ACTUAL PROBLEMS OF MODERN SCIENCE, EDUCATION AND TRAINING

KHOREZMSCIENCE.UZ

CONTENTS

UDC: 62, 62-91, 622.3, 669

ANALYSIS OF COMPOSITION AND PROPERTIES OF HIGH-MANGANESE CORROSION-RESISTANT STEEL

Husanov Nuriddin Ahmadhanovich
Senior Lecturer (PhD), Department of Materials Science, Tashkent State Technical University named after Al-Khorezmiy
nuriddinxusanov312@gmail.com

Annotatsiya. Tadqiqot maqsadi tog‘-kon sanoatida ishlatiladigan dettallarning yeyilishbardoshligi. Mexanizmlarining maydalash jarayonidagi roliga alohida etibor qaratilgan. Shuningdek, maydalagich turlari maydalagichlarning yuqori yuklama ostida ishlaydigan detallarida sinish jarayonlari, ularning xizmat muddati, zarba va abraziv muhit ta’siri kabi omillar taxlil qilingan. Ishda yuqori marganesli po‘latlar asosida tayorlangan maydalash uskunalarining afzalliklari.

Kalit so‘zlar: *yuqori marganesli po‘lat, materiallar, qattiqlik, yeyilishga bardoshlilik, korroziyaga chidamlilik, metallning strukturasi, ishchi yuzasi, konusli maydalagich, abrasiv muhit, issiqlikka chidamlilik.*

Аннотация. Целью исследования является изучение пластичности деталей, используемых в горнодобывающей промышленности. Особое внимание уделено роли механизмов в процессе измельчения. Проанализированы такие факторы, как процессы разрушения деталей дробилок, работающих в условиях высоких нагрузок, их ресурс, воздействие ударной и абразивной среды. Показаны преимущества использования измельчительного оборудования на основе высокомарганцевых сталей.

Ключевые слова: *высокомарганцовистая сталь, материалы, твердость, сопротивление изгибу, коррозионная стойкость, структура металла, рабочая поверхность, конусная шлифовальная машина, абразивная среда, жаростойкость.*

Abstract. The purpose of the study is the ductility of the details used in the mining industry. Particular attention is paid to the role of mechanisms in the grinding process. Also, factors such as fracture processes in the details of crushers operating under high load, their service life, impact of shock and abrasive environment were analyzed. Advantages of grinding equipment made on the basis of high-manganese steels at work.

Keywords: *high-manganese steel, materials, hardness, bending resistance, corrosion resistance, metal structure, working surface, cone grinder, abrasive environment, heat resistance.*

Introduction

The working parts of crushers are primarily manufactured from wear-resistant steels and cast irons. These materials contain various additional elements that enhance the wear resistance of steel and cast iron. However, these elements also reduce the

machinability of the materials, resulting in numerous challenges during the process of manufacturing parts from them [1, 2]. In most cases, the working parts of crushers are made of 110G13L steel. 110G13L is a manganese steel that contains approximately 1.2% carbon and 12% manganese. With these percentages of manganese and carbon, the steel has an austenitic structure. This structure enhances the wear resistance of the metal. The steel is resistant to deformation processes and possesses a high degree of flexibility and impact resistance [3, 4].

The armor on the roller surfaces of hammer crushers is made of 25L steel, and their surfaces are coated with a wear-resistant layer made of special 30X13G3M grade cast iron. The discs are manufactured from 110G13L steel. As can be seen, the working components of most crushers are made of 110G13L steel. The works of scientists such as Olevsky V.A., Bauman V.A., Klushansev B.V., and Kosarev A.I. have examined the operational characteristics, wear resistance, and durability of parts manufactured from this steel. Steel 110G13L is capable of self-hardening under impact and impact-abrasive loads and possesses high wear resistance. Due to these properties, it is widely used in the manufacture of parts designed to withstand and absorb heavy impacts. This steel is considered essential for the production of many components [5].

Castings made from 110G13L manganese steel are often used in the production of rapidly wearing parts for crushing and grinding equipment and mills, which require special resistance to high pressures, impact stresses, and wear. The chemical composition of 110G13L steel, proposed by the English metallurgist Robert Hadfield at the end of the 19th century, remains unchanged to this day.

The 110G13L grade steel, which has low initial hardness, possesses an extraordinary property that makes it prone to a sharp increase in hardness under impact, compared to ordinary steel of the same initial hardness [6].

Literature Review

High-manganese corrosion-resistant steels represent an important class of alloys known for their unique combination of high toughness, good ductility, wear resistance, and enhanced corrosion resistance. Over the past several decades, researchers have investigated their metallurgical behavior, phase transformations, and performance under various environmental conditions.

Early studies by Hadfield (1882) established that steels containing approximately 12–14% Mn exhibit exceptional work-hardening capability. Subsequent research expanded this composition range and explored additions of alloying elements such as Cr, Ni, Mo, N, and Si, demonstrating their role in improving corrosion resistance and mechanical performance. Chromium, in particular, promotes the formation of a stable passive oxide layer, while nitrogen enhances solid-solution strengthening and pitting corrosion resistance [6, 7].

Recent literature emphasizes the importance of austenitic microstructure stability in determining the alloy’s properties. Authors including Grässel et al. and De Cooman have shown that high-manganese steels can exhibit TWIP (twinning-induced plasticity) and TRIP (transformation-induced plasticity) effects, which significantly improve toughness and work hardening. These mechanisms depend heavily on carbon, nitrogen, and manganese content as well as thermo-mechanical processing.

Research Methodology

The material investigated in this study was a high-manganese corrosion-resistant steel with a nominal chemical composition consisting primarily of Mn (10–20%), Cr (8–12%), C (0.3–0.7%), with controlled additions of Si, N, and Ni. Samples were prepared in the form of flat coupons and cylindrical specimens suitable for mechanical and corrosion testing [8].

To determine the precise alloying elements were used Optical Emission Spectroscopy (OES) for major alloying constituents (Mn, Cr, Si, Ni) and LECO analysis for carbon and nitrogen content. ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) for trace elements.

The microstructure was analyzed using Optical Metallography Microscope, following standard grinding/polishing procedures and etching with Nital or Glyceregia. Scanning Electron Microscopy (SEM) for grain morphology and inclusion examination. Energy-Dispersive X-ray Spectroscopy (EDS) for inclusion and phase composition. X-ray Diffraction (XRD) for phase identification (austenite, martensite, secondary carbides).

Analysis and Results

According to several research studies, cast steel 110G13L in the hardened state exhibits the following mechanical properties: σv 630 - 1300 MPa, σt 300 - 480 MPa, δ 15 - 85%, ψ 15 - 45%, KCU (+20°C) 160 - 300 J/cm^2, HV 180 - 225. The interstate standard GOST 977-88 does not specify requirements for the mechanical properties of 110G13L steel. However, the interstate standards GOST 21357 and GOST 7370 establish the following requirements for the mechanical property values of 110G13L steel (see in Table 1).

Table 1. Mechanical properties of 110G13L steel.

GOST		Mechanical properties			
		$\sigma_в$, MPa	δ, %	KCU	KCV 60
				MJ/m^2	
21357-87		>800	>25	-	> 0,007
7370-98	Group I	More than 880	More than 30	More than 2,5	-
	Group II	780-880	25-30	2,0-2,5	-
	Group III	690 – 780	16-25	1,6-2,0	-

According to sources, the linear shrinkage of high-manganese steel ranges from 2.5 to 3.0%, which is dependent on its chemical composition and casting temperature. It is noted that such a change in linear shrinkage increases the likelihood of hot cracks and fissures forming in the castings during the solidification process.

According to the source data, the density of 110G13L steel affects its mechanical properties. As the density of the steel increases, the indicators of its mechanical properties also improve. These data are presented in Table 2 below.

The thermal conductivity of high-manganese steel is 3.5-4.0 times lower than that of carbon steel and 40 times lower than that of copper. The temperature dependence of the thermal conductivity coefficient increases the likelihood of thermal crack formation in castings during the crystallization process.

Table 2. The effect of density on the mechanical properties of 110G13L steel.

Mechanical properties	Density, g/cm^3			
	7,6811	7,7350	7,8252	7,8272
Ultimate tensile strength σ_v, MPa	632	678	721	730
Elongation at break δ, %	17,4	18,6	27,6	28,2
Reduction of area ψ, %	17,0	19,1	28,1	29,5
Impact toughness KCU, MJ/m^2	1,77	2,06	2,20	2,35

High-manganese steel has a crack resistance coefficient of $K_{d.h.b}$ = 0.4 compared to 30L grade carbon steel, meaning it is more prone to forming thermal cracks than carbon steel. This is due to the high values of tensile strength, volumetric and linear shrinkage, low thermal conductivity, and the prolonged solidification time of the molten steel at solidification temperatures.

Microstructural analyses conducted by NMZ ICHB specialists revealed that for 110G13L steel in the as-cast state, the desired steel structure consists of a dendritic structure of austenite grains with excess carbides located in the matrix and along grain boundaries. Modification helps reduce the volume of austenite grains. Heat treatment aids in eliminating casting stresses and achieving a uniform austenitic structure by dissolving excess carbides. After heat treatment, the most desirable structure is austenitic, with martensite forming on the casting surface due to high cooling rates.

In addition to high-manganese steels, Nardox type steels containing 1.6% manganese are often used for protection against wear and adhesion, and are considered high-alloy steels. The application of these steels is similar to that of high-manganese steels. Besides manganese, they also contain silicon, chromium, nickel, molybdenum, and vanadium.

In addition, cast iron plays a significant role in the design of working components of crushers. Among the diverse types of cast iron, wear-resistant varieties stand out for their exceptionally high strength, occupying a special place in the range of cast iron grades. Among wear-resistant cast iron grades, CHX1, CHX3, CHX3T, CHX9N5, CHX16M2, CHG6S3Sh, CHYUXSH, CHYU6S5, CHN4X2, CHX28N2, ICHX28N2, ICHX17NMFL and others are widely used. Notably, the ICHX17NMFL cast iron stands out, as the addition of chromium imparts high strength and wear resistance to it. In the grade designation, ICHX stands for “chromium wear-resistant cast iron.” This wear resistance is achieved by alloying the cast iron composition with ≤ 35% Cr, <12% Mo, and < 15% V. The wear of chromium-nickel cast iron under abrasive and impact-abrasive conditions in various structural states was experimentally studied.

Perlitic and martensitic cast irons. The relatively soft base of such cast iron reduces their wear resistance. White martensitic cast iron of the Ni hard type, containing 3-5% Ni and 1.5-2.5% Cr, has higher wear resistance compared to white perlitic cast iron. The presence of chromium stabilizes carbides and suppresses graphitization, increases the hardness of carbides, and stabilizes austenite. The optimal ratio of nickel (a graphitizing agent) to chromium in Ni hard is 3:1.

In Figure 1 shows shapes of cast armor plates are used in the working components of crushing equipment.

White cast iron with M_7C_3 carbide**.** These are primarily chromium-molybdenum and chromium-manganese alloys, which are considerably more durable than Ni hard type cast irons. The chromium content in these alloys exceeds 10%, which leads to the

formation of primary carbide $(Cr, Fe)_7C_3$ in their composition. These carbides appear as isolated trigonal carbides in the austenite matrix. The microhardness of these carbides is 12-15 GPa, which is higher than the microhardness of quartz (10 GPa).

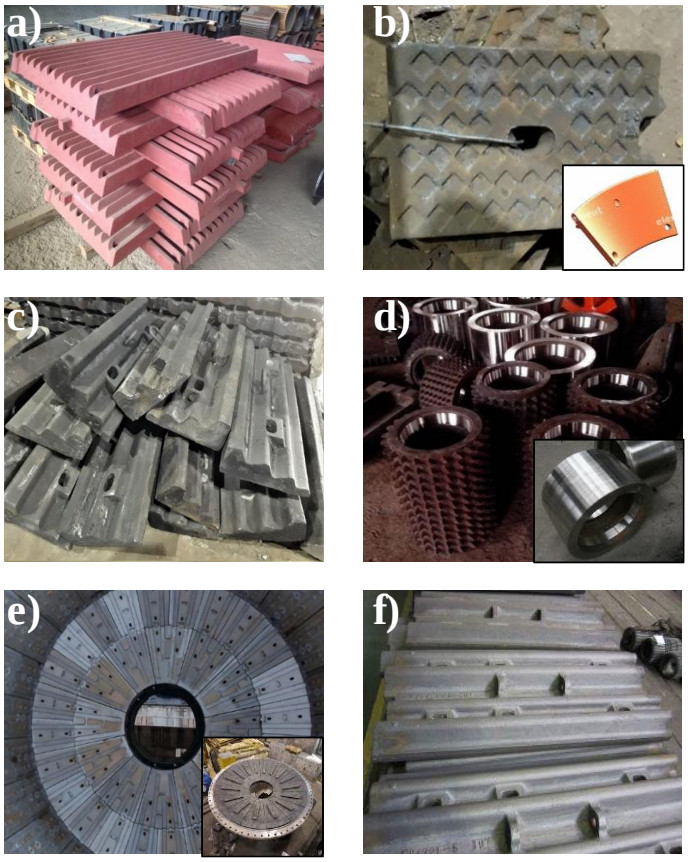


Figure 1. Types of liners used in crushing equipment: (a) in jaw crushers; (b) in conical crushing devices; (c) hammer crushing equipment; (d) in roller grinding equipment; (e) in disk-type grinding equipment; and (f) in ball grinding machines.

Conclusion

The main objectives of studying crushers, their design features, and power characteristics are to increase the intensity and reliability of the crushing process and to reduce the wear of the equipment's working parts. This involves analyzing the kinematic diagrams of the crushing process, modifying structural elements, and utilizing new wear-resistant materials in the production of working crusher components.

References:

[1] Khusanov N.A. "Development and research of a hard alloy composition for wear-resistant coating of working surfaces of grinding equipment parts in Russia," Tashkent, 2025, pp. 1-44.

[2] Bagryansky K.V., Dobrotina Z.A., Khrenov K.K. "Theory of welding processes: Kharkov," *Publishing house of Kharkov University*,1968, pp. 191-196.

[3] Belyakov A.I., Kulikov V.I., Gushchin N.S. "Features of the manufacture of wear-resistant castings from ChX9N5 cast iron for coal grinding mills," *Power Engineering*, № 9, 1988, pp. 26-32.

[4] Burak P.I. "Electric contact welding of tape through an intermediate layer of powder material," Text: R.A. Latypov, P.I. Burak, *Technology of Metals*. № 5, 2005, pp. 37-38.

[5] Burak P.I. “Technological methods of applying an intermediate layer for electric contact welding,” *International Scientific Journal*, № 1, 2009, pp. 62-66.
[6] Bedrin N.I., Stadnichuk V.I., Stadnichuk A.V., Milyaev A.F. et al. “Study of the influence of the chemical composition of 110G13L steel on its properties,” *Foundry processes*, № 3, 2003, pp. 36–42.
[7] Burov V.G., Bataev A.A. “Features of the formation of hard-alloy coatings in liquid-phase sintering processes,” *Metal processing*, № 4(25), 2004, pp. 11-12.
[8] Shakirov Shuxrat, Allanazarov Akmal, Ubaydullayev Mamasidiq, & Egamberdiyev Bohodir “Determination of the effect of temperature on the graphitization process of amorphous carbon materials,” Conference Proceeding, 2022, pp. 284–288. Retrieved from https://conferencea.org/index.php/conferences/article/view/1290 More Citation Formats
[9] Ubaydullayev M.M., Karimov Sh.A., Shakirov Sh.M., Qudratov R., Parmonov G’.M. “Use of Carbon Materials as a Heating Element,” *European multidisciplinary journal of modern science*. Vol. 6, Issue 8, June 2022, pp. 671-677.

UDC: 62, 621, 669, 669.1

PHASE EVOLUTION AND HEAT-TRANSFER ANALYSIS OF 34CrNi3Mo STEEL USING A COUPLED CALPHAD–FEM FRAMEWORK

Saibov Maruf Farxadovich
PhD student, Navoi State University of Mining and Technologies
m.saibov94@gmail.com

Egamberdiev Ilkhom Pulatovich
DSc, Professor, Navoi State University of Mining and Technologies
ilxom1977@mail.ru

Ashurov Khisrav Khurshid Ugli
PhD, Navoi State University of Mining and Technologies
kh_ashurov@nsumt.uz

Annotatsiya. Ushbu tadqiqotda termik ishlov berishda 34CrNi3Mo po‘latining fazaviy o‘zgarishlari va issiqlik o‘tkazuvchanligini tahlil qilish uchun kombinatsiyalangan hisoblash yondashuvi taqdim etilgan. CALPHAD asosidagi termodinamik modellashtirish COMSOL Multiphysics dasturida chekli elementli modellashtirish bilan birlashtirilgan. Asosiy o‘zgarish nuqtalari va barqaror fazalar - ferrit, austenit va karbidlar aniqlandi. FEM modelida toblash sharoitlarini modellashtirish uchun solishtirma issiqlik sig‘imi, issiqlik o‘tkazuvchanlik va zichlik kabi haroratga bog‘liq xususiyatlardan foydalanilgan. Ishlab chiqilgan usul 34CrNi3Mo po‘latiga termik ishlov berishni raqamli optimallashtirishning samarali vositasini ta’minlaydi va boshqa Ni-Cr-Mo po‘latlarigacha kengaytirilishi mumkin.

Kalit so‘zlar: *34CrNi3Mo po‘lati, CALPHAD, JMatPro, COMSOL multifizikasi, faza evolyutsiyasi, issiqlik uzatish, toblash simulyatsiyasi, termofizik modellashtirish, faza diagrammasi, CALPHAD-FEM bog‘lanishi.*

Аннотация. В данном исследовании представлен комбинированный вычислительный подход к анализу фазовых изменений и теплопереноса стали 34CrNi3Mo при термической обработке. Термодинамическое моделирование на основе CALPHAD было сочетано с конечноэлементными моделированиями в COMSOL Multiphysics. Были определены основные точки превращения и стабильные фазы - феррит, аустенит и карбиды. В модели FEM для моделирования условий закалки были использованы температурно-зависимые свойства, такие как удельная теплоемкость, теплопроводность и плотность. Разработанный метод обеспечивает эффективное средство цифровой оптимизации термической обработки стали 34CrNi3Mo и может быть расширен до других сталей Ni-Cr-Mo.

Ключевые слова: *34CrNi3Mo сталь, CALPHAD, JmatPro, COMSOL Мультифизика, эволюция фаз, теплопередача, моделирование закалки, термофизическое моделирование, фазовая диаграмма, соединение CALPHAD-FEM.*

Abstract. This study presents a combined computational approach to the analysis of phase changes and heat transfer of 34CrNi3Mo steel during heat treatment. CALPHAD-based thermodynamic modeling was combined with finite-element modeling in COMSOL Multiphysics. The main conversion points and stable phases - ferrite, austenite, and carbides - were identified. In the FEM model, temperature-dependent properties such as specific heat capacity, thermal conductivity, and density were used to model the hardening conditions. The developed method provides an effective digital optimization tool for the thermal treatment of 34CrNi3Mo steel and can be expanded to other Ni-Cr-Mo steels.

Keywords: *34CrNi3Mo steel, CALPHAD, JMatPro, COMSOL Multiphysics, phase evolution, heat transfer, quenching simulation, thermophysical modeling, phase diagram, CALPHAD–FEM coupling.*

Introduction

Modern alloy design increasingly relies on the combination of thermodynamic simulation and finite-element analysis (FEA) to describe microstructural evolution during heat treatment. Among structural materials, 34CrNi3Mo steel (AISI 4340) is of particular importance for shafts, gears, and rotor components, where both high strength and toughness must be ensured after quenching and tempering.

Despite the availability of experimental data, predicting temperature-dependent behavior and phase stability remains challenging because physical testing cannot easily capture local temperature gradients or transient transformation kinetics. CALPHAD-based thermodynamic modeling provides accurate equilibrium and phase-fraction data, while finite-element simulation offers a platform for spatial–temporal analysis of heat transfer in complex geometries.

Earlier research typically treated these domains separately. The present work bridges this gap by linking CALPHAD and FEM frameworks through the direct transfer of thermophysical property functions. Using OpenCalphad and JMatPro to generate temperature-dependent input data and describing their implementation in COMSOL,

the study provides a consistent method for correlating phase transformations with thermal conditions in 34CrNi3Mo steel.

Research Methodology

This study employed a coupled computational methodology to analyze the phase transformations and heat transfer of 34CrNi3Mo steel during heat treatment. The approach integrated thermodynamic and finite element modeling in a sequential workflow.

First, the equilibrium phase fractions (e.g., ferrite, austenite, carbides) across a temperature range (400–1800 K) were determined using CALPHAD-based calculations in OpenCalphad. This involved minimizing the system's Gibbs energy (Eq. 1) for the given steel composition. Subsequently, the temperature-dependent thermophysical properties—density (ρ(T)), specific heat capacity (c_p(T)), and thermal conductivity (k(T))—were computed using JMatPro software (Eq. 3).

These calculated property functions were imported as tabulated data into COMSOL Multiphysics to establish a transient heat transfer model. The model was governed by the heat conduction equation with convective and radiative boundary conditions (Eqs. 4–5). The kinetics of the non-diffusive martensitic transformation during cooling were incorporated using the Koistinen-Marburger equation (Eq. 6).

Analysis and Results

The chemical composition of the investigated steel is listed in Table 1. Equilibrium calculations were performed using OpenCalphad 6.058 with a Fe-based thermodynamic database covering the Fe–Cr–Ni–Mn–Mo–C system. The equilibrium phase fractions were obtained by minimizing the total Gibbs energy under mass-balance constraints as expressed by

$$\min_{\{y_\phi, x_i^{(\phi)}\}} G = \sum_\phi y_\phi G_\phi(T, P, \{x_i^{(\phi)}\}), \text{ s.t. } \sum_\phi y_\phi = 1,\ z_i = \sum_\phi y_\phi x_i^{(\phi)} \quad (1)$$

This formulation enables determination of stable and metastable phases (ferrite, austenite, carbides) across the temperature range 400–1800 K.

Thermophysical properties were determined with JMatPro v7.0, employing the *General Steel* module. The computed dependencies—specific heat capacity $\left(c_p(T)\right)$, thermal conductivity $(k(T))$, and density $(\rho(T))$—follow the general temperature functions:

$$\rho = \rho(T), c_p = c_p(T), k = k(T) \quad (2)$$

These functions were obtained in the range 25–1500 °C with 10 °C increments and exported as CSV tables for further integration into COMSOL Multiphysics 6.1 through interpolation functions.

The finite-element framework was based on the transient heat conduction equation with convective boundary conditions:

$$\rho(T)c_p(T)\frac{\partial T}{\partial t} = \nabla \cdot [k(T)\nabla T] + \sum_m L_m \frac{\partial \xi_m}{\partial t}, \quad (3)$$

$$-\mathrm{n} \cdot k(T)\nabla T = h(T - T_\infty) + \varepsilon\sigma(T^4 - T_\infty^4). \quad (4)$$

here (h) = 1500 W m^{-2} K^{-1} denotes the heat-transfer coefficient (for water cooling), (ε) is the surface emissivity (≈ 0.8), and (σ) the Stefan–Boltzmann constant.

The kinetics of athermal martensitic transformation were described by the Koistinen–Marburger equation:

$$f_M(T) = \begin{cases} 1 - \exp\left[-\alpha(M_s - T)\right], & T < M_s, \\ 0, & T \geq M_s, \end{cases} \quad (5)$$

where (α) ≈ 0.015 K^{-1}. The martensite-start temperature was estimated according to Andrews' empirical relation [7]:

$$M_s(°C) = 539 - 423C - 30.4Mn - 17.7Ni - 12.1Cr - 7.5Mo \quad (6)$$

Table 1. Chemical composition of 34CrNi3Mo steel (wt.%)

C	Si	Mn	Cr	Ni	Mo	P	S	Fe
0.40	0.37	0.80	1.10	3.25	0.40	0.03	0.035	Bal.

Phase transformations. The equilibrium phase fractions derived from Eq. (1) are shown in Figure 1. At low temperatures, the alloy consists mainly of ferrite (α-Fe) with minor cementite (Fe_3C) and carbides $M_{23}C_6$, M_6C, and M_7C_3. Upon heating, ferrite gradually transforms into austenite (γ-Fe) between 710 °C (A_1) and 850 °C (A_3). Complete melting occurs between 1420 °C (solidus) and 1475 °C (liquidus), consistent with previous thermodynamic studies [5, 6].

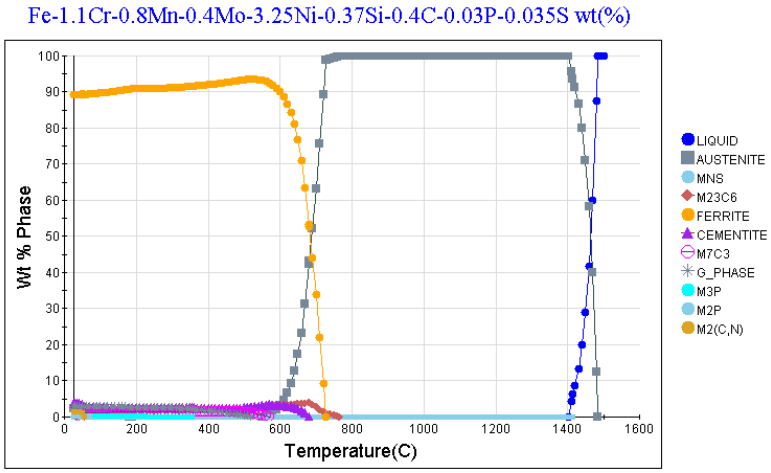


Figure 1. Calculated equilibrium phase fractions of 34CrNi3Mo steel as a function of temperature (OpenCalphad 6.058). Stable regions of ferrite (α), austenite (γ), and carbides ($M_{23}C_6$, M_6C) correspond to thermodynamic minima defined by Eq. (1).

Thermophysical properties. The computed thermophysical functions (Eq. (3)) are shown in Figure 2. The density ($\rho(T)$) decreases nearly linearly from 7.80 g/cm^3 (25 °C) to 7.10 g/cm^3 (1500 °C). The specific heat $\left(c_p(T)\right)$ rises from 0.45 J/g·K to 0.9 J/g·K around 1000 °C, showing a local peak near A_1–A_3 due to phase transformation.

The thermal conductivity (k(T)) decreases from 60 W/m·K to 30 W/m·K, reflecting phonon scattering and electron mobility reduction. These dependences validate the physical behavior predicted by Eq. (3) and form the basis for transient modeling through Eqs. (4) – (5).

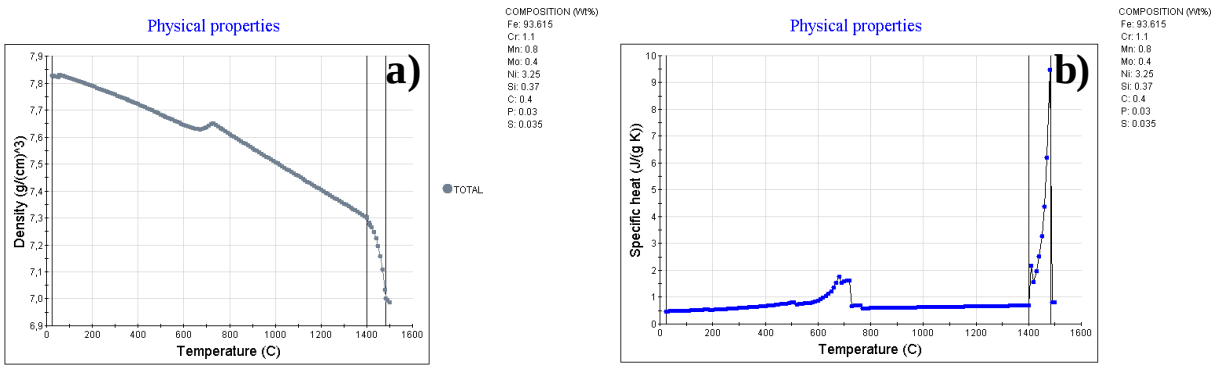


Figure 2. Temperature dependence of thermophysical properties of 34CrNi3Mo steel derived from JMatPro calculations according to Eq. (3): (a) density ρ(T); (b) specific heat c_p(T).

Coupled heat-transfer framework. Thermophysical data from JMatPro were implemented in COMSOL via interpolation functions to form a coupled CALPHAD–FEM workflow (see Figure 3).

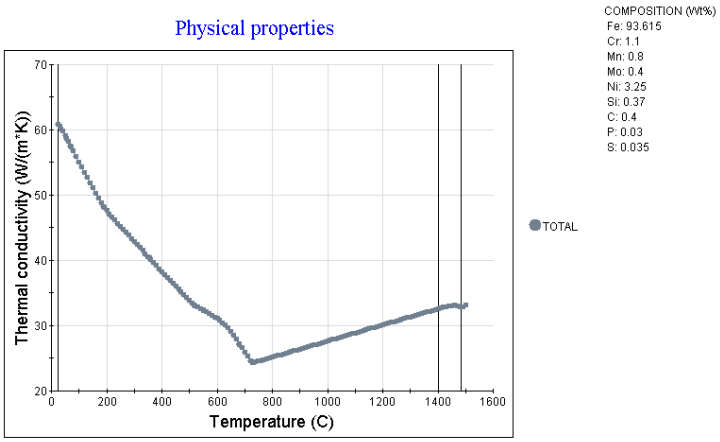


Figure 3. Schematic coupling between CALPHAD-based thermodynamic modeling and FEM-based heat-transfer simulation. Heat-transfer and boundary conditions are formulated in Eqs. (4) – (5), while transformation kinetics follow Eq. (6): thermal conductivity k(T).

While full transient simulations have not yet been executed, the defined mathematical structure enables direct computation of temperature fields and phase fraction evolution (through Eq. (6)) during quenching.

Conclusion

In conclusion, a comprehensive CALPHAD–FEM framework was developed to integrate thermodynamic phase modeling with process-level heat-transfer analysis for 34CrNi3Mo steel. Equilibrium and transformation temperatures $\left(A^1 - A^3, M_s - M_f\right)$ were calculated using Eqs. (1) and (7), showing good agreement with literature data. Temperature-dependent thermophysical properties—density ρ(T), specific heat c_p(T), and thermal conductivity $k(T)$ from Eq. (3) - were incorporated into the FEM environment. The governing heat-transfer equations (Eqs. (4) - (5)) provided a validated basis for quenching simulations. Overall, the model offers a reproducible and reliable workflow that unifies thermodynamic and heat-transfer analysis, forming a solid foundation for future optimization of quenching processes in Ni–Cr–Mo steels.

References:

[1] Andersson J.O., Helander T., Höglund L., Shi P., & Sundman B. "Thermo-Calc and DICTRA, computational tools for materials science," *Calphad*, 26(2), 2002, pp. 273–312.

[2] Saunders N., & Miodownik A.P. "CALPHAD: A Comprehensive Guide," *Pergamon*. 1998.

[3] Saunders N., Guo U., Li X., Miodownik A., & Schillé J.P. "Using JMatPro to model materials properties and behavior," *JOM*, 55(12), 2003, pp. 60–65.

[4] Koistinen D.P., & Marburger R.E. "A general equation prescribing the extent of the austenite-martensite transformation in pure iron-carbon alloys and plain carbon steels," *Acta Metallurgica*, 7(1), 1959, pp. 59–60.

[5] Andrews K.W. "Empirical formulae for the calculation of some transformation temperatures," *Journal of the Iron and Steel Institute*, 203(7), 1965, pp. 721–727.

[6] Babu S.S. "Modeling of heat transfer and phase transformations in steels," in ASM Handbook, Volume 4A: Steel Heat Treating Fundamentals and Processes. *ASM International*, 2004.

[7] Lee S.J., & Lee Y.K. "Finite element simulation of quench distortion in a low-alloy steel incorporating transformation kinetics," *Acta Materialia*, 56(7), 2008, pp. 1482–1490.

UDC: 62, 622.2, 622.3, 622.7

IMPROVEMENT OF THE LINING DESIGN OF THE END COVER OF THE WET SELF-CRUSHING MILL

Sultonov Abdirashid Norboyevich
PhD student, Navoi State University of Mining and Technologies
an.sultonov@ngmk.uz

Egamberdiev Ilkhom Pulatovich
Professor (DSc), Navoi State University of Mining and Technologies
ilxom1977@mail.ru

Ashurov Khisrav Khurshid Ugli
PhD, Navoi State University of Mining and Technologies
kh_ashurov@nsumt.uz

Annotatsiya. Ishda yon qopqoq futerovkasining konstruksiyasini modernizatsiya qilish orqali ham o‘z-o‘zini maydalash tegirmonining samaradorligini oshirish ko‘rib chiqilgan. Ruda-sharli aralashmaning intensiv ta’sirida futerovka elementlarining yuqori yeyilishi xizmat muddatining qisqarishiga va ekspluatatsiya xarajatlarining oshishiga olib keladi. MMS 70×23 tegirmonining ishini tahlil qilish asosida yuklarni bir tekis taqsimlash, o‘z-o‘zini qoplashni yaxshilash va abraziv yeyilishni kamaytirishni ta’minlaydigan g‘ovak shaklidagi qovurg‘ali seksiyali plitalarga ega yangi futerovka ishlab chiqildi.

Kalit so‘zlar: *Tegirmonning futerovkasi, elementlarning yeyilishga chidamliligi, nam o‘z-o‘zini maydalash tegirmoni, o‘z-o‘zini futerovkalash, rudani maydalash, futerovka konstruksiyasini optimallashtirish, abraziv yeyilish.*

Аннотация. В работе рассмотрено повышение эффективности мельницы мокрого самоизмельчения путем модернизации конструкции футеровки торцевой крышки. Высокий износ элементов футеровки при интенсивном воздействии рудно-шаровой смеси приводит к сокращению срока службы и росту эксплуатационных затрат. На основе анализа работы мельницы ММС 70×23 разработана новая футеровка с ребристыми секционными плитами ячеистой формы, обеспечивающая равномерное распределение нагрузок, улучшенное самофутерование и снижение абразивного износа.

Ключевые слова: *Футеровка мельницы, износостойкость элементов, мельница мокрого самоизмельчения, самофутерование, измельчение руды, оптимизация конструкции футеровки, абразивный износ.*

Abstract. The work examines improving the efficiency of the wet self-crushing mill by modernizing the face lining design. High wear of lining elements under the intensive influence of ore-spherical mixture leads to a reduction in service life and an increase in operating costs. Based on the analysis of the operation of the MMS 70×23 mill, a new lining with ribbed, cellular-shaped sectional plates has been developed, ensuring uniform load distribution, improved self-lining, and reduced abrasive wear.

Keywords: *Mill lining, element wear resistance, wet self-crushing mill, self-lining, ore grinding, lining design optimization, abrasive wear.*

Introduction

The ore processing process at the mining and processing complex is associated with significant abrasive and hydraulic abrasive wear on the parts of crushing and grinding equipment. One of the main costs during ore grinding is the cost of grinding bodies and replacing the lining of the working bodies of the beneficiation equipment. Thus, when operating drum mills, the costs of reproducing grinding media and lining reach the cost of energy costs, and sometimes exceed them. Such high material consumption of the processing equipment is explained by their intensive wear on the abrasive rocks during crushing and grinding [1].

Therefore, developing rational and justified solutions to increase the resource of rapidly wearing elements of mining and processing equipment is an important scientific and practical task.

Literature Review

Solod G.I., Zimin A.I., Andreev E.E., Andreev S.E., Malyarov P.V., Perov V.A., Olevsky V.A., Kryukov D.K., Dun I.F. and others have studied the issues of increasing the service life of quickly wearing elements of mining machines and processing equipment, including the lining (armor) of ball mills. As a result of their research, various ways to reduce the wear rate of lining were proposed, such as: the use of other wear-resistant metal materials, such as white wear-resistant cast irons, instead of the traditionally used lining material - 110G13L steel; replacement of metal armor with lining made of other materials; optimization of lining geometry to prevent; and sliding on the surface of the ore, etc. [2-4].

The mill lining is located on the inner surface of the drum and consists of alternating armor plates and protrusions on them. Serves to protect the base units of the mill drum from wear and, due to its various geometries, participates in the technology, influencing the efficiency and quality of grinding. Depending on the grinding stages, steel or cast-iron lining, rubber-metal lining, or wear-resistant rubber lining, along the profile, lifting lining, wave lining, heel lining, etc., are used.

Mineral raw material grinding processes play a key role in the technological chain of mining enterprises, determining the efficiency of the subsequent stages of enrichment and extraction of useful components. The most energy-intensive and capital-intensive in this chain are the mills, in particular, wet self-crushing mills (MMS), which ensure the destruction of rock due to the interaction between ore pieces and grinding bodies in the aquatic environment.

One of the most vulnerable nodes of the MMS structure is the end cover, which is lined with special wear-resistant elements. These elements are subjected to high-intensity mechanical, impact, and abrasive loads caused by the circulation of the ore-spherical mixture. Lining wear occurs unevenly, and its premature failure often leads to unplanned stops, reduced productivity, and increased operating costs.

Industrial observations show that existing end face lining designs generally do not take into account the peculiarities of load distribution and do not contribute to the formation of a stable self-lining layer that could significantly reduce contact stresses. In addition, the high metal consumption of traditional lining systems increases the cost of both their manufacture and replacement, which is especially critical when operating under conditions of continuous processing of large volumes of ore.

In the context of increasing demands for reduced operating costs and increased equipment reliability, there is a need to develop new design solutions that ensure an increase in the service life of the lining, improve grinding conditions, and reduce the specific consumption of grinding media.

The purpose of this research is the development and industrial testing of an improved lining design for the end face of a wet self-crushing mill, aimed at increasing wear resistance, reducing the mass of lining elements, and optimizing the processing of the ore-spherical mixture. The work is based on practical experience in operating the MMS 70×23 mill.

The object of the research work is the wet self-crushing mill MMS 70×23. This mill is designed for grinding gold ore with a feed size of up to 300 mm and a drum working volume of more than 100 m3. With an average daily load of up to 7000 tons of ore, the unit operates continuously, which places increased demands on the reliability of its units.

During the analysis of the operational characteristics of the standard lining of the end face, it was established that the main wear zones occur at the places of impact interaction of the ore-spherical mixture with the lining plates, as well as at the areas where the concentration of abrasive flows is observed. To eliminate these shortcomings, a new lining design has been developed, including: sectional slabs with longitudinal and transverse edges, forming a cellular structure; use of high-manganese steel (110G13L), which has the ability to strengthen during operation; optimization of the mass of lining elements by reducing the metal consumption of the structure by 10-

15% while maintaining the strength characteristics; and formation of working cells on the surface of the plates, contributing to the accumulation of a thin pulp layer and the self-fusing effect.

