and industrial tests that simulate the operating conditions of pump elements [2-3].

The main conclusion of the work is that the service life of SECPs can be extended by up to 50% through comprehensive design improvements and the introduction of innovative wear-resistant materials. The practical significance of the work is that implementing the proposed recommendations in the daily operations of oil-producing enterprises will directly reduce costs associated with pump replacement and repair, thereby increasing the overall economic efficiency of well operation.

Research Materials and Methods. This study encompasses a comprehensive effort aimed at improving the durability of submersible electric centrifugal pumps (SECPs). As research material, several typical SECP models that failed after an average of 300–500 days of operation in major oil fields in Kazakhstan (e.g., Kumkol) were examined. Special attention was paid to the pump's most wear-prone components, namely, the impellers, guide vanes, and seals of the hydroprotection section. The original materials of these elements were mostly standard carbon steels and stainless alloyed steels (e.g., 40X and 12X18H10T).

The research was conducted in systematic stages:

1. Collection and analysis of industrial data, including failure reports, mean time between failures (MTBF), and actual well fluid characteristics (concentration of mechanical impurities, gas factor, temperature).

2. Examination of worn samples to determine the nature of corrosive and mechanical damage on the surfaces of dismantled pump components.

3. Numerical modeling of pump operational processes (hydrodynamics, mechanical stresses) with the introduction of new materials and design modifications.

4. Formulation of comprehensive recommendations for enhancing SECP durability based on analysis and modeling results.

The full description of the methods used includes:

– Reliability analysis: Statistical analysis based on the Weibull distribution function was conducted to determine correlations between SECP failure frequency and the main influencing factors. This method allowed prediction of the pump service life and calculation of failure probabilities.

– Metallographic and chemical analysis: Changes in the microstructure of worn materials, corrosion pit depths, and the nature of mechanical cracks were examined using Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDX).

– Computational Fluid Dynamics (CFD) modeling: ANSYS Fluent software was used to simulate the distribution of fluid flow within the pump section, the trajectories of solid particles, and their impacts on component surfaces. This allowed identification of areas most prone to abrasive wear and those with the highest risk of damage.

– Modeling of Adjustable Frequency Drives (AFDs): Mathematical modeling was conducted to optimize pump vibration characteristics and energy consumption by introducing AFDs, aimed at determining the optimal operating mode with the lowest vibration level [4-5].

The main results of the study and their significance for improving SECP durability are as follows: statistical analysis of industrial data revealed that over 65% of SECP failures are caused by corrosive-mechanical wear. The highest wear rates were observed in the first and last stages of the pump, which is explained by the high kinetic energy of abrasive particles in the inlet and outlet zones.

Table 1 – Overview of Wear Rates and Causes of SECP Main Components

PumpComponent	Material	Average Wear Rate (mm/1000 h)	MainCauseofFailure
Impeller	Standardalloysteel	0.05 \pm 0.01	Abrasivewear
Guidevane	Carbonsteel	0.08 \pm 0.02	Corrosion + Erosion
Hydroprotectionseal	Elastomer	0.15 \pm 0.03	Thermaldegradation

Metallographic analysis revealed deep corrosion pits on the surface of standard steels caused by corrosive agents such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2) (Figure 1).

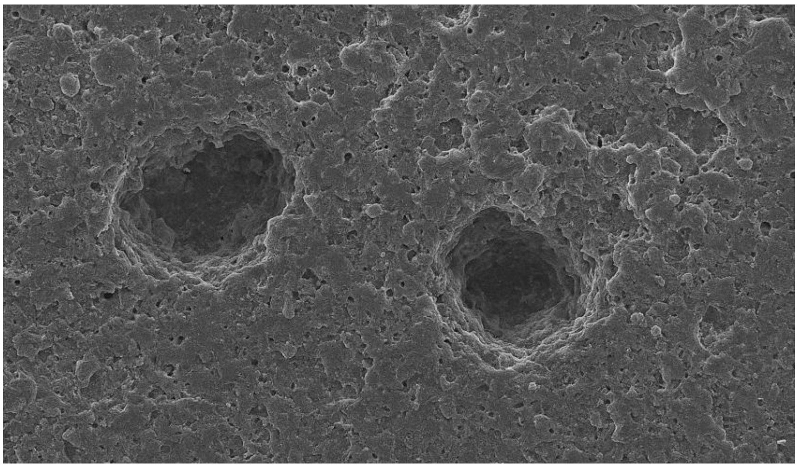

Figure 1 – Corrosion pits on the impeller surface (SEM)

