ACTUAL PROBLEMS OF MODERN SCIENCE, EDUCATION AND TRAINING

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CONTENTS

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CORRELATING PHASE, MORPHOLOGY, AND STOICHIOMETRY OF OXYGEN ANNEALING FOR CRYSTALLINE VO_2 THIN FILMS

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Annotatsiya. Ushbu maqolada turli atmosfera (havo va kislorod) va haroratning RF sputter usuli bilan qoplangan VO_2 yupqa qatlamlarning xususiyatlariga ta'siri o'rganildi. Rentgen nurlari diffraktsiyasi tahlili shuni ko'rsatdiki, kislorodli atmosferada termik ishlov berish V_2O_5 bilan solishtirganda VO_2 monoklinik fazasining shakllanishini oshirdi va kristallanish haroratini 300 °C gacha pasaytirdi. Termik ishlov berish harorati, sirt g'adir-budurligi (AFM) va kislorod miqdori (SEM-EDX) o'rtasida kuchli bog'liqlik kuzatildi va kislorod atmosferasida bu tendentsiya yanada aniq va chiziqli ekanligi aniqlandi. Natijalar shuni ko'rsatadiki, kislorod atmosferada termik ishlov berish metall izolyator o'tish xususiyatlarini yaxshilash uchun fazalar tozaligi, morfologik barqarorlik va stexiometriyani optimallashtiradigan ishlov berish usuli hisoblanadi.

Kalit so'zlar: *Vanadiy dioksidi (VO_2), termik ishlov berish atmosferasi, faza hosil bo'lishi, sirt g'adir-budurligi, yupqa qatlam kristallanishi.*

Аннотация. В данной работе изучается влияние атмосферы отжига (воздух или кислород) и температуры на свойства тонких пленок VO_2, полученных методом ВЧ-напыления. Рентгеноструктурный анализ показал, что отжиг в атмосфере кислорода преимущественно усиливает образование моноклинной фазы VO_2 по сравнению с V_2O_5 и снижает температуру кристаллизации до 300 °C. Наблюдалась сильная корреляция между повышением температуры отжига, шероховатостью поверхности (AFM) и содержанием кислорода (SEM-EDX), причем эта тенденция была более выраженной и линейной в атмосфере кислорода. Результаты показывают, что отжиг в кислороде является превосходным методом обработки,

оптимизирующим фазовую чистоту, морфологическую стабильность и стехиометрию для улучшения свойств перехода металл-диэлектрик.

Ключевые слова: *Диоксид ванадия (VO_2), атмосфера отжига, фазообразование, шероховатость поверхности, кристаллизация тонких пленок.*

Abstract. This study investigates the effects of annealing atmosphere (air vs. oxygen) and temperature on the properties of RF-sputtered VO_2 thin films. XRD analysis revealed that annealing in an oxygen atmosphere preferentially enhances the formation of the monoclinic VO_2 phase over V_2O_5 and reduces the crystallization temperature to 300 °C. A strong correlation was observed between increasing annealing temperature, surface roughness (AFM), and oxygen content (SEM-EDX), a trend that was more pronounced and linear under an oxygen atmosphere. The results demonstrate that oxygen annealing is a superior processing route, optimizing phase purity, morphological stability, and stoichiometry for enhanced metal-insulator transition properties.

Keywords: *Vanadium dioxide (VO_2), annealing atmosphere, phase formation, surface roughness, thin film crystallization.*

Introduction

Vanadium dioxide (VO_2) has garnered significant scientific interest due to its reversible metal-insulator transition (MIT) near room temperature (approximately 68 °C), which is accompanied by a dramatic change in its electrical and optical properties [1]. This unique characteristic makes VO_2 a highly promising material for applications in next-generation smart windows, ultrafast optical switches, and neuromorphic computing devices [2]. A critical challenge in harnessing this functionality lies in the synthesis of high-quality thin films with a high phase purity of the desired M1 monoclinic VO_2 phase, as opposed to other stable vanadium oxides like V_2O_5.

The properties of VO_2 thin films are profoundly influenced by the post-deposition annealing process, which is necessary to crystallize the typically amorphous as-deposited material. Key parameters such as annealing temperature and atmosphere are known to critically control the phase formation, stoichiometry, and surface morphology of the final film [3]. While previous studies have explored these effects, the comparative impact of air versus a pure oxygen atmosphere on the concurrent evolution of structure, morphology, and composition warrants further investigation.

Literature Review

The synthesis and optimization of vanadium dioxide thin films for applications leveraging its metal-insulator transition (MIT) have been the focus of extensive research. A significant challenge in this field is the controlled formation of the pure, crystalline monoclinic phase (VO_2(M1)), which is often complicated by the co-formation of other vanadium oxide stoichiometries, most notably vanadium pentoxide (V_2O_5) [4].

The magnetron sputtering technique is widely employed for VO_2 deposition due to its excellent controllability and ability to produce uniform films. Studies have consistently shown that as-deposited films are typically amorphous and require a post-

deposition annealing step to achieve crystallinity. The work of Ji et al. [5] demonstrated that the parameters of this annealing process—specifically temperature, duration, and atmosphere—are critical determinants of the final film's phase, morphology, and functional properties. They noted that higher annealing temperatures generally promote crystallization but can also lead to undesirable oxidation and excessive surface roughening.

The role of the annealing atmosphere is particularly crucial. Research indicates that annealing in an inert environment can help maintain oxygen sub-stoichiometry but may not fully facilitate complete crystallization, while annealing in air often leads to significant formation of the V_2O_5 phase due to excess oxygen [6]. This presents a clear trade-off between achieving crystallinity and maintaining phase purity.