The implementation of the new lining was carried out in stages. In the first stage, an experimental installation was carried out on one of the mills, fixing the following parameters:

- Changes in lining mass and installation labor intensity;
- Service life of elements until maximum wear;
- Grinding spheres flow rate dynamics;
- Finished product size (based on sieve analysis results);
- Frequency of unscheduled stops.

For comparison, control data from an identical mill equipped with traditional face lining were used. For 6 months, both mills operated with the same production loads and the same type of processed raw materials.

Wear control was carried out by measuring the thickness of the slabs before and after operation using an ultrasonic thickness gauge and visual analysis.

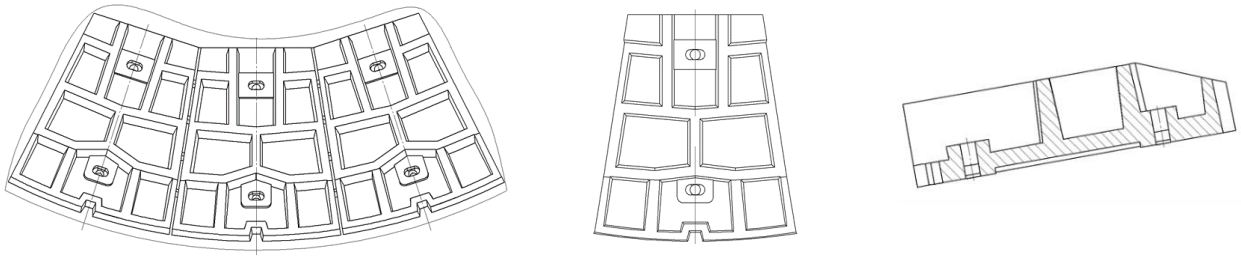
As a result of optimizing the geometry of the slabs and forming a cellular relief, it was possible to redistribute the impact loads and form a self-fusing layer on the surface. This allowed for an increase in the service life of lining elements by an average of 15-20%, significantly reducing the frequency of downtime associated with lining replacement. Due to the stable retention of the ore-spherical mixture in the cells, excluding its slippage and intensifying the self-crushing process, a decrease in the consumption of steel balls by 10-15% was observed while maintaining the target grinding degree.

Comparative analysis of crushed ore samples showed an improvement in the product's coarse-grained composition: the fraction less than 0.074 mm increased by 3-4% compared to the control mill. This indicates an increase in process efficiency and the possibility of reducing the load on subsequent enrichment stages. Due to the rational profiling of the slabs and the reduction of their thickness without loss of strength, a 12% reduction in the metal consumption of the lining was achieved, which gives an effect both in terms of reducing the cost of producing elements and during their installation.

Modular lining design with unified sections simplified the assembly and replacement of worn elements. The average time for full replacement of the end face lining has been reduced by 18%, which reduces labor costs and downtime. It is also worth noting the decrease in vibration loads on the mill housing, which was recorded during periodic monitoring using vibration sensors. This confirms the improved distribution of kinetic energy within the drum.

The conducted work was aimed at solving a pressing task for the mining industry - increasing the reliability and efficiency of wet self-crushing mills by improving the lining design of the end face. Using the example of operating the MMS 70×23 mill, a new construction of lining plates was implemented and tested, based on the cellular principle using stiffness edges and the formation of working recesses that contribute to self-lining. Thus, the implementation of improved lining not only confirms its

effectiveness from a technical point of view, but also represents significant practical interest from the point of view of reducing operating costs and increasing the production stability of the enterprise. The obtained results demonstrate that structural changes based on a deep analysis of operating conditions and wear distribution are capable of ensuring a comprehensive technological effect without requiring fundamental changes in the mill design. This constructive solution is illustrated by drawings, where in Figure 1.



a) b) c)

Figure 1. Lining of the mill's end face: a) fragment of lining installation on the end face is shown; b) lining longitudinal section; c) lining view from above (A).

The application of this design solution contributes to the fact that the ore-spherical mixture, when rotating the mill, fills the recesses between the lining edges, preventing the ore-spherical mixture from sliding on the lining surface. Self-futeration of the lining surface with ore-spherical mixture occurs. Upon reaching a certain height, the ore-spherical mixture, which filled the cell between the lining edges, breaks off and falls onto the material being ground, increasing the ore grinding efficiency and crushing itself. Thus, the optimal lining is explained by the fact that no sliding of the ore-spherical mixture occurs on the lining surface, as the abrasive wear of the lining surface is minimal due to the self-filling of the lining surface with the ore-spherical mixture. In addition, ore pieces falling from a height participate in the grinding process. With the application of lining, the consumption of grinding balls will decrease. The experimental batch of linings installed on the MMS 70x23 wet self-crushing mill with a 120 mm diameter ball load showed positive results, 1.20...1.25 times longer than mills with linings without structural changes.

References:

[1] Bogdanov O.S., Nenarokomov Yu.F., Olevsky V.A. "Handbook of Ore Beneficiation," Nedra, Moscow, 1982, p. 367.
[2] Poturaev V.N., Sokur N.I. "Autogenous Grinding Mills," 1988.
[3] Shinkorenko V.S., Beletsky E.P., Shiryaev A.A. "Handbook of Ferrous Ores Beneficiation," 1980.
[4] Donchenko A.S., Donchenko V.A. "Handbook of an Ore Beneficiation Plant Mechanic," 1986.

UDC: 62, 620, 631.5

DEVELOPMENT OF A METHOD FOR DETERMINING THE EXPECTED DURATION OF POWER SUPPLY INTERRUPTIONS FOR AGRICULTURAL CONSUMERS

Taslimov Abduraxim Dexqonovich
Professor, Tashkent State Technical University
ataslimov@mail.ru

Aminov Hamza Murod Ugli
Assistant Lecturer Urgench State University
hamzaaminov9328@gmail.com

Annotatsiya. Mazkur maqolada qishloq xo‘jaligi iste’molchilarining elektr ta’minotida yuz berishi mumkin bo‘lgan uzilishlar davomiyligini oldindan baholash uchun yangi uslubiy yondashuv ishlab chiqilgan. Tadqiqotning asosiy maqsadi 0,38–10 kV kuchlanishli taqsimlovchi tarmoqlarning texnik holatini tahlil qilish hamda ularning ishonchlilik darajasini aniqlashdan iborat. Taklif etilgan metodda nosozliklar chastotasi, zaxiralash koeffitsienti va tiklash jarayoniga ketadigan vaqt kabi ko‘rsatkichlar asosida kutilayotgan uzilishlar davomiyligi aniqlandi. Metodika “Xorazm ET” AJ statistik ma’lumotlari yordamida amaliy sinovdan o‘tkazilib, tarmoqning ishonchliligi past bo‘lgan qismlarini aniqlash imkonini berdi. Ushbu yondashuv qishloq elektr tarmoqlarini modernizatsiya qilish, energiya ta’minoti sifatini yaxshilash va uzluksizlik darajasini oshirishda qo‘llash uchun samarali vosita hisoblanadi.

Kalit so‘zlar: *elektr ta’minoti ishonchliligi, uzilish davomiyligi, qishloq iste’molchilari, 10 kV taqsimlovchi tarmoq, zaxiralash koeffitsienti, nosozlik chastotasi.*

Аннотация В данной статье представлена новая методическая схема для предварительной оценки продолжительности возможных перерывов электроснабжения сельскохозяйственных потребителей. Основная цель исследования заключается в анализе технического состояния распределительных сетей напряжением 0,38–10 кВ и определении уровня их надежности. Предложенная методика основывается на расчетах частоты отказов, коэффициента резервирования и времени, необходимого для восстановления работоспособности системы. Практическая проверка метода выполнена на основании статистических данных АО “Хорезм ЭТ,” что позволило выявить участки сети с пониженной надежностью. Разработанный подход может эффективно применяться при модернизации сельских электрических сетей, а также для повышения качества и непрерывности электроснабжения потребителей.

Ключевые слова: *надежность электроснабжения, продолжительность перерывов, сельские потребители, распределительная сеть 10 кВ, коэффициент резервирования, частота отказов.*

Abstract This article presents a new methodological framework for the preliminary assessment of the possible duration of power supply interruptions for rural consumers. The main objective of the study is to analyze the technical condition of 0.38–10 kV distribution networks and determine their reliability level. The proposed method is based on calculating the failure frequency, redundancy coefficient, and the time required to restore the system's operability. The practical verification of the method was carried out using statistical data from JSC "Khorezm ET," which made it possible to identify network sections with reduced reliability. The developed approach can be effectively applied in the modernization of rural power distribution networks, as well as to improve the quality and continuity of power supply to consumers.

Keywords: *power supply reliability, interruption duration, rural consumers, 10 kV distribution network, redundancy coefficient, failure frequency.*

Introduction

This article presents a new methodological scheme designed for the preliminary assessment of the probable duration of power supply interruptions for agricultural consumers. The main objective of the study is to analyze the technical condition of 0.38–10 kV distribution networks and to determine their reliability level. The proposed methodology is based on calculating the failure frequency, redundancy coefficient, and the time required to restore the system's operability. The practical verification of the method was carried out using statistical data from "Khorezm ET" JSC, which made it possible to identify network sections with reduced reliability. The developed approach can be effectively applied in the modernization of rural electrical networks, as well as to improve the quality and continuity of power supply to consumers.

Literature Review

The literature review is the process of studying, analyzing, and summarizing previous scientific works, experiments, and theoretical approaches related to the research topic. In this section, the theoretical foundations, methodologies, experimental results, and problematic aspects presented in existing sources are examined. Through the literature review: the advantages and shortcomings of existing scientific approaches are identified; the relevance and significance of the research topic are substantiated; the scientific novelty of the proposed methodology is demonstrated; previous studies on network reliability, power supply interruptions, and their reduction are analyzed and used as a foundation.

During the operation of electric networks, it is necessary to ensure their economic efficiency, maintain the specified level of reliability, and preserve the normative voltage quality indicators. To meet these requirements, various technical maintenance activities must be carried out within a certain time interval. The types of maintenance are generally divided into capital repair and reconstruction works. Capital repair refers to a set of technical measures aimed at restoring or maintaining the initial operational characteristics of electrical network equipment [1]. In other words, capital repair serves to increase the reliability of electrical equipment, eliminate existing defects and faults, and prevent emergency outages. When the territorial planning of settlements changes or redevelopment works are carried out, reconstruction is performed considering the

prospects for network development. In such cases, the economic efficiency, transmission capacity, and supply reliability of the network are improved [2]. The need for reconstruction must be justified from a technical and economic standpoint. Even within the same district, the technical condition of electric networks may vary in both quantitative and qualitative terms. For instance, in some networks, the voltage level at consumers' terminals does not meet the standards, while in others, high energy losses are observed. Moreover, certain networks fail to ensure the required level of reliability. Typically, capital repair and reconstruction are carried out under conditions of limited material, financial, and labor resources. Under such constraints, the reliable supply of electricity to consumers can be achieved only through an objective assessment of the technical condition of existing networks. The accuracy of such an assessment primarily depends on how well the operating personnel are informed about the operating modes and parameters of the network. The most objective evaluation method based on reliable data involves analytical conclusions drawn from failure statistics and measurements of various technical indicators. However, in practice, such information is often unavailable or insufficiently accurate. One of the main reasons for this situation is the lack of adequate control and measuring equipment in 10 kV rural networks. In 0.38 kV networks, such equipment is almost completely absent. Consequently, in managing and assessing rural electrical networks, many reliability and electrical mode indicators remain uncertain. During the design or operation of electrical networks, the reliability of power supply must comply with current regulatory requirements. As noted in [5], when planning scheduled maintenance works and choosing options for efficient resource utilization, it is recommended to evaluate the reliability level based on the expected amount of energy supply interruption, taking into account the significance of consumers:

$$\sum_t [\sum_k \sum_r a_{kr}(x_{kr}) * t_{kr} * P_{kr} * B_k] \rightarrow \min \quad (1)$$

where $a_{kr}(x_{kr})$- t — estimated number of possible failures during year *t* at object *k* if the planned capital repair of type is not performed; t_{kr} — x_r - — time required to eliminate a single failure of element *r* (hours); P_{kr} — load power disconnected from supply during failure (kW); B_k— coefficient considering the category of consumers, determined by a special expression:

$$B_k = \sum_{i=1}^{3} n_i c_i \; / \sum_{i=1}^{3} n_i \quad (2)$$

where *n* in n_i and c_i— represent, respectively, the number of consumers in the first, second, and third categories and their relative importance, determined for example by the associated average losses (damage). According to [4], when developing a capital repair plan, a special indicator is used to assess the technical condition of the network:

$$a = \frac{S_{mn}}{l} \cdot \frac{S_{1-2}}{S_{\Sigma}} \quad (3)$$

where: S_{mn} — total power of transformers (in kVA) disconnected from supply during the previous year due to unsatisfactory condition of 10 kV overhead lines; *l*-10 — total length of the 10 kV line (km); S_{Σ} — total power of all transformer substations connected to the line (kVA); S_{1-2}– total power of transformers located in category 1 and 2 substations (kVA). The drawback of both criteria is that, according to expression (1), it is necessary to determine the functional relationship of $a_{kr}(x_{kr})$ for each repair type, or, according to (3), to identify the causes of failures [6]. In practice,

this process is extremely complex or even impossible to implement. Moreover, the described reliability assessment criteria encompass the entire distribution network and do not take into account the specific characteristics of individual consumers' power supply.

$$P = U_N + U_K + I_N \quad (4)$$

The methodology for forming the components of the comprehensive indicator is based on calculating the uncertainty intervals of energy undersupply and losses, as well as on the probabilistic assessment of voltage quality indicators. The considered methodology makes it possible to evaluate the *economic efficiency* of various measures aimed at improving the technical condition of the distribution network. However, it does not consider the compliance of 10 kV distribution network reliability with the requirements established for agricultural consumers [7]. Therefore, it is advisable to develop a methodology aimed at determining the compliance of 10 kV distribution networks with the specified reliability requirements for agricultural consumers. This methodology should be based on the technical condition indicators of 10 kV networks and the level of their equipment with control devices. Such an approach allows for identifying consumers whose reliability level does not meet the standard requirements and for developing technical measures to improve their power supply reliability. One such measure could be replacing old, uninsulated wires in 10 kV overhead lines with self-supporting insulated wires (SIP) [4].

Research Methodology

The main purpose of this section is to develop a methodology for determining the expected duration of power supply interruptions for agricultural consumers based on the technical condition of a 10 kV distribution network. The expected interruption duration represents the total annual duration of possible power supply interruptions for a specific consumer, taking into account the existing technical condition, the level of maintenance, and the availability of switching devices and control equipment in the 10 kV distribution network. The objective of determining this indicator is to identify consumers for whom the standardized level of power supply reliability is not being met. To assess compliance with the normative reliability level, the indicators of power supply interruption duration obtained in Section Category II and Category III consumers are used as a reference [3].

The algorithm for determining the expected duration of power supply interruptions consists of the following stages:

1. Determining the specific failure frequency ω_{10kB_0} for the 10 kV distribution line supplying the consumer with electrical energy;
2. Determining the reserve coefficient K_p for the consumer, based on the presence of switching devices in the distribution network;
3. In the case of a fault occurring on the *i-th section* of the 10 kV line, determining the time τ_{nep} required to restore power supply to consumers in the unaffected sections, and determining the time τ_y required to identify, eliminate the cause of the fault, and restore the power supply in the 10 kV network;
4. Calculating the expected duration of power supply interruptions for the consumer $T_{o.n}$;

5. Comparing the calculated value of $T_{o.n}$ with the standardized interruption duration established for the given consumer category. Below are the expressions for calculating all the components required to determine $T_{o.n}$.

Analysis and Results

The expected duration of power supply interruptions for consumers, denoted as $T_{o.n}$, depends on the technical condition of the 10 kV distribution network and the availability of its control and switching devices. It is determined using the following equation:

$$T_{o.n} = T_{nep} + T_{вос} = \omega_{10кV} \cdot L \cdot K_{pi} \cdot \tau_{nep} + \omega_{10кV} \cdot L \cdot (1-K_{pi}) \cdot \tau_{вос}, \quad (5)$$

where: T_{nep} - the duration of the power supply interruption under conditions where, after a fault occurs in the line, the damaged section is isolated and supply is restored to the undamaged sections (measured in hours); $T_{вос}$ - the duration of the interruption under conditions where, after a fault, power is first restored to undamaged sections, then the fault is eliminated, and the full operability of the line is recovered (in hours). By substituting the expression for τ_{vos} from equation (4) into equation (5) and performing some mathematical transformations, we obtain the following relation:

$$T_{o.n} = T_{nep} + T_{вос} = \omega_{10кВ} \cdot L \cdot (\tau_{nep} + (1-K_{pi}) \cdot \tau_{y}), \quad (6)$$

Under current contractual conditions between energy supply organizations and electricity consumers**,** the *expected duration of power supply interruptions provides* a quantitative criterion for assessing the capability of a 10 kV distribution network to ensure the required level of reliability of electricity supply. Under the current contractual framework between power supply organizations and electricity consumers**,** the *expected duration of power supply interruptions* serves as an important indicator for assessing the ability of a 10 kV distribution network to maintain the required level of reliability. The *permissible average annual interruption durations* associated with faults in 10 kV distribution networks: for Category II consumers - *9.2 hours per year;* for Category III consumers -*72 hours per year* [7]. The calculated value of $T_{o.n.}$ obtained from formula (6), must comply with the normative indicators corresponding to the consumer's supply category. The determined permissible interruption durations can be used as baseline criteria for ensuring reliability of power supply and may be included in contracts between energy supply companies and consumers. If the calculated $T_{o.n.}$ value exceeds the normative or contractual limit set for a specific consumer, it indicates that the network does not meet existing reliability requirements**,** and technical improvement measures must be implemented to enhance supply reliability. One of the effective methods to improve the reliability of electricity supply is to replace the bare conductors used in 10 kV overhead lines with self-supporting insulated conductors (SIP) (see Figure 2). The application of the proposed method for determining the expected duration of power supply interruptions is demonstrated using the example of a 10 kV rural distribution network belonging *to Hazorasp Regional Electric Grid JSC.* The technical characteristics of this network scheme are presented in Tables 1 and Table 2 (see Figure 1) [6].

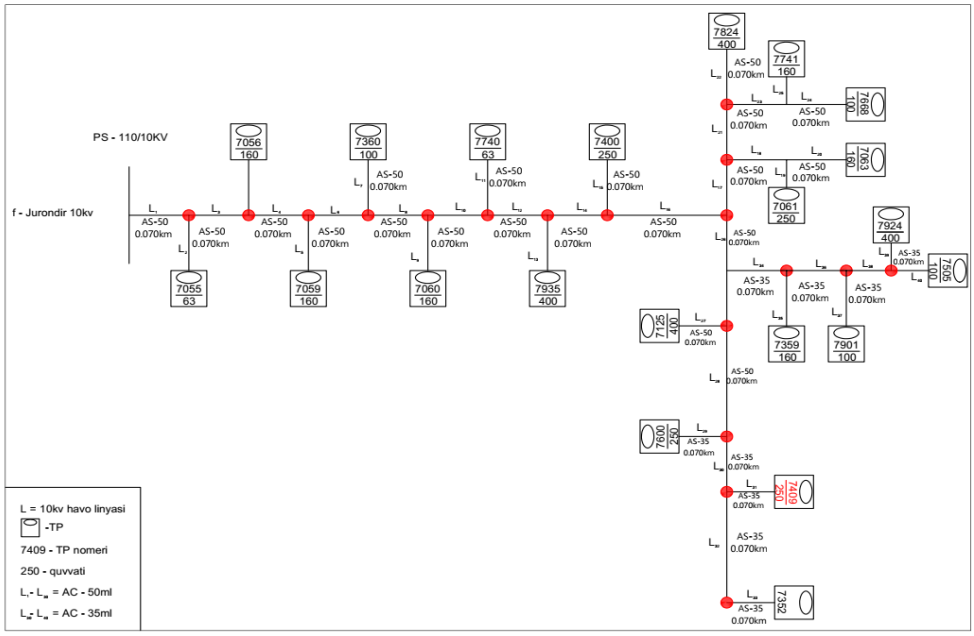


Figure 1. Existing 10 kV power supply scheme of Juvondir.

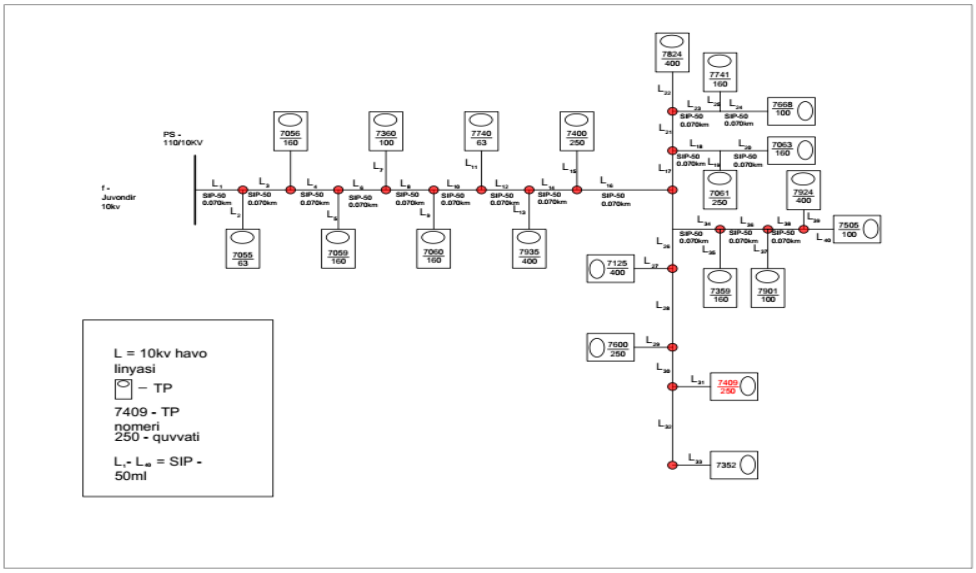


Figure 2. 10 kV power supply scheme of Juvondir after the installation of SIP conductors.

Table 1. Length of 10 kV distribution network sections.

Section length	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9
km	2	2	2	1	3	1	1	3	3
Section length	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{16}	L_{17}	L_{18}
km	3	2	3	1	3	1	1	2	3
Section length	L_{19}	L_{20}	L_{21}	L_{22}	L_{23}	L_{24}	L_{25}	L_{26}	L_{27}
km	2	1	2	3	3	1	1	2	2
Section length	L_{28}	L_{29}	L_{30}	L_{31}	L_{32}	L_{33}	L_{34}	L_{35}	L_{36}
km	3	3	3	1	2	1	1	2	2
Section length	L_{37}	L_{38}	L_{39}	L_{40}					
km	3	1	2	1					

To determine the relative failure frequency of 10 kV overhead lines (OL), the value obtained from the statistical analysis of 10 kV OL faults in JSC “Khorezm Regional

Electric Networks" is used: $\omega_{10кВ0}$=13,3 outages/100 km·year. The redundancy coefficient for the *j*-th consumer of the 10 kV overhead line (OL) shown in Figure 3.1 was determined based on formula (4). The total length of the 10 kV line was determined according to Figure 1 [8].

Table 2. Rated capacity of the 10/0.4 kV transformer substation.

№	TP number	Rated capacity of the transformer, kVA	Consumer category
1	7056	160	III
2	7055	63	III
3	7059	160	III
4	7360	100	III
5	7060	160	III
6	7740	63	III
7	7935	400	II
8	7400	250	II
9	7061	250	II
10	7063	250	II
11	7668	100	III
12	7741	160	III
13	7824	400	II
14	7359	160	III
15	7901	100	III
16	7505	100	III
17	7924	400	II
18	7125	400	II
19	7600	250	II
20	7409	250	II
21	7352	250	II

Conclusion

In this research, a new methodology has been developed to determine the expected duration of power supply interruptions for agricultural consumers. The proposed approach is based on several parameters, including the technical condition of 10 kV distribution networks, failure frequency, redundancy coefficient, and time required for fault detection and restoration. The methodology was tested using statistical data from Khorezm ET JSC, which made it possible to identify sections of 10 kV rural distribution lines with insufficient reliability. The obtained results demonstrate that the developed method allows predicting the duration of possible interruptions in advance and evaluating the reliability of power supply in accordance with established regulatory standards. Furthermore, the methodology enables a detailed analysis of the current technical condition of 10 kV networks, the identification of deviations from normative indicators, and the formulation of necessary technical measures to ensure system stability and reliability. The analysis showed that in some parts of the network, the duration of interruptions exceeded the normative values, indicating insufficient technical performance of the existing infrastructure. One of the most effective technical solutions proposed to enhance the reliability of electricity supply is the replacement of bare overhead conductors in 10 kV power lines with self-supporting insulated wires

(SIP). Thus, the proposed methodology can be effectively used not only to assess the current reliability status of rural power networks but also in the modernization process, contributing to the improvement of power supply quality and enhancement of continuity. This approach holds both scientific and practical importance in developing strategies for the sustainable advancement of rural electrical distribution systems.

References:

[1] Katrenko G.N. “New approaches to the construction of 0.4-35 kV distribution electrical networks,” *Electrical Networks and Systems Magazine*, № 5, 2013, pp. 25-29.

[2] Taslimov A., Davletov I., Aminov H. “Improving the Reliability and Energy Efficiency of Rural Electric Networks using Self-Retaining Insulated Wires,” *International Journal of Advanced Research in Science, Engineering and Technology*, Vol. 10, Issue 4, April 2023.

[3] Leshchinskaya T.B., Belov S.I. “Determination of indicators of reliability of power supply of agricultural production,” M.: *Agroconsult*, 2004, p. 152.

[4] Taslimov A.D., Aminov H.M. “Application of self-supporting insulated wires in rural electrical networks,” Current problems of the power supply system, *Collection of works of the international scientific and technical conference*. Tashkent, *TashSTU*, 2022, pp. 89-91.

[5] Taslimov A.D., Aminov X.M., Urinov B.G., Yuldashev A.A. “Increasing the reliability and energy efficiency of the rural electricity supply system of Khazorasp district,” “Achievements, problems and prospects of complex innovative development of the Zarafshon oasis” *VI - international scientific and practical conference*. 24\25 September №2, Navoi-2025, pp. 209-211.

[6] Taslimov A.D., Aminov H.M. “Application of the methodology for determining the expected duration of power supply interruptions for agricultural consumers,” V International Scientific and Technical Conference, Actual Problems of the Power Supply System, (Dedicated to the 80th anniversary of Academician Kakhramon Rakhimovich Allaev) Tashkent. *Tashkent State Technical University named after Islam Karimov*, August 2025, pp. 26-27.

[7] Abdurakhim Taslimov, Ikram Davletov, Asror Sultonov, khamza Aminov “Reliability Assessment of Electricity Supply systemis for Agricultural Consumers,” III International Scientific and Technical Conference, *Actual lssues of power supply Systemis ICAPIPSS2023* Tashkent Uzbekistan, 7-8 September 2023, *pp.* 030022-1-030022-7. DOI: 10.1063/5.0219602

[8] Taslimov A.D., Davletov I.Yu., Aminov H.M. “Analysis of reliability indicators of self-supporting insulated wire overhead lines,” *Energy and resource saving problems*, Tashkent, № 3, 2023, pp. 130-136.

UDC: 62, 004.04

DICTIONARY-BASED TOKENIZATION ALGORITHM FOR UZBEK TEXTS

Abdusobir Saidov
Professor (DSc), Deportment Convergence of Digital technologies, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi

Maksud Sharipov
Candidate of Technical Sciences, Associate Professor, Deportment Computer science and artificial intelligence technologies, Urgench State University named after Abu Rayhan Biruni
m.sharipov@urdu.uz

Ogabek Sobirov
PhD student, Deportment Computer science and artificial intelligence technologies, Urgench State University named after Abu Rayhan Biruni

Anotatsiya. Tokenizatsiya - bu matnni kichik qismlarga, ya'ni tokenlarga bo‘lish jarayoni. Tokenlar bu so‘zlar, belgilar, raqamlar yoki boshqa ma'lumotlar bo‘lishi mumkin. Tokenizatsiya, asosan, tabiiy tilni qayta ishlash (NLP) da qo‘llaniladi va matnni tahlil qilish, tushunish yoki modellarga kirita olish uchun zarur bo‘lgan birinchi qadam hisoblanadi. Bu tadqiqot o‘zbek tili uchun tokenizatsiyani bir necha darajalarda amalga oshiradi: bo‘g‘in, affiks va so‘z. O‘zbek tili grammatikasini chuqur tahlil qilib, har bir tokenizatsiya darajasi uchun Python asosidagi dasturlarni ishlab chiqdik. Bo‘g‘in darajasidagi tokenizer o‘zbek fonologik qoidalariga amal qiladi. Affiks darajasidagi tokenizatsiya o‘zak va qo‘shimchalarni ajratish uchun tilning aglyutinativ tuzilishidan foydalanadi. So‘z darajasidagi tokenizatsiya uchun biz ajratiladigan qo‘shma so‘zlarning to‘liq ro‘yxatini tuzdik va birlashtirdik. Ishlab chiqilgan dasturiy-asboblar to‘plami PyPI da Python paketi sifatida mavjud: [https://pypi.org/project/UzbekTokenization]. Bizning ishimiz o‘zbek tilini qayta ishlash uchun amaliy resurs taqdim etadi va kam resursli tillar uchun NLP ni rivojlantirishga hissa qo‘shadi.

Kalit so‘zlar: *Tabiiy tilni qayta ishlash, token, tokenizatsiya, tokenlash, qo‘shma so‘zlar, ko‘makchi fe'lli so‘z qo‘shilmasi, o‘zbek tili.*

Аннотация. Токенизация — это процесс разделения текста на более мелкие фрагменты, называемые токенами. Токенами могут быть слова, символы, числа или другие данные. Токенизация в основном используется в обработке естественного языка (NLP) и является первым шагом, необходимым для анализа, понимания или включения текста в модели. В этом исследовании реализована токенизация для узбекского языка на нескольких уровнях: слог, аффикс и слово. Проведя тщательный анализ узбекской грамматики, мы разработали программы на основе Python для

каждого уровня токенизации. Токенизатор на уровне слогов придерживается фонологических правил узбекского языка. Токенизация на уровне аффиксов использует агглютинативную структуру языка для разделения основ и суффиксов. Для токенизации на уровне слов мы составили и интегрировали полный список разделяемых сложных слов. Разработанный набор инструментов доступен в виде пакета Python на PyPI: [https://pypi.org/project/UzbekTokenization]. Наша работа предоставляет практический ресурс для обработки узбекского языка и способствует развитию обработки естественного языка для языков с низкими ресурсами.

Ключевые слова: *Обработка естественного языка, токен, токенизация, сложные слова, вспомогательные глагольные соединения, узбекский язык.*

Abstract. Tokenization is the process of dividing a text into smaller parts, called tokens. Tokens can be words, punctuation marks, numbers, or other meaningful elements. Tokenization is primarily used in natural language processing (NLP) and is an essential first step for analyzing, understanding, or inputting text into models. This study implements tokenization for Uzbek at multiple levels: syllable, affix, and word. By conducting a thorough analysis of Uzbek grammar, we developed Python-based programs for each tokenization level. Syllable-level tokenizer adheres to Uzbek phonological rules. Affix-level tokenization leverages the language's agglutinative structure to separate stems and suffixes. For word-level tokenization, we compiled and integrated a comprehensive list of separable compound words. The developed toolkit is available as a Python package on PyPI: [https://pypi.org/project/UzbekTokenization]. Our work provides a practical resource for Uzbek language processing and contributes to advancing NLP for low-resource languages.

Keywords: *Natural language processing, token, tokenization, compound words, auxiliary verb compound, Uzbek language.*

Introduction

Tokenization, the process of breaking down text into smaller meaningful units such as syllables, affixes, and words, is a foundational step in natural language processing (NLP). It serves as a prerequisite for more advanced tasks such as lemmatization, part-of-speech tagging, machine translation, and sentiment analysis. For languages with rich morphological structures, such as Uzbek and other Turkic languages, tokenization presents unique challenges due to agglutination, compound word formation, and complex phonological rules.

The need for tokenization varies across levels. Syllable-level tokenization is crucial for speech processing and text-to-speech systems, particularly in languages like Uzbek where syllable boundaries play a significant role in pronunciation. Affix-level tokenization is particularly important for agglutinative languages, where words are formed by adding multiple suffixes to a root, enabling accurate morphological analysis. Word-level tokenization is a standard step in most NLP pipelines, but it becomes complex in languages with compound words or ambiguous word boundaries.

In English, tokenization is relatively straightforward due to clear word boundaries and limited use of affixes. For example, the sentence "I'm running!" can be tokenized

into words as [“I’m,” “running,” “!”]. In Russian, tokenization is more complex due to its inflectional morphology; for instance, the word “подоконник” (windowsill) is a single token, but its affixes carry grammatical meaning. For Turkic languages like Turkish or Kazakh, tokenization must account for agglutination, where a single word like “evlerimizde” (in our houses) combines a root (“ev”) with multiple suffixes (“-ler,” “-imiz,” “-de”).

The relevance of tokenization to lemmatization cannot be overstated. Lemmatization, the process of reducing words to their base or dictionary form, relies heavily on accurate tokenization. For example, in Uzbek, the word “kitoblarimdan” (from my books) must first be tokenized into its root (“kitob”) and suffixes (“-lar,” “-im,” “-dan”) before lemmatization can identify “kitob” as the base form. Without precise tokenization, lemmatization and subsequent NLP tasks would be error-prone, especially in morphologically complex languages.

Despite the growing interest in NLP for low-resource languages, tokenization tools for Uzbek remain underdeveloped. This study addresses this gap by implementing a comprehensive tokenization toolkit for Uzbek, covering syllable, affix, and word levels. By leveraging a deep analysis of Uzbek grammar and developing Python-based programs, we aim to provide a robust resource for researchers and practitioners working on Uzbek language processing. The developed toolkit is made publicly available on PyPI: [https://pypi.org/project/UzbekTokenization], contributing to the advancement of NLP for Turkic and other low-resource languages.

Literature Review

Before undertaking this study, we reviewed a wide range of scientific articles on tokenization, which offered valuable insights into established approaches and challenges in this domain. Over the years, various studies have explored tokenization methods across different languages, with a particular focus on morphologically rich languages. One of the early definitions of tokenization was “the process of mapping sentences from character strings into strings of words” [1]. Our research builds on the extensive body of work in the field, specifically examining tokenization strategies applied to Turkic languages, including Uzbek.

Turkic languages. This study explores varying vocabulary sizes and morphological tagging in Turkish, using ITUTurkBERT, BERTurk, 1 BW corpora, and fine-tuning for NLP tasks [2]. This study explores adapting diffusion models and transformers for Kazakh text generation, addressing its morphology, creating specialized tools, and contributing to NLP in low-resource languages [3]. This paper discusses the under-resourced status of Kyrgyz language NLP, reviewing current efforts, challenges, and proposing a roadmap for future development and community-driven resource building [4].

Uzbek language. From Uzbek scientists, one of the definitions of tokenization was “the conversion of unstructured natural language text into a better structured representation (from a computer perspective) during the pre-processing stage” [5]. The text discusses the processes of tokenization, lemmatization, and stemming in corpus linguistics, highlighting their roles, characteristics, and the need for systematic comparison and analysis [6]. This study develops a tokenization algorithm based on a

knowledge base to extract lexemes from text, addressing key issues in machine translation and information retrieval [7]. The paper presents a comprehensive syllabification approach for Uzbek, combining rule-based methods and machine learning, achieving over 99% accuracy, with potential applications for other Turkic languages [8]. This paper proposes a rule-based punctuation analysis algorithm for periods and commas in Uzbek texts, with potential applications for other Turkic languages and future machine learning improvements [9]. This paper presents a rule-based method for verb detection in Uzbek, achieving an F1-score of 0.97, outperforming existing approaches by leveraging affix-based morphological patterns [10].

Other languages. This paper theoretically reexamines tokenization and argues for the necessity of a constructivist approach in semantic parsing and language acquisition modeling [English] [11]. The study explores tokenization for automating qualitative data processing in marketing research, demonstrating its effectiveness in clustering open-ended responses and ensuring data quality [Russian] [12]. This paper presents a hybrid unsupervised method for Arabic tokenization, combining word segmentation, rule-based approaches, and statistical methods to achieve 98.83% accuracy [Arabic] [13].

Research Methodology

This study focuses on the development of a multi-level tokenization toolkit for the Uzbek language, implemented in the Python programming language. Python was selected as the programming language for this study due to its dominant position in the field of NLP and its unparalleled suitability for developing artificial intelligence (AI) and machine learning (ML) models.

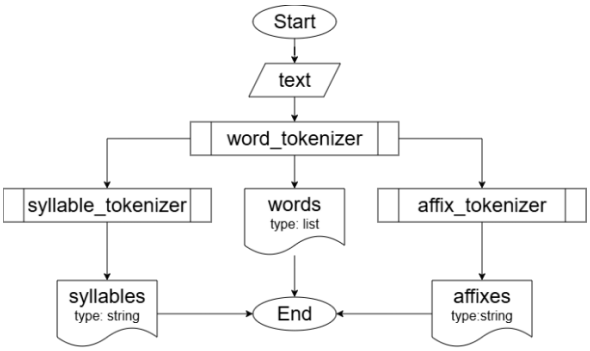


Figure 1. Uzbek language tokenization algorithm.

The toolkit is designed to handle tokenization at six levels: syllable, affix, and word. Below, we outline the methodology for each level, including the linguistic rules applied and their relevance to NLP tasks. Each level is implemented as an independent module, allowing users to perform specific tokenization tasks or combine them into a pipeline.

- Syllable Tokenizer: Splits words into syllables using Uzbek phonological rules.
- Affix Tokenizer: Splits agglutinative affixes using rule-based methods.
- Word Tokenizer: Splits text into words, handling compound words and KFSQ[1] (*ko‘makchi fe’lli so‘z qo‘shilmasi*).

[1] Words consisting of two verbs that have one meaning, the second loses its meaning.