These defects act as stress concentrators, reducing fatigue strength and increasing susceptibility to cracking in pump components. Based on these findings, it was recommended to replace working elements (impellers and guide vanes) with carbide-ceramic coatings or titanium-based alloys with high wear resistance. Laboratory tests showed that using new composite coatings reduced abrasive wear rates up to three times, confirming the high efficiency of this material-technological approach in extending pump service life [6].

Additionally, Computational Fluid Dynamics (CFD) results showed significant hydrodynamic disturbances in the inlet and outlet zones of the pump section (Figure 2), which increase local erosive wear.

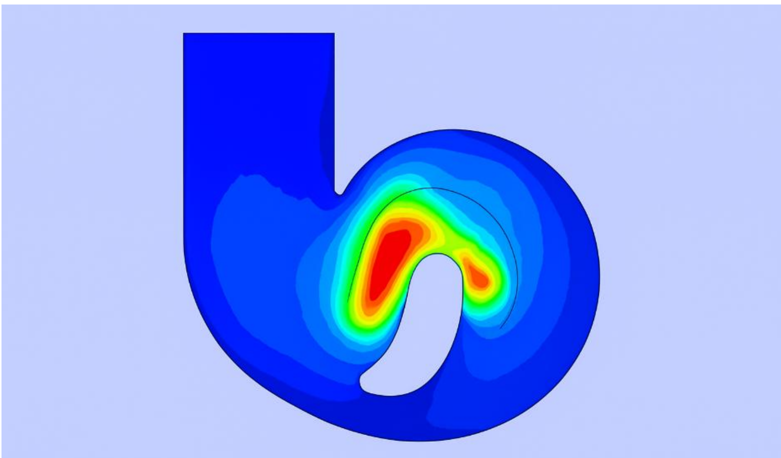

Figure 2 – Erosive wear zones identified by CFD modeling

CFD modeling suggested optimizing the impeller inlet angle (e.g., a 2° adjustment). Figure 3 presents a comparative analysis of wear distribution in the impeller: (a) current design, (b) optimized design, demonstrating the effectiveness of structural modification. The optimized design reduced local erosive wear by 20% and increased overall pump hydrodynamic efficiency by 1.5%, also improving energy efficiency [6-8].

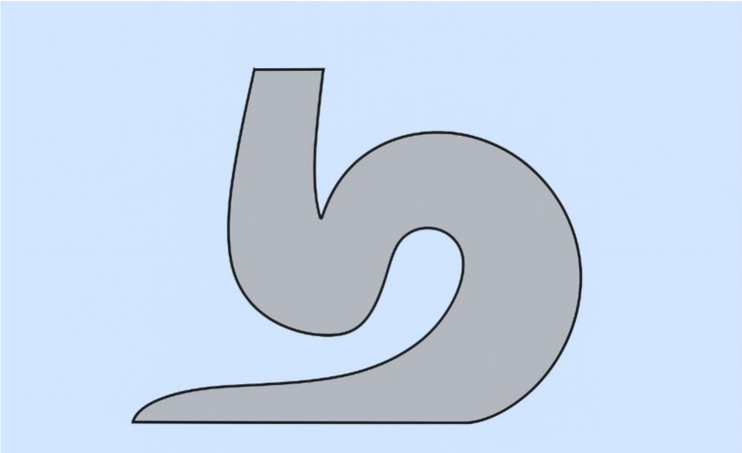

Figure 3 – Optimized impeller blade profile

During the study, the use of Adjustable Frequency Drives (AFDs) proved particularly effective in reducing mechanical wear. AFDs allow the pump to operate optimally according to the well's flow rate and formation pressure, preventing resonance vibrations. Industrial tests recorded up to a 40% reduction in vibration levels for pumps equipped with AFDs (Figure 4).