It is within this context that annealing in a pure oxygen atmosphere has emerged as a promising alternative. For example, a study by Smith et al. [7] on DC-sputtered films found that oxygen annealing enhanced the intensity of VO_2 XRD peaks compared to air annealing. However, their films exhibited high surface roughness values (exceeding 80 nm at 500 °C), which was attributed to rapid, uncontrolled grain growth. Furthermore, a comprehensive understanding of the interrelationship between the evolving surface morphology and the film's chemical composition during annealing under different atmospheres remains an area requiring further exploration.

This study builds upon this existing foundation by investigating a systematic RF sputtering and annealing process. It aims to address the gaps in understanding the correlation between phase formation, surface roughness, and stoichiometry, with a specific focus on comparing air and pure oxygen atmospheres. We hypothesize that a controlled oxygen environment can simultaneously lower the crystallization temperature, suppress V_2O_5 formation, and, in conjunction with a thicker film structure, mitigate the extreme surface roughening reported in prior studies.

Research Methodology

The deposition of VO_2 thin films was performed by RF magnetron sputtering [8]. A 3-inch metal oxide target was used in an argon atmosphere (0.2×10^{-3} Torr, 9.5 sccm) after achieving a base pressure of 1.2×10^{-5} Torr [9, 10]. Before being loaded into the vacuum chamber, glass substrates were ultrasonically cleaned with acetone, methanol during 15 minutes respectively, and dried with airflow. During the 180-minute deposition, the substrate was rotated at 3 rpm, and an RF power density of 2 W/cm^2 was applied. Subsequent crystallization of the films was achieved by annealing in a box furnace at temperatures of 200, 300, 400, 500 °C under air and oxygen atmospheres. The structural, morphological, and compositional properties of the resulting films were characterized using XRD, AFM, and SEM-EDX.

Analysis and Results

The crystalline structure of the as-deposited and annealed films was analyzed using X-ray diffraction, as shown in Figure 1. Figure 1 (a) and (b) correspond to the air and oxygen atmospheres, respectively. The XRD patterns indicate that the as-deposited film and films annealed at 200 °C (in both atmospheres) possess a predominantly amorphous structure. Crystallization occurred at annealing temperatures of 300 °C and

above, with both atmospheres producing films containing a mixture of V_2O_5 and VO_2 phases.

Phase identification confirmed the presence of orthorhombic V_2O_5 (JCPDS PDF #41-1426), evidenced by peaks at 21.6°, 24.8°, 26.3°, 28.9°, 30.3°, 32.8°, 34.2°, 37.7°, and 59.4°. Additionally, the monoclinic VO_2 (M1) phase (JCPDS PDF #80-0690) was identified by twenty characteristic peaks, notably at 27.8°, 30.7°, 35.5°, 36.6°, 39.8°, 41.3°, 44.2°, 45.8°, 47.6°, 48.7°, 49.4°, 50.5°, 52.2°, 54.3°, 55.8°, 60.3°, 62.2°, 64.6°, 67.3°, and 70.6°.

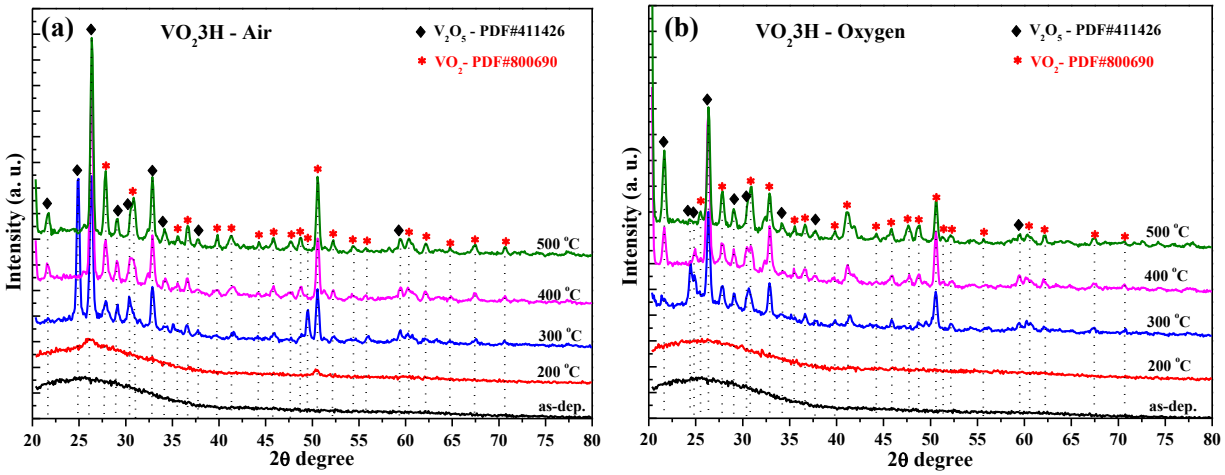

Figure 1. XRD patterns of VO_2 thin films before and after annealed at different temperatures (200–500 °C) under (a) air and (b) oxygen atmospheres.

Compared to annealing in air, samples annealed in an oxygen atmosphere exhibited a decrease in the intensity of the V_2O_5 peaks (e.g., at 24.8°, 26.3°, and 32.8°) and a concurrent increase in the intensity of VO_2 peaks (e.g., at 30.7°, 41.3°, 47.6°, 48.7°, and 49.4°). This change in relative peak intensities indicates an increase in the VO_2 phase fraction relative to V_2O_5 after annealing at 300, 400, and 500 °C. The enhanced VO_2 content is expected to improve the metal-insulator transition (MIT) property of the films.