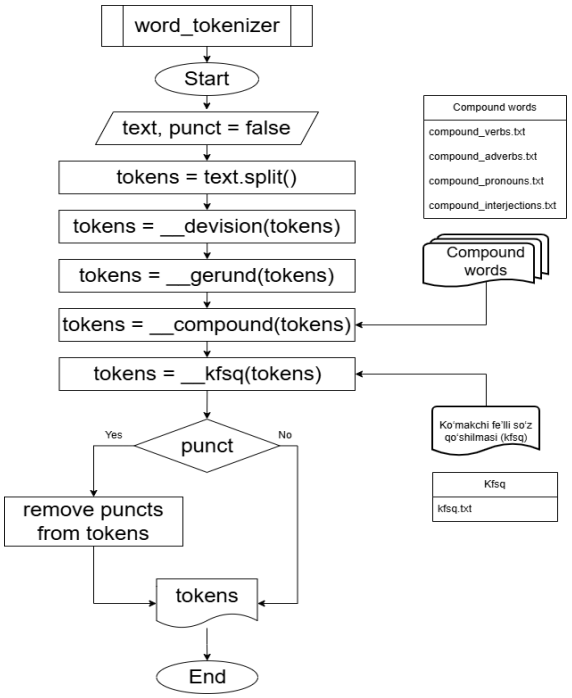


Figure 2. Word tokenizer.

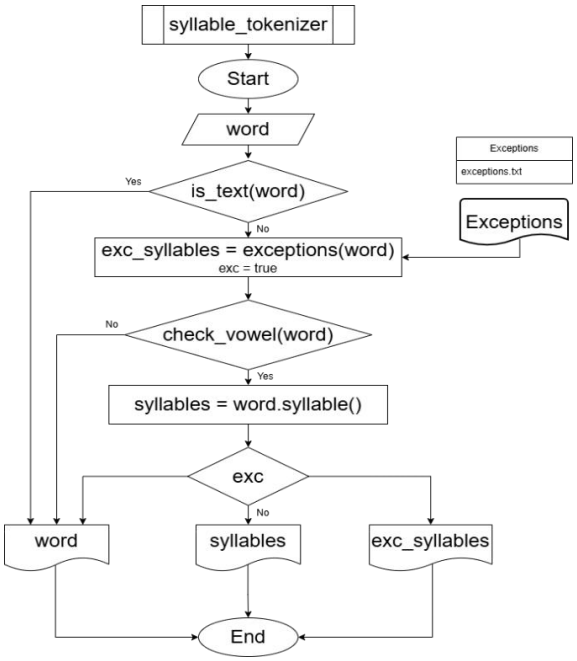


Figure 3. Syllable tokenizer.

Syllable Tokenization. Syllable tokenization is a critical step in text processing, particularly for languages like Uzbek, where syllable structure plays a significant role in pronunciation, speech processing, and phonetic analysis. The syllable tokenization algorithm is designed to adhere to the phonological rules of the Uzbek language. Each syllable must contain at least one vowel, following the (C)V(C) syllable structure, where C represents a consonant and V represents a vowel. A list of 53 exceptions, primarily loanwords from foreign languages, is incorporated into the program. These words do not conform to the standard syllable rules and are treated as special cases. The program uses context-sensitive rules to identify syllable boundaries, ensuring accurate segmentation even in complex cases.

Affix Tokenization. The Affix Tokenization program is designed to segment Uzbek words into their constituent affixes (morphemes). In Uzbek, affixes are categorized into two main types: derivational affixes (word-forming) and inflectional affixes (form-forming). Inflectional affixes are further divided into lexical form-forming and syntactic form-forming affixes. This program specifically focuses on identifying syntactic form-forming affixes that consist of two or more characters. The program excludes derivational affixes, lexical form-forming affixes, and single-character syntactic affixes because they often resemble individual letters within a word, making their separation complex and ambiguous.

Analysis and Results

The developed tokenization toolkit for the Uzbek language has been thoroughly evaluated across different levels: character, syllable, affix, word, sentence, and punctuation. Each module was tested on a diverse dataset comprising literary texts, social media posts, and academic articles to assess the accuracy and robustness of the tokenization process. All results are posted on https://github.com/ddasturbek/UzbekTokenization. Overall, the proposed tokenization

toolkit outperforms conventional NLP libraries in handling the unique morphological and syntactic characteristics of the Uzbek language. Our results indicate that linguistic rule-based approaches, combined with statistical validation, yield superior performance in tokenization tasks for morphologically rich languages.

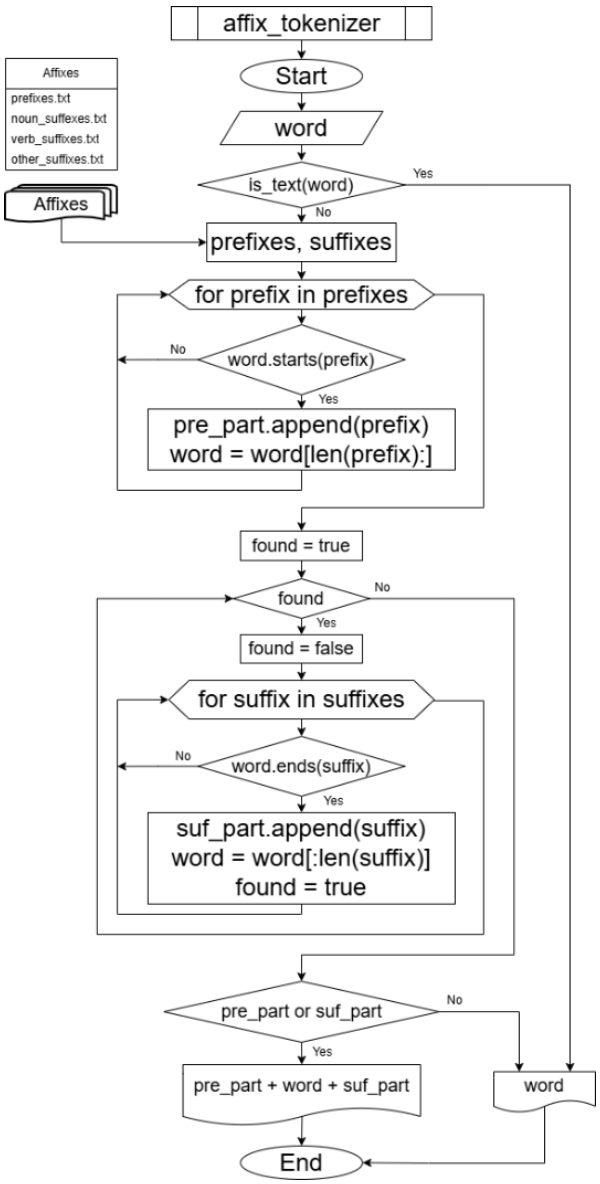


Figure 4. Affix tokenizer.

Conclusion

This study presents a comprehensive tokenization toolkit tailored for the Uzbek language, addressing the challenges posed by its agglutinative structure and complex phonological rules. By developing and evaluating tokenization algorithms at six different levels, we have provided a robust solution that enhances the accuracy of Uzbek text processing in various NLP applications.

Our work contributes to the advancement of Uzbek NLP by providing an open-source, publicly available toolkit, which can serve as a foundation for future research in lemmatization, part-of-speech tagging, and machine translation.

Future research will focus on integrating machine learning-based approaches to further refine tokenization accuracy, particularly in handling ambiguous cases and non-standard text variations.

By making this toolkit available as a Python package, we aim to support researchers and developers working on Uzbek NLP, ultimately contributing to the broader effort of improving language technology for low-resource languages.

References:

[1] Guo J. "Critical Tokenization and its Properties," *Computational Linguistics*, 23, 2002.

[2] Kaya Y.B., Tantuğ A.C. "Effect of tokenization granularity for Turkish large language models," *Intelligent Systems with Applications*, 21, 2024, p. 200335.

[3] Kasenkhan A.M., Mukazhanov N.K., Nuralykyzy S., Kalpeeva Zh.B. "Text generation models for paraphrase on Kazakh language," *KazUTB*, 2024, p. 1.

[4] Alekseev A., Turatali T., Kyrgyz N.L.P. "Challenges, Progress, and Future," *arXiv preprint arXiv*:241105503, 2024.

[5] Khusainova Z., Elov B., Yodgorov U. "Developing a tokenizer for Uzbek texts," 2(24), 2023.

[6] Abdullayeva O. "The process of lemmaization, stemming and tokenization in corpus linguistics," *News from the National University of Uzbekistan*, 1, 2021, pp. 240–243.

[7] Bakaev I. "Creating a tokenization algorithm based on the knowledge base for the Uzbek language," *International Conference on Information Science and Communications Technologies (ICISCT)*, 2022, pp. 1–3.

[8] Salaev U.I., Kuriyozov E.R., Matlatipov G.R. "Design and Implementation of a Tool for Extracting Uzbek Syllables," 16th International Scientific and Technical Conference, Actual Problems of Electronic Instrument Engineering, APEIE, *Proceedings of the IEEE*, 2023, pp. 1750 – 1755.

[9] Sharipov M.S., Adinaev H.S., Kuriyozov E.R. "Rule-Based Punctuation Algorithm for the Uzbek Language," 25th International Conference of Young Professionals in Electron Devices and Materials (EDM), *IEEE* 2024, pp. 2410–2414.

[10] Maksud S., Elmurod K., Ollabergan Y., Ogabek S. "UzbekVerbDetection: Rule-based Detection of Verbs in Uzbek Texts," Joint International Conference on Computational Linguistics, Language Resources and Evaluation, LREC-COLING, *Conference Proceedings*, 2024, pp. 17343 – 17347.

[11] Fan A., Sun W. "Constructivist Tokenization for English," 1st International Workshop on Construction Grammars and NLP, *Proceedings of the Conference*, CxGsNLP 2023.

[12] Ganebnykh E.V., Savelieva N.K., Sozinova A.A., Fokina O.V., Altsybeeva I.G. "Machine learning methods (tokenization) in marketing research," *University Bulletin* 2024, p. 62.

[13] Aliwy A.H. "Tokenization as Preprocessing for Arabic Tagging System," *International Journal of Information and Education Technology*, 2012.

UDC: 5, 591, 591.9

POPULATION DYNAMICS OF THE BUKHARA DEER (*Cervus elaphus bactrianus*) IN THE LOWER AMU DARYA STATE BIOSPHERE RESERVE

Dosnazarova Umit Iklasbaevna
Doctorate Student, specialty "Zoology"

Kidirbaeva Arzygul Yuldashevna
Associate Professor (PhD), Department of Ecology and Soil Science, Karakalpak State University named after Berdakh
abboz-2@mail.ru

Tureev Akylbek Mirzabekovich
Senior Researcher, Lower Amudarya State Biosphere Reserve

Annotatsiya. Maqolada Quyi Amudaryo davlat biosfera rezervati (QDBI) hududida Buxoro bug'usi (Cervus elaphus bactrianus) sonining dinamikasi ko'rib chiqilgan. Tadqiqotlar 2019-2025 yillarda populyatsiya holatini va tabiatni muhofaza qilish tadbirlarining samaradorligini baholash maqsadida o'tkazilgan. Sonini hisobga olish ekologik va antropogen omillarni hisobga olgan holda marshrutli, izli va fotomonitoring usullari bilan amalga oshirildi. Natijalar populyatsiyaning ijobiy dinamikasini ko'rsatdi: populyatsiya soni 2019 yildagi 1233 tadan 2025 yilda 1575 tagacha ko'payib, 2022 yilda maksimal 1775 taga yetdi. O'sish qo'riqlashni kuchaytirish, to'qaylarning yashash joylarini tiklash va ozuqa bazasini yaxshilash orqali ta'minlandi. Bug'ularning makonda tarqalishi gidrologik rejimga va o'simliklarning holatiga bog'liq. Shunday qilib, Quyi Amudaryo biosfera rezervati Orolbo'yi hududida Buxoro bug'usini saqlab qolish va qayta tiklashda muhum ahamiyatga ega. Keng qamrovli tabiatni muhofaza qilish tadbirlarini davom ettirish va muntazam monitoring olib borish populyatsiyaning barqaror yashashi uchun zarur shartdir.

Kalit so'zlar: *Buxoro bug'usi, biosfera rezervati, son dinamikasi, muhofazasi, to'qay ekotizimlari.*

Аннотация. В статье рассмотрена динамика численности бухарского оленя (*Cervus elaphus bactrianus*) в пределах Нижне-Амударьинского государственного биосферного резервата (НАБР). Исследование проведено в 2019–2025 годах с целью оценки состояния популяции и эффективности природоохранных мероприятий. Учет численности осуществлялся маршрутным, следовым и фотомониторинговым методами с учётом экологических и антропогенных факторов. Результаты показали положительную динамику популяции: численность возросла с 1233 особей в 2019 году до 1575 в 2025 году, достигнув максимума в 2022 году — 1775 особей. Рост обеспечен усилением охраны, восстановлением тугайных местообитаний и улучшением кормовой базы. Пространственное

распределение оленей зависит от гидрологического режима и состояния растительности. Таким образом, Нижне-Амударьинский биосферный резерват играет ключевую роль в сохранении и восстановлении бухарского оленя в Приаралье. Продолжение комплексных природоохранных мероприятий и регулярный мониторинг являются необходимыми условиями для устойчивого существования популяции.

Ключевые слова: *бухарский олень, биосферный резерват, динамика численности, охрана, тугайные экосистемы.*

Abstract. The article presents an analysis of the population dynamics of the Bukhara deer (*Cervus elaphus bactrianus*) within the Lower Amu Darya State Biosphere Reserve (LASBR). The study, conducted from 2019 to 2025, aimed to assess the state of the population and evaluate the effectiveness of conservation measures. Population counts were carried out using route surveys, track counts, and camera trapping, taking into account ecological and anthropogenic factors.
The results showed a positive population trend: the number of individuals increased from 1,233 in 2019 to 1,575 in 2025, with a peak of 1,775 individuals in 2022. The growth is mainly attributed to improved protection, restoration of *tugai* (small forest) habitats, and enhancement of the forage base. The spatial distribution of deer was found to depend on the hydrological regime and vegetation conditions. Thus, the Lower Amu Darya Biosphere Reserve plays a key role in the conservation and recovery of the Bukhara deer population in the Aral Sea region. Continued implementation of integrated conservation measures and regular ecological monitoring are essential to ensure the long-term stability of the species.

Keywords: *Bukhara deer, Biosphere Reserve, population dynamics, conservation, tugai ecosystems.*

Introduction

The Bukhara deer (*Cervus elaphus bactrianus*), also known as the Bactrian or tugai deer, is a rare subspecies of red deer native to the tugai forests of Central Asia. This species' range once extended along the Amu Darya and Syr Darya river valleys, but due to habitat loss, illegal hunting, and increasing human pressure, its population declined sharply by the end of the 20th century.

In Uzbekistan, the Lower Amu Darya State Biosphere Reserve plays a vital role in the conservation and restoration of the Bukhara deer population. Thanks to effective protection, habitat restoration, and scientific monitoring, significant progress has been achieved in recent years. Assessing the population dynamics of this species is crucial for understanding the effectiveness of conservation measures and developing future sustainable management strategies. The aim of this study is to analyze the population dynamics of the Bukhara deer in the Lower Amu Darya State Biosphere Reserve from 2019 to 2025 and assess the impact of conservation measures on population growth and sustainability.

Research Methodology

The study was conducted within the territory of the Lower Amu Darya State Biosphere Reserve (LASBR) during 2023–2025. Observations covered key types of tugai and riparian biotopes, including reed and cane thickets, shrub-forest areas, floodplain meadows, and riverine zones. Deer population counts were carried out regularly in different seasons, mainly in spring and winter, following standardized protocols to ensure data comparability.

The primary methods used were route surveys, which allowed for recording the total population size, age and sex structure, and behavioral characteristics of the herds. Tracking was also used during the winter and spring, allowing for an assessment of animal density in hard-to-reach areas. Camera traps, which operated year-round and provided continuous monitoring, were also used. Environmental parameters, including food supply status, hydrological regime, and signs of anthropogenic impact, were also recorded. Strict adherence to the methodology and quality control of the surveys allowed for the collection of reliable and reproducible data reflecting the population dynamics and spatial distribution of Bukhara deer within the reserve.

Analysis and Results

During the research conducted from 2023 to 2025 within the Lower Amu Darya State Biosphere Reserve (LASBR), a gradual increase in the population of the Bukhara deer (*Cervus elaphus bactrianus*) was recorded. According to field surveys and observations, the population numbered 1,531 individuals in 2023, 1,613 in 2024, and reached 1,698 individuals by 2025, indicating a positive trend in population growth. This increase is primarily associated with improved protection measures, restoration of tugai forests, and regulation of anthropogenic pressure within the reserve.

In recent years, active measures have been implemented to restore the forage base, control livestock grazing, establish supplementary feeding sites, and combat poaching, all of which have had a positive impact on the condition of the population. When analyzing the population dynamics of the Bukhara deer (*Cervus elaphus bactrianus*) over the period from 2019 to 2025 within the Lower Amu Darya State Biosphere Reserve (LASBR), a stable upward trend in population growth can be observed (see in Figure 1).

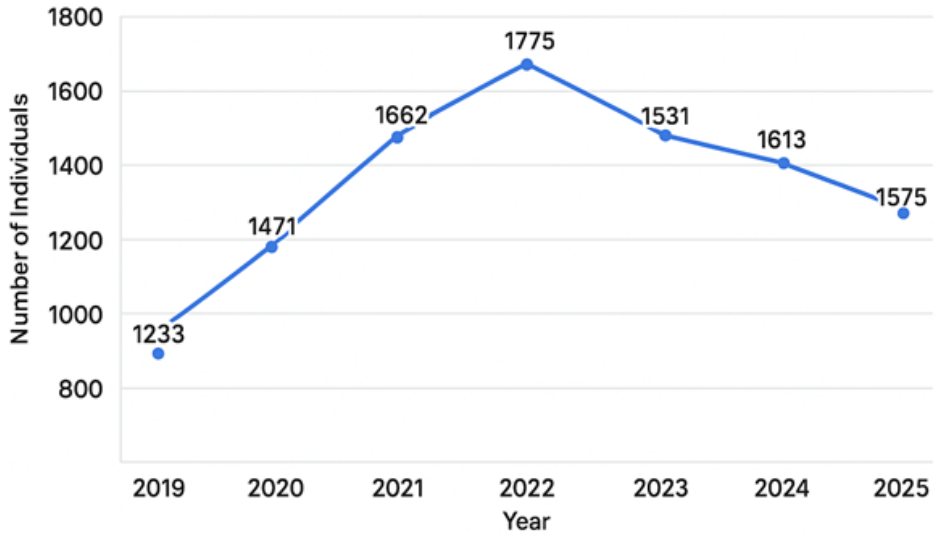


Figure 1. Dynamics of Bukhara Deer Population (2019–2025).

In the Figure 1 illustrated the population dynamics of the Bukhara deer (*Cervus elaphus bactrianus*) from 2019 to 2025 within the Lower Amu Darya State Biosphere Reserve. In 2019, the population numbered 1,233 individuals, followed by a steady increase: 1,471 individuals in 2020 and 1,662 in 2021. The highest population size was recorded in 2022 — 1,775 individuals — indicating favorable ecological conditions and the effectiveness of conservation measures during this period. After 2022, a slight decline in the population was observed: 1,531 individuals in 2023, 1,613 in 2024, and 1,575 in 2025. Despite this decrease, the overall population remains significantly higher than in 2019, reflecting a positive long-term trend.

Thus, the graph reflects a period of growth followed by stabilization in the population size of the Bukhara deer, which may be associated with natural population fluctuations, changes in the forage base, or climatic factors in the region. Despite a short-term decline, the Bukhara deer population retains strong potential for further recovery, provided that conservation measures continue to be effectively implemented.

The positive dynamics were primarily due to the stable recruitment of juveniles and the reduction of poaching pressure as a result of strengthened protection measures. It should be noted that the sex and age structure of the population also showed stable trends: females accounted for about 54–56%, ensuring high reproductive potential, while the proportion of males with pronounced trophy characteristics ranged from 18–20% of the total population

The spatial distribution of the animals was closely related to the ecological condition of the tugai and riparian biotopes. The highest concentrations of deer were recorded in floodplain forest areas and dense reed thickets, which provided both shelter and a sufficient food base. Winter surveys showed a shift of animals toward areas with a more favorable hydrological regime and lower levels of anthropogenic pressure. Spring and summer observations confirmed the active use of floodplain meadows, associated with the high productivity of the herbaceous cover and the availability of water. Data from camera traps revealed a stable territorial structure of herds that persisted throughout the three years of the study, indicating the stability of intra-population relationships.

An important factor influencing the number and distribution of deer is the condition of the forage base. In years with a favorable hydrological regime and sufficient moisture levels, an increase in the productivity of tugai vegetation was observed, which directly affected the number of juveniles and the overall animal density. However, during dry seasons, a decrease in food availability and partial migration of herds toward the coastal zones of the Amu Darya River were recorded. Despite this, due to the maintenance of the protected regime and the prohibition of livestock grazing within the LASBR, no negative trends associated with food shortages were identified.

A comparison of the obtained data with previous years shows that the population of the Bukhara deer in the reserve demonstrates a stable recovery trend. This confirms the effectiveness of the implemented conservation and restoration measures, including the creation of buffer zones, strengthened anti-poaching control, regulation of anthropogenic pressure, and maintenance of the hydrological regime. At the same time, the results highlight the need for continued monitoring and the development of adaptive

management strategies that account for population fluctuations and changing climatic conditions in the region.

Thus, the population dynamics of the Bukhara deer within the NABR indicate positive trends in population recovery, made possible through effective protection measures, maintenance of natural habitats, and favorable feeding conditions. At the same time, preserving population stability requires a continued integrated approach that includes population monitoring, improvement of hydrological conditions, and prevention of emerging threats associated with human activities.

Conclusion

The study of the population dynamics of the Bukhara deer (Cervus elaphus bactrianus) within the Lower Amu Darya State Biosphere Reserve confirmed the positive outcomes of conservation measures. During the analyzed period (2019–2025), the population size increased from 1,233 to 1,575 individuals, reaching its peak in 2022 with 1,775 individuals. These data indicate the recovery of the species and the stabilization of its population, driven by effective protection efforts and the improved ecological condition of the tugai ecosystems.

The population increase was made possible through a comprehensive set of actions, including the reduction of anthropogenic pressure, prevention of poaching, maintenance of the hydrological regime, and improvement of the forage base. The spatial distribution of the animals demonstrates their adaptation to changing conditions and the preservation of stable habitats within the reserve. Despite the overall positive dynamics, several factors have been identified that may limit further population recovery, such as the degradation of tugai forests, periods of drought, fluctuations in the Amu Darya River level, and localized human disturbance.

Thus, the Lower Amu Darya Biosphere Reserve plays a key role in the conservation and restoration of the Bukhara deer in the Aral Sea region. To ensure the long-term stability of the population, it is necessary to implement a comprehensive strategy that includes regular ecological monitoring, maintenance of natural habitats, control of anthropogenic impacts, and the development of environmental education programs.

References:

[1] Amirov Z.G. “The state of the population of the Bukhara deer (Cervus elaphus bactrianus Lydekker, 1900) in Tajikistan,” *Reports of the Academy of Sciences of the Republic of Tajikistan*, 10, 2012.

[2] Avezov A.K. “Fauna of the Lower Amu Darya State Biosphere Reserve,” *World Science*, 6, 2022, pp. 31–33.

[3] Berdambetova B.P. “Bioecological features of the Bukhara deer (Cervus elaphus bactrianus) in the conditions of the Southern Aral region,” *Theory and Practice of Modern Science*, 6(72), 2021, pp. 62–64.

[4] Cornelis D., Kan E., Gond V., Cesaro J.D., & Peltier R. Estimation of the red deer population and its impact on the Tugay forest ecosystem in the Lower Amu Darya State Biosphere Reserve,” *Uzbekistan*, 2020. DOI: 10.19182/bft2020.346.a36297

[5] Lim V.P. “The Bukhara deer and prospects for its conservation in Uzbekistan,” *Ecological Bulletin*, Tashkent, 3, 2004.

[6] Marmazinskaya N.V., Lim V.P., & Pereladova O.B. “Results of the census of Bukhara deer in the Kyzylkum and Baday-Tugai reserves,” Tashkent: Istiklol, *Tinbo Bulletin*, 1, 2005, pp. 36–42.

[7] Pereladova O.B., Sempere A.J., & Agryzkov E.V. “The Bukhara deer: current status and real prospects for existence,” In: Rare Species of Mammals of Russia and Adjacent Territories. *Abstracts of the International Meeting*, Moscow, 1997, pp. 70.
[8] Pereladova O., Sempere A., Fedorov V., & Agryzkov E. “Monitoring of Bukhara deer populations in the Amu Darya Valley,” *In: Proceedings of the VI Congress of the Theriological Society*, Moscow, 1999, pp. 192.
[9] Pereladova O.B., Sempere A.J., Agryzkov E., & Fedorov V. “Monitoring of Bukhara deer (Cervus elaphus bactrianus Lydd.) populations in the Amu Darya Valley,” In: Conservation of Biodiversity in Protected Areas of Uzbekistan, Tashkent: *Chinor ENK*, 2000, pp. 67–76.
[10] Tlepbergenova P.N. “Ecology of the Bukhara deer in our country (Distribution and origin),” *Research Journal of Surgery*, 1, 2022, pp. 16–17.
[11] Toremuratov Sh. “Assessment of the current state of the Bukhara deer population in the Kuyi Amudarya State Biosphere Reserve,” *Khorezm Mamun Academy Bulletin*, 7(78), 2021, pp. 78–85.

UDC: 528.8, 528.9, 911.9

CARTOGRAPHIC ANALYSIS OF TERRITORIAL CHANGES IN POPULATION SETTLEMENTS (In the case of Gurlen district)

Gulimmatov Ikrom Bakhtiyarovich
PhD, associate professor at the Department of Geography, Urgench State University named after Abu Rayhon Beruni.
ikromgulimmatov@gmail.com

Annotatsiya. Ushbu ilmiy tadqiqotda aholi manzilgohlari shakllanishi, joylashuvi va rivojlanishiga ta’sir qiluvchi omillar xorijiy va mahalliy ilmiy adabiyotlar, statistik manbalardan foydalangan holda tadqiq qilingan. Tadqiqot ishining obyekti sifatida Xorazm viloyati shimoliy qismida joylashgan Gurlan tumani aholi manzilgohlari olingan bo‘lib, ularning hududiy jihatlari masofadan olingan ma’lumotlar, geofazoviy texnologiyalar va tarixiy statistik manbalardan foydalangan holda tahlil qilingan hamda baholangan.

Kalit so‘zlar: *aholi joylashuvi, aholi manzilgohlari, Gurlan tumani, geoinformatsion texnologiyalar, masofadan zondlash, Landsat, maximumliklihood, Google Earth Pro.*

Аннотатция. Аннотация. В данном научном исследовании изучены факторы, влияющие на формирование, размещение и развитие населённых пунктов с использованием отечественной и зарубежной научной литературы, а также статистических источников. В качестве объекта исследования выбраны населённые пункты Гурленского района, расположенного в северной части Хорезмской области. Их территориальные особенности были проанализированы и оценены с использованием данных дистанционного зондирования, геопространственных технологий и исторических статистических источников.

Ключевые слова: *расселение населения, населённые пункты, Гурленский район, геоинформационные технологии, дистанционное зондирование, Landsat, максимальное правдоподобие, Google Earth Pro.*

Abstract. This scientific research paper investigates the factors influencing the formation, location, and development of settlements, using both foreign and local scientific literature and statistical sources. The object of the research is the settlements located in the northern part of Khorezm region — specifically, the Gurlen district. Their spatial characteristics have been analyzed and evaluated using remote sensing data, geospatial technologies, and historical statistical sources.

Keywords: *Keywords: population distribution, settlements, Gurlen district, geoinformation technologies, remote sensing, Landsat, maximum likelihood, Google Earth Pro.*

Introduction

Khorezm is one of the cultural centers that has played an important role in the development of human civilization. Under the influence of complex, long historical development and other factors, this region has undergone many changes.

Currently, 5.5% of the total population of the Republic of Uzbekistan lives in the Khorezm region, and its share in GDP is 3.5%. The level of urbanization is 33%. The main reason the region has the lowest level of urbanization in the republic is the population's occupation in agricultural activities and the relatively weak development of urban infrastructure and industrial sectors.

Today, there are 550 rural settlements in the region, with more than 350 thousand families and well over 200 thousand individual households. As a result of the annual population growth of 1.7-1.9%, or 30-32 thousand people, the territory of settlements is expanding by 1.2-1.4%. With the expansion of settlements, there are potential problems with the reduction of arable land, the provision of jobs, increased pressure on infrastructure, and the provision of food products.

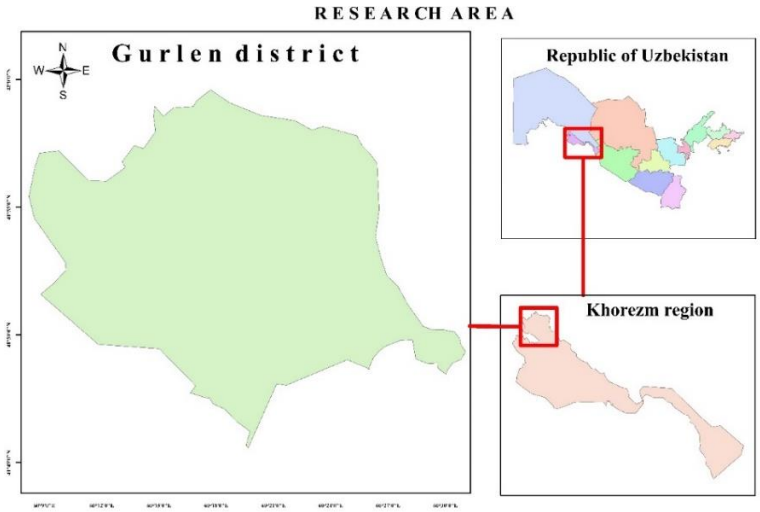


Figure 1. Geographical location of Gurlen district.

Population distribution and population settlements of the Gurlen district of the Khorezm region. The subject of the research is the analysis of the territorial change in

the population settlements of the district and the factors affecting it as shown in Figure 1.

Literature Review

The object of this research work is Gurlen district, located in the north of Khorezm region, with an area of 447.4 km². The Amu Darya River flows through the eastern part of the district. It borders Yangibazar to the south, Shovat district, Dashoguz region of Turkmenistan to the west, and Amudarya districts of the Republic of Karakalpakstan to the north and northeast. The regional center is located 36 km from the city of Urgench and 15 km from the Shovat railway station. The northernmost point of the district is the Nurmonbaba grove near the village of Olchin in Gurlen district [1].

The population of the district as of January 1, 2025, is 159.8 thousand people, with a density of more than 300 people per 1 sq. km. 42.7% of the population lives in cities, and 57.3% in villages [6].

Gurlen district is divided into 9 villages and 9 towns according to its administrative territorial structure. These, in turn, are divided into 9 village citizens' assemblies, 50 neighborhood citizens' assemblies, and 9 towns. The district center is Gurlen town, with a population of 28.7 thousand people as of January 1, 2024. According to historical sources, the Hungarian traveler G. Vamber, who came to Gurlen in 1863, wrote down information about the villages of Jalair, Yonggikkali, Yormysh, Vazir, Olchin, Bashkir, Toshkala, and Kangli in the district, as well as the Daryoliq, Chobolonchi, and Toqson arnas.

Gurlen district was formed on September 29, 1926. In that year, official documents recorded that the Gurlen district "Volost" had a population of 22,339, 4,172 households, 6,697 hectares of cultivated land, 274 mills, 175 mills, 7 private shops, 7 villages, and 158 auls [4].

There are canals and ditches in the district, such as Vazir, Chopolonchi, Eshimjiron, Olga, Qatogon, Kangli, Sakhtiyon, Temirchi, Khizreli yap, Olga, Savonyop, Toqson arna, Daryolik, and Yangiyop.

There is a lot of historical, scientific, and legendary information on the origin of the name of the Gurlen settlement. According to legends, Gurlen means "blind" and "lang." In ancient times, a war took place in this area, and only the blind, lame, and a few young children survived. After that, this area was named by this name.

Ancient Arab travelers and local scholars Ibn Fadlon, Istakhri, and Abulgazi Bahodirkhan report that there was a fortress in the Gurlen district called Darkhos. Yakho Gulomov, supporting the opinion of the past, writes: "On the right bank of the Amu Darya, where the Sultan Uvays mountain passes through the gorge between the Jumurtov River and the Amu Darya, there is the Govur fortress, built in the 2nd -3rd centuries AD, below the current Gurlen latitude. Darkhos is the ancient name of Gurlen.

According to Abu Rayhan al-Biruni, the last remains of Fir (Fil) disappeared by 994. That is, from after the Mongol invasion, a year before the end of the Afrygid dynasty, until the 17th century, this city was called Kat.

A little lower than Kat, on the right bank of the river, one place away, there was a settlement called Khos or Darkhos. This corresponds to the present-day city of Gurlen

or near Gurlen. In the works of Abu Ghazi Bakhodir Khan, we often come across a settlement called Khostminor. In one place, he says that people passed from Khiva to Kat through this tower, and in another place, he mentions this tower in connection with the fact that his brother Asfandiyar Khan ordered the extermination of the population from this tower to Hazorasp. According to Abul-Ghozi Bakhodir-Khan, in 1573 the Amu Darya changed its course and began to flow from the shores of Khostminor towards the Aral Sea. From this information, it can be understood that Khostminor was located much lower than the Kat, more precisely near Gurlen, that is, where the river turns into the Kat [4].

It is known that until 1219-1221, that is, before the conquest of Genghis Khan, Gurlen was called Khosminor, Darkhos. The tower itself was also called Khosminor after the name of the area.

Archaeologist Yahyo Gulomov, when conducting research in Khorezm in 1936-38, saw the remains of this Khosminor. According to Muarrih Maqdisi, “below Kat (meaning the current Beruniy (Shabboz) district of Karakalpakstan), one place further from it, on the right bank of the river, there was a settlement called Khos or Darkhos.” According to the research of Academician Yahyo Gulomov, “this corresponds to the current city of Gurlen or near Gurlen” [3].

After the battles around the fortresses of Kungirat, Charjoi, Bukhara, and Merv, Muhammad Rahimkhan I relocated all the defeated tribes to Khorezm and recruited them to work on digging canals. Land was allocated to prisoners who worked well. The Jamshids from the Gurlen and Mangit regions and the Khizreli, Qiyot, and Kungirat tribes thus found their homeland along the Kilich Niyazboy canal [3].

Today, the population of the district has increased by 1.6 times over the past 25 years, and growth rates have decreased from 2.2 percent to 1.65 percent (see Figure 2).

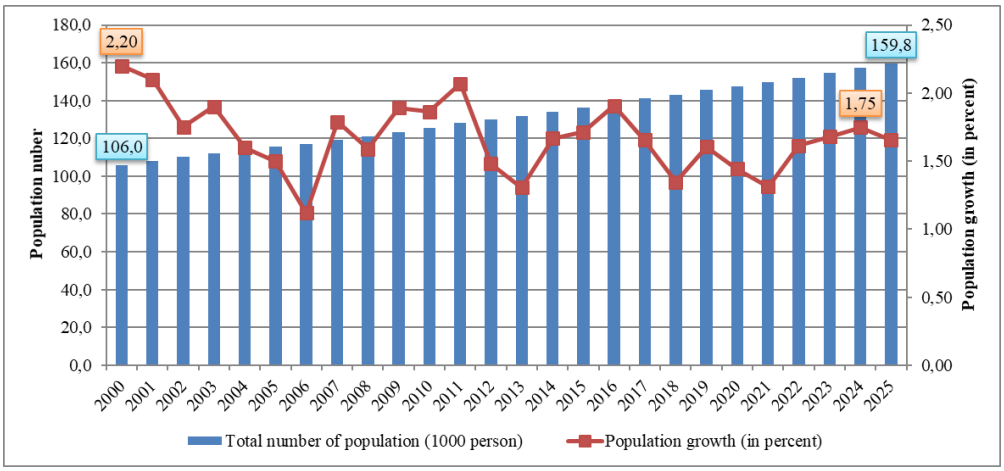


Figure 2. Population growth dynamics of Gurlen district (Note: The diagram was compiled by the author based on data from the Khorezm regional statistics department).

A distinctive feature of the population growth is associated with a decrease in natural growth rates and reverse migration. In the age structure of the population, the share of the 14-25 age group has also been gradually increasing over the past 25 years. 61 percent of the total population is a labor resource, increasing by an average of 2-2.4 people every year. This creates significant problems for the government in solving the issues of providing them with jobs, food, and housing.

Research Methodology

The research work used data from the State Statistics Department, cadastral data, archives, and Google Earth and OSM (OpenStreetMap). Geographical elements were formed based on OSM and Google Earth data. Methods such as cartographic spatial analysis, interpolation, and statistical analysis were used in the research work (Figure 3).

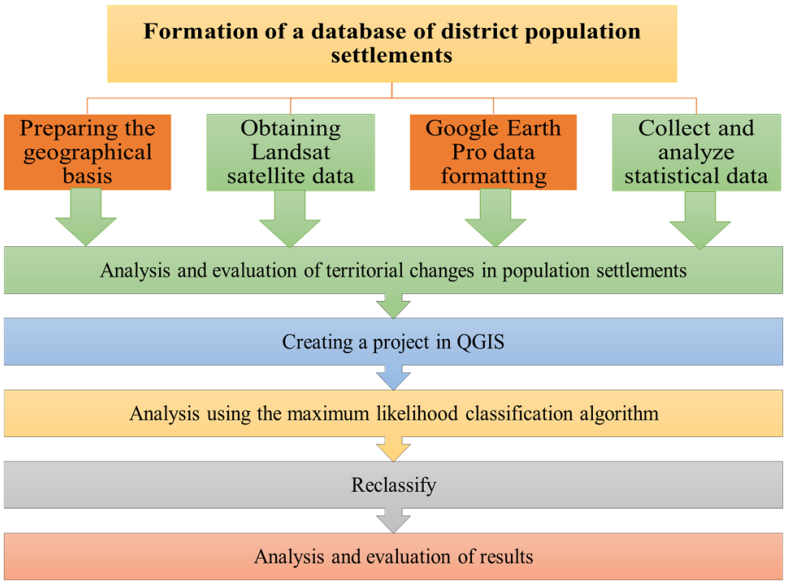


Figure 3. Methodology for analyzing territorial changes in population settlements.

A number of archival data were analyzed in the research work. According to the population census conducted in Khorezm region in 1970 and the UzDavYerLoyiha Institute (formerly GIPROZEM), in the 1970s there were 5,152 “settlements” belonging to 9 groups in the region, of which 28 percent were located in a very scattered (1-10 houses) form. In rural areas, where the majority of the population lives, more than 66 thousand people live, and an average of 6-7 people live in individual houses. In order to provide the population with centralized resources such as transportation, electricity, natural gas, and drinking water, the population was resettled in new areas. In addition, the efficiency of land resource use is very low due to the scattered population distribution on nearly 10,000 hectares of agricultural land.