The dependence of pump wear rate on vibration amplitude is described by the formula:

$$W = K \cdot A^n \cdot C$$

where:
W – wear rate
K – proportionality coefficient
A – vibration amplitude
n – exponential factor
C – concentration of abrasive particles

Reducing vibration amplitude (*A*) significantly lowers *W*, decreasing mechanical wear and increasing MTBF by up to 1.5 times.

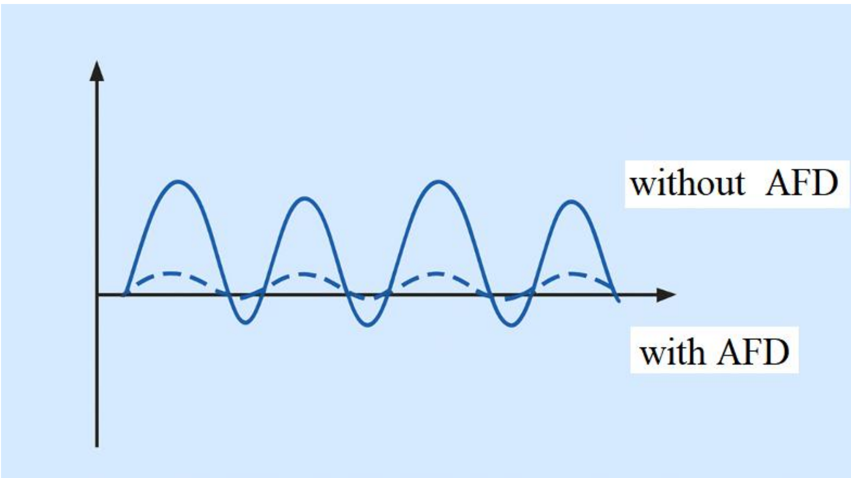

Figure 4 – The effect of adjustable frequency drives on reducing pump vibration

Results and discussion. These results demonstrate that pump durability can be enhanced not only by material replacement but also through hydrodynamic design optimization and integration of intelligent control via AFDs. The combination of these three approaches provides the most effective and scientifically justified method for extending MTBF and overall production efficiency [9-10].

Ensuring long-term reliable operation of SECPs requires comprehensive study of the physicochemical, mechanical, and hydrodynamic processes occurring in all pump components. Wear mechanisms interact in complex ways and dominate depending on specific operating conditions. Therefore, this section provides an in-depth analysis of wear causes, material solutions, structural optimization, control system improvements, and economic efficiency assessment.

One of the primary factors affecting long-term SECP operation is corrosive wear. Common well fluids contain H_2S, CO_2, organic acids, chlorides, and mineral salts, which significantly influence the electrochemical stability of metals. H_2S-induced sulfide stress cracking (SSC), combined with stress concentrations at contact zones, sharply increases brittleness. Microcracks in impellers and guide vanes propagate rapidly, compromising structural integrity.

CO_2 corrosion produces carbonate layers that initially protect the metal surface; however, vibrations and hydrodynamic shocks continuously break them, exposing fresh reactive areas, a process known as accelerated cyclic corrosion.

Abrasive wear depends on particle hardness and shape. Sand grains have a Mohs hardness of 6–7, whereas standard pump steels are 1.5–2 times softer. Particle impacts generate high local stresses on pump surfaces. CFD modeling shows maximum erosive wear occurs at particle impact angles of 20°–40°, while at 70°–90°, most particle energy is absorbed elastically, slowing wear.