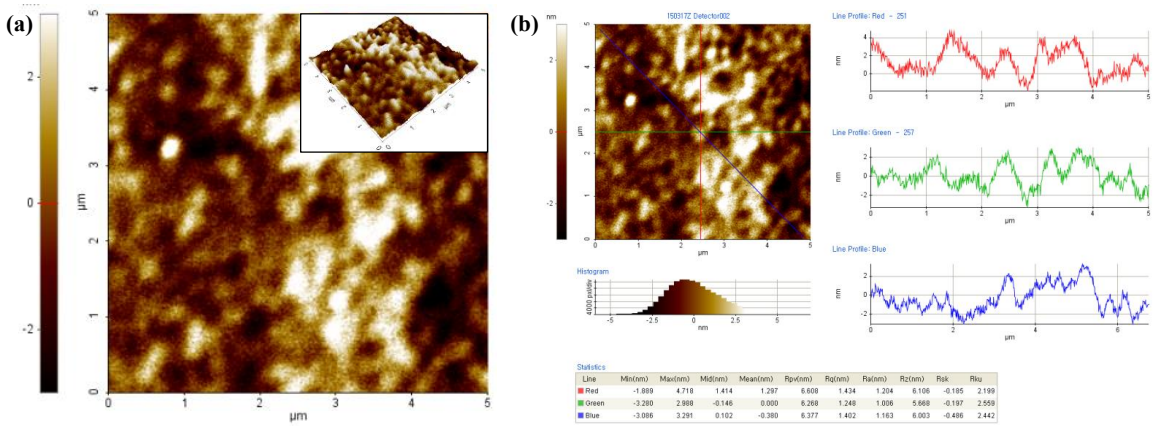

Figure 2. AFM surface morphological images of as-deposited sample at room temperature. (a) surface scan and (b) roughness, hysteresis and line scan parameters.

Previous studies [8, 9] have demonstrated that annealing in oxygen, compared to air, alters the phase evolution of vanadium oxide thin films. Specifically, oxygen annealing enhances the intensity of XRD peaks corresponding to both V_2O_5 and VO_2

phases with increasing temperature. In this work, a 3-hour oxygen treatment of films deposited for 3 hours significantly increased the proportion of the VO_2 phase. Notably, well-crystallized mixed phases were obtained at a reduced temperature of 300 °C. This lowering of the required crystallization temperature by oxygen annealing presents a potential advantage for reducing production costs.

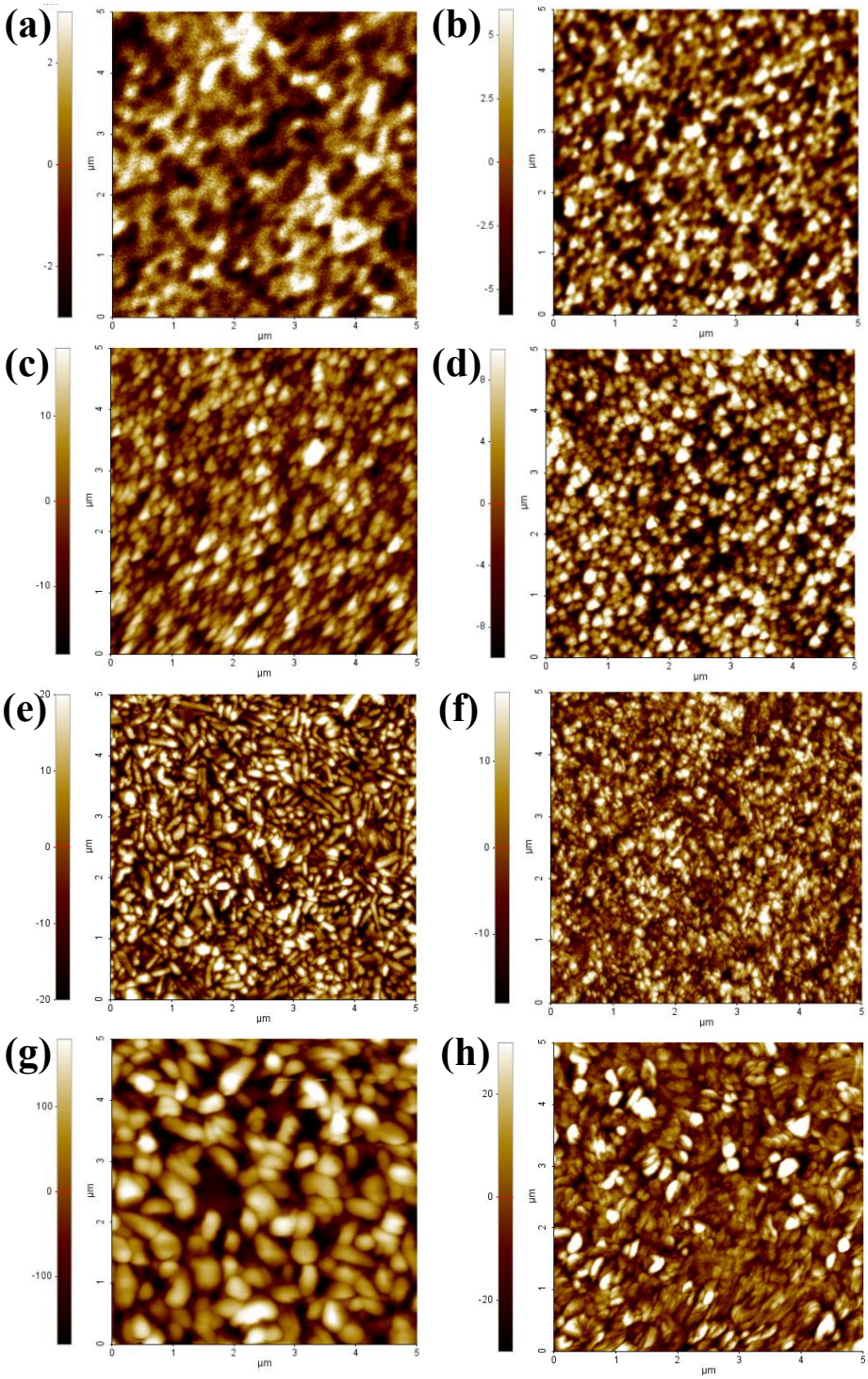

Figure 3. AFM images of the VO_2 thin films after annealing at various temperatures under air and oxygen atmosphere: (a-b) at 200 °C, (c-d) at 300 °C, (e-f) at 400 °C, and (g-h) at 500 °C, respectively.