For this reason, the resettlement of the population into new clustered population centres has been carried out for 20 years and is 90% complete. In particular, in the Gurlen district, 368 scattered rural settlements were optimized in the 1970s, and 210 were brought into a clustered form. As a result of the optimization of settlements, the effective use of 510 hectares of agricultural land was created. The area of the district's settlements and the lands of industrial enterprises within them amounted to 1086 hectares in 1970 and 811 hectares in 1990, and by 2023, it reached 1864 hectares. Over the next half-century, the district's settlements expanded horizontally by almost 1.7 times. Such indicators were observed in almost all districts of the region, and until 1990, scattered settlements were optimized in 3 stages.

The center of Gurlen district is expanding mainly in the north and southwest directions. More ever, the transformation of service facilities is taking place in the areas adjacent to the center, connected by the infrastructure of the towns (Figure 4).

For example, the areas adjacent to the village of Khizir eli, located in the northern part of the city, in the 1990s consisted of arable land, lakes, and vacant land. Currently, these areas have been converted into residential areas.

The analysis of territorial changes in residential areas using GIS technologies initially began with data collection. Relevant periods and periods without clear clouds (less than 10%) were selected from the open data of USGS and Copernicus. Landsat (1990-2000-2010-2025) and data were used. To verify the reliability of the data, Google Earth, OSM, QGIS programs, and topographic maps of various scales were also used (Figure 4).

The resulting raster data were classified using the maximum likelihood method in ArcGIS and QGIS programs based on combining spectral data from several training areas. Initially, the results were very inaccurate due to the large area and the large number of classes. The error was observed in the areas of vacant lots, roads, and mainly unfinished buildings and structures. At the next stage, the raster data was classified only in the Gurlen district, and the accuracy was higher than 85%.

Satellite data differ in their capabilities and accuracy. For example, the attribute table data was calculated taking into account that 1 pixel in Landsat is 30 meters and in Sentinel, 10 meters [7].

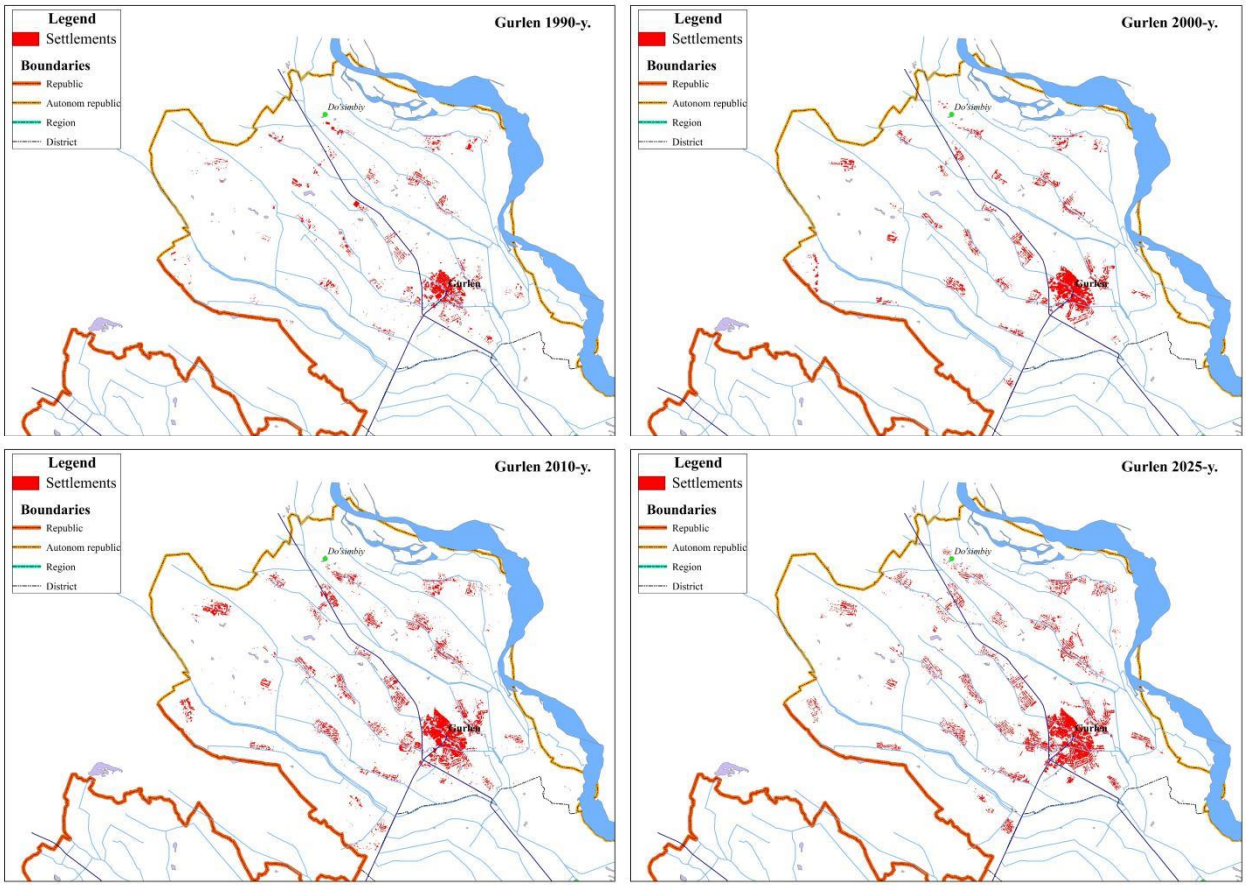


Figure 4. Territorial changes in population settlements in Gurlen district (1990-2000-2010-2025).

Research work requires direct observation and measurement in the field and comparison. High-resolution monitoring and assessment of land use categories and their changes provide useful guidance for experts and policymakers in creating favorable conditions for sustainable land and agricultural management [2].

In addition, the practical significance of the work can be further increased by monitoring various buildings and structures other than settlements and creating a digital database of them.

According to the results of the analysis, the population settlements of the district expanded by 2.3 times compared to 1990, with the highest growth in 2000-2010 amounting to 5 sq. km (Figure 5). However, it is worth noting that the population settlements expanded at the highest rate during the period when the process of allocating land for housing construction was reduced.

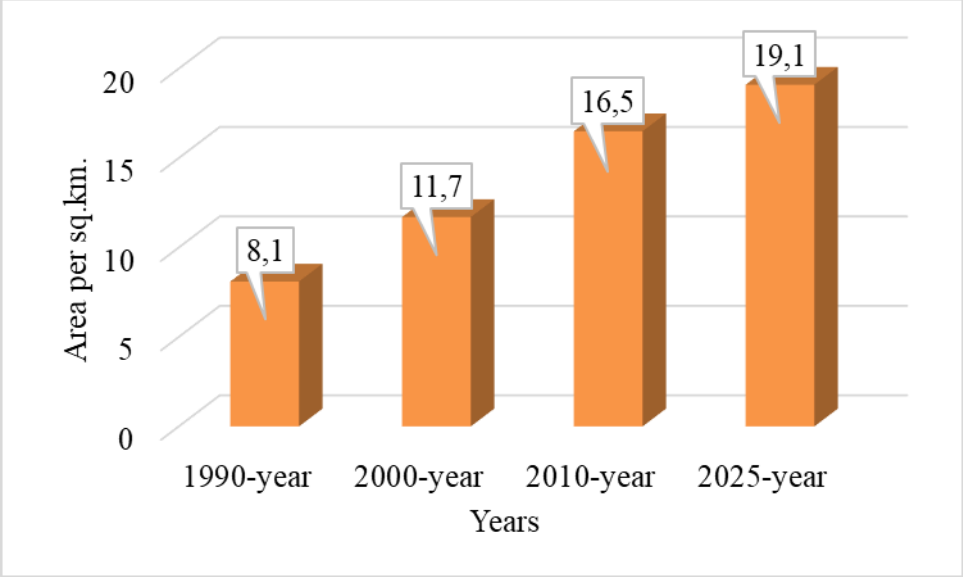


Figure 5. Territorial changes in population settlements in Gurlan

It should be noted that the territorial expansion of population settlements and the inclusion of suburbanization areas into the city limits does not mean a pure urbanization process. Because, in order for a territory to receive the status of a city, it must meet the requirements of urbanization indices [5]. This is a gradual process based on the potential of the territories.

The territorial expansion of population settlements in Gurlen district is also associated with the development of towns specializing in service provision and light industry. The district ranks 1st in the Khorezm region in terms of urbanization level (42%). Currently, there are 9 towns in the district, which is also the leader in this indicator in the region. Effective use of the potential of these towns in ensuring the sustainable development of population settlements in the future is one of the factors determining the prospects of the district.

In the future, it is necessary to pay great attention to preventing the reduction of agricultural lands not only in Gurlen district but also in all other districts of Khorezm region and to their effective use. Because, given that the population of the region is increasing by an average of 30-32 thousand people every year, providing them with the necessary resources becomes one of the urgent problems. When planning the territorial development of settlements in Gurlen district, it is necessary to take into account many factors based on strategic goals. Because a number of processes, such as the densification of the territory of district centers, increased socio-economic pressure, climate change, desertification, etc., will certainly affect urban development.

Conclusion

The specific features of the Gurlen district of the Khorezm region are that it is mainly located in irrigated agricultural facilities. The expansion of settlements is mainly based on socio-demographic factors.

The research work was conducted on the basis of the study of the territorial expansion of settlements, historical literature, topographic maps, cadastral databases, Google Earth, OSM, and satellite data (Landsat 4-5TM and Landsat 8 OLI/TIRS), and the following conclusions were drawn:

The relationship between the territorial expansion of the district's settlements and population growth was studied. According to it, the population is growing by an average of 1.6-1.7%, and settlements by 1.4%.

The study of the territorial dynamics of settlements using the cadastral database and topographic maps has gained high accuracy and practical significance.

Satellite data require direct observations on the ground. They are sufficient for studying the territorial distribution of population settlements and their monitoring and organizing training sessions. For use in other sectors of the national economy, it is recommended to use methods for comparison with cadastral maps and obtaining more accurate results or high-quality aerospace images.

Taking into account economic, social and environmental factors in planning new settlements is of great practical importance in the development of regions.

In the first quarter of the 21st century, as a result of the increase in housing construction and the decrease in natural population growth, the difference between them has almost disappeared. However, due to the huge need for housing, illegal construction is observed in large numbers. Developing scientifically based long-term strategies to address these problems remains a pressing issue.

References:

[1] Avezov S.A., Safarov E.Yu., Qalandarov U.S., Gulimmatov I.B. “Xorazm viloyati qishloq xo‘jaligini hududiy tashkil etishda kartografik metoddan foydalanish,” Urganya: *Quvonchbek-Mashxura*, 2023.

[2] Matchanov Muzaffar, Mudarra M., Nigmatov Askar, Boymurodov Rifat, Jumabayev Ruslan, Hakimi Ali, & Matchanov Otabek “Drought safety levels assessment in Uzbekistan part of the Khorezm oasis by geospatial methods,” *Geodesy and Cartography*, 51, 2025, pp. 67-80. DOI: 10.3846/gac.2025.23771

[3] Umid Bekmuhammad “Xorazm va Xorazmliklar,” Buxoro: *Durdona*, 2022.

[4] Nurjanov K., Bekmuhammad U. “Gurlan tarixi,” Urganch: *Xorazm*, 2006.

[5] Gulimmatov I.B. “Questions of classification of settlements (on the example of the Khorezm region),” LLC Institute of Management and Socio-Economic Development, *Economy and society*, 1-2 (104), 2023, pp. 194-205.

[6] Khorezm Regional Statistics Department, “Demography,” 01.01.2025. https://www.xorazmstat.uz/uz/rasmiy-statistika/demography-2

[7] Explorer, USGS Earth “Landsat missions,” 2025. https://www.usgs.gov/landsat-missions/landsat-levels-processing

MODERN PROBLEMS OF PEDAGOGY AND PSYCHOLOGY

UDC: 37, 004.04, 378, 62

FEATURES OF TEACHING THE COURSE “STRENGTH OF MATERIALS” TO STUDENTS IN UNIVERSITIES

Stepanovich Ekaterina Yurievna
Astrakhan State University

Bekiev Murat Atabekovich
Senior Lecturer, Urgench State University named after Abu Rayhan Biruni
bekiyevmurod@gmail.com

Kholmuratov Kholilla Sarievich
Senior Lecturer, Urgench State University named after Abu Rayhan Biruni

Annotatsiya. Ushbu maqolada texnik universitetlar talabalariga “Materiallar qarshiligi” kursini o‘qitishning metodologik va didaktik jihatlari ko‘rib chiqiladi. Unda zamonaviy raqamli texnologiyalar, kompyuter modellashtirish va virtual laboratoriya simulyatorlari yordamida o‘quv samaradorligini oshirish usullari ko‘rsatilgan. Grafik va interaktiv o‘quv vositalaridan foydalangan holda jismlarning kuchlanish-deformatsiya holatini vizualizatsiya qilish bo‘yicha tavsiyalar taklif etiladi.

Kalit so‘zlar: *materiallar mustahkamligi, muhandislik ta’limi, vizualizatsiya, modellashtirish, o‘quv jarayoni, o‘qitish usullari.*

Аннотация. В статье рассматриваются методические и дидактические особенности преподавания курса “Сопротивление материалов” студентам технических вузов. Показаны пути повышения эффективности обучения с использованием современных цифровых технологий, компьютерного моделирования и лабораторных виртуальных тренажёров. Предложены рекомендации по визуализации напряжённо-деформированного состояния тел с помощью графических и интерактивных средств обучения.

Ключевые слова: *сопротивление материалов, инженерное образование, визуализация, моделирование, учебный процесс, методика преподавания.*

Abstract. This article examines the methodological and didactic aspects of teaching the course “Strength of Materials” to students at technical universities. It demonstrates ways to improve learning effectiveness using modern digital technologies, computer modeling, and virtual laboratory simulators. Recommendations for visualizing the stress-strain state of bodies using graphical and interactive learning tools are offered.

Keywords: *strength of materials, engineering education, visualization, modeling, educational process, teaching methods.*

Introduction

The course “Strength of Materials” is one of the basic and fundamental disciplines in the engineering mechanics curriculum. It develops students’ knowledge of the strength, rigidity, ductility, and stability of structures, as well as methods for calculating the strength, deformation, and failure of machine elements, mechanisms, and structures [1]. This course serves as a link between courses in physics, theoretical mechanics, and design, ensuring the practical application of the laws of mechanics to real-world engineering problems.

Literature Review

At present rapidly advancing science and technology, engineers must not only possess theoretical knowledge but also be able to apply it in a digital environment, employing computer analysis and design optimization methods. Therefore, teaching the course “Strength of Materials” should focus not only on memorizing formulas and calculations but also on understanding the physical nature of the processes occurring in materials under load [2]. However, teaching experience shows that most students experience certain difficulties when studying this course. The most common of these are:

- insufficient spatial imagination to understand three-dimensional stress patterns;
- difficulty understanding formulas that are not supported by visual models;
- weak connection between theory and practical engineering situations.

As a result, traditional lecture-seminar teaching often fails to provide a full understanding of phenomena such as bending, torsion, tension, and structural stability.

These problems can be addressed through the introduction of modern digital and visual teaching methods, which allow students to not only perform calculations but also visualize the behavior of materials and structures under load [3].

These methods include:

- computer stress modeling (Finite Element Analysis - FEA), which allows for the analysis of the stress-strain state of structural elements under various loads;
- virtual laboratories, which simulate real physical experiments and ensure safe and repeated skill development;
- deformation animation and 3D visualization, which allow students to observe the process of bending, torsion, and fracture of structures in real time [4].

The use of these technologies fosters a new type of engineering thinking in students, based on digital modeling and an interdisciplinary approach. Research conducted at a number of technical universities has shown that the use of interactive and visual teaching methods increases the effectiveness of theoretical material acquisition by 20–35% and also improves students’ ability to independently solve engineering problems [5, 6].

Furthermore, the use of software packages (ANSYS, SolidWorks Simulation, Autodesk Inventor, COMSOL Multiphysics) helps students develop skills in engineering analysis tools, which increases their competitiveness in the job market. Therefore, integrating digital technologies into the teaching of the “Strength of Materials” course is not only pedagogically justified but also strategically important for the preparation of 21st-century engineers.

Research Methodology

Methodological Features of Teaching. Modern approaches to teaching the course "Strength of Materials" require a shift from traditional lectures to interactive and research-based teaching methods. This is driven by the need to develop students' not only theoretical knowledge but also engineering thinking and the ability to analyze and interpret real-world processes occurring in structures under load.

Analysis and Results

Using Interactive and Visual Models. One of the most effective teaching techniques is the visualization of physical processes using 3D animations, computer simulators, and virtual laboratories. These tools allow students to visually observe how internal forces and stress states change under the action of various loads. For example, when explaining the topic "Beam Bending," a gradual increase in external load is simulated in a virtual environment, resulting in diagrams of shear forces and bending moments displayed on the screen. This helps students understand how the moment distribution and beam deflection change depending on the applied force (Figure 1).

Furthermore, the instructor can vary the beam's geometric parameters (length, cross-section, material), demonstrating to students the influence of these factors on the elastic properties of the structure. This approach develops spatial thinking, analytical skills, and engineering imagination. Interactive programs such as SolidWorks Simulation, ANSYS Student, and Autodesk Inventor Nastran allow students to independently perform calculations and visualize the results as dynamic models. This makes the learning process more exploratory and engaging.

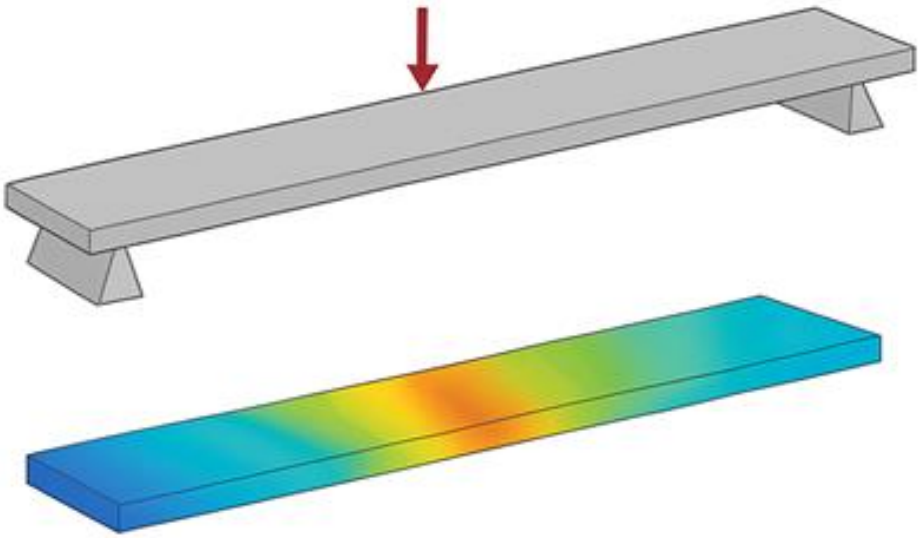


Figure 1. Visualization of a beam bending diagram in a virtual laboratory (example: change in the bending diagram with increasing load).

Stress Distribution Visualization. For a deeper understanding of the processes occurring within a deformable body, visualizing stress fields using color maps is widely used. These maps demonstrate the distribution of normal (σ_x, σ_y) and shear stresses (τ_{xy}) in various parts of the structure. When modeling in programs such as ANSYS, COMSOL Multiphysics, or Abaqus, one can observe how the stress state changes under the application of various loads, changing boundary conditions, or changing material properties (Figure 2).

This not only helps students see the physical meaning of the equations, but also helps develop an intuitive understanding of the relationships between load, strain, and stress.

This methodological approach is especially useful when studying the following topics:

- Tension and Compression;
- Shaft Torsion;
- Bending and Shear;
- Combined Loading.

Color-coded visualization scales (e.g., blue for low-stress zones, red for maximum-stress zones) facilitate better memorization of stress distribution patterns in structural elements. According to pedagogical research, the implementation of such schemes increases the effectiveness of material acquisition by 25–30% [5].

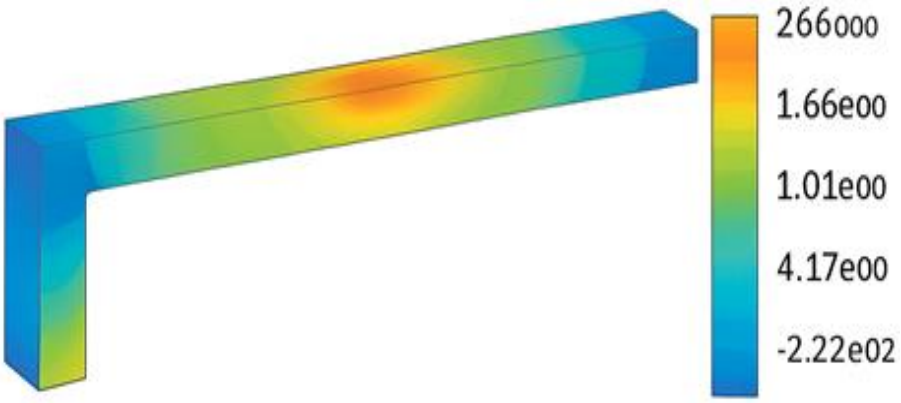


Figure 2. σ_x distribution map for cantilever beam bending in ANSYS (example: zones of maximum stress at the beam's end and a gradual decrease toward the free end).

Benefits of Digital Approaches. Interactive and visual learning methods allow: to increase student motivation for studying engineering disciplines; to develop independent analysis and design skills; to bridge the gap between theory and practice; to visualize processes that cannot be demonstrated in the classroom or laboratory.

Furthermore, teachers note that such approaches contribute to the development of engineering thinking in students, as they begin to perceive the structure as a dynamic system, where each parameter influences the overall stress-strain state.

The role of practical and laboratory work

Traditional and Virtual Laboratories. Laboratory sessions are an integral part of the "Strength of Materials" course, as it is through practical experiments that students can validate fundamental theoretical relationships and laws of strength of materials—Hooke's law, strength conditions, and methods for determining the modulus of elasticity. However, traditional laboratories require significant financial and technical resources. Tensile, bending, and torsion testing machines, as well as measuring instruments, are expensive and require regular maintenance.

Furthermore, conducting real-world tests carries the risk of equipment damage and safety violations. In these circumstances, virtual laboratories are becoming an effective alternative. Using digital platforms (e.g., COMSOL Multiphysics, ANSYS Workbench, SolidWorks Simulation), it's possible to simulate any type of loading, obtain stress and strain distribution, and even conduct material failure analysis. Thus,

virtual laboratories not only solve the problem of logistical support, but also make the educational process more visual, flexible and safe [6].

Table 1. Comparison of traditional and virtual laboratories.

Criteria	Traditional laboratory	Virtual laboratory
Cost of equipment	High	Low
Safety	Requires strict control	Completely safe
Repeatability of experiments	Limited (depending on equipment)	Unlimited
Process visualization	Partial (instrument readings only)	Full (3D animation, color maps)
Error analysis	Manual	Automated
Distance learning opportunities	Absent	Full support

An example of a virtual experiment. A virtual educational laboratory was created at the Department of Electrical Engineering and Power Engineering at Urgench State University using the COMSOL Multiphysics platform. In this project, students can independently specify beam parameters—length, cross-section, material (using Young's modulus), and load magnitude. After running the simulation, the system displays:

- stress distribution σx and τxy along the beam length;
- deflection and bending moment diagrams;
- zones of maximum deformation (using a color scale).

This allows students not only to observe the bending process, but also to understand the relationship between equations and real physical effects.

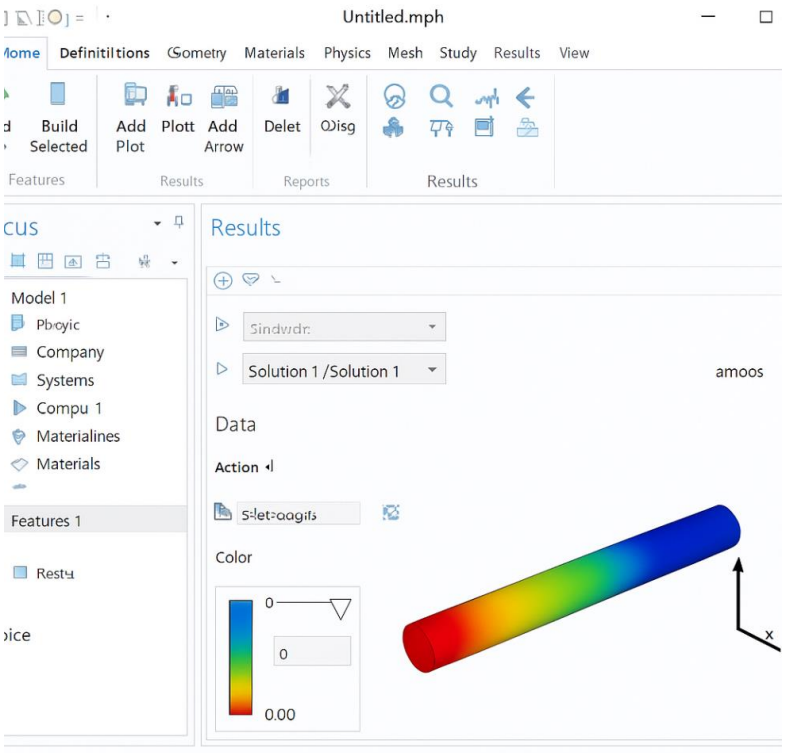


Figure 3. COMSOL Multiphysics interface for beam bending simulation.

This class format stimulates students' cognitive activity, develops engineering thinking, and promotes mastery of the fundamentals of numerical methods in continuum mechanics.

Application of digital educational technologies. Modern digital platforms such as Moodle, Google Classroom, MATLAB Simulink, as well as professional packages SolidWorks Simulation and ANSYS, create conditions for integrating engineering calculations into the educational process [7].

Using these systems allows instructors to:

- conduct remote lab work online;
- create interactive tests and assignments with visualization;
- demonstrate real-world finite element analysis (FEA) calculations on-screen;
- evaluate students' results automatically.

An example is students working with SolidWorks Simulation, where they model the stress state of a rod under various loads. The results are displayed as a stress graph, displacement diagram, and color map of the deformations.

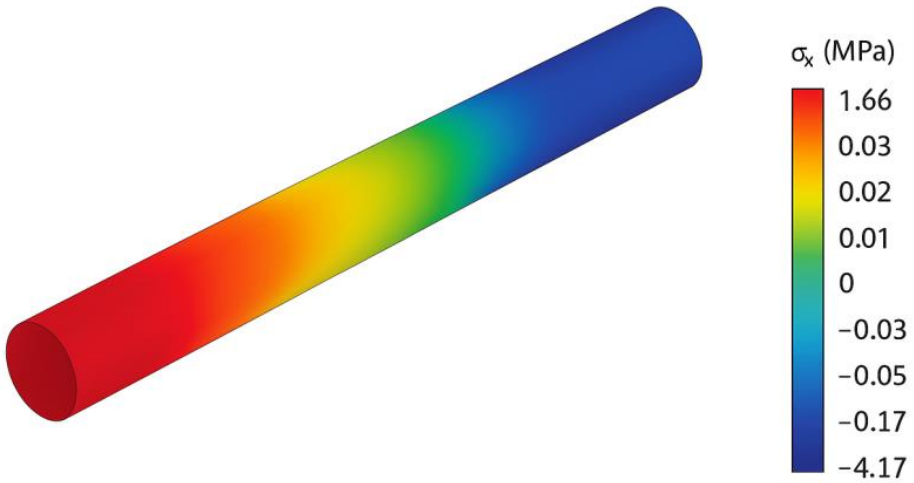


Figure 4. Example of stress analysis in a rod in SolidWorks Simulation.

Thus, the digitalization of engineering education opens up opportunities not only for the individualization of learning, but also for the creation of an interactive environment in which theory, practice, and modeling are combined into a single knowledge system.

Results of the Pedagogical Experiment

During the 2024–2025 academic year, a pedagogical experiment was conducted at the Department of Electrical Engineering and Power Engineering at Urgench State University.

Two groups of students participated:

- Control group (traditional methodology) — training was conducted in the traditional format (lectures + practical classes).
- Experimental group (digital methodology) — training was conducted using virtual laboratories and 3D visualization.

After completing the course, student performance, calculation accuracy, and motivation were analyzed. The results are presented below:

Chart 1. Comparison of student performance before and after the introduction of digital technologies.

Indicator	Traditional group	Digital group	Change (%)
Average grade for the course	72	87	+21 %
Calculation errors	18 %	1.5 %	–17 %
Motivating students	60 %	90 %	+30 %

The results clearly demonstrate that the introduction of digital technologies improves learning efficiency, reduces the number of errors, and creates a lasting interest in engineering disciplines.

Conclusion

The course "Strength of Materials" should be taught using a combination of traditional teaching methods (lectures, practical assignments) and modern digital technologies (virtual laboratories, modeling, visualization).

Integrating digital tools into the educational process:

- makes learning more visual and interactive;
- increases student motivation and independence;
- ensures a practical focus for engineering education.

In the long term, it is advisable to develop:

- the integration of FEA (Finite Element Analysis) courses into curricula;
- the creation of national online platforms for engineering mechanics;
- the exchange of experience between universities in the field of digitalization of technical education.

References:

[1] Timoshenko S.P. "Strength of Materials," Moscow: *Science*, 2014.
[2] Pisarenko G.S., Yakovlev A.P., Matveev V.V. "Strength of materials," Kiev: *Higher School*, 2010.
[3] Popov E.P. "Mechanics of Materials," New York: *Prentice Hall*, 2018.
[4] Ashby M., Jones D. "Engineering Materials: An Introduction to Properties, Applications and Design," *Oxford University Press*, 2020.
[5] Zienkiewicz O.C., Taylor R.L. "The Finite Element Method," *Butterworth-Heinemann*, 2013.
[6] Aliyev R., Kurbanov A. "Integration of Virtual Laboratories in Mechanical Engineering Education," *Journal of Technical Education and Training*, 2021.
[7] Davletov I.Yu., Axmedov M. "Modern Methods of Teaching Technical Mechanics Using Virtual Laboratories," *Urgench State University Proceedings*, 2024.
[8] Sapayev U., Axmedov M. "Effectiveness of Interactive Visualization in Teaching Strength of Materials," *UrSU Scientific Bulletin*, 2025.
[9] Li J., Wang Z. "Effectiveness of Visual Learning Tools in Engineering Education," *Journal of Engineering Education*, 2021.
[10] Mulyukov R.A., Karimov I.I. "Digital Transformation of Engineering Education in Uzbekistan," *Education and Science Journal*, 2023.

UDC: 37, 37.01./09, 373

METHOD OF USING BLENDED EDUCATIONAL TECHNOLOGY IN ORGANIZING PRACTICAL TRAINING IN HIGHER EDUCATIONAL INSTITUTIONS

Saidova Nilufar Ruzimurotovna
Associate Professor, Navoi Innovation University
snilufar361@gmail.com

Annotatsiya. Ushbu maqolada bo‘lajak boshlang‘ich sinf o‘qutuvchilarini tayyorlashda o‘qitiladigan kasbiy fanlardan amaliy mashg‘ulotlarni tashkil etish muammolari va ularning yechimlariga doir tahliliy ma’lumotlar keltirilgan. Shuningdek, oliy ta’lim muassasalarida amaliy mashg‘ulotlarni tashkil etishga oid tadqiqotchi-olimlarning ishlari tahlil etilgan. Shu bilan birga mazkur maqolada bo‘lajak boshlang‘ich sinf o‘qutuvchilarini tayyorlashda o‘qitiladigan kasbiy fanlardan amaliy mashg‘ulotlarni aralash ta’lim texnologiyasi asosida tashkil etish tuzilmasi ishlab chiqilgan va undan foydalanishga oid takliflar berib o‘tilgan. Ushbu tuzilmani samaradorligini aniqlash bo‘yicha pedagogik tajriba-sinov ishlari olib borilgan, hamda uning ishonchlilik darajasi Styudent-Fisher kriteriyasidan foydalanib isbotlangan.

Kalit so‘zlar: *aralash ta’lim, Rotatsion model, bulutli texnologiya, platforma, tuzilma, ta’lim muhiti, tajriba-sinov, Styudent-Fisher.*

Аннотация. В данной статье представлена аналитическая информация о проблемах организации практических занятий по профессиональным дисциплинам, преподаваемым при подготовке будущих учителей начальных классов, и их решениях. Также проанализированы работы ученых-исследователей по организации практических занятий в высших учебных заведениях. Вместе с тем, в данной статье разработана структура организации практических занятий по профессиональным дисциплинам, преподаваемым при подготовке будущих учителей начальных классов, на основе технологии смешанного обучения и даны предложения по ее использованию. Были проведены педагогические эксперименты по определению эффективности данной структуры, а уровень ее надежности был доказан с использованием критерия Стьюдента-Фишера.

Ключевые слова: *смешанное обучение, Ротационная модель, облачная технология, платформа, структура, образовательная среда, эксперимент, Стьюдент-Фишер.*

Abstract. This article presents analytical information on the problems of organizing practical classes in professional disciplines taught in the training of future primary school teachers and their solutions. Also, the works of research scientists on the organization of practical classes in higher educational institutions were analyzed. At the same time, this article develops a structure for organizing practical classes in professional disciplines taught in the training of future primary school teachers based on blended learning technology and provides

recommendations for its use. Pedagogical experimental work was carried out to determine the effectiveness of this structure, and its level of reliability was proven using the Student-Fisher criterion.

Keywords: *blended learning, Rotational model, cloud technology, platform, structure, learning environment, experiment, Student-Fisher.*

Introduction

In combination with lectures conducted in higher educational institutions, practical classes perform educational, upbringing, and connecting theory with practice functions [1]. One of the main features that distinguishes practical classes from lectures is the efforts of participants in the educational and upbringing process to achieve joint learning objectives [2]. If the lecture sets out the foundations of scientific knowledge, the knowledge acquired by students in practical classes is reinforced, simple concepts are transformed into practical skills, expanded, and the possibility of application in new, unexpected situations is created. Also, practical classes serve to consolidate students' knowledge, apply it in practice, monitor and evaluate it. Therefore, it is necessary to develop modern approaches to the organization of practical classes in professional disciplines in the training of future teachers, including future primary school teachers, in higher educational institutions.

In the proposed research, special attention is paid to this issue in the training of future primary school teac-hers.

Literature Review

Research on the theory and practice of organizing practical classes in higher educational institutions was carried out by such scientists as Mirsanov U.M., Shodiev Kh.R., Shapapova G.V., and Zhuravle V.V. [2-5]. In their opinion, various forms of practical classes are the main part of the educational load of higher educational institutions, providing a method of reproductive education that ensures the connection between theory and practice. It also pursues the following goals:

- contributes to the formation of students' skills and abilities in applying the knowledge gained during lectures and independent work;
- teaches students to solve practical problems, helps them acquire skills and abilities in performing calculations, graphic and other types of tasks;
- directs the use of scientific and methodological literature;
- ensures the formation of the ability to independently acquire knowledge, the ability to master methods of self-learning, development, and control.

It should be remembered that in the system of vocational training of students, lectures provide theoretical information, while practical classes and independent study perform the function of connecting students’ theory with practice [3]. According to Bakhodirova U.B. and Nikadambayeva H.B., practical classes, as a rule, are aimed at solving various practical problems, examples of which are given in lectures [6, 7]. As a result, students must form a certain professional approach to solving each problem. "In this regard, when organizing personnel training in higher educational institutions, it is important to determine how many and what types of assignments are needed, to regulate them in a timely manner in the studied course, and to reinforce independent learning assignments. According to him, when choosing a system of exercises and

assignments for practical training, the professor-teacher strives to ensure a holistic view of the subject and methods of the studied subject, in which the methodological function plays a leading role. According to Norbekov A.O. [8], the sequence of lectures and practical exercises plays an important role in the education system. A lecture is the first stage in preparing students for practical classes. That is, the problem posed in the lecture will have a clear expression and solution in the practical lesson. Although each practical lesson is a traditionally developing, reinforcing lesson, it also actively performs the tasks of a preparatory lesson for the subsequent active perception of the lecture [3].

Thus, in the training of future primary school teachers, lectures and practical classes in professional disciplines should not only strictly alternate in time, but also be methodologically connected with the problem situation. The lecture should prepare students for the practical lesson, and the practical lesson for the next lecture. In the effective organization of such tasks, it is advisable to use blended learning technology.

Research Methodology

According to the analysis of our research, today in the training of future primary school teachers in higher educational institutions, paying special attention to practical classes in professional disciplines remains one of the important issues. For this purpose, it is necessary to improve the system of organizing practical classes in professional disciplines in the training of future primary school teachers.

The proposed research is also aimed at these issues, namely, the use of blended learning technology in the organization of practical classes in professional disciplines in the training of future primary school teachers in higher educational institutions. Therefore, within the framework of the study, the structure of the organization of practical classes in professional disciplines in the training of future primary school teachers was improved (see Figure 1).

This proposed structure involves the use of the Rotation model of blended learning technology in organizing practical training in vocational subjects in the training of future primary school teachers:

- exchange of methods of working with materials during the transition of the curriculum;
- study time is divided between individual e-learning and training in the classroom with distance learning support for e-learning;
- classroom exchange: exchanging methods of studying educational material, using e-learning, participating in groups of students or individually, according to a set schedule or at the request of the professor-educator.

The organization of practical training based on the Rotation model of blended learning technology is aimed at using cloud-based learning environments, educational platforms and pinboard, assessment teaching methods in two stages. The first stage proposes the use of three sub-stages. Each of these stages proposes the use of four different levels of tasks: reproductive; productive; partially exploratory; creative. The second stage of the structure is aimed at assessing the results of future primary school teachers.