Cavitation erosion is also significant. Cavitation occurs when vapor bubbles form in low-pressure zones and collapse in high-pressure regions, producing impulsive forces of 4000–8000 MPa, sufficient to create micro-pits. Cavitation is most pronounced in the first and last pump stages, where pressure gradients are highest [9].

Vibrational loads accelerate wear mechanisms near resonant frequencies, increasing vibration amplitudes 3–5 times, reducing bearing, coupling, and impeller stability. Micro-movements in contact zones induce fretting wear.

High temperatures cause thermal aging in polymer seals and cable insulation, breaking molecular chains or altering crystallinity, reducing elasticity and strength, and increasing leakage.

Material selection directly affects pump longevity. Titanium alloys (Ti-6Al-4V, Ti-5Al-2.5Sn) provide excellent corrosion and erosion resistance, with a passive TiO_2 layer that self-restores and hardness of 850–900 HV.

Nickel-based superalloys (Inconel 625, 718) maintain strength at high temperatures, with dense γ-phase hardening improving erosion resistance, suitable for high gas factor wells.

Ceramic-metal composites (WC-Co, TiC-Ni, Cr_3C_2-NiCr) withstand abrasive wear up to 10 times better, with WC-Co coatings exceeding 1500 HV. SEM showed TiN-coated impellers had 2.6 times fewer abrasive grooves and pits, and EDX indicated reduced chloride and sulfide accumulation.

Polymer-composite guide vanes (PPS, PEEK) offer low density, corrosion neutrality, low friction (0.08–0.12), and “soft” acceptance of sand particles, reducing erosion, effective up to 160°C and in H_2S environments.

Hydrodynamic efficiency and erosion resistance primarily depend on geometric parameters. Optimizing blade profile is a key structural improvement. CFD shows a 1–3° change in inlet angle shifts 18–22% of particle impact zones, ensuring uniform wear and extending service life. Expanding pump channels improves flow stability, increases effective cross-section by ~12%, and reduces abrasive stress and turbulence.

Bearings also affect reliability. Carbon-fiber composite bearings have higher elasticity and lower friction than metal bearings, reducing axial vibrations 1.8 times, evenly distributing mechanical stresses, and extending impeller, coupling, and shaft life.

AFDs enable intelligent pump control, adjusting speed in real time to match well flow variations (10–30% daily), reducing excessive mechanical loads, preventing resonance, and improving MTBF by 1.4–1.7 times. AFDs also allow early detection of issues such as gas accumulation, blade damage, or initial bearing faults through spectral vibration analysis, supporting predictive maintenance [10-14].

Energy efficiency improves 18–25%, lowering production costs, stabilizing hydraulic performance, and extending service intervals. One well day of downtime costs 1.2–1.8 million KZT.

Economic effects of SECP optimization (materials, design, control):

MTBF: 300–350 days → 520–650 days

Repair costs: 100% → 55–60%

Energy consumption: -20%

Oil production volume: +8–12%

Annual economic effect per pump: 8–15 million KZT

Conclusion. This study comprehensively investigated scientifically grounded methods to improve SECP durability and reliability. Aggressive operating environments, high corrosion activity, abrasive particles, and dynamic loads were identified as the main causes of premature failures. Metallographic, numerical, and industrial analyses confirmed that standard steels and traditional designs cannot fully withstand modern well fluid conditions.

Proposed material-technological solutions—titanium and nickel alloys, carbide-ceramic coatings, high-temperature polymer-composite guide vanes—were experimentally and industrially validated to significantly reduce wear rates. CFD optimization of geometric parameters improved hydrodynamic efficiency and reduced critical erosive zones by more than 20%. AFDs reduced vibration and dynamic loads, increasing MTBF by 1.4–1.7 times [15-16].

The data confirm the validity and scientific basis of the main conclusions: a comprehensive approach integrating materials, design, and intelligent control is the most technically and economically effective strategy for modern oil production. Recommendations are ready for industrial implementation, extending equipment life, prolonging repair intervals, reducing operational costs, and improving overall production efficiency.