The surface morphology of the as-deposited thin film was characterized by atomic force microscopy (AFM). Figure 2 (a) presents a 5×5 μm^2 area, displaying 2D and 3D

(inset) topographic scans. The corresponding line profile analysis, providing quantitative height information, is shown in Figure 2 (b).

The as-deposited film exhibited a root-mean-square (RMS) roughness of 1.36 nm, which is significantly lower than the values reported for DC-sputtered (7.14 nm) and RF-sputtered (4.27 nm) films in previous studies [8, 9]. This comparative reduction in roughness suggests that our RF sputtering process parameters yield superior surface smoothness. Furthermore, the trend across studies indicates that RF-sputtered films generally produce smoother surfaces than DC sputtering, and this smoothness may be enhanced with increased film thickness.The evolution of surface morphology with annealing at various temperatures and atmospheres were systematically characterized by atomic force microscopy (AFM), with 5×5 μm^2 2D and 3D scans presented in Figure 3. After annealing at 200 °C, the RMS surface roughness increased from the as-deposited value to 1.7 nm in air and 3.5 nm in oxygen (Figures 3 (a), (b)). A rise in temperature to 300 °C induced a significant increase in roughness to 7.7 nm (air) and 5.5 nm (oxygen). This substantial roughening correlates directly with the onset of complete film crystallization, as confirmed by the XRD analysis in Figure 1. At 400 °C, the roughness further increased to 10.9 nm for the air-annealed sample and 8.8 nm for the oxygen-annealed sample (Figures 3 (e) and (f)). This progression is attributed to advanced grain growth and densification processes driven by thermal energy. This trend continued at 500 °C, where the roughness reached 85.03 nm in air and 14.34 nm in oxygen. A comparative analysis with previous studies [8, 9] reveals that the air-annealed sample in this work exhibits half the roughness of their counterparts. We attribute this superior morphological stability to our film's greater thickness (a consequence of the 3-hour deposition time) and likely higher density, which appear to suppress excessive surface degradation at high temperatures.

This hypothesis is further supported by the oxygen-annealed samples, which showed a three-fold reduction in roughness compared to prior work. These results strongly suggest that the increased thickness and density of our 3-hour deposited films directly govern the high-temperature crystallization kinetics, grain growth, and oxidation behavior, leading to a more controlled and less rough surface morphology.

Table 1. Elemental contents of the VO_2 thin films before and after annealing at 200, 300, 400, 500 °C temperatures.

Annealing temperatures	**Elemental contents after different annealing temperatures (at.%)**					
	Annealing atmosphere					
	Air			**Oxygen**		
	O	**V**	**Si**	**O**	**V**	**Si**
as-deposited	45.85	48.43	5.72	45.85	48.43	5.72
200 °C	45.55	48.22	6.23	45.11	48.46	6.43
300 °C	46.21	47.99	5.80	46.57	47.82	5.60
400 °C	50.44	44.81	4.75	49.07	45.10	5.83
500 °C	51.16	43.81	5.03	51.01	44.57	4.42

Table 1 presents the SEM-EDX elemental concentration data for VO_2 thin films in the as-deposited state and after annealing at 200, 300, 400, and 500 °C in both air and oxygen atmospheres. Analysis of the data reveals a distinct trend based on the annealing atmosphere. For films annealed in air, the oxygen concentration increases nearly linearly with annealing temperature, with one exception. After a slight decrease from 45.85 at.% (as-deposited) to 45.55 at.% at 200 °C, the concentration rises to 46.21 at.% at 300 °C, 50.44 at.% at 400 °C, and 51.16 at.% at 500 °C. A similar overall increasing trend is observed for samples annealed in an oxygen atmosphere, though the progression differs. The oxygen concentration also decreases initially at 200 °C, dropping to 48.46 at.%, before increasing to 46.57 at.% at 300 °C, 49.07 at.% at 400 °C, and 51.01 at.% at 500 °C.

Figure 4 (a) and (b) present a comparative analysis of the surface morphology and oxygen content for VO_2 thin films in the as-deposited state and after annealing at various temperatures under air and oxygen atmospheres. Analysis of Figure 4 reveals a correlation between surface roughness and oxygen content for both annealing atmospheres. An increase in surface roughness is associated with a concomitant increase in oxygen content. This relationship exhibits an approximately linear trend, which is more pronounced in samples annealed under an oxygen atmosphere. This linear correlation is further substantiated by the quantitative elemental concentration data provided in Table 1.