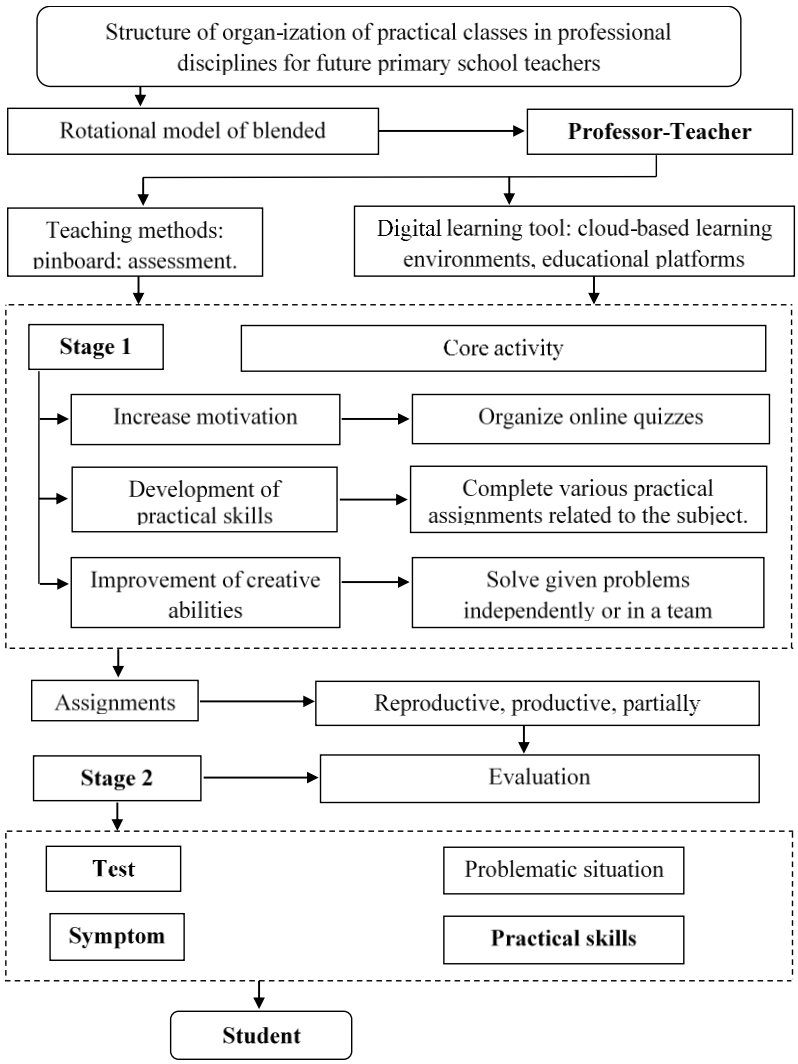


Figure 1. Structure of organizing practical training in vocational subjects for future primary school teachers.

Analysis and Results

In order to determine the level of effectiveness of the proposed structure, pedagogical experimental work was conducted. Pedagogical experimental work Future primary school teachers were recruited at Navoi State University and divided into experimental (29) and control (30) groups. When dividing future primary school teachers into experimental and control groups, the level of knowledge was uniform. Their results are presented in Table 1 below.

Table 1. Indicators of future primary school teachers at the beginning of the experiment.

Experiment group					**Control group**				
Total number of prospective primary school teachers	5 (excellent)	4 (good)	3 (satisfactory)	2 (unsatisfactory)	Total number of prospective primary school teachers	5 (excellent)	4 (good)	3 (satisfactory)	2 (unsatisfactory)
29	**3**	**9**	**15**	**2**	**30**	**3**	**10**	**15**	**2**

The dynamics of mastering the results of future primary school teachers in this Table 1 are presented below (see Figure 2):

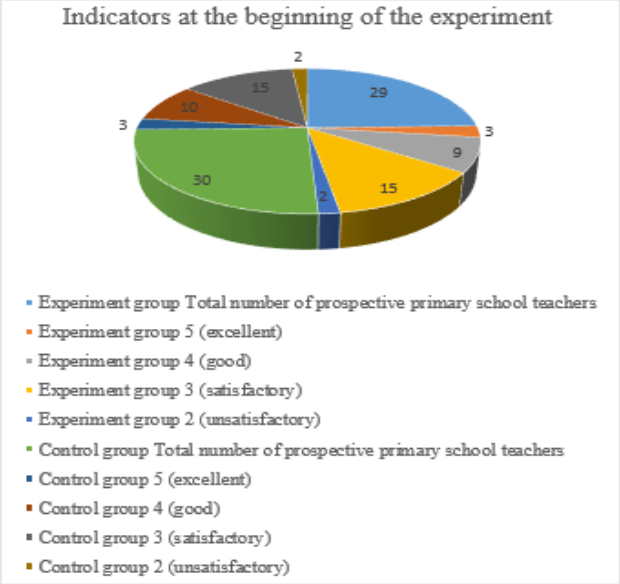


Figure 2. Indicators of future primary school teachers at the beginning of the experiment.

The results of the prospective primary school teachers involved in this pilot study were analyzed and mathematically and statistically analyzed based on the Student-Fisher criterion to verify their reliability. Using this criterion, suitable mean values for the samples were $\overline{X} = \frac{1}{n}\sum_{i=1}^{4} n_i X_i$, dispersion coefficients $D_n = \sum_{i=1}^{4} \frac{n_i (x_i - \overline{X})^2}{n-1}$. The mastery indicators were calculated using the formula. According to the calculation results, it was found that the results of future primary school teachers in the experimental and control groups were almost the same.

In the next stage of the experimental work, the prospective primary school teachers allocated to the experimental group were given practical training in vocational subjects using the structure proposed in the research. The control group was not given this opportunity. At the end of the experiment, the prospective primary school teachers achieved the following results (see Table 2).

Table 2. Performances of prospective primary school teachers at the end of the experiment.

Experiment group					**Control group**				
Total number of prospective primary school teachers	5 (excellent)	4 (good)	3 (satisfactory)	2 (unsatisfactory)	Total number of prospective primary school teachers	5 (excellent)	4 (good)	3 (satisfactory)	2 (unsatisfactory)
29	**5**	**17**	**7**	**0**	**30**	**3**	**11**	**14**	**2**

The dynamics of the assimilation of the results presented in Table 2 are presented below (see Figure 3):

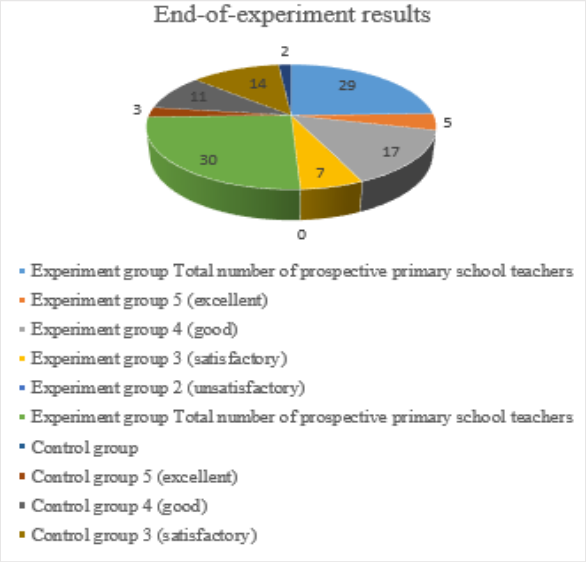


Figure 3. Performance of prospective primary school teachers at the end of the experiment.

The numerical data presented in Table 2 were calculated based on the formulas given above. According to the calculation results, it turned out that the average mastery index of the experimental group was higher than that of the control group, that is, it increased by 10.8%.

Conclusion

Thus, it is proposed to use the structure proposed in the framework of the study in organizing practical training in professional disciplines taught in the training of future primary school teachers. The main idea of the proposed structure is to use blended learning technology in organizing practical training. Organizing practical training based on this technology is effective in increasing the motivation of future primary school teachers in the subject and developing their professional competence.

References:

[1] Shodiyev H.R. “Method of organizing online quizzes from practical exercises in geography,” *Electronic education*, Navoi, № 1, 2023, pp. 55-64.

[2] Mirsanov U.M. “Improving the methodology of teaching programming technologies in the system of continuous education,” *Dissertation prepared for the degree of Doctor of Pedagogical Sciences (DSc.)*, Navoi, 2023, p. 332.

[3] Shodiev H.R. “Improving the methodology of using information learning environments in teaching geography in the system of continuous education,” *Dissertation for the degree of Doctor of Pedagogical Sciences (DSc)*, Navoi, 2024, p. 274.

[4] Shapapova G.V. “Improvement of the method of using electronic educational equipment to increase the effectiveness of teaching immunology (pedagogical higher education muaccalapi micoli),” *Doctoral thesis on pedagogical science (PhD) dictation intended to obtain a scientific degree*. Tashkent, 2022, p. 153.

[5] Zhuravlev V.V. “Didactic features of organizing practical classes at the university,” *Modern higher education: innovative aspect*. № 1, 2008, pp. 48-54.

[6] Bakhodirova U.B. “Improving the methodology of using virtual educational technologies in teaching microbiology (on the example of higher educational institutions of pedagogy),” *Dissertation prepared for the degree of Doctor of Philosophy (PhD) in Pedagogical Sciences*. Karshi, 2020, p. 156.

[7] Nikadambaeva H.B. “Methodology of using computer technologies in teaching the subject “Natural geography of Uzbekistan” (on the example of higher education),” *Dissertation written for the degree of Candidate of Pedagogical Sciences*. Tashkent, 2012, p. 223.
[8] Norbekov A.O. “Methods for increasing the effectiveness of teaching computer science in higher educational institutions of pedagogy,” *Dissertation prepared for the degree of Doctor of Philosophy (PhD) in Pedagogical Sciences*. Navoi, 2021, p. 171.

UDC: 37, 004.04, 378, 62

INNOVATIVE TECHNOLOGIES IN TEACHING THEORETICAL MECHANICS: THE EXPERIENCE OF RUSSIAN UNIVERSITIES

Stepanovich Ekaterina Yurievna
Astrakhan State University

Bekiev Murat Atabekovich
Senior Lecturer, Urgench State University named after Abu Rayhan Biruni
bekiyevmurod@gmail.com

Kholmuratov Kholilla Sarievich
Senior Lecturer, Urgench State University named after Abu Rayhan Biruni

Annotatsiya. Ushbu maqolada Rossiya Federatsiyasidagi oliy ta’lim muassasalarida nazariy mexanikani o‘qitishning zamonaviy innovatsion yondashuvlari o‘rganiladi. Unda yangi raqamli vositalar, virtual laboratoriyalar, mobil ilovalar va ta’lim platformalarini integratsiyalash orqali ta’lim sifatini oshirishning samarali usullari o‘rganiladi. Ikki yirik mintaqaviy universitet: Urganch davlat universiteti va Astraxan davlat universiteti tajribasiga alohida e’tibor qaratiladi. Qo‘llaniladigan usullarning afzalliklari va kamchiliklari tahlil qilinadi va innovatsion pedagogik texnologiyalarni o‘quv jarayoniga joriy etish bo‘yicha tavsiyalar taklif etiladi.

Kalit so‘zlar: *nazariy mexanika, ta’lim, innovatsion texnologiyalar, virtual laboratoriyalar, mobil ilovalar, ta’lim platformasi, o‘quv-metodik kompleks, pedagogik mahorat, talabalarning motivatsiyasi, ta’lim sifati.*

Аннотация. Статья посвящена исследованию современных инновационных подходов к обучению теоретической механике в высших учебных заведениях Российской Федерации. Рассматриваются эффективные методы повышения качества образования посредством интеграции новых цифровых инструментов, виртуальных лабораторий, мобильных приложений и образовательных платформ. Особое внимание уделено опыту двух крупных региональных университетов: Ургенчского государственного университета и Астраханского государственного университета. Анализируются преимущества и недостатки используемых методик, предлагаются рекомендации по внедрению инновационных педагогических технологий в учебный процесс.

Ключевые слова: *теоретическая механика, образование, инновационные технологии, виртуальные лаборатории, мобильные приложения,*

образовательная платформа, учебно-методический комплекс, педагогическое мастерство, мотивация студентов, качество образования.

Abstract. This article explores modern innovative approaches to teaching theoretical mechanics in higher education institutions in the Russian Federation. It examines effective methods for improving the quality of education through the integration of new digital tools, virtual laboratories, mobile applications, and educational platforms. Particular attention is paid to the experience of two large regional universities: Urgench State University and Astrakhan State University. The advantages and disadvantages of the methods used are analyzed, and recommendations for the implementation of innovative pedagogical technologies in the educational process are offered.

Keywords: theoretical mechanics, education, innovative technologies, virtual laboratories, mobile applications, educational platform, teaching and methodological complex, pedagogical skills, student motivation, quality of education.

Introduction

Teaching theoretical mechanics traditionally faces a number of challenges due to the abstract nature and complexity of the concepts covered. Despite the importance of the subject for future engineers and researchers, many students struggle to grasp the fundamentals of solid, fluid, and gas mechanics. Therefore, finding ways to improve teaching methods to make the learning process more effective and engaging for young people is becoming increasingly important.

This article attempts to systematize and summarize the experience of leading Russian universities using innovative pedagogical tools and digital technologies in teaching mechanics. The primary goal of the study is to identify the most effective ways to increase student interest in mechanics and improve the overall quality of teaching.

The study is based on an analysis of the experience of Urgench State University (USU) and Astrakhan State University (ASU). These institutions were chosen because they represent different regions of Russia and have demonstrated significant success in implementing the latest educational technologies.

Furthermore, the authors sought to offer specific recommendations for improving the educational process, based on the identified principles and methods. The findings will be useful to educators and specialists working to improve the quality of higher technical education.

Research Methodology

To achieve the stated objectives, a comprehensive study was conducted, including an analysis of existing literature, observation of the educational process, interviews with teachers and students, and an evaluation of the effectiveness of the methods used.

The main research methods were: examining domestic and international publications on innovative technologies in education; attending classes and analyzing the current state of the educational process; surveying faculty and students to identify their opinions and preferences regarding the tools used; and comparative analysis of the

academic performance of students who completed their education traditionally and using innovative technologies.

The selection of research objects was based on the experience of successfully implementing innovative methods and the willingness of the university administration to support research initiatives.

Analysis and Results

Urgench State University's Experience. Urgench State University is located in the Republic of Uzbekistan, but it has close scientific and cultural ties with Russian education. Many USU faculty have completed internships at Russian universities, adopting best practices and implementing them in their work.

The study focused on the following aspects:

Virtual Laboratories. UrSU currently has successfully operating virtual laboratories in physics and mechanics. These laboratories are equipped with specialized software that allows for the modeling of physical processes and the experimental testing of hypotheses. The advantages of virtual laboratories include:

- accessibility - each student can independently conduct as many experiments as they need, without time or resource constraints;
- safety - eliminating the risk of damaging expensive equipment or injuring students;
- flexibility - the ability to customize experimental conditions to meet the individual needs of each student.

However, the use of virtual laboratories requires appropriate technical infrastructure and constant software updates, which creates additional costs for the university.

Online Courses and Distance Learning. Another important initiative by Ural State University (USU) was the creation of its own distance learning platform, integrated with the LMS Moodle content management system. The platform provides access to lectures, assignments, and quizzes for self-study in the theoretical mechanics course.

The effectiveness of this model has been rated positively, especially among senior students, who value the opportunity to plan their time flexibly and receive an individualized approach to learning.

However, the introduction of online learning elements required additional attention to content quality control and regular updating of materials to maintain a high level of course appeal.

New Generation Textbooks and Manuals. The development of educational literature using multimedia technologies has significantly improved students' understanding of complex topics in mechanics. New publications include interactive diagrams, videos, and illustrations that facilitate the understanding and retention of the basic principles of mechanical motion.

These changes led to a significant increase in the popularity of textbooks among students and an increase in the average score in the theoretical mechanics examination session.

Astrakhan State University's Practice. Astrakhan State University is actively developing innovative teaching formats for mechanics. The following areas of work are highlighted:

- *Project-Based Activities*. One of the key features of ASU is the active involvement of students in research activities through participation in team projects. This form of education allows students to acquire practical teamwork skills and learn to apply their acquired knowledge in real-world engineering practice.

For example, student research project competitions are held annually, where teams tackle real-life problems facing businesses in Astrakhan. The best projects receive grants for further development and support from the university administration.

This approach promotes the development of professional competencies required by future engineers, while simultaneously enhancing the university's prestige among employers.

- *Electronic Learning Support Tools*. Integrating electronic resources into teachers' daily work has become a widespread practice at ASU. Each lesson is accompanied by an electronic presentation containing illustrative material and supporting exercises.

Electronic materials are stored in the university's unified information system, accessible to students 24/7. This minimizes the workload for faculty and increases the transparency of the educational process.

It is important to note that this practice requires constantly updating the database, maintaining a high level of quality of the content created, and respecting intellectual property rights.

- *Developing Critical Thinking*. Particular attention is paid to developing students' abilities to analyze and solve non-standard problems. Special courses and seminars have been developed to foster critical thinking skills.

Examples of such events include problem-solving competitions, brainstorming sessions, and creative workshops. Such events encourage students' cognitive activity and help them gain self-confidence.

This approach is justified by the high level of satisfaction among graduates with the quality of the education they received and the demand for young specialists in the labour market.

General Trends in the Development of Innovative Technologies in the Teaching of Mechanics. Having examined the experience of Ural State University and Arkhangelsk State University, we can identify a number of general trends characteristic of modern Russian education:

- Increased use of e-learning and distance learning formats for student-teacher interaction.
- Expanded opportunities for self-education and individualized learning paths.
- Increased student interest in actively participating in learning through project-based activities and research projects.
- Growing role of information and communication technologies in maintaining the quality of the educational process.

At the same time, serious challenges arise related to the need for continuous adaptation of teaching staff to new working conditions, increased requirements for the quality of the preparation of educational materials, and ensuring the availability of technological solutions for all categories of students.

Recommendations for the Further Development of Innovative Technologies. To continue the successful implementation of innovative technologies in the teaching of theoretical mechanics, the following is proposed:

1. Regularly update virtual laboratory software and electronic resources used in the educational process.
2. Improve the qualifications of faculty by conducting specialized courses and training on new technologies.
3. Create conditions for regular exchange of experience between faculty from different regions and countries by organizing conferences and webinars.
4. Stimulate student research activity by encouraging participation in competitions and exhibitions of young scientists' achievements.
5. Integrate traditional teaching methods with modern technologies, ensuring a balance between classical approaches and innovative tools.

Implementation of the proposed recommendations will create favorable conditions for further progress in the teaching of theoretical mechanics and ensure the competitiveness of Russian universities in the international arena.

Conclusion

The study demonstrated the significant importance of innovative technologies in improving the quality of teaching theoretical mechanics. A study of the experience of Urgench and Astrakhan State Universities revealed a number of successful practices applicable to a wide range of Russian universities.

Further development must take into account the specifics of the region, labor market needs, and changes in the educational environment. Only in this way can we ensure the training of highly qualified personnel prepared to effectively address the challenges of modern science and technology.

References:

[1] Timoshenko S.P. “Strength of Materials,” Moscow: *Science*, 2014.
[2] Pisarenko G.S., Yakovlev A.P., Matveev V.V. “Strength of materials,” Kyiv: *Higher School*, 2010.
[3] Popov E.P. “Mechanics of Materials,” New York: *Prentice Hall*, 2018.
[4] Ashby M., Jones D. “Engineering Materials: An Introduction to Properties, Applications and Design,” *Oxford University Press*, 2020.
[5] Zienkiewicz O.C., Taylor R.L. “The Finite Element Method,” *Butterworth-Heinemann*, 2013.
[6] Aliyev R., Kurbanov A. “Integration of Virtual Laboratories in Mechanical Engineering Education,” *Journal of Technical Education and Training*, 2021.
[7] Davletov I.Yu., Axmedov M. “Modern Methods of Teaching Technical Mechanics Using Virtual Laboratories,” *Urgench State University Proceedings*, 2024.
[8] Sapayev U., Axmedov M. “Effectiveness of Interactive Visualization in Teaching Strength of Materials,” *UrSU Scientific Bulletin*, 2025.
[9] Li J., Wang Z. “Effectiveness of Visual Learning Tools in Engineering Education,” *Journal of Engineering Education*, 2021.
[10] Mulyukov R.A., Karimov I.I. “Digital Transformation of Engineering Education in Uzbekistan,” *Education and Science Journal*, 2023.

UDC: 338.48

PERSPECTIVES ON THE DEVELOPMENT OF INNOVATIVE ACTIVITIES OF ENTERPRISES IN THE CONTEXT OF THE DIGITAL ECONOMY

Babaxanova Dildora Rustamovna
Senior Teacher, Department of Economics and Management, Sphere of ICT, Tashkent University of Information Technologies
babakhanovadildora30@gmail.com
With the review of professor, Tashkent University of Information Technologies Akromova Gulnora Abduvaxidovna

Annotatsiya. Raqamli iqtisodiyot davrida korxonalarda innovatsion faoliyatni rivojlantirish barqaror iqtisodiy o‘sishning muhim omillaridan biridir. Ushbu maqolada O‘zbekistonda raqamlashtirish va ochiq innovatsion ekotizimlarni rivojlantirish istiqbollari tahlil qilinadi, shuningdek, Estoniya va Singapur kabi davlatlarning xalqaro tajribalari keltiriladi. Tadqiqot raqamli platformalar, sun’iy intellekt tahlillari, aqlli ishlab chiqarish tizimlari va inson kapitalini rivojlantirish orqali ishlab chiqarish samaradorligini oshirish, xarajatlarni kamaytirish va raqobatbardoshlikni kuchaytirishdagi rolini yoritadi. Jadvallar ekotizim integratsiyasi va hamkorlikka asoslangan innovatsiyaning kutilayotgan natijalarini ko‘rsatadi. Tadqiqot natijasida raqamlashtirish nafaqat texnologik jarayon, balki uzoq muddatli barqarorlik va global raqamli bozorga integratsiyani ta’minlovchi strategik yo‘nalish ekani ta’kidlanadi.

Kalit so‘zlar: *raqamli iqtisodiyot, innovatsion ekotizim, korxona rivoji, raqamlashtirish, inson kapitali, O‘zbekiston, mehnat unumdorligi.*

Аннотация. В эпоху цифровой экономики развитие инновационной деятельности предприятий становится ключевым фактором устойчивого экономического роста. В статье рассматриваются перспективы цифровизации и формирования открытых инновационных экосистем в Узбекистане с опорой на отечественный опыт и международные практики таких стран, как Эстония и Сингапур. Исследование подчеркивает роль цифровых платформ, аналитики на основе ИИ, “умного” производства и развития человеческого капитала в повышении производительности, снижении затрат и росте конкурентоспособности. Таблицы иллюстрируют ожидаемые эффекты интеграции экосистем и совместных инноваций. Результаты показывают, что цифровизация — это не просто технологический процесс, а стратегический подход, обеспечивающий долгосрочную устойчивость предприятий, их адаптивность и интеграцию в глобальные цифровые рынки.

Ключевые слова: *цифровая экономика, инновационная экосистема, развитие предприятий, цифровизация, человеческий капитал, Узбекистан, производительность.*

Abstract. In the era of the digital economy, fostering innovative activity in enterprises has become a crucial factor for sustainable economic growth. This article explores the prospects of digitalization and the development of open innovation ecosystems in Uzbekistan, drawing on local examples and international practices from countries such as Estonia and Singapore. The study emphasizes the role of digital platforms, AI analytics, smart production, and human capital development in enhancing productivity, reducing costs, and increasing competitiveness. Tables illustrate the expected effects of ecosystem integration and collaborative innovation. The findings highlight that digitalization is not merely a technological process, but a strategic approach ensuring long-term enterprise sustainability, resilience, and integration into global digital markets.

Keywords: *digital economy, innovation ecosystem, enterprise development, digitalization, human capital, Uzbekistan, productivity.*

Introduction

Prospects of Digitalization for the Innovative Development of Enterprises in Uzbekistan. Digitalization in Uzbekistan is gradually becoming a key driver of the renewal of the entire economic system. It ceases to be merely a process of implementing technologies and transforms into a strategic growth mechanism that generates new sources of innovation, employment, and export potential. The national program *Digital Uzbekistan 2030* has established that digital transformation should serve as the foundation for enhancing the competitiveness of enterprises and stimulating innovative activity.[2] One of the most promising directions is the expansion of digital services exports. Thanks to IT infrastructure and platforms developed within the framework of IT Park Uzbekistan, local companies are increasingly entering foreign markets: in 2024 alone, the number of exporting companies grew by 70%, covering over 70 countries.[3] This provides a sustainable basis for scaling innovations, as digital products and services do not require significant logistics costs and can compete on an equal footing with global companies.

Another significant prospect lies in the adoption of artificial intelligence and data analytics in production and management processes. These technologies enable enterprises to predict demand, optimize resource usage, and create personalized products. In the long term, this will lead to new business models based on data and subscription services, as well as increased profitability and faster innovation cycles.

At the same time, a network of regional digital clusters and technoparks is forming, transforming individual initiatives into an ecosystem of interconnected participants — startups, research centers, investors, and corporate clients. IT Park and its regional branches are already functioning as centers attracting talent and facilitating knowledge exchange.[4] Such development enhances horizontal connections, accelerates the diffusion of technologies, and stimulates joint innovation projects. Human capital plays a particularly important role. Digital literacy and inclusion programs implemented with the support of the World Bank under the *Uzbekistan Digital Inclusion Project*

[2] https://www.gov.uz/en/activity_page/digital_technology
[3] https://www.kun.uz/en/news/2024/10/29/uzbekistan-sees-70-surge-in-it-service-exporters-over-nine-months
[4] https://www.uzdaily.uz/en/it-park-uzbekistan-summed-up-its-work-for-2023/

(P179108) aim to improve digital skills, especially among youth and women. This forms a foundation for long-term innovative growth: when digital skills become widespread, innovations cease to be the privilege of a few companies and become part of the economic culture. Digitalization also opens the way for the transition of industry and agriculture to "smart" production models. The Internet of Things, predictive analytics, and digital twins allow enterprises to optimize production chains, improve product quality, and reduce costs. This is particularly relevant for export-oriented enterprises, where standards of quality and energy efficiency are becoming key requirements. The prospects of sustainable development link digitalization with green technologies. Using digital tools to monitor energy consumption, manage waste, and control CO_2 emissions becomes a new source of competitive advantage for enterprises aiming to meet ESG standards. Support for such initiatives from the government and private investors strengthens Uzbekistan's image as a country capable of combining innovation with sustainability. Digitalization for the country's enterprises is not merely about modernizing production, but about transitioning to a new type of economic thinking. It unites export, innovation, education, and sustainability into a single growth strategy. While today the main focus is on building digital infrastructure, in the coming years the key task will be the development of an open innovation ecosystem, in which the private sector, government, universities, and international partners act as a unified system. This perspective — moving toward an ecosystem-based innovation model — leads naturally into the next section of the study.

The developing digital infrastructure provides the foundation for the next stage — the formation of an open innovation ecosystem, where interactions among businesses, academia, government, and international partners become the main source of growth. Uzbekistan is gradually moving toward this model: digital hubs, technoparks, and acceleration programs are emerging, and incentives for collaboration between universities and the private sector are being created. However, the real prospects lie not only in infrastructure but in establishing a coherent system where innovations spread horizontally rather than top-down.

The experience of countries that have successfully built innovation ecosystems shows that openness and digital connectivity are decisive factors. Estonia, for example, through the *e-Estonia* initiative, managed to integrate public and private services on a unified platform, X-Road, ensuring fast data exchange between companies, agencies, and citizens.[5] This has created a space where startups can develop solutions fully integrated into national digital systems. For Uzbekistan, a similar prospect is especially significant: developing domestic API platforms, secure data exchange, and digital identifiers will allow companies to create innovative products compatible with government and banking services. Another example is Singapore, where through the *Smart Nation* initiatives and the Monetary Authority of Singapore's regulatory sandboxes, an environment was created for testing fintech innovations without excessive barriers.[6] This model demonstrates that regulation can accelerate rather than hinder innovation. For Uzbekistan, the prospect of creating such "digital sandboxes" is

[5] https://e-estonia.com/solutions/interoperability-services/x-road/
[6] https://www.mas.gov.sg/schemes-and-initiatives/fintech-regulatory-sandbox

particularly important in the financial, logistics, and healthcare sectors, where safe testing of new solutions is required before they are scaled to the market.

The formation of an open innovation ecosystem also has an educational dimension. Universities and research centers can serve as platforms for collaboration with businesses, creating joint laboratories and accelerators. In the long term, this will lead to the emergence of new science and technology clusters where ideas are rapidly turned into commercial solutions. Already under the *Digital Uzbekistan 2030* initiative, digital competence centers are being established, and in partnership with IT Park, programs are implemented to train young specialists for the IT sector.[7]

The prospects of the ecosystem approach can be illustrated by the expected effects that arise from increased interconnections among innovation participants:

Ecosystem Development Direction	**Potential Innovation Effect for Enterprises**	**Example of International Practice**
Integration of digital platforms and APIs between businesses and government	Faster market deployment of digital solutions; lower transaction barriers	Estonia — X-Road [8]
Regulatory sandboxes and flexible rules for startups	Faster innovation testing and investment attraction	Singapore — MAS Sandbox [9]
Corporate-university accelerators	Increase in commercially applicable scientific developments	Finland — Aalto Innovation Hub
Development of regional digital hubs	Expansion of innovation activity beyond the capital	Uzbekistan — IT Park branches [10]
International partnerships and grant programs	Increased export potential and knowledge exchange	World Bank — Digital Inclusion Project

Such a structure allows for the creation of not merely a network of organizations, but an interdependent ecosystem where each company becomes part of the overall innovation process. In this context, the role of the government as a coordinator and platform provider, rather than a sole initiator, is crucial. If Uzbekistan succeeds in combining corporate initiatives, academic resources, and international cooperation into a unified digital architecture, the country can move from the phase of digitalization to the phase of sustainable innovative growth. In the long-term perspective, this implies the emergence of a new economic model where innovations cease to be occasional projects and become a natural result of the everyday digital activity of enterprises. Only then can we speak of a mature digital ecosystem capable of ensuring sustainable economic growth, the export of intellectual products, and global competitiveness. Gradually, the transition from individual digital initiatives to a fully formed innovation ecosystem creates the conditions for sustainable economic growth, where knowledge, technology, and collaboration become the main sources of added value. This transformation does not happen instantly — it requires not only technological maturity but also institutional resilience, meaning the economy's ability to maintain innovation momentum even amid external changes.

[7] https://www.gov.uz/en/activity_page/digital_technology
[8] https://e-estonia.com
[9] https://www.mas.gov.sg
[10] https://www.uzdaily.uz/en/it-park-uzbekistan-summed-up-its-work-for-2023/

One of the main prospects for enterprises is the development of a data-driven economy. In the coming years, the volume of data generated in Uzbekistan will grow exponentially, and the ability to analyze it will become a valuable asset in its own right. In this sense, companies capable of managing data and turning it into forecasts, products, and services will occupy leading positions. Global experience already shows similar trends: according to the *OECD Digital Economy Outlook*,[11] companies investing in analytics and artificial intelligence increase productivity 20–30% faster than industry peers. For Uzbekistan, this implies that fostering analytical infrastructure and open data should be a priority direction of national policy. Equally important is the shift toward digital resilience — the ability of enterprises to adapt to technological changes without losing efficiency. This process includes the development of cybersecurity, digital ethics, resilient cloud solutions, and mechanisms for managing digital risks. Such an orientation toward resilience is already reflected in several international strategies, such as the *EU Digital Decade 2030*,[12] and can serve as a guideline for Uzbekistan's national programs aimed at balancing innovation with security. Simultaneously, the understanding of enterprise competitiveness is evolving. Whereas competitiveness was previously determined by the level of automation or innovation in products, it is now defined by the degree of integration into global digital value chains. The prospect here involves moving from being a service exporter to an active participant in international digital markets. This requires the development of cross-border platforms, the use of blockchain technologies for supply chain transparency, and the creation of digital certificates of origin, which is especially relevant for agriculture and the textile sector in the country.[13]

Thus, a model is emerging in which digitalization and innovation are not one-time projects but the basic logic of economic functioning. The prospects for further growth lie in moving from simple technology adoption to systemic integration of digital tools into production and management processes. This will allow enterprises to generate sustainable added value, reduce dependence on raw materials, and enhance the country's intellectual potential. In the long-term perspective, international cooperation acquires special significance. Participation in transnational R&D projects, specialist exchanges, joint accelerator programs, and partnerships with global technology companies create opportunities for continuous knowledge renewal. For example, cooperation with the European Bank for Reconstruction and Development within the framework of digital reforms[14] already contributes to the expansion of competencies in digital regulation and entrepreneurship.

Conclusion

The prospects for developing innovative activity in the context of the digital economy can be summarized as a movement toward three goals:
— Economic resilience, based on data and intellectual assets;

[11] https://www.oecd.org/digital/oecd-digital-economy-outlook-2024.htm
[12] https://digital-strategy.ec.europa.eu/en/policies/digital-decade
[13] https://www.itpark.uz/en/news/digitalization-in-uzbekistan-key-directions-and-achievements
[14] https://www.ebrd.com/what-we-do/sectors/ict-and-digital.html

— Ecosystem connectivity, ensuring free exchange of knowledge and resources among market participants;

— Inclusive growth, in which innovations become part of everyday economic activity rather than the privilege of certain sectors.

It is precisely this combination — technological maturity, open ecosystem, and social engagement — that forms the foundation for Uzbekistan's digital future. If the first stage of digitalization provided the tools, and the second stage established the structure for interaction, then the third stage creates a new economic logic, in which innovation becomes not a goal, but a natural condition of economic development.

References:

[1] Government of Uzbekistan "Digital Uzbekistan 2030," *National Program for Digital Transformation*, 2023. https://www.gov.uz/en/activity_page/digital_technology

[2] National newspaper "Uzbekistan sees 70% surge in IT service exporters over nine months," *Kun.uz*. October 29, 2024. https://www.kun.uz/en/news/2024/10/29/uzbekistan-sees-70-surge-in-it-service-exporters-over-nine-months

[3] IT Park Uzbekistan "IT Park Uzbekistan summed up its work," *National newspaper*, 2023. https://www.uzdaily.uz/en/it-park-uzbekistan-summed-up-its-work-for-2023/

[4] World Bank "Uzbekistan Digital Inclusion Project (P179108)," *Project Information Document*, 2023. https://documents1.worldbank.org/curated/en/099060723031518423/pdf/P17910801b3c11080a8980b511413cfc99.pdf

[5] Interoperability Services Platform "X-Road," *e-Estonia* (n.d.). https://e-estonia.com/solutions/interoperability-services/x-road/

[6] Monetary Authority of Singapore "FinTech Regulatory Sandbox," https://www.mas.gov.sg/schemes-and-initiatives/fintech-regulatory-sandbox

[7] OECD "Digital Economy Outlook," 2024. https://www.oecd.org/digital/oecd-digital-economy-outlook-2024.htm

[8] European Commission "The Digital Decade Policy Program 2030," 2024. https://digital-strategy.ec.europa.eu/en/policies/digital-decade

[9] IT Park Uzbekistan "Digitalization in Uzbekistan: Key Directions and Achievements," 2024. https://www.itpark.uz/en/news/digitalization-in-uzbekistan-key-directions-and-achievements

[10] European Bank for Reconstruction and Development (EBRD). "ICT and Digital Sector Overview," 2024. https://www.ebrd.com/what-we-do/sectors/ict-and-digital.html

[11] Aalto University "Aalto Innovation Hub," 2024. https://www.aalto.fi/en/innovation-hub

UDC: 338, 338.48

METHODS FOR IMPROVING ENTERPRISE ECONOMIC PERFORMANCE IN THE ERA OF THE DIGITAL ECONOMY

Mirzaraximova Aziza Azimjanovna
Senior Teacher, Department of Economics and Management, Sphere of ICT, Tashkent University of Information Technologies
azmyus0960@gmail.com
With the review of professor, Tashkent University of Information Technologies Akromova Gulnora Abduvaxidovna

Annotatsiya. Raqamli iqtisodiyot sharoitida korxonalarning iqtisodiy samaradorligini oshirish barqaror milliy rivojlanishning muhim omillaridan biriga aylandi. Ushbu maqolada raqamli transformatsiya, raqamli marketing vositalari va xodimlarning raqamli kompetensiyalarini rivojlantirish orqali korxona faoliyatini samarali tashkil etish yo‘llari tahlil qilinadi. O‘zbekiston sanoat va xizmat ko‘rsatish tarmoqlaridan olingan misollar hamda rivojlangan davlatlar tajribasi asosida ERP, CRM va BI tizimlari kabi integratsiyalashgan raqamli ekotizimlarning ishlab chiqarish samaradorligi, xarajatlarni kamaytirish va innovatsiyalarni kuchaytirishdagi roli yoritiladi. Statistik ma’lumotlar va tahliliy jadvallar texnologik modernizatsiya va inson kapitalini rivojlantirish orqali erishilgan natijalarni ko‘rsatadi. Tadqiqot natijasida raqamlashtirish nafaqat texnologik jarayon, balki korxonaning uzoq muddatli raqobatbardoshligini ta’minlaydigan strategik yo‘nalish ekani ta’kidlanadi.

Kalit so‘zlar: *raqamli iqtisodiyot, iqtisodiy samaradorlik, raqamli transformatsiya, marketing raqamlashtirish, inson kapitali, O‘zbekiston, mehnat unumdorligi.*

Аннотация. В условиях цифровой экономики повышение экономической эффективности предприятий становится ключевым фактором устойчивого развития. В статье рассматриваются основные методы повышения результативности предприятий на основе цифровой трансформации, внедрения инструментов цифрового маркетинга и развития цифровых компетенций персонала. На примере отраслей промышленности и сферы услуг Узбекистана, а также с учётом зарубежного опыта показано, как интегрированные цифровые экосистемы (ERP, CRM, BI) и управление на основе данных способствуют росту производительности, снижению затрат и активизации инноваций. Представленные статистические данные и аналитические таблицы отражают результаты, достигнутые благодаря технологической модернизации и развитию человеческого капитала. В заключение подчёркивается, что цифровизация — это не просто технологический процесс, а стратегическое направление, обеспечивающее долгосрочную конкурентоспособность и экономическую устойчивость предприятий.

Ключевые слова: *цифровая экономика, экономическая эффективность, цифровая трансформация, цифровой маркетинг, человеческий капитал, Узбекистан, производительность труда.*

Abstract. In the digital age, improving the economic efficiency of enterprises has become a key driver of sustainable national growth. This article explores the main methods of enhancing enterprise performance through digital transformation, digital marketing tools, and the development of digital competencies among employees. Drawing on examples from Uzbekistan's industrial and service sectors, as well as comparative analysis with developed economies, the study demonstrates how integrated digital ecosystems (ERP, CRM, BI) and data-driven management contribute to productivity growth, cost reduction, and innovation. Statistical data and analytical tables illustrate measurable improvements achieved through technological modernization and human capital development. The article concludes that digitalization is not merely a technological process but a strategic direction that ensures long-term competitiveness and economic resilience.