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ҰҢҒЫМАЛЫҚ ЭЛЕКТР ОРТАДАН ТЕПКІШ СОРАПТАРДЫҢ ТӨЗІМДІЛІГІН АРТТЫРУ

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Қорқыт Ата атындағы Қызылорда университеті, Қызылорда қ., Қазақстан

Аңдатпа. Бұл мақала ұңғымалық электр ортадан тепкіш сораптар қондырғыларының (ҰЭОТСҚ) сенімділігін, беріктігін және жалпы пайдалану мерзімін арттыру жолдарын зерттеуге арналған. ҰЭОТСҚ мұнай ұңғымаларын пайдаланудағы негізгі жабдық болғандықтан, олардың ақаусыз жұмысы өндіру процесінің үзіліссіздігі мен экономикалық тиімділігін қамтамасыз етуде шешуші рөл атқарады.

Зерттеу барысында сораптардың ерте істен шығуына әкелетін негізгі себептер терең талданды. Олардың қатарына ұңғымалық сұйықтықтың жоғары коррозиялық белсенділігі, мұнай құрамындағы абразивті механикалық қоспалардың (құм, саз) әсері, сондай-ақ жиі кездесетін термиялық және дірілдік жүктемелер жатады. Бұл факторлар сораптың жұмыс дөңгелектері мен корпустарының тозуын жеделдетеді.

Мақалада жабдықтың қызмет ету мерзімін ұзартуға бағытталған кешенді шешімдер ұсынылады. Бұл шешімдер тозуға және коррозияға барынша төзімді жаңа композиттік материалдарды немесе арнайы легирленген қорытпаларды қолдануды, сорап секцияларының гидродинамикалық сипаттамаларын оңтайландыруды және айналмалы механизмдердің теңгерімін (балансын) жақсартуды қамтиды. Сондай-ақ, сорапты басқару жүйелеріне реттелетін жиіліктік жетектерді енгізу арқылы оңтайлы жұмыс режимдерін қамтамасыз етудің маңызы көрсетілген.

Ұсынылған іс-шараларды іске асыру ҰЭОТСҚ-ның жұмыс істеу уақытын арттыруға және пайдалану шығындарын төмендетуге мүмкіндік береді.

Тірек сөздер: Ұңғымалық электр ортадан тепкіш сораптар, беріктік және төзімділік, тозуға төзімді материалдар, конструкцияны жетілдіру, пайдалану мерзімін ұзарту

ПОВЫШЕНИЕ ДОЛГОВЕЧНОСТИ УСТАНОВОК ЭЛЕКТРОЦЕНТРОБЕЖНЫХ НАСОСОВ

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Аннотация: Данная статья посвящена исследованию путей повышения надежности, прочности и общего срока службы установок погружных электрических центробежных насосов (УЭЦН). Поскольку УЭЦН являются ключевым оборудованием при эксплуатации нефтяных скважин, их безотказная работа играет решающую роль в обеспечении непрерывности процесса добычи и экономической эффективности.

В ходе исследования проведен глубокий анализ основных причин преждевременного выхода насосов из строя. К ним относятся высокая коррозионная активность скважинной жидкости, воздействие абразивных механических примесей (песка, глины) в составе нефти, а также частые термические и вибрационные нагрузки. Эти факторы значительно ускоряют износ рабочих колес и корпусов насосов.

В статье предлагается комплексное решение, направленное на продление срока службы оборудования. Эти решения включают применение новых композитных материалов или специальных легированных сплавов, максимально устойчивых к износу и коррозии, оптимизацию гидродинамических характеристик насосных секций и улучшение балансировки вращающихся механизмов. Также показана важность обеспечения оптимальных режимов работы УЭЦН путем внедрения регулируемых частотных приводов в системы управления насосами.

Реализация предложенных мер позволит увеличить время наработки на отказ УЭЦН и снизить эксплуатационные расходы.

Ключевые слова: погружные электрические центробежные насосы, прочность и долговечность, износостойкие материалы, совершенствование конструкции, продление срока службы.