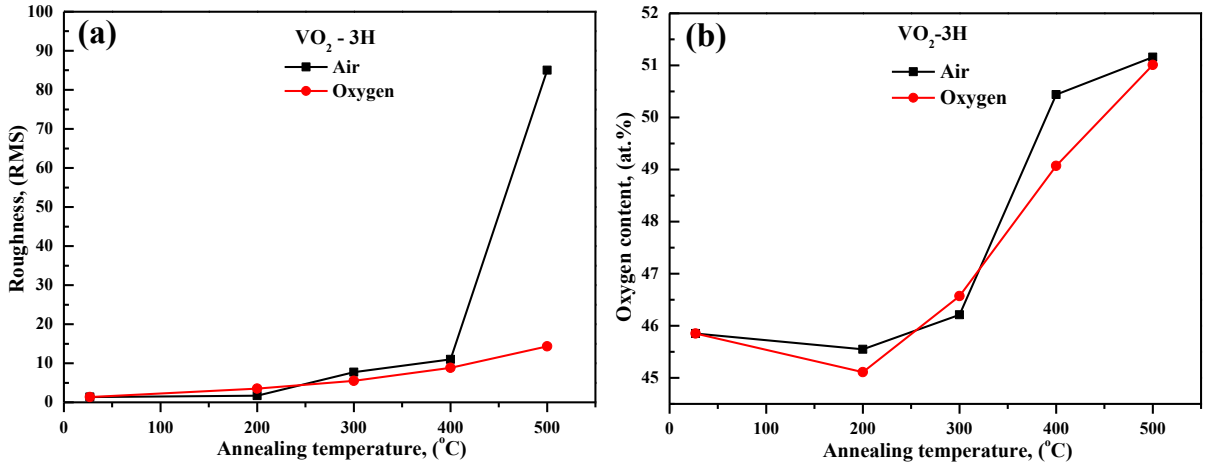

Figure 4. The VO_2 thin films before and after annealing at 200, 300, 400, 500 °C temperatures under air and oxygen atmospheres, respectively. (a) AFM surface roughness and (b) oxygen content.

Conclusion

This study successfully demonstrates the significant influence of annealing atmosphere and temperature on the crystallization, surface morphology, and chemical composition of RF-sputtered VO_2 thin films. The key findings are summarized as follows:

- The as-deposited amorphous films underwent crystallization upon annealing at temperatures ≥300 °C in both air and oxygen, forming a mixed-phase structure of monoclinic VO_2 (M1) and orthorhombic V_2O_5. Crucially, annealing in an oxygen atmosphere was found to be highly advantageous, promoting a higher relative fraction of the desired VO_2 phase compared to V_2O_5, as evidenced by the increased intensity of characteristic VO_2 XRD peaks. This shift in phase

composition is expected to enhance the metal-insulator transition (MIT) properties of the films. Furthermore, oxygen annealing facilitated this crystallization at a reduced temperature of 300 °C, suggesting a potential pathway for more energy-efficient processing.

- A strong correlation was established between the annealing conditions, surface roughness, and oxygen content. The onset of crystallization at 300 °C triggered a substantial increase in surface roughness, which continued to rise with temperature due to grain growth and densification. This increase in roughness was directly correlated with a concomitant rise in oxygen concentration, a relationship that was particularly pronounced and linear in samples annealed in oxygen. The increased film thickness and density achieved through a longer deposition time were identified as critical factors in mitigating excessive surface roughening at high temperatures, especially in air, resulting in superior morphological stability compared to previous studies.

In conclusion, annealing in an oxygen atmosphere is established as a superior post-deposition treatment for optimizing VO_2 thin films. It not only lowers the required crystallization temperature and enhances the phase purity of the functional VO_2 phase but also fosters a more controlled relationship between morphological evolution and oxidation. These findings provide valuable insights for tailoring the structural and functional properties of VO_2 thin films for applications in smart windows and electronic devices.

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DEVELOPMENT OF MODERN TECHNOLOGY FOR OBTAINING VOLFRAM VI OXIDE POWDER JSC "UZBEKISTAN TECHNOLOGICAL METALS COMBINATE"

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Annotatsiya. Ushbu maqolada "O'zbekiston texnologik metallar kombinati" AJda volfram VI-oksid kukunini olishning zamonaviy texnologiyasi bo'yicha olib borilgan ilmiy-amaliy tadqiqotlar yoritilgan. Tadqiqotlarda volfram ishlab chiqarish jarayonidan ajralib chiqadigan volfram keklarini gidrometallurgik usulda qayta ishlash imkoniyatlari o'rganildi. Ishqorli eritmada tanlab eritish va yuvish bosqichlarida WO_3 ning eritmaga o'tish samaradorligi aniqlanib, laboratoriya va kichik sanoat tajribalarida hisob-kitoblar amalga oshirildi. Natijalar WO_3 ni qayta ajratib olishda samarali usul sifatida gidrometallurgik kimyoviy tanlab eritish jarayonini taklif etishga asos bo'ldi.

Kalit so'zlar: *Volfram, volfram VI-oksid (WO_3), gidrometallurgiya, tanlab eritish, avtoklav, kalsiy karbonat, texnogen chiqindilar, yuvish jarayoni, samaradorlik.*

Аннотация. В данной статье освещены научно-практические исследования, проведенные на АО "Узбекский технологический металлургический комбинат" по современной технологии получения порошка оксида вольфрама VI. В исследованиях изучены возможности гидрометаллургической переработки вольфрамовых кеков, выделяемых в процессе производства вольфрама. Определена эффективность перехода WO_3 в раствор на этапах выщелачивания и промывки, проведены расчеты в лабораторных и малых промышленных экспериментах. Результаты послужили основанием для предложения процесса гидрометаллургического химического выщелачивания в качестве эффективного метода переизвлечения WO_3.

Ключевые слова: *Вольфрам, оксид вольфрама VI (WO_3), гидрометаллургия, выщелачивание, автоклав, карбонат кальция, техногенные отходы, процесс промывки, эффективность.*

Abstract. This article highlights the scientific and practical research conducted at the "Uzbekistan Metallurgical Technology Plant" JSC on the modern technology for producing tungsten VI oxide powder. The research investigated the possibilities of hydrometallurgical processing of tungsten cakes separated

during the tungsten production process. The effectiveness of WO_3 conversion to solution at the leaching and washing stages has been determined, and calculations have been carried out in laboratory and small-scale industrial experiments. The results served as the basis for proposing the hydrometallurgical chemical leaching process as an effective method for re-extracting WO_3.