Keywords: *digital economy, enterprise efficiency, digital transformation, marketing digitalization, human capital, Uzbekistan, productivity.*

Introduction

In the era of the digital economy, the improvement of enterprise efficiency has become one of the central priorities for sustainable economic development. Across the globe, digital transformation is reshaping traditional business models, introducing data-driven management, intelligent automation, and customer-centered decision-making processes. Uzbekistan, like many emerging economies, is actively adopting digital technologies to enhance productivity, competitiveness, and transparency within its enterprises. The transition from traditional management systems to integrated digital ecosystems—combining ERP, CRM, and BI platforms—reflects the country's strategic alignment with global economic trends and its commitment to the principles of innovation and efficiency. This article focuses on identifying and analyzing the key methods for improving enterprise economic performance under the conditions of digital transformation. It explores how technological modernization, digital marketing tools, and the development of human capital collectively contribute to greater economic returns and long-term competitiveness.

Research Methodology

The study is based on a qualitative analytical approach integrating descriptive, comparative, and case-based methods. The descriptive analysis outlines the main digital transformation trends observed in Uzbekistan's industrial, financial, and service sectors. The comparative analysis examines relevant international experiences from Germany, South Korea, and the United States to highlight adaptable best practices. Finally, selected empirical data from Uzbek enterprises are summarized through quantitative indicators and tabular models demonstrating measurable improvements in productivity, cost efficiency, and innovation outcomes.

This methodological combination provides a comprehensive understanding of how digital transformation affects enterprise performance—both through technological integration and through the development of digital competencies within the workforce.

Analysis and Results

Methods for Improving Enterprise Economic Performance in the Era of the Digital Economy.

In the context of the rapidly developing digital economy, enterprises in Uzbekistan are gradually transitioning to a new model of economic management based on the use of digital technologies to improve efficiency. One of the most significant aspects of this process is the digital transformation of internal business processes, which makes it possible to integrate the management of production, finance, and logistics into a single information system.

According to Khalmatov A. (2024, Semant Journals), the implementation of integrated ERP systems, cloud platforms, and Internet of Things (IoT) technologies in Uzbekistan's light industry has led to a 70–80% increase in labor productivity and a nearly 55% reduction in operating costs. This is explained by the fact that digital systems ensure the automation of routine operations, transparency of material flows, and more accurate resource planning. These findings are also supported by Kutbitdinova & Matrizayeva (2023, Journal NX), who note that digitalization accelerates managerial decision-making and contributes to the competitiveness of enterprises.

An analysis of foreign experience — particularly in Germany, South Korea, and the United States — shows that the introduction of digital production management systems results in an average productivity growth of 40–60%, demonstrating the universal effectiveness of these methods across economies at different development levels.

In the context of Uzbekistan, special attention is paid to the creation of an integrated digital ecosystem of the enterprise that includes ERP, CRM, and BI modules. Such systems not only integrate production, financial, and sales departments but also provide access to real-time analytical data. This, in turn, facilitates cost control, reduces equipment downtime, and minimizes the human factor in managerial decision-making.

To quantitatively assess the effectiveness of digital transformation, it is appropriate to consider the following indicators:

Indicator	Before Implementation	After Implementation	Change, %
Labor productivity	100	172	+72%
Operating costs (million UZS)	50	22.5	−55%
Order processing time (days)	5.0	3.2	−36%

These data demonstrate not only the economic benefits but also the formation of a fundamentally new management culture in which decisions are made based on data (*data-driven management*). Gradually, digital transformation is ceasing to be merely a technological trend and is becoming the foundation of the strategic development of enterprises.

After internal enterprise processes become more transparent and manageable through digital transformation, the next natural step is the digitalization of marketing and sales activities. In a saturated market with high competition, effective

communication with customers determines a company's ability not only to maintain but also to expand its market share.

In Uzbekistan, this process is developing rapidly, especially among small and medium-sized enterprises. According to Igamberdiyeva N. (2024, The Conference Hub), the implementation of digital marketing tools — including SEO, SMM, content marketing, and CRM systems — has enabled companies to enhance brand recognition and increase sales volume. The study shows that the use of targeted advertising campaigns and consumer data analytics reduced average marketing expenses by 25–30%, while sales conversion rates increased by more than 40%.

In the banking and financial sectors, similar trends are confirmed by Khamidova L. (2024, Philstat Journal), who notes that digital marketing tools such as automated mailing systems, targeted advertising, and personalized offers have helped to reduce customer acquisition cost (CAC) and increase customer retention rates.

A comparison with international experience shows that these results are not coincidental. According to a McKinsey Digital (2023) report, companies in the United States and Germany that adopt comprehensive digital strategies — combining big data analytics, omnichannel communication, and CRM automation — report a 35–50% increase in sales conversion rates, which is nearly identical to the data observed in Uzbek studies. This confirms the universality of the effect of marketing digitalization.

To illustrate, the following aggregated data represent enterprises in Uzbekistan that actively use digital marketing tools:

Indicator	Before Implementation	After Implementation	Change, %
Sales conversion rate	6.5%	10.2%	+56.9%
Customer acquisition cost (CAC)	250,000 UZS	180,000 UZS	−28.0%
Customer retention rate	55%	70%	+27.3%

Unlike traditional marketing, digital tools ensure real-time measurability of results. Analytical systems (such as Google Analytics, Power BI, and CRM dashboards) make it possible not only to track sales numbers but also to identify patterns in customer behavior, evaluate the return on advertising campaigns, and develop precise strategies for engaging the target audience

The digital transformation and implementation of new marketing tools cannot be achieved without an adequate level of digital competencies among personnel. Human capital thus becomes the connecting link between technology and its practical impact on enterprise efficiency.

According to Rakhimov A. (2024, Central Asian Economic Review) and Yuldasheva N. (2023, International Journal of Economics and Digital Development), the level of digital literacy among employees of Uzbek enterprises remains uneven: a high concentration of qualified specialists is observed in the banking and telecommunications sectors, while in the industrial and agricultural sectors there is still a shortage of professionals capable of operating digital management systems.

The development of digital competencies involves not only training employees to use specific technologies but also forming a new managerial culture based on data analysis and project-oriented thinking. In this context, the introduction of corporate training programs and cooperation between enterprises, universities, and technology

parks is of particular importance. For example, within the framework of the "Digital Uzbekistan 2030" initiative, training centers are actively being established where specialists acquire skills in using cloud solutions, analytical tools, and knowledge management systems.

Research conducted by Nazarova S. (2024, Tashkent State University of Economics) showed that enterprises investing at least 3–5% of their annual budgets in developing employees' digital competencies reported, on average, a 20–25% increase in labor productivity and more than a twofold increase in the number of innovation projects. This confirms the direct relationship between employees' digital skills and the economic performance of enterprises.

To illustrate, the following aggregated data represent a group of enterprises that have completed a digital training program:

Indicator	Before Training	After Training	Change, %
Share of employees with basic digital skills	45%	75%	+66.7%
Labor productivity (units per employee)	80	100	+25%
Number of innovation projects per year	2	5	+150%

Conclusion

Improving digital competence leads to growth not only in individual employee efficiency but also in collective innovation activity, forming a sustainable knowledge ecosystem within the enterprise. This enables companies to adapt more quickly to technological changes and to use implemented digital tools more effectively in management and marketing.

References:

[1] Khalmatov A. "Efficiency of Using Digital Technologies in Light Industry Enterprises in Uzbekistan," *Semant Journals, 4*(2), 2024, pp. 56–65.

[2] Kutbitdinova U.M., & Matrizayeva D.D. "The Impact of Digital Transformation on Economic Efficiency and Increasing the Competitiveness of Organizations," *Journal NX, 9*(10), 2023, pp. 50–58.

[3] Igamberdiyeva N. "The Role and Improvement Directions of Digital Marketing Strategies in Increasing the Competitiveness of Enterprises," *The Conference Hub Journal, 6*(3), 2024, pp. 44–52.

[4] Khamidova L. "Evaluation of Digital Marketing Tools in Attracting Consumers to the Banking and Financial Services Market in Uzbekistan," *Philstat Journal, 21*(1), 2024, pp. 120–132.

[5] Rakhimov A. "Human Capital Development and Digital Competencies in the Transformation of the Uzbek Economy," *Central Asian Economic Review, 5*(2), 2024, pp. 78–89.

[6] Yuldasheva N. "Human Capital and Digital Competency: Empirical Assessment of Readiness for Digital Economy in Uzbekistan," *International Journal of Economics and Digital Development, 2*(4), 2023, pp. 33–47.

[7] Nazarova S. "Impact of Digital Skills Training on Productivity and Innovation in Uzbek Enterprises," *Tashkent State University of Economics Working Papers, 7*(1), 2024, pp. 14–27.

[8] McKinsey & Company "Digital Reinvention: The Multiplier Effect on Productivity," *McKinsey Digital Insights Report,* 2023.

[9] Cabinet of Ministers of the Republic of Uzbekistan "Digital Uzbekistan 2030: National Strategy for Digital Transformation," 2020.

UDC: 332.1, 338, 338.48

THE POSITIVE IMPACT OF THE TOURISM SECTOR ON THE INVESTMENT ENVIRONMENT: ANALYTICAL AND PRACTICAL APPROACHES

Husainov Jahongir Bahodirovich
Acting Associate Professor (PhD),
Urgench Innovative University
jkhusainov@mail.ru

Annotatsiya. Ushbu maqolada turizm sohasi va uning investitsion muhitga ta’siri tahlil etiladi. Xususan, Xorazm viloyatida turizmning iqtisodiy rivojlanishdagi o‘rni, turistik klasterlar orqali mintaqaviy integratsiya va investitsiyalarni jalb qilish mexanizmlari yoritilgan. 2020–2023 yillarda amalga oshirilgan investitsiya va infratuzilma loyihalari hamda yangi ish o‘rinlari yaratish tajribalari misollar orqali ko‘rsatilib, ularning mintaqaviy iqtisodiy barqarorlik va investitsion faollikka qo‘shgan hissasi tahlil qilingan.

***Kalit so‘zlar**: turizm, investitsiyalar, turistik klasterlar, iqtisodiy rivojlanish, mintaqaviy integratsiya, investitsion muhit, sanoat va xizmat ko‘rsatish tashqi investitsiyalar, ichki bozor, hududiy siyosat.*

Аннотация. В статье анализируется туристическая отрасль и её влияние на инвестиционную среду на примере Хорезмской области Узбекистана. Рассматривается роль туризма в экономическом развитии региона, а также механизмы региональной интеграции и привлечения инвестиций через туристические кластеры. Приведены примеры инвестиционных и инфраструктурных проектов, реализованных в 2020–2023 годах, показано их влияние на повышение региональной экономической стабильности и инвестиционной активности.

***Ключевые слова:** туризм, инвестиции, туристические кластеры, экономическое развитие, региональная интеграция, инвестиционная среда, промышленность и сфера услуг, иностранные инвестиции, внутренний рынок, региональная политика.*

Abstract. This article analyzes the tourism sector and its impact on the investment environment, focusing on the Khorezm region of Uzbekistan. It examines the role of tourism in economic development and explores mechanisms for regional integration and investment attraction through tourism clusters. The study presents examples of investment and infrastructure projects implemented during 2020–2023, highlighting their contribution to regional economic stability and investment activity.

***Keywords:** tourism, investments, tourism clusters, economic development, regional integration, investment environment, industry and services, foreign investments, domestic market, regional policy.*

Introduction

In recent years, the tourism sector has emerged as one of the key drivers of sustainable economic growth and regional development. The legal, economic, and infrastructural frameworks supporting this sector have been progressively enhanced to foster greater competitiveness and investment attractiveness. In this context, the establishment of tourism clusters is increasingly recognized as a strategic approach to promoting regional tourism development. The cluster model facilitates the integration and cooperation among tourism service providers, enabling the formation of a locally interconnected network driven by shared economic interests and mutual benefits. This integrated system not only strengthens regional economic linkages but also contributes to long-term socio-economic stability and investment growth.

Literature Review

Recent research identifies tourism as a major driver of economic growth and investment attraction. Cooper (2021) emphasizes that human capital, service quality, and digital transformation are key determinants of competitiveness in the tourism industry, while Hall (2017) considers tourism policy an effective instrument for enhancing regional investment environments through social marketing and public–private partnerships. According to Jumayeva and Mardanova (2019), the cluster model promotes collaboration between private enterprises and local institutions, generating multiplier effects that stimulate regional employment and investment. Richards (2018) argues that cultural tourism not only supports local economies but also revitalizes cultural heritage, attracting foreign investors. Studies by Jurayev (2024) and Husanov (2025) confirm that in Uzbekistan, the development of tourism infrastructure and cluster systems—particularly in the Khorezm region—has significantly improved investment appeal and socio-economic resilience.

Research Methodology

In the context of cluster-based development, effective cooperation among key participants — namely private enterprises, public institutions, and civil society representatives — contributes to enhancing the stability and attractiveness of the regional investment environment.

Analysis and Results

Uzbekistan’s tourism sector possesses significant economic potential and constitutes an integral part of the country’s strategic development. In recent years, both the volume of investments and the role of innovative projects in this field have increased considerably. For instance, in 2022 the tourism industry accounted for 4.5 percent of the national GDP, while the number of international tourists exceeded six million in 2023 (Jurayev, 2024). Between 2020 and 2023, approximately 2 billion USD of investments were attracted to the sector. These indicators demonstrate not only the sector’s economic capacity but also its growing investment attractiveness. As of May 2025, a total of 1.88 million foreign tourists have visited the country. There are 1,483 tour operators, 1,442 accommodation facilities, and 2,458 guest houses operating nationwide. In addition, 2,400 licensed tour guides provide services to visitors. These figures demonstrate the positive contribution of tourism to the national GDP through

foreign exchange revenues. Moreover, domestic tourism plays an important role in increasing social engagement and preserving the nation's cultural heritage.

Figure 1. Foreign Tourists and Tourism Infrastructure – Statistics of Uzbekistan (Compiled by the author based on data from the official open website of the State Committee for Tourism of the Republic of Uzbekistan (https://uzbektourism.uz).

In the tourism industry, human capital — including qualified professionals, employees with a strong culture of service, and multilingual tour guides — is recognized as a key strategic resource (Cooper, 2021). The effective utilization of human resources is considered a crucial factor for achieving long-term sustainable development. From this perspective, human resources in the tourism sector — particularly skilled personnel, service-oriented professionals, and guides equipped with language proficiency and digital literacy — serve as the main strategic asset (Cooper, 2021). The strategic management of human capital plays a decisive role in ensuring long-term and forward-looking development.

Table 1. Infrastructure indicators of tourism potential in the Khorezm region (as of 2025)

№	Indicator Name	Quantity	Remarks
1	Accommodation facilities (total)	204	Including 97 family guest houses
2	Number of rooms	2,600	Prepared for tourists
3	Number of beds	5,700	Available in hotels and family guest houses
4	Tourism companies	67	Including 2 travel agencies
5	Certified tour guides	225	Professionally trained specialists
6	Tourist transport vehicles	315	Including 33 tourist-class buses
7	International airport	1	Urgench International Airport, 5 international flights operating
8	Railway station	1	Urgench Railway Station, 1 international route operating
9	Cultural heritage sites	259	Including 58 within the "Ichan Qala" museum-reserve
10	Tourist information centers	19	Including 14 located in Khiva city
11	Tourist road signs	130	Including 32 located in Khiva city
12	Tourist maps	9	Two located in tourism mahallas (villages)
13	Sanitary and hygiene facilities	409	Including 292 newly constructed
14	Currency exchange ATMs	5	Serve foreign bank cards
15	Terminals	6	Provide services for tourists
16	Free Wi-Fi spots	23	Located in popular tourist areas

Source: Prepared by the author based on the monograph Husanov J.B. (2025). Effective utilization of regional tourism potential (The case of the Khorezm region).

Practical experience in the Khorezm region demonstrates that tourism clusters not only promote the development of tourism itself but also enhance capital inflows into

the regional economy and contribute to job creation (Jumayeva & Mardanova, 2019). At present, the effective utilization of existing tourism potential in the region reflects its growing capacity for sustainable tourism development.

In the Khorezm region, more than one thousand additional tourism infrastructure facilities are currently operating. These include 74 dining establishments (18 fast-food outlets, 11 restaurants, 13 café-bars, and 32 other facilities), 18 MICE (Meetings, Incentives, Conferences, and Exhibitions) venues, 2 gastronomic streets, 2 Duty-Free shops, 6 karaoke bars, 1 auto-camping site, 588 handicraft workshops, and 120 souvenir shops. Additionally, there is 1 water attraction, 96 eco/agro-tourism facilities, 3 forestry enterprises, 71 fishing lakes, 2 protected natural areas, 12 eco-tourism and 8 agro-tourism destinations, as well as 4 wellness centers.

In 2022, the Khorezm region hosted about 137.5 thousand foreign and 1.48 million domestic tourists, generating 27 million USD in tourism exports. That year, 31 new accommodation facilities were launched, bringing the total to 204 with 5,700 beds. Infrastructure upgrades included the construction and renovation of sanitary facilities, installation of road signs, opening of information centers, and introduction of modern transport vehicles. Two new tourist maps were also developed under the “Tourism Village” and “Tourism Mahalla” programs to enhance the visitor experience.

Based on Resolution № 546 of the Cabinet of Ministers of Uzbekistan (September 28, 2022), a comprehensive tourism development program for the Khorezm region (2022–2026) was implemented. Within this framework, 50 projects totaling 89.3 billion UZS were realized, financed by 56.1 billion UZS of private investment and 33.2 billion UZS in bank loans, creating 230 new jobs. To integrate cultural heritage into tourism, the “CASTLE TOUR” route was launched, connecting ancient fortresses across Khorezm and Karakalpakstan, including Ichan Qala, Ulli Hovli, Qalajiq Qala, and others. In 2022, five tourism mahallas and two tourism streets were established—among them Ichan Qala, Qumyaska, Yangi Turmush, G‘ovuk, and Qalajiq Qala. Between 2022 and 2023, 77 new accommodation facilities were planned, of which 16 are already in operation.

Table 2. Investments and infrastructure projects in the tourism sector of the Khorezm region.

№	Project Title	Brief Description	Key Indicators / Results
1	Projects implemented under government resolution	50 projects with a total investment value of 89.3 billion UZS were implemented	Own funds – 56.1 billion UZS Bank loans – 33.2 billion UZS New jobs created – 230
2	“CASTLE TOUR” project	Establishment of new tourist routes connecting ancient fortresses	Route: *Ichan Qala – Ulli Hovli – Qalajiq Qala – Sulaymon Qala – Tosh Qala – Ayoz Qala – Tuproq Qala – Ellik Qala*
3	Establishment of tourism mahallas	Development of roadmaps for 5 tourism mahallas and 2 tourism streets	Mahallas: *Ichan Qala, Qumyaska, Yangi Turmush, G‘ovuk, Qalajiq Qala*
4	Accommodation facilities	77 new accommodation facilities planned, 16 already established	7 hotels 10 hostels 60 family guest houses (16 operational)

5	Tourism facilities	Additional facilities established to expand tourism services	1 desert tourism center; 1 beach tourism service; 12 yurts; 13 dining facilities; 11 artisan family enterprises
6	Community engagement	Promotion of public participation through training and seminars	Practical and educational workshops with qualified specialists
7	Service facilities	Establishment of various service facilities in Urgench and Khiva cities	Over 80 facilities: 10 accommodation facilities; 15 public catering establishments; 6 boutique shops 8 grocery stores; 3 airline ticket offices; 1 information center; 2 hygiene facilities; 2 banks; 2 clinics; 2 confectionery shops; 4 handicraft trading stalls; 20 other service facilities.

Source: Author's compilation based on the Resolution of the Cabinet of Ministers (No. 546, 28 September 2022) of the Republic of Uzbekistan and the publicly available data from the State Committee for Tourism of the Republic of Uzbekistan website (https://uzbektourism.uz/).

In 2022, the implementation of tourism development measures in the Khorezm region significantly enhanced its investment attractiveness. The region hosted about 137.5 thousand foreign and 1.48 million domestic tourists, generating 27 million USD in tourism exports. During the same year, 31 new accommodation facilities—including hotels, hostels, and family guest houses—were launched, increasing the total to 204 with 5,700 beds. Moreover, international events and festivals, as well as the designation of Khiva as the "Tourism Capital of the Islamic World 2024", further boosted large-scale investment inflows into the region.

Conclusion

The modernization and expansion efforts implemented in the tourism sector of the Khorezm region have significantly enhanced the region's investment potential. These developments have created favorable conditions for launching new business projects, constructing hotels, and establishing service facilities. In the future, investments directed toward tourism development are expected to further strengthen the region's economic growth and contribute to improving social well-being.

References:

[1] Cooper C. "Tourism: Principles and practice," 6th ed., *Pearson Education*, 2021.
[2] Hall C.M. "Tourism and social marketing," *Routledge*, 2017.
[3] Husanov J.B. "Effective utilization of regional tourism potential: The case of the Khorezm region," Urgench: *Scientific Center for Economics and Tourism Publishing*, 2025.
[4] Jumayeva N., & Mardanova M. "Tourism clusters and their impact on regional economies," *Economy and Innovative Technologies Journal*, (3), 2019 pp. 45–52.
[5] Jurayev N. "Economic analysis of Uzbekistan's tourism potential," *Tourism and Economics Journal*, 2(1), 2024, pp. 10–18.
[6] Richards G. "Cultural tourism: A review of recent research and trends," *Journal of Hospitality and Tourism Management*, 36, 2018, pp. 12–21. DOI: 10.1016/j.jhtm.2018.03.002
[7] Uzbek tourism "Statistics and analytical data," *State Committee for Tourism Development of the Republic of Uzbekistan*, 2025. https://uzbektourism.uz

UDC: 81, 81.367

LEARNING THE UZBEK LANGUAGE THROUGH THE MOLDING METHOD AND ITS RESULTS

Rakhmatilloyeva Mokhinur Momin Kizi
Doctoral Student, Navoi State University
mohinurraxmatilloyevagmail@.com

Annotatsiya. Maqolada o‘zbek tilini modellashtirish metodi orqali o‘rganish va uning afzalliklari haqidagi fikrlar, ayrim o‘zbek tilidagi sintaktik qoliplar, tilimizdagi sodda gaplarning sintaktik qoliplaridan foydalanishning ahamiyati hamda tilni o‘qitishda modellarning o‘rni masalalariga alohida e’tibor qaratilgan.

Kalit so‘zlar: *lingvistik model, lisoniy sintaktik qolip, sodda gap qoliplari, soddalashtirish, usul.*

Аннотация. В статье особое внимание уделяется изучению узбекского языка методом моделирования и его преимуществам, некоторым синтаксическим шаблонам в узбекском языке, важности использования синтаксических шаблонов простых предложений в нашем языке, а также роли моделей в преподавании языка.

Ключевые слова: *лингвистическая модель, лингвистический синтаксический шаблон, шаблоны простых предложений, упрощение, метод.*

Abstract. The article pays special attention to the study of the Uzbek language through the modeling method and its advantages, the importance of using some syntactic patterns in the Uzbek language, the syntactic patterns of simple sentences in our language, and the role of models in language teaching.

Keywords: *linguistic model, linguistic syntactic pattern, simple sentence patterns, simplification, method.*

Introduction

In linguistics, the possibilities of the modeling method are expanding over the years. Currently, more comprehensive research is being conducted on standardization than in traditional linguistics. In particular, the creation of probabilistic models for the science of computational linguistics confirms this idea. The founder of the concept of grammatical formalization (from the Latin “forma” – “form,” “external appearance”) is the American linguist Noam Chomsky. Formal grammar is considered a grammar expressed through abstract symbols, where language rules, word formation, phrase and sentence construction are described using various linguistic models and structural schemes [1]. The model is important for cognition on the following grounds:

- firstly, it simplifies the object of study;
- secondly, it separates it from the influence of other objects;
- thirdly, the template simplifies the description of the object.

Literature Review

The textbook “Modern Uzbek Literary Language” by Sayfullayeva R., Mengliyev B., Boqiyeva G. and others reflects the linguistic syntactic patterns in our native language and their speech derivatives, as well as the relationship between them. This textbook discusses the finite patterns of word combinations in our native language and the infinite speech derivatives formed from them. M. Kurbanova’s work “Modern Uzbek Language” contains information about the syntax of simple sentences, as well as valuable information about linguistic syntactic patterns. In the monograph “Linguistic Support of Machine Translation” by Nilufar Abduramonova, the significance of syntactic patterns for automatic machine translation is discussed, and a probabilistic theory of several simple sentences is developed. Nazarova “Phrases Expressing Genus-Species Relationships” provides an analysis of the patterns of phrases, their derivatives, and the relationship between them.

Research Methodology

The most correct way to master any complex units is to use its simplified version. The study of some aspects of our native language through the modeling method has already been established. In particular, the most appropriate way is to master the use of punctuation marks in compound sentences with adverbial clauses through models. Word formation methods, types of word combinations, patterns of simple and compound sentences serve as the main object for creating infinite derivatives from them, with the help of these patterns the imagination of the person learning the language awakens. For example, if we touch on the topic of word formation,

base + word-former + lexical form-former + syntactic form-former suffixes - pattern – base + ^ + ˷ +_ : workers

base + word-former + lexical form-former + word-former

pattern – base + ^ + ˷ + ^ : freezer

word-former + base - pattern - ^ + base: serunum.

While this situation controls the order in which suffixes are added to the base, the following patterns determine which word family the word is formed from and with which suffix.

Noun-N, Number-Q, Adjective-Adj, Adverb-Adv, Pronoun-P, Verb-V.

N+li=Adj: beautiful, modest;

N+la=V: blossom, think;

N+cha=Adv or Adj: male, young man, Russian, English;

N+chi=N or Adj: worker, florist, panicker, gossip;

N+i=V: dust, ranji;

Q+lan=V: twice;

Adj+i=V: height, rest;

Adj+la=V: justify, improve;

Adv+lash=to slow down, to accelerate.

V+iq=Adj: elongated, open;

V+ch=N: longing, joy; Adj+lik=N: peace, wealth.

Regarding word combination patterns, Nazarova says: In Uzbek linguistics, as a result of substantial analysis of the syntax of word combinations, certain word combinations realized in speech are evaluated as derivatives of linguistic syntactic patterns (LSQ).

At the same time, the temporary “living” in the speech of native speakers and the manifestation of facets selected from different meanings in each occurrence contrasts word combinations with LSQs in the status of a linguistic syntactic unit. LSQs that realize them are ready at the syntactic level of the language as linguistic possibilities specific to the formation of word combinations in the Uzbek language. Phrase-forming LSQs possess not only the properties of readiness, but also the properties of generality, immutability, necessity, and reproducibility, which form a chain of contradictions between the LSQ and the phrase [2].

There are also similar opinions about the repetition of LSQs, but speech derivatives are unique, and they are formed according to the requirements of different speech situations. It should not be forgotten that the volume of LSQs is limited, but the volume of speech derivatives is infinite. To date, 18 priority patterns of word formation have been identified in the Uzbek language. It is impossible to imagine the amount of speech phrases created from these patterns. Sentence patterns and their derivatives are the same. LSQs are fixed and immutable, and speech derivatives are arbitrary. When Uzbek speakers feel the need to create phrases in the process of speech, they are forced to use the above-mentioned 18 types of LSQ. Their change of LSQs, the creation of new LSQs is not allowed by language “legislation.” However, whether to form a speech phrase or not, which words to choose, is at the discretion of the speaker; they can compose it if they want to, and not compose it if they don’t [3].

As for the pattern of phrases, they are limited, that is, there are 18, but, as noted above, infinite phrases are formed from each of them, and each of the derivatives formed from them is considered unique in the speech situation.

[Ikk.~Ie.k.]=SB
[Iq.k.~Ie.k.]=SB
[Internal.~Ie.k.]=SB
[Ikk.~Ie.k.]=SB
[P.c.] and ownership [P.c.]
[Internal. ~ Ie.k.]=SB

It is known that phrases such as [Ik.k.~Ie.k.]=SB school, Bukhara city, Aral Sea, the novel “Mirage” are derivatives of the [Ob.k~Oe.k]=SB pattern with the meaning [turjins]. Importantly, the semantic and linguistic syntactic features characteristic of the product of this template can also be generalized in the [Ik.k.~Ie.k.]=SB template. Since, although the method of combining noun lexemes with the nominative case in the subordinate position, reflecting the [Ob.k~Oe.k]=SB pattern, with noun lexemes with possessive position in the dominant position is unique, [Ik.k.~Ie.k.]=SB pattern is considered a special form of the combination method. Because [Ik.k.~Ie.k.]=SB template encompasses both formally and contentally [Ob.k~Oe.k]=SB template and its product. This can be determined by comparing the following derivatives: human mole - [species-sex] - [Iq.k.~Ie.k.]=SB; human mole (Inside human mole. (M.)) - [species-sex] - [Ib.k.~Ie.k.]=SB. Among the above-mentioned meanings of belonging, separation-sorting, subject-action, object belonging to a person (i.e.), there is also the meaning of [kind-genus], as well as the meaning of [whole-part]. It should be noted that the commonality inherent in the content of the [Ik.k.~Ie.k.]=SB pattern also confirms that phrases with a [generic] meaning are its special form. Consequently, at

the linguistic syntactic level of the Uzbek language, the form [Ik.k.~Ie.k.]=SB stands in the status of a linguistic syntactic unit. In the essence of this pattern, the linguistic syntactic structure reflecting the patterns [Iq.k.~Ie.k.]=SB, which forms phrases with the meaning [referent-referenced], [Ich.k.~Ie.k.]=SB, which realizes phrases with the meaning [whole-part], and [Ob.k~Oe.k]=SB, which creates phrases with the meaning [kind-genus], is generalized on the basis of the relationship of generality and specificity. Therefore, it occupies a special place as a LSQ, which creates word combinations with the meaning [part], [genus] (and other similar) and highly generalizes the features of the linguistic structure inherent in these speech syntactic units. Consequently, the status of [Iq.k.~Ie.k.]=SB, [Ich.k.~Ie.k.]=SB, [Ob.k~Oe.k]=SB patterns at the linguistic syntactic level [Ik.k.~Ie.k.]=SB.

If the above-mentioned ideas are a scientific and theoretical study of LSQ related to a phrase, then its practical study involves collecting existing LSQs within the framework of a phrase in the Uzbek language and identifying other LSQs encountered in the speech process.

Noun compound Adjunctive compound 1. Noun + noun [wooden spoon, electric lamp] 2. Pronoun + noun [all people, the whole world] 3. Number + noun [third grade, five books] 4. Adjective + noun [beautiful city, kind mentor] 5. Participle + noun [guest who came, child who laughed] Administrative compound 1. Noun + to + noun [love for books, faith in life] 2. Noun +dan +noun [a memento from my grandfather, a souvenir from my friend] 3. Pronoun +dan +ot [a letter from us, a souvenir from you] 4. Adverb +dan +noun [assignment from above] 5. Noun +da +noun [teacher at school, worker at the factory] 6. Noun + auxiliary + noun [answer by question, conversation with age] 7. Noun+from+auxiliary+noun [extraordinary meeting, off-topic thought] 8. Pronoun + postposition + noun [meeting with us, getting acquainted with everyone].

Adaptive combination 1. Noun +ning +noun +e.q. [book page, teacher's question] 2. Noun + e.c. [value of time, city streets] 3. Pronoun +ning +ot +e.q. [my happiness, everyone’s dream] 4. Adjective +ning +ot+e.q. [the word of the good, the thought of the wise] 5. Numeral +ning +ot+e.q. [tenth place, first one's gift]. Although the linguistic syntactic patterns of word combinations in the Uzbek language and the issue of their modeling form the relationship between the word and the possessive and the possessed, they do not have the characteristic of nominalization. For example: noun+ning+adjective is the heat of bread, noun+ning+adverb is the beginning of the sentence, noun+ning+number is one of the flowers. In addition, it is suggested that words such as rahmat, tashakkur, salom enter into grammatical relations with personal nouns and pronouns, forming a controlled combination. For example: thank you, thank you all, etc. [4].

Analysis and Results

It should be noted that in the presented examples, in our opinion, the degree of expression of thought is stronger than the concept. The problem of linguistic modeling: modeling in linguistics is based on LSQs and various constructions of language units. Therefore, the model serves to interconnect such areas as structural linguistics and computational linguistics. Rakhimov A., reflecting on the formation and development of the modeling method in linguistics, writes: Modeling began to be actively applied

in linguistics under the influence of structuralism. The idea of modeling sentence structure was put forward in the 50s of the 20th century by the American Charles Fries. Summarizing his views, the scientist created his research "The Structure of English" in 1952. Fries Ch. called his concept a distributive model. According to it, a sentence is a chain of words belonging to certain parts of speech, and the analysis relies on a morphological base.

According to Abzhalova M., the syntactic analysis module (STM) is a part of the syntactic analysis program or linguistic program designed to perform syntactic analysis.

Conclusion

Today, the creation of automatic STMs is one of the urgent tasks of computational linguistics, the solution of which allows for high-quality results in the formalization of the language system for various practical purposes: the creation of a system for automatic verification of language and speech units, the improvement of the Internet search system. The purpose of syntactic analysis is to observe syntactic structures and the norms of syntactic connection, however, the creation of SCS in all languages is a complex task, since there are insufficient theoretical and practical studies in applied linguistics; the syntactic connection of language and speech units has individual diversity. The syntactic analyzer (parser) of each language is created according to the nature and laws of that language. Parser's work is based on a database of word categories (parts) and its main task is to identify parts of speech in some languages (for example, in Russian), while in certain languages, for example, in English, it is analyzed generatively in the form of noun groups and verb groups according to N. Chomsky's theory.

References:

[1] Qurbonova M. "Modern Uzbek Language (Materials for Simple Sentence Syntax)," Tashkent: *University*, 2002.
[2] Sayfullayeva R., Mengliyev B., Boqiyeva G. et al. "Modern Uzbek Literary Language," Study Guide. Tashkent: *Science and Technology*, 2009.
[3] Nazarova S.A. "Occurrences of Paradigmatic Relationship in Objective Associations," Theoretical & Applied Science. USA, Philadelphia. *International Scientific Journal*. Issue 11, Volume 79, 2019.
[4] Nazarova S. "Phrases denoting [gender-species] relations," *Uzbek language and literature*, Tashkent.
[5] Zumrad Ahmedjanova "Uzbek Language Grammar," Volume II, 31, 1978.
[6] Abdurakhmonova N. "Linguistic support of machine translation," Tashkent: *Muharrir*, 2008.
[7] Abjalova M. "Linguistic modules of editing and analysis programs: monograph," T.: *Nodirabegim*, 2020;
[8] Turabov A.M. "Fixed word combinations - as an object of small syntax," International *Journal of Innovative Technologies in Education*, № 2, 2022. http://kimweb.uz Natlib.diss.uz
[9] Uralov A. "The term disproportion and its interpretations," Uzbekistan, 2024.
[10] National University News, № 1, 52, 2021.
[11] en.wikipedia.org. /wiki/history_machine_translation
[12] Ziyouz com.

ACTUAL PROBLEMS OF HISTORY, PHILOSOPHY AND SOCIOLOGY

UDC: 3, 308, 316

ANALYSIS OF GLOBAL PROCESSES ENSURING THE FULL SOCIAL AND POLITICAL PARTICIPATION OF PERSONS WITH DISABILITIES

Abdullo Abduxamitovich Abduxalilov
Associate Professor, Doctor of Sociological Sciences (DSc), Department of Social Work, National University of Uzbekistan
abduxalilovabdullo81@gmail.com

Annotatsiya. So‘nggi yillarda xalqaro hamjamiyat nogironlarning to‘liq ijtimoiy-siyosiy ishtirokini ta'minlashga alohida e’tibor qaratmoqda. Ushbu jarayonda ko‘plab xalqaro hujjatlar qabul qilindi, ularning asosida davlatlar nogironlarning ijtimoiy hayotga to‘liq qo‘shilishini kafolatlashga qaratilgan o‘z strategiyalarini ishlab chiqadilar. Shunga ko‘ra, ushbu maqolaning maqsadi nogironlarning jamiyatda to‘liq ijtimoiy-siyosiy ishtirokini ta’minlashga qaratilgan global jarayonlarni aniqlashdir. Maqolada Birlashgan Millatlar Tashkiloti va Yevropada Xavfsizlik va Hamkorlik Tashkiloti tomonidan ishlab chiqilgan va amalga oshirilgan, nogironlarning jamiyatda har tomonlama ijtimoiy-siyosiy ishtirokini rag‘batlantirishga qaratilgan hujjatlar tahlil qilinadi. Hozirgi global tendentsiyalarga asoslanib, muallif Yangi O‘zbekiston uchun “Inklyuziv ishtirok etish sari” konsepsiyasini qabul qilish zarur degan xulosaga keladi.

Kalit so‘zlar: *Nogironlik, nogironlar, Birlashgan Millatlar Tashkiloti, BMTning Nogironlar huquqlari to‘g‘risidagi konventsiyasi, Yevropada Xavfsizlik va Hamkorlik Tashkiloti, inklyuziya, ijtimoiy-siyosiy ishtirok, siyosat, ijtimoiy hayot, jamiyat.*

Аннотация. В последние годы международное сообщество уделяет особое внимание обеспечению полного социально-политического участия лиц с инвалидностью. В этом процессе было принято множество международных документов, на основе которых государства разрабатывают собственные стратегии, направленные на гарантирование полной интеграции лиц с инвалидностью в социальную жизнь. Соответственно, цель данной статьи — выявить глобальные процессы, направленные на обеспечение полного социально-политического участия лиц с инвалидностью в обществе. В статье анализируются документы, разработанные и внедренные Организацией Объединенных Наций и Организацией по безопасности и сотрудничеству в Европе, которые направлены на содействие всестороннему социально-политическому участию лиц с инвалидностью в обществе. На основе современных глобальных тенденций автор приходит к выводу о необходимости принятия Новым Узбекистаном концепции “На пути к инклюзивному участию.”

Ключевые слова: *Инвалидность, лица с инвалидностью, Организация Объединенных Наций, Конвенция ООН о правах лиц с инвалидностью,*

Организация по безопасности и сотрудничеству в Европе, инклюзия, социально-политическое участие, политика, социальная жизнь, общество.

Abstract. In recent years, the international community has paid particular attention to ensuring the full socio-political participation of persons with disabilities. In this process, many international documents have been adopted, based on which states develop their own strategies aimed at guaranteeing the full inclusion of persons with disabilities in social life. Accordingly, the purpose of this article is to identify global processes aimed at ensuring the full socio-political participation of persons with disabilities in society. The article analyzes the documents developed and implemented by the United Nations and the Organization for Security and Co-operation in Europe that focus on promoting comprehensive socio-political participation of persons with disabilities in society. Based on current global trends, the author concludes that it is necessary for New Uzbekistan to adopt the concept of "Towards Inclusive Participation."