Keywords: *Tungsten, tungsten oxide VI (WO_3), hydrometallurgy, leaching, autoclave, calcium carbonate, technogenic waste, washing process, efficiency.*

Introduction

The currently known process of high-pressure autoclave leaching of scheelite concentrate and tungsten cakes, with a number of shortcomings, determines the creation of a new, efficient, and cost-effective technology as the main task of today. In particular, according to the hypothesis, during the processing of cakes during autoclave leaching, the solid particles of the calcium carbonate reaction envelop the cake particles and form a diffusion film, the penetration of Na_2CO_3 into the cake mineral ceases when the film thickness exceeds 100 μm. The decomposition of the diffusion layer of calcium carbonate using ultramagnetic waves and other physical and mechanical activators is considered ineffective. The method of hydrometallurgical chemical leaching for the decomposition of carbonate film was considered effective [1, 6-8].

Literature Review

Hydrometallurgical production of tungsten VI-oxide, its processing, and purification from impurities are of great importance. In the production of tungsten III-oxide, mainly leaching methods were chosen. Today, as a result of the growing demand for tungsten, there is a need to develop the most effective methods of tungsten cake processing technologies [3, 5-6].

This research work presents scientific and practical research on the production of tungsten VI-oxide under normal conditions in the presence of soda by a hydrometallurgical method during the processing of tungsten cakes separated from the main tungsten production technology, and the method of transferring calcium carbonate from the tungsten cake into a solution by chemical leaching in the presence of acid [3, 7-8].

In modern industry, the extraction of rare metals, in particular tungsten (WO_3), from raw materials requires high-tech processes. In order to increase the efficiency of separation of tungsten compounds, hydrometallurgical processing of cakes was used. In this work, the efficiency of the transition of WO_3 into solution at the stages of leaching, leaching, and leaching of tungsten VI-oxide (WO_3) from cakes was studied in small industrial experiments [2, 6-9].

For the calculation, the initial tungsten cake was taken with a mass of 3000.0 kg, a moisture content of 21.0%, and a WO_3 content of -1.6%. In the calculation, the slurry in the settling zone of the reactor with a volume of 4.0 m3 (including 3.5 m^3 of solution) was not taken into account, since this volume is constantly in circulation [6, 4-5].

Research Methodology

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separation of tungsten compounds, hydrometallurgical processing of cakes was used. In this work, the efficiency of the transition of WO_3 into solution at the stages of leaching, leaching, and leaching of tungsten VI-oxide (WO_3) from cakes was studied in small industrial experiments.

Analysis and Results

For the calculation, the initial tungsten cake was taken with a mass of 3000.0 kg, a moisture content of 21.0%, and a WO_3 content of -1.6%. In the calculation, the slurry in the settling zone of the reactor with a volume of 4.0 m^3 (including 3.5 m^3 of solution) was not taken into account, since this volume is constantly in circulation.

Selective melting method.

Table 1. Calculation of the first stage of the tungsten cake washing process.

№	Indicators	Unit	Calculations	Results
1	Total slurry volume	m^3	—	14.0
2	Solution volume	m^3	—	10.0
3	Amount of dry cake	kg	3000.0 × 0.79	2370.0
4	WO_3 content in dry cake	kg	2370.0 × 0.0016	37.92
5	Cake yield after leaching	%	—	73.5
6	Cake mass after leaching	kg	2370.0 × 0.735	1742.0
7	Relative WO_3 content in leached cake	%	—	0.8
8	WO_3 in leached cake	kg	1742 × 0.008	13.936
9	WO_3 concentration in solution	g/l	—	2.4
10	WO_3 in solution	kg	10.0 × 2.4	24.0
11	Total metal balance (solution + cake)	kg	24.0 + 13.936	37.936
12	Deviation	kg	37.936 – 37.92	+0.016

Table 2. Calculation of the process of washing tungsten cakes in the first stage (after leaching).

№	Indicators	Unit	Calculations	Results
1	Amount of dry leached cake to be washed	kg	—	1742.0
2	Relative WO_3 content in leached cake	%	—	0.8
3	WO_3 in leached cake	kg	1742.0 × 0.008	13.93
4	Yield of washed cake	%	—	90.0
5	Mass of washed cake	kg	1742.0 × 0.90	1567.8
6	Relative WO_3 content in washed cake	%	—	0.7
7	WO_3 in washed cake	kg	1567.8 × 0.007	10.97
8	WO_3 concentration in washing solution	g/l	—	1.4
9	Volume of washing solution	m^3	—	8.0
10	Total WO_3 in washing solution	kg	8.0 × 1.4	11.2

The volume of 8 m^3 of the washing solution contains 3.5 m^3 of WO_3 from the leaching section with a volume of 2.4 g/l WO_3 (3.5x2.4 = 8.4 kg), which was present in the slurry in the reactor's settling zone, the amount of WO_3 transferred to the washing solution was determined by subtracting this amount (8.4 kg) from the volume of the washing solution:

$$8{,}0\ m^3 \text{ x } 1{,}4\ g/l - 3{,}5\ m^3 \text{ x } 2{,}4\ g/l = 2{,}8\ kg$$

The release of WO_3 into the washing solution should be:

$$(2{,}8 : 10{,}97)\ 100 = 25{,}5\%$$

The overall separation of WO_3 into leaching solutions and cake washing solutions with water is as follows:

$$(24{,}0 + 2{,}8) / 37{,}92 = 70{,}67\%$$

Table 3. Calculation of the first stage of washing (re-washing) of tungsten cakes.