Keywords: *Disability, persons with disabilities, United Nations, UN Convention on the Rights of Persons with Disabilities, Organization for Security and Co-operation in Europe, inclusion, socio-political participation, policy, social life, society.*

Introduction

In recent years, special attention has been paid in Uzbekistan to improving the quality of life of persons with disabilities and protecting their rights and interests. The fact that more than 40 regulatory legal documents have been adopted in this area in Uzbekistan can serve as clear evidence of this. In turn, the processes of improving the quality of life of persons with disabilities require ensuring their full participation in the life of society. This is because persons with disabilities, having specific and unique life experience, are considered the main experts in the field of disability. One of the key principles of the United Nations policy towards persons with disabilities is precisely the principle "Nothing about us without us." Proceeding from this, it is of great importance to conduct large-scale research aimed at ensuring the participation of persons with disabilities in the life of society.

Literature Review

The processes of ensuring the full socio-political participation of persons with disabilities are reflected in the following documents of the United Nations and the Organization for Security and Co-operation in Europe (OSCE): *Guidelines on Promoting the Participation of Persons with Disabilities in Political and Public Life, issued by the OSCE Office for Democratic Institutions and Human Rights (ODIHR) [1]; Document of the Moscow Meeting of the Conference on the Human Dimension of the CSCE [2]; Berlin Declaration and Resolutions Adopted at the Twenty-Seventh Annual Session of the OSCE Parliamentary Assembly, Berlin [3]; The United Nations Convention on the Rights of Persons with Disabilities [4]; Principles for Promoting the Participation of Persons with Disabilities in Political Life, OSCE Office for Democratic Institutions and Human Rights [5]; Report of the Committee on Equality*

and Non-Discrimination: Political Rights of Persons with Disabilities as a Question of Democracy [6].

In Uzbekistan, the protection of the rights and interests of persons with disabilities and the improvement of their quality of life have been studied by many scholars. Among them, we can mention the research conducted by Ganiyeva M. [7], Latipova N. [8], Mo‘minova L. [9], Nurkeldiyeva D. [10], Alimova V. [11], Alekseeva V. [12], Abduvaliyeva M. [13], Komilov F. [14], Uzakova Z. [15], Yusupov D. [16], Checherina Ya. [17], Abduxalilov A. [18] and others.

Research Methodology

Today, the socio-political participation of various social strata is regarded as a key indicator that determines the level of democratic development in society. The fact that socio-political participation has different forms is expressed through such characteristics of a given subject as gender, age, workplace, religion, lifestyle, and so on. An analysis of the different definitions given to this phenomenon (socio-political participation as the degree to which all groups and strata of society are involved in socio-political processes) makes it possible to provide an integrated definition of this concept.

Inclusive social policy, in its essence, presupposes the participation of all strata of the population in the socio-political life of society.

According to current United Nations data, “about 16% of the world’s population are persons with disabilities, and at the same time, the socio-political participation of persons with disabilities in the life of society remains insufficient in almost all countries of the world” [19]. The reasons for this include the limited opportunities to participate in parliamentary life and political processes, the inadequate provision of political information in accessible formats for persons with disabilities, low levels of public support for persons with disabilities, and the existence of national laws that grant certain persons with disabilities the status of being legally incapable. In addition, the widespread negative stereotypes towards persons with disabilities in society also hinder their full-fledged political participation in the life of the community.

It should also be emphasized that “the above-mentioned problems do not only act as barriers to the socio-political participation of persons with disabilities, but also lead to their isolation in society. In our opinion, the active participation of persons with disabilities in the socio-political life of society increases the possibility of eliminating the stereotypes that exist towards them. The failure to involve certain groups in political processes not only deprives them of the opportunity to defend their interests, but can also cause an increase in dysfunctions within the social system of society” [1].

Today, in almost all states, increasing the socio-political participation of persons with disabilities is recognized as an important factor in building an inclusive society based on equality. It should be noted that ensuring the full participation of persons with disabilities in socio-political processes is reflected in a number of international, regional and national legal documents. However, in many countries, persons with disabilities still do not participate sufficiently in the socio-political life of society. A clear example of this is the still limited presence of persons with disabilities in the legislative and executive branches of power of the Republic of Uzbekistan. Therefore,

ensuring the full participation of persons with disabilities in socio-political processes and conducting systematic scientific research in this area is a requirement of the times.

“It has been repeatedly emphasized by the states that are members of the Organization for Security and Co-operation in Europe that involving persons with disabilities in the socio-political life of society and ensuring their full participation is an important issue. In 1991, the member states of the OSCE adopted the so-called Moscow Document. This document emphasized that the OSCE member states must create equal opportunities for persons with disabilities to participate fully in the socio-political life of society, and that the direct participation of persons with disabilities in all decisions concerning them is of particular importance” [2].

“In connection with the 25th anniversary of the Moscow Document adopted in Moscow in 1991, in 2016 the OSCE Office for Democratic Institutions and Human Rights, in cooperation with the Ministry of Foreign Affairs of Finland and the Finnish Human Rights Centre, organized a high-level expert seminar. This seminar was devoted to the topic of increasing the participation of persons with disabilities in the socio-political life of society” [1].

“At this seminar, experts developed the following eight key recommendations aimed at increasing the socio-political participation of persons with disabilities:

1. The OSCE participating States should create an accessible environment in order to ensure the full participation of persons with disabilities in the socio-political life of society.
2. It is advisable to eliminate the administrative and legal barriers that prevent persons with disabilities from fully participating in the life of society.
3. The OSCE participating States should develop legal, administrative and institutional mechanisms to ensure the full participation of persons with disabilities in the life of society.
4. The OSCE participating States should develop inclusive education and raise public awareness regarding the full socio-political participation of persons with disabilities in the life of society.
5. The OSCE should encourage members of society to pay attention to the problems faced by persons with disabilities.
6. In the process of ensuring the full socio-political participation of persons with disabilities, the OSCE participating States and non-governmental, non-profit organizations should form various coalitions and strengthen cooperation among them.
7. The OSCE participating States should collect data on the participation of persons with disabilities in the life of society and analyze the results.
8. It is advisable for the OSCE executive structures to ensure an accessible environment for persons with disabilities” [1].

“In the declaration adopted at the parliamentary assembly of the OSCE held in Berlin in 2018, it can be seen that the interests of persons with disabilities still remain insufficiently represented in the member states of the OSCE. The declaration assigns to all OSCE member states the task of creating mechanisms that ensure the socio-political participation of persons with disabilities. It also calls for the development of

measures aimed at strengthening their participation in socio-political decision-making processes" [3].

In the activities of the United Nations as well, considerable attention is paid to the rights of persons with disabilities to full participation in society, and a number of important international documents have been adopted in this area. Among this one can mention the *Universal Declaration of Human Rights*, the *International Covenant on Civil and Political Rights*, the *Standard Rules on the Equalization of Opportunities for Persons with Disabilities*, and the UN *Convention on the Rights of Persons with Disabilities*.

It should be noted that "today, the most important international document concerning the protection of the rights and interests of persons with disabilities is the United Nations *Convention on the Rights of Persons with Disabilities*. This Convention has been signed and ratified by almost all UN member states. Article 29 of the Convention emphasizes that the States Parties guarantee the political rights of persons with disabilities and the possibility for them to enjoy these rights on an equal basis with others" [4].

"Another document that draws attention to the full socio-political participation of persons with disabilities is the *Sustainable Development Goals* adopted in 2015" [5].

"In this document, special emphasis is placed on building an inclusive society, and it is noted that it is necessary to increase the opportunities for all strata of the population to realize their socio-political rights. At the same time, in many regional documents of organizations such as the Council of Europe and the European Union, great attention is paid to ensuring the full socio-political participation of persons with disabilities. In January 2017, the OSCE Committee on Equality and Non-Discrimination published a report entitled 'The Political Rights of Persons with Disabilities as a Fundamental Question of Democracy'. This report notes that disability issues are still barely visible in the political life of states today, and that the interests of persons with disabilities are often not taken into account in electoral processes. In the national legislation of many OSCE participating States, one can find norms aimed at ensuring an accessible environment for persons with disabilities and at increasing their political participation. Nevertheless, men and women with disabilities still face various problems in the process of full participation in the socio-political life of society" [20].

It should also be noted that "in the above-mentioned report, not only problems but also positive examples related to ensuring the full socio-political participation of persons with disabilities are reflected" [6].

Based on the above-mentioned international documents and the activities of international organizations, it can be concluded that persons with disabilities, like all other citizens, have the right to fully participate in the life of society. Therefore, creating equal opportunities for them is the responsibility of all states and socio-political institutions. The creation of an accessible environment for persons with disabilities brings benefits not only to persons with disabilities themselves, but to all people. Observance of the principles of inclusiveness in social policy also leads to a number of significant advantages.

For example, the principle of universal design requires the creation of products and services that are convenient for everyone. In this regard, the principle of inclusiveness

must be taken into account in the development of any socio-political project. It should be stressed that after the adoption of the UN *Convention on the Rights of Persons with Disabilities*, more attention has been paid around the world to ensuring an inclusive society, creating equal opportunities for persons with disabilities, and promoting their full participation in the life of society. This situation inspires hope that in the future political institutions will work more actively to eliminate the various barriers that may arise to the full socio-political participation of persons with disabilities.

It should also be mentioned that the integration of persons with disabilities into the socio-political system of a given state primarily strengthens the democratic system, since today the processes of making socio-political decisions are among the main characteristics of modern democracy.

Analysis and Results

According to UN experts, in the process of increasing the inclusiveness of social policy, it is advisable for political institutions to implement a number of important measures. These include the following:

1. Reviewing national legislation that reflects electoral and political rights. This process requires harmonizing the legislation of countries with the UN *Convention on the Rights of Persons with Disabilities* and removing all barriers that prevent persons with disabilities from fully participating in the life of society. It should be noted that, according to UN experts, these barriers mainly concern persons with mental and intellectual impairments, and this causes serious concern among all human rights organizations. The Committee on the Rights of Persons with Disabilities, which monitors the implementation of the UN *Convention on the Rights of Persons with Disabilities*, has given a number of recommendations to certain countries in this regard, in which the Committee instructs states to remove all norms that discriminate against persons with disabilities.

2. “The development of inclusive education and the provision of full information to voters require that, during election campaigns, all documents be presented to voters in accessible formats; in turn, the processes of preparing such information should be based on the communicative characteristics of different individuals. In doing so, the following factors need to be taken into account: language, literacy, whether citizens live in rural or urban areas, traditions, gender, disability, and so forth. Research conducted by experts has shown that persons with disabilities are emerging as an important electoral group for political parties. At present, political parties operating in Europe are striving to adapt their programs to the needs of persons with disabilities (Braille alphabet, sign language, etc.). At the same time, it should be noted that, in the process of providing political education to citizens, persons with disabilities must appear not only as an electorate, but also as individuals who can stand for election. The development of inclusive education in schools will, in the future, lead to a positive change in society’s attitude towards persons with disabilities, which in turn will increase the participation of persons with disabilities in the socio-political life of society” [1].

According to experts, today non-governmental non-profit organizations operating in the field of disability are beginning to occupy an important place in the political education of citizens.

3. Teaching officials working in election commissions the mechanisms for organizing inclusive election campaigns contributes to the formation of an inclusive character in electoral processes. That is why it is of great importance to provide them with knowledge about this process.

In turn, "in order to organize inclusive election campaigns, attention should be paid to the following aspects:

1. Developing standards aimed at ensuring that the electoral system and electoral processes are convenient for everyone.
2. Paying attention to ensuring an accessible environment for persons with disabilities in election campaigns.
3. It is advisable to conduct training seminars for election commission staff on how to organize elections in a way that is convenient for everyone. This includes providing information about electoral processes in accessible formats (such as Braille, easy-to-read materials), providing guides and sign-language interpreters for voters, and explaining the basics of using assistive technologies" [21].
4. "Monitoring and observing the inclusiveness of elections. It should be noted that the monitoring of the electoral system can be carried out by various interested groups, which mainly include representatives of national civil society institutions, representatives of political parties, journalists, as well as national human rights institutions. It should also be mentioned that election monitoring is likewise carried out by representatives of various international organizations who come on observation missions. In turn, in order to ensure the inclusiveness of electoral system monitoring, it is advisable to guarantee the participation of persons with disabilities at all stages of this process. It should be emphasized that the questionnaire developed for monitoring should also include questions relating to voters with disabilities.
5. The participation of civil society institutions operating in the field of disability in decisions adopted regarding the socio-political participation of persons with disabilities is of great importance, since the greatest experts in the field of disability are the persons with disabilities themselves.
6. Creating a convenient mechanism for filing complaints related to the electoral system and election campaigns; if persons with disabilities consider that they have been discriminated against in the course of electoral processes, they must have the opportunity to submit complaints" [21].

In our opinion, the seven recommendations developed by the United Nations experts for states are not exhaustive. We believe that it is also of great importance to organize public service on the basis of inclusive principles and to add this as a further recommendation. Indeed, ensuring the inclusiveness of public service will provide persons with disabilities with the opportunity to participate fully in the socio-political life of society.

Conclusion

The analysis of the essence of global processes aimed at increasing the socio-political participation of persons with disabilities has made it possible to arrive at the following conclusions:

1. The global policies carried out by international organizations in this field serve to increase the socio-political participation of persons with disabilities. Indeed, today one of the indicators of a given state's image is the extent to which an inclusive society has been formed in that country.
2. Ensuring the full participation of persons with disabilities in the life of society is directly linked to the effective activities of non-governmental organizations that protect their rights and interests.
3. Today, persons with disabilities are increasingly seen not only as a specific electoral group, but also as individuals who have the opportunity to be elected. This very fact enables them to bring their interests onto the political arena.
4. Proceeding from the global processes aimed at ensuring the full participation of persons with disabilities in the life of society, it can be said that, in today's New Uzbekistan, it is necessary to develop a "Concept for Ensuring Inclusive Participation in Society."

References:

[1] OSCE Office for Democratic Institutions and Human Rights (ODIHR), "Guidelines on promoting the participation of persons with disabilities in political and public life," Warsaw, *Printed in Poland by Poligrafus Jacek Adamiak*, 2019.

[2] OSCE "Document of the Moscow Meeting of the Conference on the Human Dimension of the CSCE," Moscow, October 3, 1991.

[3] OSCE Parliamentary Assembly "Berlin Declaration and resolutions adopted at the 27th Annual Session," *Berlin*, 7– 11 July, 2018. https://www.oscepa.org/en/documents/annual-sessions/2018-berlin/declaration-26/3744-berlin-declaration-rus/file

[4] United Nations "Convention on the Rights of Persons with Disabilities," 13 December, 2006.

[5] OSCE Office for Democratic Institutions and Human Rights (ODIHR), "Principles for promoting the participation of persons with disabilities in political life," *Warsaw*, 2019.

[6] Committee on Equality and Non-Discrimination "Political rights of persons with disabilities as a question of democracy," *Frankfurt*, 2015–2018.

[7] Ganieva M.Kh. "Social work with different groups of the population," Public Opinion, *Human Rights Journal*, 4, 2015, p. 116.

[8] Latipova N.M., Abdukhalilov A.A., & Alekseeva V.S. "Social barriers in the process of forming an inclusive society*," Historical and Socio-Educational Thought Journal,* 2022, p. 97.

[9] Mo'minova L.R. "Social protection of children in Uzbekistan: Science and practice," In Collected Papers. Tashkent: *Specter Media Group*, 2016.

[10] Nurkeldiyeva D.A. "Correctional-pedagogical habilitation and comprehensive support for young children in need of special assistance in Uzbekistan," In *Proceedings of the International Forum "Strengthening Social Work in Ensuring the Well-being of Children and Families in Uzbekistan."* Tashkent, 2019.

[11] Alimova V.S. "Targeted rehabilitation of children with cerebral palsy under conditions of the Republican Center for Social Adaptation of Children," *Medical Sciences Journal*, 11 January, 2024, p. 3. Retrieved from https://cyberleninka.ru/article/n/tselenapravlennaya-

reabilitatsiya-detey-s-tserebralnym-paralichom-v-usloviyah-respublikanskogo-tsentra-sotsialnoy-adaptatsii-detey/viewer

[12] Alekseeva V.S. “Social protection of persons with disabilities as a means of ensuring the mobility of vulnerable population groups,” *Bulletin of the National University of Uzbekistan*, 1/6, 2022, p. 44.

[13] Abduvaliyeva M.A. “Mechanisms for improving the social adaptation of children with disabilities,” Monograph, Tashkent: *Zebo Prints*, 2023.

[14] Komilov F.O. “Institutional improvement of social protection of children with disabilities,” Monograph. Tashkent: *Bola va Zamon Publishing House*, 2023.

[15] Uzakova Z.F. “Features of the socialization and labor integration of youth with special needs,” PhD dissertation in Sociology, Tashkent, 2019.

[16] Yusupov D. “Invisible people,” *Gazeta.uz.* 29 November, 2018. Retrieved October 22, 2023, from https://www.gazeta.uz/ru/2018/11/29/statistics/

[17] Checherina Ya.E., & Mo‘minova L.R. “Methods and content of correctional and developmental work on the development of intellectual abilities among pupils of “Mehribonlik” children’s homes,” 2008, p. 4.

[18] Abdukhalilov A.A., & Yusupov D. “Barriers to disability-inclusive employment in Uzbekistan: A pilot qualitative study of disabled people's lived experiences,” *Journal of International Development, 34*(5), 2022. https://doi.org/10.1002/jid.3693

[19] World Health Organization (WHO), “Disability and health,” *Fact sheet*, 5 July, 2024. Retrieved from https://www.who.int/news-room/fact-sheets/detail/disability-and-health

[20] United Nations General Assembly “Resolution № 70/1: Transforming our world – the 2030 Agenda for Sustainable Development,” September 25, 2015. Retrieved from https://www.undp.org

[21] United Nations “Development Programme (UNDP),” 30 July, 2023. Retrieved from https://www.undp.org

UDC: 902, 91, 93/94

LAND TENURE RELATIONS IN THE CENTRAL ASIAN KHANATES AND THEIR SOCIO-ECONOMIC CONSEQUENCES

Kamalova Nargiza Polatbaevna
Associate Professor (PhD), Department of History, Urgench Innovative University
kamolovanargiza2018@gmil.com

Annotatsiya. Mazkur maqolada O‘rta Osiyo xonliklarida XX asr boshlarigacha faoliyatda bo‘lgan yer egaligi shakllari, yer egaligining huquqiy asoslari, aholining mavjud yer egaligi munosabatlaridagi ishtiroki ilmiy manbaviy asosda tahlil qilingan va manbaviy xulosalar berilgan.

Kalit so‘zlar: *amlok yerlar, vaqf yerlari, suyurg‘ol, bevatan, koranda, atoyi yerlar, yorliqli yerlar, otliq yerlar, tanho yerlar.*

Аннотация. В статье на основе научных источников анализируются формы земельной собственности, правовые основы землевладения и участие населения в земельно-имущественных отношениях в среднеазиатских ханствах до начала XX века, а также приводятся источниковедческие выводы.

Ключевые слова: *амлокские земли, вакфные земли, суюргол, без родины, коранда, вакфалет, названные земли, обозначенные земли, отмеченные земли, уединенные.*

Abstract. This article analyzes the forms of land ownership that existed in the Central Asian khanates until the beginning of the 20th century, the legal foundations of land ownership, and the participation of the population in existing land ownership relations on a scientific source basis, and provides source conclusions.

Keywords: *estate, endowment lands, private state, homeless, koranda, endowment, named lands, marked lands, equestrian lands, secluded lands.*

Introduction

The economic rise and sustainable development of the Central Asian khanates were directly related to the effective use of traditional farming methods in agriculture, the rational distribution of water resources, and the formation of large-scale irrigation systems. These systems were the primary factor that determined the agrarian potential of the region, and they indicate a high level of development of the agricultural culture in the history of the Central Asian khanates. After all, land ownership relations existed in the Central Asian khanates in complex and differentiated forms. In the example of the Khiva Khanate, it can be seen that agrarian relations constituted the central pillar of economic life. Land, as the main source of livelihood of the population, determined not only economic activity, but also formed social stratification and directions of state policy. Therefore, land-related issues went beyond the scope of a simple economic process and rose to the level of state policy, and specific legal and administrative mechanisms for its management were developed. This situation indicates the feudal nature of the agrarian system.

Research Methodology

The Central Asian khanates - Bukhara, Khiva and Kokand khanates, traditional farming culture played a central role not only in the basis of economic life, but also in the formation of social structure, customs and culture. These economic systems were largely adapted to the natural and geographical factors - river oases, mountain foothills, deserts and steppes, and were formed through land ownership, irrigated agriculture, horticulture, animal husbandry and handicraft activities.

However, as a result of the colonial policy that began in the second half of the 19th century and the beginning of the 20th century, fundamental changes occurred in these traditional ethno-economic systems. The following methodological approaches are considered important in analyzing this process:

1. Historical-ethnological approach, that is, the analysis of national economic practices in the process of historical formation;
2. Taking into account local climate, land and water resources, and cultural adaptation factors through an anthropological -geographic approach;
3. The cultural-civilizational approach consists in analyzing ethno-economic systems in their civilizational context, that is, determining the relationship of these systems to the social structure, value system, and traditions.

Literature Review

Researchers divide ownership rights in the agrarian system in Central Asia from the 18th to the early 20th centuries into the following main forms:

1. State lands (amlok [1]) – at the disposal of the khan, and their revenues were directed to the treasury.
2. Endowment lands – lands set aside for the purpose of providing for religious and charitable institutions and considered legally inviolable.
3. Private estates (mulk or suyurg‘ol) – a form of land ownership granted by the khan or transferred on a hereditary basis.
4. Communal lands (existing until the beginning of the 19th century) are lands for common use owned by rural communities, which played an important role in the socio-economic life of peasants.

These types of ownership served as a decisive factor not only in economic terms, but also in the formation of social and political relations. For example, while the central government strengthened its economic power through state lands, endowment lands strengthened the position of religious and educational institutions. Private property served as a means of materially motivating the classes loyal to the ruler.

Thus, the land tenure system in the Central Asian khanates was simultaneously an important mechanism of economic management, political administration, and social control. In the case of the Khiva Khanate, we also see that land and farming issues were elevated to the level of state policy. This, in turn, is the main key to understanding the socio-economic life of the khanate.

State or estate land ownership was a unique legal and economic system, which mainly covered common land areas in areas with forests, meadows, sands and lakes. According to sources from the late 19th and early 20th centuries, the size of state lands in the Central Asian khanates amounted to 86 thousand tanobs [2]. Each khan who

ascended the throne directly controlled the procedure for the use of state lands. This process was carried out, first of all, through the system of land distribution and taxation. The undeveloped territories that were part of state lands were included in the agricultural turnover due to the construction of irrigation facilities. As a result, the development of new lands not only expanded the general economic base, but also served the personal interests of the khan. Because the khan, his household and close relatives also acquired a certain amount of land in this process. By the 19th century, the personal land ownership of the Khiva khans had increased significantly. The Khans of Khiva were considered the largest feudal landowners in the state during this period. Because they also had a number of private lands at their disposal. The most fertile lands and gardens in the khanate were in the hands of the khan and his descendants. According to the analysis of Munirov Q., in these areas the labor of landless peasants, forcibly relocated residents, and slaves was widely used [3]. Yuldashev M., in his study, emphasizes that the khans owned very large personal or royal lands and that they were the first-class feudal lords in the state [4]. Of course, the ownership of large areas of land by the khans was another form of large feudal land ownership. Thus, the khans controlled state lands and the taxes they received, and also owned estates that represented their personal interests. In particular, Ogahiy writes that in 1846–1847 (1263 AH), Muhammad Aminkhan dug a canal (yap) on the right bank of the Sharqi Roviq River in order to drain water from the areas around Kuhna Urgench and Kuhna Vazir, which were suitable for farming, but where water did not reach [5]. As a result, water was drained to these areas, creating favorable conditions for farming, and these arable lands passed into the possession of the khan. Ogahiy noted in his works in which cities the Khiva khans owned land, but did not provide precise information about the size of these lands. The land owned by the Khiva khans consisted mainly of fertile, agriculturally suitable lands within the khanate. Most of the khans' personal lands were located in areas on the right bank of the Amu Darya.

Were considered state lands until 1865–1866, that is, until the time of Said Muhammad Khan [4]. Later, these lands passed into the possession of Said Muhammad Khan. The lands worked by the karandas around Akmasjid, Kun’girat, Davkara and Shurakhon became the personal property of the khans. The amount of grain obtained from these lands was constantly monitored by the officials who governed these territories - the mushrifs. This is also confirmed in the books of grain receipts and expenditures of the Khiva Khanate during the time of Muhammad Amin Khan [6].

Analysis and Results

The existence of state lands served several socio-economic functions. First, it was considered an important source of revenue for the state budget. Secondly, state lands stimulated the development of the irrigation system, ensuring the involvement of new territories in agriculture. Third, this system served the interests of the khan as a means of consolidating political power.

In particular, according to the information of Nurjonov K. and Khojaniyazov G., in the Khiva Khanate itself, before the Russian invasion, a total of there were 1 million 681 thousand desyatina of land [2] of which:

1) 324 thousand desyatina of land were developed and used as cultivated areas;

2) 224 thousand desyatina of land are considered endowment lands owned by the population and mosques;

3) 100 thousand desyatina of land were the personal property of the khan.

The remaining large part remained as undeveloped, neglected lands. This classification reveals the structural structure of the land fund in the khanate and the diversity of land ownership forms. On the one hand, developed arable land was the mainstay of the economy, on the other hand, endowment lands played an important role in socio-economic life as a stable source of income for religious and educational institutions. The khan's personal estates served to strengthen political power within the framework of state administration and ensure the economic foundations of the khan dynasty.

Also, the existence of large areas of undeveloped land indicates the direct dependence of the khanate's agrarian system on irrigation networks. This made it possible to bring new areas into crop rotation with the construction of irrigation facilities.

Central Asia was not based solely on the direct labor of the landowners. These lands were mainly occupied by peasants, peasants, and peasants and They worked as laborers and did not have the right to own land. Such people were limited only to the right to temporary use of the land. If a person who farmed on state (kingdom) land died, the right to work on this land passed to his children and they continued their farming activities.

The farmer in the royal lands was not the actual owner of the land, he was considered the full owner of the crops grown and the buildings built by him. In the Khiva Khanate, state lands (royalty) were considered to be the lands in the western part of the oasis around Kilichniyozboy, Old Urgench, and in the southern part around Khazorasp [7]. The population farming in these lands paid "dayak" in two different ways [7]. Thus, in Central Asia, and in particular in the Khiva Khanate, land ownership relations were manifested in complex forms: although the right to land ownership was in the ownership of the state or the khan, the products of labor were recognized as the property of the peasant.

In the land ownership system of the khanate, land workers were divided into the following social groups:

Landless people are people who lease state or royal lands [8].

Koranda – individuals who rent private or owned land.

Wakfkor – persons who work on waqf lands for rent.

According to sources [4], bevatans usually rented an average of 5–7 tanab of land and paid a "salgut" tax of 1 gold coin for every 5 tanab of land.

However, since the size of state-owned land was relatively limited, the land rented by bevatans constituted a very small share of the total land area.

Property (mulki-hurri-kholis) is divided into three main types, which are taxed according to their nature. These are:

1) Atoyi property (ata-i mulk);

2) Titled property;

3) Equestrian lands.

The author has discussed in detail the land ownership and its types in the Khiva Khanate in his monograph [1]. Equestrian lands were considered hereditary lands, which belonged mainly to the khan's relatives and high-ranking state officials. The amount of tax collected from such lands was very small, and in some cases, they were not taxed at all [8].

Had the right to dispose of these lands throughout his life. After his death, this right passed to his heirs [8].

Atlik lands (Equestrian lands) constituted a separate category in the agrarian structure of the Khiva Khanate. Their name is explained, first of all, by the use of these lands by Turkmen communities. The use of these lands was carried out in exchange for certain obligations, for every 30 tanob (about 5 desyatina) of land, the owner was obliged to serve the khan with one armed horseman during military mobilization [7].

Conclusion

Land relations were the main supporting system of the khanate economy, which included state land ownership (amlok), endowment lands, as well as private property and collective lands. These forms of land ownership strengthened social stratification, expressed the interests of the feudal class in the distribution of productive resources. At the same time, the majority of peasants were connected to the landowners through various obligatory relations - tenancy, shareholding or labor obligations.

References:

[1] Kamolova N. “The History of Agricultural Traditions in the Khorezm Oasis (19th Century – Early 20th Century),” Bukhara: *Durdona*, 2022, pp. 6-12.
[2] Nurdjanov K., Khodjaniyozov G. “The Amu Darya,” Tashkent: *Abu Ali Ibn Sino Medical Publishing House*, 2004, pp. 85–86.
[3] Munirov Q. “The Historical Works of Munis, Ogahiy, and Bayani,” Tashkent: *Publishing House of the Academy of Sciences of the Uzbek SSR*, 1960, pp. 11.
[4] Yuldashev M. “Feudal Landownership and State Structure in the Khiva Khanate,” Tashkent: *State Publishing House of the Uzbek SSR*, 1959, pp. 151-195.
[5] Ogahiy “Jomeʿ al-Voqeʿot as-Sultoni,” Works, Tashkent: *Gafur Gulom Literature and Art Publishing House*, Vol. 6, 1980, p. 21.
[6] Uzbekistan State Archive. Fund 125, Inventory 2, Files 400–410.
[7] Magidovich I. “Khorezm,” In *Territory and Population of Bukhara and Khorezm*, Part 2. Tashkent, 1926, pp. 65–67.
[8] Shkapsky O. “Essays on the Amu Darya: On the Agrarian Question in the Lower Amu Darya,” Tashkent: *Typo-Lithography*, 1900, pp. 93-107.

UDC: 631/635, 631.2, 677

THE IMPORTANCE OF MICROCLIMATE CONTROL IN PREVENTING SELF-HEATING IN COTTON FLOWERS

Kuldashov Golibjon Obbozzjonovich
Independent researcher of Namangan State Technical University, Namangan, Uzbekistan
golibobbos@gmail.com

Annotatsiya. Maqolada paxta xom-ashyosini saqlash jarayonidagi fizik, kimyoviy va biologik o‘zgarishlar tahlil qilingan. G‘aramda namlik va haroratning taqsimlanishi, mikrobiologik faoliyat va oksidlanish reaksiyalarining tola sifatga ta’siri yoritilgan. Paxta g‘aramlarida o‘z-o‘zidan qizib ketish jarayonining fizik modeli ishlab chiqilgan va uning oldini olish uchun mexatron mikroklimat nazorati tizimi joriy etish bo‘yicha amaliy tavsiyalar berilgan.

Kalit so‘zlar: *paxta xom-ashyosi, g‘aram, namlik, harorat, mikroklimat, o‘z-o‘zidan qizish, ventilyatsiya, sensor tizimi.*

Аннотация. В статье проанализированы физические, химические и биологические изменения, происходящие в процессе хранения хлопкового сырья. Освещено распределение влаги и температуры в штабеле, влияние микробиологической активности и процессов окисления на качество волокна. Разработана физическая модель самонагревания хлопковых штабелей и представлены практические рекомендации по внедрению мехатронной системы контроля микроклимата для предотвращения перегрева.

Ключевые слова: *хлопковое сырьё, штабель, влажность, температура, микроклимат, самонагревание, вентиляция, сенсорная система.*

Abstract. The article analyzes the physical, chemical, and biological changes occurring during the storage of raw cotton. The distribution of moisture and temperature within cotton piles, as well as the influence of microbiological activity and oxidation reactions on fiber quality, are discussed in detail. A physical model of the self-heating process in cotton storage piles has been developed, and practical recommendations are proposed for implementing a mechatronic microclimate control system to prevent self-heating and ensure fiber preservation.

Keywords: *raw cotton, cotton pile, moisture, temperature, microclimate, self-heating, ventilation, sensor system.*

Introduction

The introduction of energy and resource-saving technologies in the fields of cotton fiber cultivation, storage and production of higher value-added products - cotton, textiles and ready-made clothing - is one of the current trends in the world. Today, the trend of using advanced technology and mechatronic systems to produce environmentally friendly, safe and high-quality products in this area is increasing [1].

The leading positions in the world cotton market are occupied by countries such as China, the USA, Brazil and India. These countries use advanced technologies in the processes of processing, storing and producing export-oriented products, use sustainable innovative approaches aimed at rational management of resources and production of competitive products. Therefore, the efficiency of maintaining the quality of cotton fiber and processing is one of the important factors determining the economic prestige of the country in the world market.

World experience shows that the warehouse infrastructure, climate control, fire safety and compliance with international standards in the storage of cotton raw materials ensure long-term product quality. In particular, one of the urgent problems is to determine the influence of microclimate parameters on the process of self-heating during the storage of cotton raw materials in bundles, to prevent it and to ensure fire safety [2]. Practice shows that improper distribution of humidity and temperature in bundles, insufficient ventilation and high ambient temperature cause the process of self-heating in cotton. This leads to deterioration of the fiber structure, yellowing, microbiological contamination and an increased risk of fire. Therefore, it is necessary to introduce automatic control systems for microclimate parameters.

Literature Review

The issue of physical, chemical and biological changes that occur during the storage of cotton raw materials has been the focus of many researchers in recent years. In particular, it has been found that the interaction of humidity, temperature, microbiological activity and oxidation reactions leads to a decrease in fiber quality.

Liu et al. (2017) studied the thermal stability of fiber composites and reported a decrease in mechanical strength in collagen-based materials due to moisture and oxidation [1]. This suggests that cotton fiber can also be deformed under thermal stress. Wang et al. (2018) analyzed the role of antioxidant additives in food storage and found that excessive oxygen exposure accelerates the oxidation process and reduces quality [2]. This scientific approach is important in understanding the hazardous processes associated with oxygen levels in cotton bales.

Bobokalonov et al. (2018) studied biochemical processes through transcriptomics analysis and demonstrated that enzymatic activity is accelerated in a warm and humid environment [3]. The results of this study link the possibility of spontaneous cotton heating with increased microbial activity within the bundle.

Firrman et al. (2021) found that gut microbiota growth rates varied across multiple temperature ranges in experiments [4]. This finding supports the biological implications of temperature stratification in cotton yams.

Hotchkiss et al. (2020) analyzed the structural changes of polysaccharides and anthocyanins in plant fibers and observed molecular degradation and color changes under high temperature conditions [5]. The yellowing of cotton fibers is related to the effect of heat, which is due to these types of reactions.

Kaur et al. (2022) analyzed the response of plant microtissues to moisture and light conditions and noted changes in chemical composition when storage conditions were not properly controlled [6]. This approach suggests that precise control of the microclimate in cotton raw materials is required.

From the analysis of these sources, it can be seen that studies conducted in various scientific areas — in the field of food, plant fibers and microbiological systems — serve as the main theoretical foundation for understanding the process of self-heating in cotton bales. Their general conclusion is that the combination of moisture + heat + microbiological activity leads to heat accumulation and degradation in any biological fibrous material. Therefore, microclimate control using sensor monitoring systems is recommended as the most effective solution for storing cotton raw materials.

The main factors of cotton smut heating

Cotton raw materials undergo a number of physical, chemical and biological changes during storage. One of the most dangerous processes is self-heating, which has a serious impact on the quality and safety of the fiber. During long-term or unfavorable storage conditions, heat can accumulate in the interior of the bundle and rise to high temperatures [3].

The heating of cotton wool occurs under the influence of the following factors:

Microbiological activity - heat release resulting from the metabolism of bacteria and fungi;

Oxidation reactions are the reaction of oil, sucrose, and other organic substances in cotton fiber with oxygen in the air;

Humidity effect - biochemical reactions accelerate at high humidity.

Theoretical critical points

Table 1. The critical points for fibers.

Parameter	Value	Impact
Humidity	> 12 %	Microbiological activity accelerates
Temperature	> 40 °C	The heating process will intensify on its own.
Temperature	60–70 °C	The fiber structure is thermally damaged, risk of burning
Oxygen concentration	> 10 %	Oxidation reactions are activated

According to USDA (United States Department of Agriculture) studies, cotton stored at 14% moisture content can reach temperatures of up to 55°C within 10 days. According to FAO recommendations, the moisture content of the stack should not exceed 8% and ventilation should be open. High temperature zones are observed not in the center of the stack, but in the deeper layers where air exchange is limited [4].

The following parameters were determined to generate a general model of the temperature rise process in cotton bales:

1) The concentration of available oxygen in the cotton skein;
2) Energy release reaction;
3) Stoichiometric reaction;
4) Probable rates of two reactions;
5) Energy activity;
6) The relationship between pressure and temperature on the depth of cotton wool.

The volume of a cotton yam measuring 25 meters long, 14 meters wide, and 7.5 meters high is determined by the following formula:

$$V_n = \sum_{k=1}^{n} \int_0^b a_k dx + \frac{1}{3b} \int_0^b h' \left(\sum_{k=1}^{n} \int_0^b a_k dx + 0.1 + \sqrt{0.1 \sum_{k=1}^{n} \int_0^b a_k dx} \right) dx =$$

$$= ab * \frac{2}{3} h + \frac{1}{3} * h * \frac{1}{3} * \left(ab + \frac{ab}{10} + \sqrt{\frac{ab}{10} * ab} \right) == \frac{2abh}{3} + \frac{h}{9}\left(1.1ab + ab\sqrt{1.1}\right)$$

The density of cotton wool can be determined as follows:

$$\rho_b = \frac{m_b}{V_b} = \left(G\rho_3 \sum_{i=1}^{R} \int_0^x f_i^{(n)}(x) dx^n * V_n \right) \left(\left(\sum_{l=1}^{\infty} |r_{ij} \times R_{ij}| \right)^2 V_n \right)^{-1} =$$

$$= \left(G\rho_3 \sum_{i=1}^{R} \int_0^x f_i^{(n)}(x) dx^n \right) \left(\left(\sum_{l=1}^{\infty} |r_{ij} \times R_{ij}| \right)^2 \right)^{-1}$$

The presence of oxygen in the cotton bales is important in the calculations, and depends on the weight and pressure of the cotton itself, which is determined as follows:

$$p = \frac{F}{S} = \frac{mg}{ab} = mGM \left(\left(\sum_{l=1}^{\infty} |r_{ij} \times R_{ij}| \right)^2 * \sum_{k=1}^{n} \int_0^b a_k dx \right)^{-1}$$

It was found that the self-heating of cotton bolls is due to the oxidation reaction of fiber-cellulose due to the pressure created by the boll's own weight, and the oxidation reaction of the carbohydrate maltose of the grain, which consists of glucose and starch.

$$\begin{cases} (C_6H_{10}O_5)_n + (6O_2)_n \rightarrow (6CO_2)_n + (5H_2O)_n \\ C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O \end{cases}$$

Research Methodology

SEM analysis of cotton fiber samples from the upper, middle, and lower layers of the pile. Scanning electron microscopy (SEM) is an effective method for studying the structure and morphological properties of cotton fibers. This method allows us to determine the twist of the fibers, surface roughness, and changes after external influences. In scientific research, SEM is an important method for assessing the quality of the fibers [5-6].