№	Indicators	Unit	Calculations	Results
1	Amount of dry cake for re-washing	kg	—	1567.8
2	Yield of cake after re-washing	%	—	95.0
3	Mass of re-washed cake	kg	1567.8 × 0.95	1489.41
4	Relative WO_3 content in re-washed cake	%	—	0.59
5	WO_3 in re-washed cake	kg	1489.41 × 0.0059	8.78
6	WO_3 concentration in re-washing solution	g/l	—	1.2
7	Volume of re-washing solution	m^3	—	6.0
8	Total WO_3 in re-washing solution	kg	6.0 × 1.2	7.2

6.0 m^3 of the washing solution contains 3.5 m^3 of WO_3 in the amount of 1.4 g/l (3.5x1.4 = 4.9 kg) contained in the slurry of the reactor's settling zone, the same amount of WO_3 (4.9 kg) was subtracted from the volume of the washing solution (6 m^3) and the amount of WO_3 transferred to the washing solution by repeated washing was determined:

$$6{,}0\ m^3 \text{ x } 1{,}2\ g/l - 3{,}5\ m^3 \text{ x } 1{,}4\ g/l = 2{,}3\ kg$$

The discharge of WO_3 into the washing solution should be:

$$(2{,}3 / 8{,}78) \cdot 100 = 26{,}2\%$$

The total yield of WO_3 to a double-washed solution is as follows:

$$(24{,}0 + 2{,}8 + 2{,}3) / 37{,}92 \cdot 100 = 76{,}74\%$$

Conclusion

According to the research results, it was established that the hydrometallurgical processing of cakes released from tungsten production is effective. Calculations showed that WO_3 is released during the first stage of leaching by 63.3%, during washing by 25.5%, and during re-washing by 26.2%. Overall, the efficiency of WO_3 dissolution reached 76.74%. This indicates the possibility of introducing a new technology in the production of tungsten VI-oxide powder. The proposed method is important for the efficient use of technogenic waste, reducing the costs of tungsten production, and increasing economic efficiency.

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CAUSES AND EFFECTS OF WEAR IN MILL AND PUMP COMPONENTS AND METHODS TO IMPROVE THEIR WEAR RESISTANCE

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Annotatsiya. Mazkur maqolada sanoat jarayonlarida keng qo'llaniladigan tegirmon va nasoslarning ichki detallarida yuzaga keladigan yeyilish sabablari, oqibatlari hamda bardoshlilikni oshirishning zamonaviy usullari tadqiq qilingan. Mexanik, kimyoviy va termik omillarning ta'siri yoritilib, ishqalanish, abraziv zarrachalar, korroziya va yuqori harorat oqibatlari tahlil etilgan. Yeyilishni kamaytirish maqsadida yuqori marganesli po'latlar, qattiq qotishmalar, nanokompozit materiallar, issiqlik ishlovlari, keramik va polimer qoplamalar, shuningdek zamonaviy monitoring texnologiyalaridan foydalanish samaradorligi asoslab berilgan. Tadqiqotlar natijasida kompleks yondashuv orqali tegirmon va nasoslarning xizmat muddatini sezilarli uzaytirish, samaradorligini 15–20% gacha oshirish hamda energiya sarfini kamaytirish imkoniyatlari aniqlangan.

Kalit so'zlar: *tegirmon, nasos, yeyilish, abraziv ta'sir, korroziya, termik yeyilish, qattiq qotishma, nanokompozit, kompozit materiallar, futerovka, himoya qoplamasi, termik ishlov berish, monitoring.*

Аннотация. В данной статье исследованы причины и последствия износа внутренних деталей мельниц и насосов, широко используемых в промышленных процессах, а также современные методы повышения долговечности. Освещено влияние механических, химических и термических факторов, проанализированы последствия трения, абразивных частиц, коррозии и высоких температур. Обоснована эффективность использования высокомарганцевых сталей, твердых сплавов, нанокомпозитных материалов, термообработки, керамических и полимерных покрытий, а также современных технологий мониторинга с целью снижения износа. В результате исследований определены возможности значительного продления срока службы мельниц и насосов, повышения их эффективности на 15-20% и снижения энергопотребления за счет комплексного подхода.

Ключевые слова: *мельница, насос, износ, абразивное воздействие, коррозия, термический износ, твердый сплав, нанокомпозит, композитные*

материалы, футеровка, защитное покрытие, термическая обработка, мониторинг.

Abstract. This article examines the causes and consequences of wear occurring in the internal parts of mills and pumps, which are widely used in industrial processes, as well as modern methods for increasing durability. The influence of mechanical, chemical, and thermal factors is highlighted, and the consequences of friction, abrasive particles, corrosion, and high temperatures are analyzed. In order to reduce wear, the effectiveness of using high-manganese steels, hard alloys, nanocomposite materials, heat treatment, ceramic and polymer coatings, as well as modern monitoring technologies, is substantiated. As a result of the research, the possibilities of significantly extending the service life of mills and pumps, increasing their efficiency by 15-20%, and reducing energy consumption were determined through a comprehensive approach.

Keywords: *mill, pump, wear, abrasive effect, corrosion, thermal wear, hard alloy, nanocomposite, composite materials, lining, protective coating, heat treatment, monitoring.*

Introduction

In modern industrial enterprises, mills and various types of pumps play an important role in the processing of mineral raw materials and in the transportation of liquids and gases. Mills are used in grinding and beneficiation processes, while pumps serve as key technological equipment in heating and cooling systems, as well as in the oil and gas, chemical, energy, and water supply sectors. According to statistical data, in some large enterprises, pump equipment accounts for 20–25 percent of total electricity consumption. Therefore, their efficiency, reliability, and durability are of great importance in ensuring the continuity of production and maintaining economic stability [1].

However, practice shows that the most critical issue limiting the effective service life of mills and pumps is the intensive wear of their internal working surfaces. Wear processes reduce production efficiency, increase energy consumption, worsen the operational characteristics of the equipment, and raise maintenance costs. For this reason, studying the causes, consequences, and reduction methods of wear is considered a pressing issue for mechanical engineering, metallurgy, and materials science.