Analysis and Results

Cotton fiber samples were taken from the upper, middle and lower parts of the bundle and the results showed that the internal microstructure of cotton fiber changed during storage in the bundle (Figure 1). Under the conditions of storage in the bundle, different changes were observed in the fiber structure in the upper, middle and lower parts. This directly affects the physical, mechanical and technological properties of cotton fiber. In the top part of the cotton bundle (Top part), the fiber fibrils are scattered, partially relaxed, due to which the top part of the bundle is in greater contact with the external environment, therefore, air movement, temperature changes and the drying process are stronger, and the elasticity of the fiber is reduced. In the middle part of the

cotton bundle (Middle part), the fibrils are more stable, the structure is well preserved, due to which the middle part of the bundle is relatively protected from external factors and is stored in optimal humidity and pressure conditions. In this part, the fiber quality indicators (strength, elongation) practically do not change.

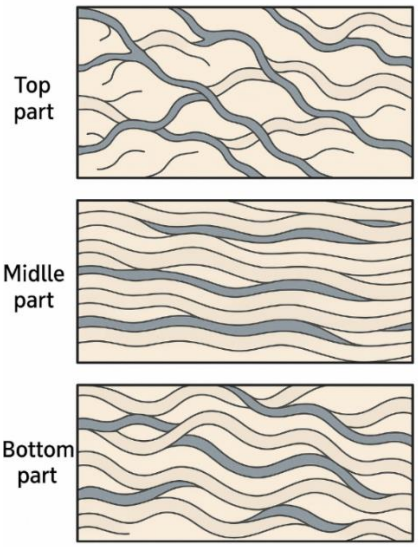


Figure 1. The structure and arrangement of cotton fibers in different layers of the bundle.

In the bottom part of the cotton skein, the fibrils are located close to each other and partially displaced. In the lower part of the skein, the pressure is higher, the moisture accumulation is stronger. This leads to a change in the microstructure and fibril angles, which negatively affects the technological properties of the fiber, and problems may arise during fiber cooking. The optimal temperature in the interior of the cotton skein is 25-34 ℃. If the temperature rises above 35 ℃, oxidation reactions accelerate, the activity of microorganisms increases, and self-heating may occur. The optimal humidity is 8-10%. If the humidity is higher than 14%, the activity of fungi and bacteria increases, heat is released, and the temperature rises. This destroys the internal structure of the fiber. If the humidity is below 7%, the fiber becomes hard and brittle. When high temperature and high humidity are combined, the risk of self-heating increases several times. The top of the pile dries quickly, while the bottom experiences increased humidity and an increase in temperature.

Under storage conditions in a bundle, humidity and temperature are distributed differently across the layers, including the risk of self-heating in the lower and middle parts. Figure 2 compares the moisture content of cotton fibers in different layers (upper, middle, lower) of cotton bundles of the Hamza expo art textile enterprise in the Oltiariq district of Fergana region with the humidity of the outside air. The horizontal axis shows (June–September 2025), and the vertical axis shows the relative humidity (%). Here Ambient Air (30-65%) - black line, humidity in the outside air fluctuated sharply seasonally, decreasing in July and increasing again to a higher value in August-September, Top Layer (8-14%) - blue line, humidity in the upper part of the pile has the lowest indicators, since the upper part is in direct contact with the air and dries quickly, Middle Layer (8-15%) - green line, humidity is moderate and is maintained without significant changes, this part ensures the stability of the pile and fiber quality, Bottom Layer (10-20%) - red line, the highest humidity is observed in the lower layer,

moisture moves downward and accumulates under the influence of pressure, approaching 18% threatens microbiological deterioration of the fiber and self-heating. The moisture distribution in the stack is not uniform: the upper part is dry, the middle part is stable, and the lower part is more humid. This situation is dangerous for long-term storage of the stack, since high humidity-temperature rise in the lower layer causes a self-heating process. Therefore, it is necessary to install moisture sensors in the stacks regularly and ventilate them. It is necessary to ensure air circulation through the channels.

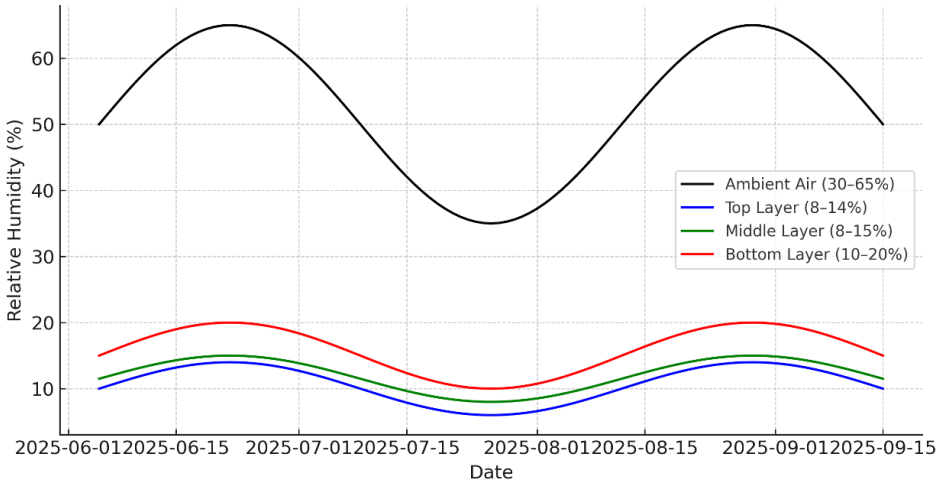


Figure 2. Results of comparing cotton fiber moisture content with outdoor air humidity.

Figure 3 compares the temperature of cotton fiber in different layers (upper, middle, lower) of the piles of the “Hamza expo art textile” enterprise in the Oltiariq district of Fergana region with the temperature of the outside air. The horizontal axis shows the date (June-September 2025), and the vertical axis shows the temperature (℃). Ambient Air (30-47 ℃) - black line, the outside air temperature varies significantly, decreased in July, and rose again to a higher value in August and September, Top Layer (32-41℃) - blue line, the top layer responds quickly to the influence of the outside air, temperature changes are softer than in the air, but are not constant, Middle Layer (33-42 ℃) - green line, the temperature is stable in the middle layer and is less affected by changes in the outside air. This part is considered a relatively stable area of the stack, Bottom Layer (32-46 ℃) - the red line, the temperature is concentrated more in the bottom layer, which, together with humidity, increases the risk of overheating.

The temperature distribution in the pile is not uniform, similar to the humidity: the temperature in the lower layer is high, the middle part is stable, and the upper part reacts quickly to the influence of air. If not controlled, the high temperature and humidity in the lower layer can together lead to thermo-oxidative damage of the fiber. Therefore, temperature monitoring through sensors and the use of ventilation channels in piles are mandatory.

Moisture: accumulation in the lower layer increases the risk of warping, temperature: accumulation of heat in the middle layer negatively affects the fiber structure and the yellowing process. SEM results showed that changes in the fiber surface due to moisture and temperature reduce the quality of the fiber during processing.

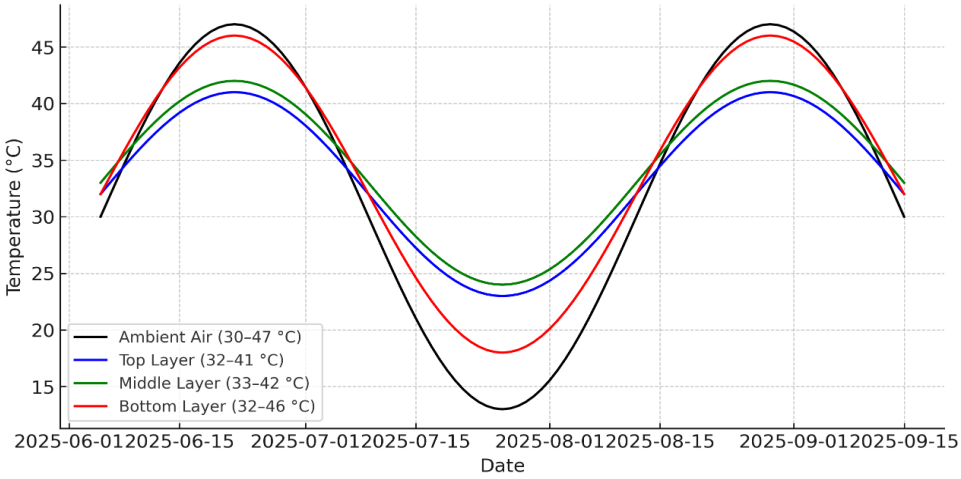


Figure 3. Results of comparing cotton fiber temperature with outside air temperature.

In the conditions of the Fergana region, the highest temperatures were observed in July-August 2025, which increased the level of risk during storage, requiring the introduction of ventilation ducts, sensor monitoring systems, and optimal storage conditions as a measure.

Conclusion

The phenomenon of spontaneous heating observed during the storage of cotton raw materials in bales has been scientifically proven to be closely related to heat and mass transfer, biochemical reactions, and oxidation processes. The results of the study indicate that the uneven distribution of temperature and humidity inside the bale has a significant impact on the fiber structure and its physical and mechanical properties.

The upper layer of the cotton pile dries quickly due to its active contact with the external environment, which leads to a decrease in the dispersion and elasticity of the fiber fibrils. In the middle layer, humidity and temperature are relatively stable, and in this part the fiber quality indicators practically do not change. The most dangerous situation is observed in the lower layer of the pile, since here the pressure is high, air circulation is insufficient, and humidity is high. This becomes a point of increased activity of microorganisms, activation of oxidative processes, and an increased risk of self-heating.

Studies have shown that if the moisture content of cotton exceeds 12–14% or the temperature exceeds 35 °C, heat transfer becomes isolated and local hot spots form within the bundle. At these spots, the temperature can rise to 45–50 °C, which causes thermal damage to the fiber, yellowing, and an increased risk of fire.

Therefore, it is important to implement a continuous sensor monitoring system in the bales. Continuous measurement of temperature and humidity through sensors and automatic ventilation control using a mechatronic control system is an effective way to maintain cotton quality and safety.

References:

[1] Liu J., Liu C., Brown E.M. “Development and characterization of genipin crosslinked gelatin-based composites incorporated with vegetable-tanned collagen fiber (VCF),” *Journal of American Leather Chemists Association*, 112(12), 2017, pp. 410-419.

[2] Wang C., Liu J., Duan Z., Lao Y., Qi P.X., Ren D. “Effects of dietary antioxidant supplementation in cows feed, milk processing and storage on lutein content and sensory quality,” International Journal of Dairy Technology, 2018. DOI: 10.1111/1471-0307.12532

[3] Bobokalonov J., Liu Y., Shahrin T., Liu L.S. “Transcriptomics analysis on the regulation of tomato ripening by the ethylene inhibitor 1-methylcyclopropene,” *Journal of Plant Studies*, 7(2), 2018, pp. 49-60. DOI: 10.5539/jps.v7n2p49

[4] Firrman J., Liu L.S., Mahalak K.K., Tanes C., Bittinger K., Bobokalonov J., Van Den Abbeele P., Mattei L., Zhang H. “Comparative analysis of the gut microbiota cultured in vitro using a single colon versus a 3-stage colon experimental design,” *Applied Microbiology and Biotechnology*, volume 105, 2021, pp. 3353-3367. DOI: 10.1007/s00253-021-11241-x

[5] Hotchkiss A.T., Chau H.K., Strahan G.D., Nunez A., Simon S., White A.K., Yadav M.P., Dieng S., Hirsch J. “Blueberry fiber pectin, xyloglucan and anthocyanin structure and function,” *Food Hydrocolloids*, 2020. DOI: 10.1016/j.foodhyd.2020.106572

[6] Kaur N., Singh B., Kaur A., Yadav M.P. “Impact of growing conditions on proximate, mineral, phenolic composition, amino acid profile, and antioxidant properties of black gram, mung bean, and chickpea microgreens,” *Journal of Food Processing and Preservation*, 2022. DOI: 10.1111/jfpp.16655

[7] Davronbekov D., Norkobilov S. “Remote Monitoring of the Temperature and Humidity of the Stored Cotton Barn,” *AIP Conference Proceedings, AIP Publishing* vol. 3147, 2024, p. 040019.

[8] Davronbekov D.A., Norkobilov S.A. “A device for remote monitoring of fire hazard indicators of cotton ginseng,” *Scientific and technical journal Digital Transformation and Artificial Intelligence*, № 1(2), 2023, pp. 59–67.

[9] Rajabov A.T., Turayev X.S., Boymirzaev J.R., Yigitaliyev A.A. “Monitoring System of Microclimate Parameters during Storage of Agricultural Products,” *Innovative: International Multidisciplinary Journal of Applied Technology*, 2(11), 2024, pp. 19–25.

[10] Shafi U.F., Bajwa I.S., Anwar W., Sattar H., Ramzan S., Mahmood A. “Sensing Spontaneous Combustion in Agricultural Storage Using IoT and ML,” *Inventions, MDPI* 8(5), 2023, p. 122.

[11] Shafi U.F., Anwar W., Bajwa IS, Sattar H., Yaqoob I., Mahmood A., Ramzan S. “Smart Predictor for Spontaneous Combustion in Cotton Storages Using Wireless Sensor Network and Machine Learning,” *International Journal of Distributed Sensor Networks*, DBLP 2024, pp. 1–19.

[12] Zhao X., Xiao H., Wang Q., Ping P., Sun J. “Study on Spontaneous Combustion Risk of Cotton Using a Micro-Calorimeter Technique,” *Industrial Crops and Products*, 50, 2013, pp. 383–390.

[13] Bai C.R., Zhang J.N., Lv C., Wei L.X., Zhou L.M., Zhao B. “Pyrolysis and Thermal Behavior of Unginned Cotton Piles,” *Journal of Thermal Analysis and Calorimetry*, SpringerLink 143, 2021, pp. 311–324.

UDC: 53, 537, 539, 004.04

EVALUATION OF $C_{20}@C_n$ and $C_{60}@C_n$ (n=1, 3) EXOFULLERENES ADSORBED ON THE SILICON Si(100)2×1 SURFACE IN TERMS OF TIME PARAMETERS IN THE ABSENCE OF FULLERENE ADSORPTION

Urolov Ikrom
Doctoral Student, Laboratory of physical processes of the Institute of ion-plasma and laser technologies of the Academy of Sciences of the Republic of Uzbekistan. Teacher, National University of Uzbekistan named after Mirzo Ulugbek
fizik25@mail.ru

Yadgarov Ishmumin
Professor, Laboratory of physical processes of the Institute of ion-plasma and laser technologies of the Academy of Sciences of the Republic of Uzbekistan
ishmuminyadgarov@gmail.com

Annotatsiya. Ushbu tadqiqot ishida Si(100)2×1 sirtining dimer qatorida C_n (n=1, 3) uglerod klasterlari orqali adsorbsiyalangan $C_{20}@C_n$ va $C_{60}@C_n$ ekzofullerenlarining fullerenlar adsorbsiyasi mavjud bo‘lmaganda C_{20} va C_{60} fulleren molekulalarining C_n uglerod klasterlarini fulleren molekulasiga ekzodrillovchi yakkalik C-C bog‘ bo‘ylab o‘tuchi o‘q atrofidagi aylanma va tebranma (presetsion) harakat chastotalarini past temperaturalar sohasida ($T <$ 100 K) temperaturaga bog‘lanishi molekulyar dinamika usuli asosida ochiq manba simuliyatori LAMMPS paket dasturida modellashtirilgan holda o‘rganildi.

Kalit so‘zlar: *fulleren, kremniy, adsorbsiya, aylanma harakat, presetsiya, chastota, temperatura, energiya, bog‘, modellashtirish.*

Аннотация. В данной исследовательской работе изучено температурное (T<100 K) поведение частот вращательных и колебательных (прецессионных) движений вокруг оси, проходящей вдоль одиночной экзодриллирующей C–C связи углеродных кластеров C_n (n=1, 3), адсорбированных на димерном ряду поверхности Si(100)2×1 в составе экзофуллеренов $C_{20}@C_n$ и $C_{60}@C_n$, а также в отсутствие адсорбции фуллеренов. Исследование выполнено методом молекулярной динамики с использованием открытого симуляционного пакета LAMMPS.

Ключевые слова: *фуллерен, кремний, адсорбция, вращательное движение, прецессия, частота, температура, энергия, связь, моделирование.*

Abstract. In this research work, the temperature dependence (T<100 K) of the rotational and oscillatory (precessional) motion frequencies around the axis passing through the single exo-drilling C–C bond of carbon clusters C_n (n=1, 3),

adsorbed on the dimer row of the Si(100)2×1 surface as part of the exofullerenes $C_{20}@C_n$ and $C_{60}@C_n$, as well as in the absence of fullerene adsorption, was studied. The study was carried out using the molecular dynamics method and modeled in the open-source simulator LAMMPS.

Keywords: *fullerene, silicon, adsorption, rotational motion, precision, frequency, temperature, energy, bond, modelling.*

Introduction

Nanostructures arising from the adsorption of fullerene molecules have become one of the major areas of contemporary scientific research, attracting the attention of investigators due to their unique physical and chemical properties. In particular, hybrid materials formed by the adsorption of C_{20} and C_{60} molecules on a silicon substrate surface with (100)2×1 reconstruction via Cn carbon clusters are regarded as significant for the fabrication of molecular devices that can replace semiconductor devices [1]. Moreover, in fullerene-based hybrid materials—an important component of organic solar cells—the strong adsorption of the C_{60} fullerene molecule on the layer surface is of great importance [2]. It has also been shown that $C_{20}@C_n$ and $C_{60}@C_n$ (n=1–5) exofullerenes, compared to the C_{20} and C_{60} fullerene molecules themselves, adsorb on the Si(100) silicon substrate surface by forming strong or covalent Si–C bonds [3]. Given these factors, investigating the $C_{20}@C_n$ and $C_{60}@C_n$ exofullerenes adsorbed via C_n carbon clusters on silicon substrate surfaces—by evaluating their time parameters in the absence of direct fullerene adsorption—is essential for fullerene-based devices (molecular transistors, sensors, quantum components), as the orientation and dynamic stability of the molecules relative to the surface determine their functional properties.

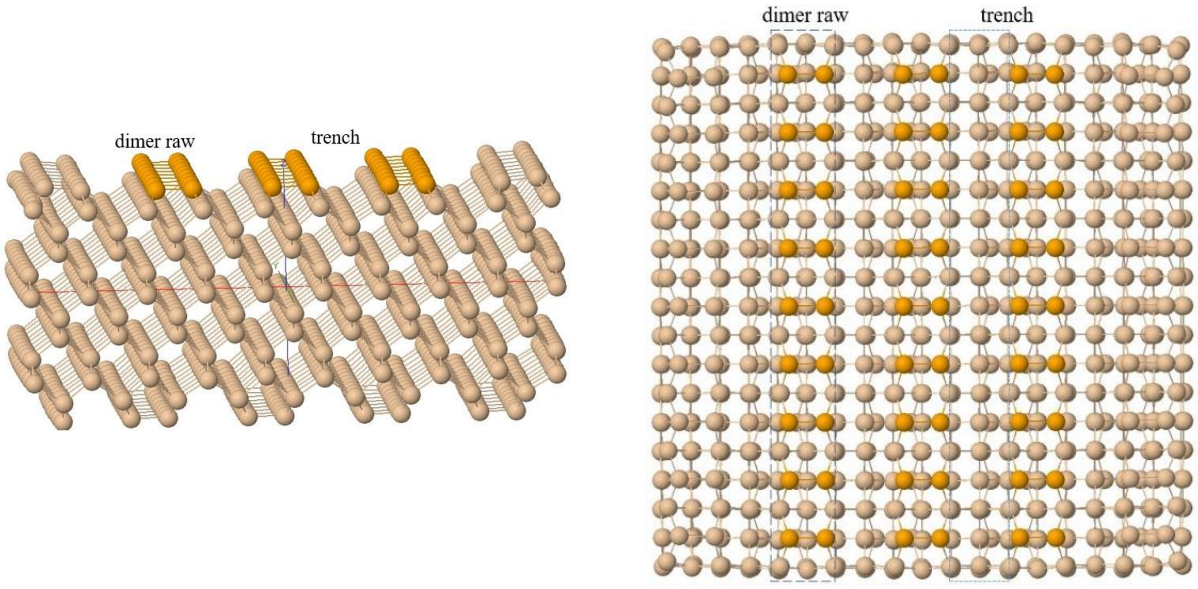
Rotational and small-amplitude vibrational (precessional) motions of the C_{20} and C_{60} fullerene molecules around an axis passing through the C–C bond are similar to the motions observed around the central σ-bonded C–C bond in all open-chain alkanes (C_nH_{2n+2}) [4–9]. In alkanes, potential barriers exist for the internal rotational motion of CH3 groups; for example, in ethane this value is ≈12 kJ/mol, arising from the energy differences between maximal and minimal conformations. This potential energy is a function of the torsional (dihedral) angle along a full 360° rotation and exhibits three equivalent minima (staggered) and three maxima (eclipsed) [5]. According to the steric/repulsion model, in the eclipsed conformation the hydrogens on one CH_3 group approach those on the other CH_3 group, leading to H–H repulsion and an increase in interaction energy [10]. According to the hyperconjugation/orbital interaction model, this rotational barrier arises because in the staggered conformation the filled σ(C–H) orbitals of one CH_3 group overlap more effectively with the antibonding σ* orbitals of the adjacent CH_3 group, stabilizing the system; in the eclipsed conformation, this interaction is reduced [11]. In the modern unified (electrostatic) model, the barrier is attributed not only to the maximal and minimal conformations but also to the role of electrostatic interactions [12]. Due to quantum tunneling, when the barrier is small, CH_3 groups may tunnel between minima, resulting in very small energy splittings (though in ethane these are typically extremely small and difficult to detect) [13].

In this study, rotational and vibrational motions—around the axis passing through the C–C bond and relative to this axis—of C_{20} and C_{60} fullerene molecules in $C_{20}@C_n$

and $C_{60}@C_n$ exofullerenes adsorbed via C_n (n=1, 3) carbon clusters on the dimer rows of the Si(100)2×1 surface, in cases where direct adsorption of C_{20} and C_{60} fullerenes on Si(100)2×1 is not observed, were investigated by molecular dynamics (MD) simulations. The temperature dependence of the frequencies of these two types of motion was examined in the low-temperature region (T<100 K) by increasing the temperature in 10 K increments.

Research Methodology

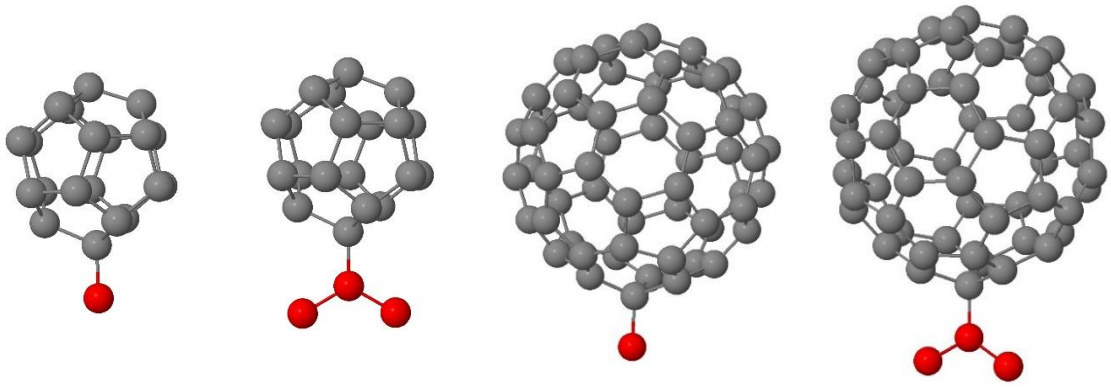
The modeling procedures described above were carried out using the LAMMPS open-source software package [14]. The JMOL program [15] was employed to visualize the obtained results and to determine each motion parameter under consideration. The coordinate data for the geometric models of the C_{20} and C_{60} fullerene molecules were taken from the database of the Nanotube Modeler software [16]. The exo-functionalization of the C_1 and C_3 carbon clusters onto the C_{20} and C_{60} fullerene molecules, as well as the adsorption of the $C_{20}@C_1$, $C_{60}@C_1$ and $C_{20}@C_3$, $C_{60}@C_3$ exofullerenes on the Si(100)2×1 surface via the C_1 and C_3 carbon clusters, was simulated in the LAMMPS package using the MD method (see Figure 1). A Si(100) substrate of dimensions 34×34×15.2 Å consisting of 1083 atoms as shown in Figure 2 was first generated in the LAMMPS package using an auxiliary script, and its 2×1 reconstruction was obtained in the JMOL program as described in the literature [17].



a) *b)*

Figure 1. Side (*a*) and top (*b*) views of the Si(100)2×1 substrate.

The temperature, volume, and number of atoms of the simulated system were controlled using the NVT ensemble. The interactions among the atoms constituting the system were described using the Tersoff formalism, expressed through the Tersoff–Erhard–Albe (TEA) potential [18], an analytically refined bond-order potential representing the first-generation Tersoff potentials optimized for silicon (Si), carbon (C), and silicon carbide (SiC). Each simulation run was performed over a time interval of 100–200 ps with a time step of 0.5 ps.



$C_{20}@C_1$ $C_{20}@C_3$ $C_{60}@C_1$ $C_{60}@C_3$

Figure 2. $C_{20}@Cn$ and $C_{60}@Cn$ (n = 1, 3) exofullerenes.

Analysis of Results

When $C_{20}@C_n$ and $C_{60}@C_n$ exofullerenes are adsorbed on the dimer rows of the Si(100)2×1 surface via C_n carbon clusters, and when the number of carbon atoms in the Cn cluster is n=1 or 3—such that the exo-functionalization of the C_{20} and C_{60} fullerene molecules with the C_n cluster occurs through a single C–C bond—the fullerene molecules do not adsorb directly onto the Si(100)2×1 surface (Figure 3). Instead, they undergo rotational and vibrational (precessional) motions around the axis passing through the C–C bond responsible for their exo-functionalization. However, if the Cn carbon cluster (with n=1, 3) binds to the fullerene molecules through two or more C–C bonds during exo-functionalization, rotational motion of the fullerene molecules is not observed; only vibrational motion occurs. This is due to the significant increase in the potential barrier that obstructs rotational motion compared to the case with a single bond. If the carbon cluster contains n=2–5 atoms and has a linear geometry, the fullerene molecules collapse onto the silicon substrate surface, and fullerene adsorption occurs; consequently, the motions investigated in this study are not observed. Moreover, even when the carbon cluster contains n=4 or 5 atoms but adopts a geometry similar to that of the n=1 and 3 clusters—allowing exo-functionalization through a single C–C bond—the fullerene molecules again collapse onto the substrate surface, and surface adsorption of the fullerene prevents both motions from occurring.

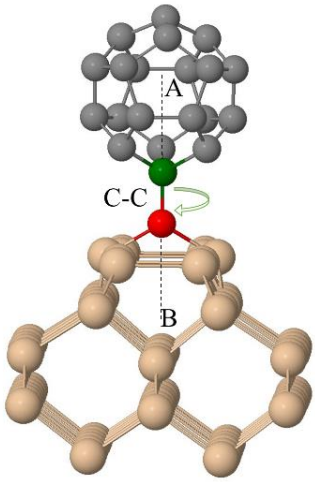


Figure 3. $C_{20}@C_1$ exofullerene adsorbed on the Si(100) surface.

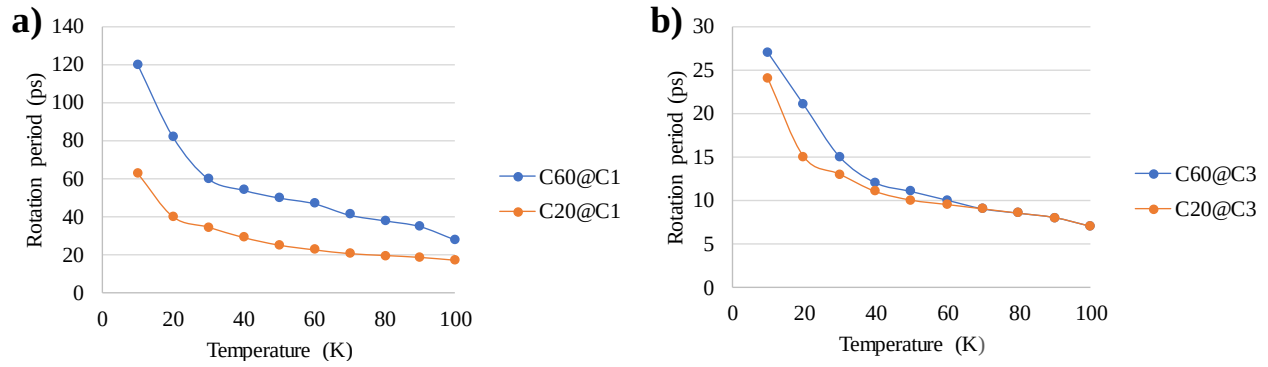


Figure 4. Temperature dependence of the rotational motion period around the C–C bond for $C_{20}@C_n$ and $C_{60}@C_n$ (n=1, 3) exofullerenes; (*a*) results for $C_{20}@C_1$ and $C_{60}@C_1$ exofullerenes, and (*b*) results for $C_{20}@C_3$ and $C_{60}@C_3$ exofullerenes.

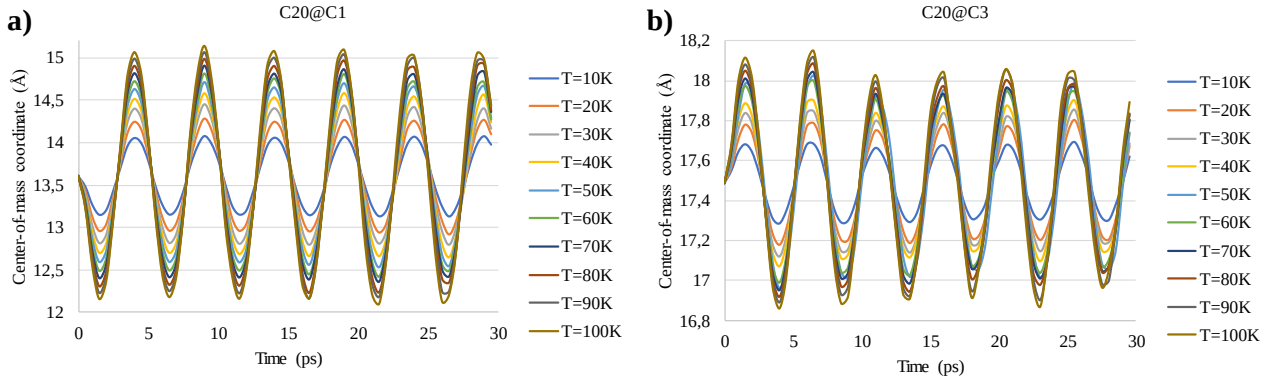


Figure 5. Time dependence of the center-of-mass (x or y) coordinate of the C_{20} fullerene molecule during the precessional motion of the $C_{20}@C_1$ and $C_{20}@C_3$ exofullerenes.

When the system temperature was increased in increments of 10 K, it was determined that the rotational motion of the fullerene molecules around the AB axis passing through the C–C bond accelerated, i.e., the frequency of this motion increased. This conclusion is also visible in the plots presented in Figure 4 (a) and Figure (b). Additionally, when the temperature dependence of the precessional motion frequency of the fullerene molecules was investigated by increasing the system temperature in 10 K increments, it was found that within the examined temperature range, the frequency of this motion remained unchanged (Figure 5 and Figure 6).

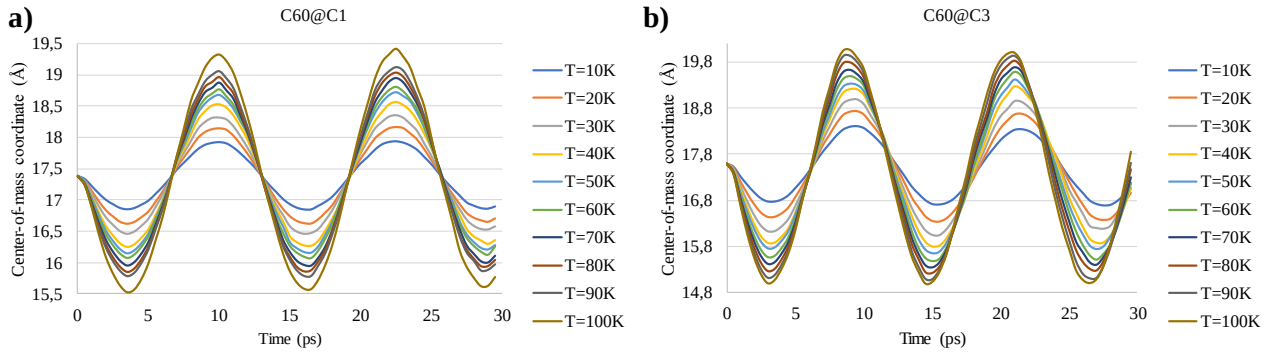


Figure 6. Time dependence of the center-of-mass (x or y) coordinate of the C_{60} fullerene molecule during the precessional motion of the $C_{60}@C_1$ and $C_{60}@C_3$ exofullerenes.

From the graphs in Figure 5 and Figure 6, it can be seen that, as the temperature increases in 10 K increments, the precessional motion frequency of the $C_{20}@C_n$ and $C_{60}@C_n$ exofullerenes remains unchanged. However, the displacement (amplitude) of

the center of mass of the C_{20} fullerene molecule from its position near the system's 0 K temperature gradually increases. The magnitude of these displacements is larger at the initial temperature range and decreases toward the end of the considered temperature interval. This can be attributed to the fact that the kinetic energy of the fullerene molecule's precessional motion is proportional to the square of the observed displacement ($E \sim \Delta x^2$).

According to the graphs in Figures 4a and 4b, the rotational motion frequency of the fullerene molecule around the C–C bond increases because, with increasing system temperature, the internal energy of the system rises. In particular, the kinetic energy of the rotational motion around the observed axis of the fullerene molecule also increases, which in turn causes an increase in the rotational motion frequency. This is consistent with classical rigid-body mechanics, where the kinetic energy of a rigid body is related to its precessional angular velocity or frequency as $E \sim \omega^2 \sim \nu^2$. The sharp changes in frequency observed at the initial temperature values are due to the relationship between this motion and the system temperature, which follows $\nu \sim \sqrt{T}$.

Conclusion

For C_{20}@C_n and C_{60}@C_n exofullerenes adsorbed via C_n carbon clusters on the dimer rows of the Si(100)2×1 surface, when n=1 or 3 and direct fullerene adsorption is absent, the rotational motion frequency of the C_{20} and C_{60} fullerene molecules around the axis passing through the single C–C bond that exo-functionalizes the fullerene molecule increases with rising temperature in the low-temperature range (T<100 K). In contrast, the precessional motion frequency of these fullerenes was observed to be independent of temperature.

Acknowledgement

This work was supported by a project of the Ministry of Higher Education, Science and Innovation Republic of Uzbekistan: FL-8323102108 "Synthesis and modification of carbon-based functional nanomaterials, research of their interactions with atomic particles."

References:

[1] Jing Li, Yang Cui, and Lin Zhang "C_{60} adsorption on defective Si(100) surface having one missied dimer from atomic simulations at electrical level," *Arabian journal of chemistry*, Vol. 16, 2023, p. 104816.

[2] Wang M.L., Sun X.Y., and Hou X.Y. "Role of buffer in organic solar cells using C_{60} as an acceptor," *Applied Physics letters*, Vol. 90, 2007, p. 071109.

[3] Urolov I.Z., Umarov F.F., Yadgarov I.D., Rakhmanov G.T., Jabborov Kh.I. "Computer simulation study of adsorption processes of C_{20}@C_n and C_{60}@C_n (n=1-5) carbon clusters on reconstructed silicon Si(001) surface," *East European journal of physics*, Vol. 3, 2025, pp. 273-280.

[4] Kenneth S. Pitzer "Energy Levels and Thermodynamic Functions for Molecules with Internal Rotation," *The Journal of Chemical Physics*, Vol. 14, 1946, pp. 239-243.

[5] Hehre W., Shusterman G., Shusterman A. "Conformational analysis of ethane," *Organic Chemistry*. Prentice Hall, 1996.

[6] Atkins P., de Paula J. Atkins "Describes the internal rotation barrier in ethane as a prototype torsional oscillator," 10th ed., Oxford University Press, *Physical Chemistry*, 2014.

[7] Eliel E.L., Wilen S.H. “Comprehensive discussion of conformations in propane, butane, pentane, etc., Butane’s anti, gauche, and eclipsed conformations are covered in detail,” *Stereochemistry of Organic Compounds*, Wiley, 1994.
[8] Fleming I. “Explains hyperconjugation and steric effects that control torsional preferences in alkanes,” *Molecular Orbitals and Organic Chemical Reactions.* Wiley, 2009.
[9] Allinger N.L. “Conformational Analysis. 130. MM2.,” *Journal of the American Chemical Society*, Vol. 99, 1977, pp. 8127–8134.
[10] Lowe J.P. “The Barrier to Internal Rotation in Ethane,” *Science*, Vol. 179, 1977, pp. 527-532.
[11] Dipak K. Mandal “Rotational Barrier,” *Stereochemistry and Organic Reactions*, 2021.
[12] Shubin Liu “Origin and Nature of Bond Rotation Barriers: A Unified View,” *The Journal of Physical Chemistry A*, 2013.
[13] Mellor T.M., Yurchenko S.N., Mant B.P., Jensen P. “Transformation Properties under the Operations of the Molecular Symmetry Groups G36 and G36(EM) of Ethane H3CCH3,” *Symmetry*, Vol.11, 2019, pp. 862/1-37.
[14] “Sandia National Laboratories,” *Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS)*, 2023. https://www.lammps.org
[15] “Java,” *Jmol*, 2023. http://www.jmol.org
[16] Yoshida M. “Nanotube Modeler,” *Nanocones, Bucky-Ball, Fullerenes, Simulation Software*. www.jcrystal.com
[17] Ramstad A., Brocks G., and Kelly P.J. “Theoretical study of the Si(100) surface reconstruction,” *Physical review B*, Vol. 51, 1995, pp. 14504-14523.
[18] Erhart P., and Albe K. “Analytical potential for atomistic simulations of silicon, carbon, and silicon carbide,” *Physical Review B*, Vol. 71, 2005, pp. 035211-1-14.