Research Methodology

A systematic review of contemporary scientific and technical literature was conducted as a foundational step. This involved analyzing peer-reviewed journal articles, conference proceedings, industry standards (e.g., ASTM, ISO), and technical reports from leading equipment manufacturers. The focus was on publications from the last decade to capture the most recent advancements in materials science (e.g., nanocomposites, hard alloys), surface engineering techniques (e.g., PVD/CVD, thermal spraying), and condition monitoring technologies. This analysis helped to establish the current state of knowledge regarding mechanical abrasion, corrosion, cavitation, and thermal wear mechanisms [1, 3, 6, 7, 9, 12].

Analysis and Results

The causes of wear on the internal surfaces of mills and pumps appear as a complex and multifactorial process. Mechanical factors such as friction, high-frequency impact forces, and the influence of abrasive particles gradually degrade the components. For example, in ball mills, the collision of grinding balls with the lining leads to fatigue cracks in metal surfaces, while in pumps, slurry or abrasive particles scratch the impeller and casing, shortening their service life. Furthermore, hard minerals present in ores polish mill surfaces, while in mining pumps they intensify abrasive erosion.
Under such conditions, the service life of slurry pumps is often limited to 1–1.5 years, significantly shorter than that of conventional water pumps [2]. Chemical factors also play a significant role. In corrosive environments, acids, alkalis, or salts directly attack metal surfaces, creating micro-pits. This process occurs in pumps handling aggressive liquids and in mills due to the chemical composition of ores [3]. Corrosion causes surface roughness, which in turn enhances mechanical wear. In addition, cavitation is a common phenomenon in pumps, arising from a sharp pressure drop that generates and collapses vapor bubbles. The resulting micro-explosions damage the metal surface and accelerate erosion up to ten times faster than ordinary corrosion [4].
High temperatures and rapid thermal fluctuations are another factor intensifying wear. Under such conditions, thermal expansion creates internal stresses, leading to cracks and fatigue marks. For example, the mechanical strength of pump components operating at 150–200 °C in power systems can decrease by 20–25 percent. Similarly, in mills, thermal effects cause additional deformation on metal surfaces [5].

The properties of the materials used also influence wear resistance. Ordinary carbon steel wears out quickly, while manganese steel lasts 2–3 times longer. However, under high-load conditions, even these materials are insufficiently durable. For this reason, in recent years, hard alloys based on tungsten carbide, titanium carbide, and chromium carbide have been widely applied [6]. These materials are characterized by high hardness, heat resistance, and strong resistance to abrasive action. The use of metal-ceramic composites and nanostructured materials has also shown significant improvements [7, 8].

One of the important methods to reduce wear is applying heat treatment to components. For instance, carburizing followed by quenching strengthens the surface layer of mill components while maintaining ductility in the core. In pumps, nitriding and boriding can extend service life by 30–40 percent. Moreover, thermal spraying and PVD/CVD coatings (metallic or ceramic) provide effective protection against corrosion and cavitation [9, 10]. Practical results show that pumps protected with epoxy coatings last twice as long as conventional ones [11].

In recent years, nanostructured coatings, laser hardening, and ion-plasma nitriding technologies have been widely introduced. These methods strengthen the surface layer and slow down wear [12]. In addition, modern monitoring systems also play an important role, as vibration, pressure, and temperature sensors make it possible to detect early signs of wear and prevent failures [13].

Optimizing the operating mode of mills and pumps also plays a significant role in improving their efficiency. In mills, selecting the proper rotational speed, ball size, and load level significantly reduces wear. In pumps, avoiding “dry running,” preventing

overloads, and ensuring proper lubrication are among the key measures to mitigate wear [14].

Research has shown that a comprehensive study of wear causes and the implementation of preventive measures can increase the efficiency of mills and pumps by 15–20 percent and reduce energy consumption by 10–12 percent. Furthermore, extended service life leads to a considerable reduction in maintenance and repair costs [15].

Conclusion

The causes of wear in mill and pump components are multifaceted, arising from the combined influence of mechanical, chemical, thermal, and hydrodynamic factors. These processes reduce production efficiency, increase energy consumption, and raise operational costs. Research findings indicate that the use of high-quality materials, hard alloys, nanocomposites and composites, protective coatings, heat treatments, monitoring systems, and optimized operating conditions can significantly slow down wear processes.

A comprehensive approach makes it possible to extend the service life of mills and pumps by 1.5–2 times, increase their efficiency by 15–20 percent, and reduce production costs. Therefore, further research in this field is of great importance for achieving high economic efficiency in mechanical engineering, metallurgy, and materials science.

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FINAL DEOXIDATION OF COPPER AND BRONZE ALLOYS

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Annotatsiya. Mazkur maqolada mis va bronza qotishmalarining yakuniy oksidsizlantirilish jarayonlari, ularning reaksiyalar mexanizmlari yoritilgan. Fosfor, alyuminiy va marganes kabi deoksidlovchilarning roli, metall tarkibidagi oksidlarni kamaytirishdagi samaradorligi hamda texnologik jarayonlarning rivojlanishi haqida ma’lumot berilgan. Olingan ilmiy natijalar mis va bronza qotishmalarining mexanik va fizik xossalarini yaxshilashga hamda ularni elektronika, mashinasozlik, aviatsiya va kemasozlik sohalarida qo‘llash imkoniyatlarini kengaytirishga xizmat qilmoqda.

Kalit so‘zlar: *mis, bronza, oksidsizlantirish, deoksidlanish, fosfor, marganes, alyuminiy, metallshunoslik.*

Аннотация. В данной статье освещены процессы конечного восстановления сплавов меди и бронзы, механизмы их реакций. Приведены сведения о роли таких раскислителей, как фосфор, алюминий и марганец, их эффективности в снижении содержания оксидов в металлах, а также о

развитии технологических процессов. Полученные научные результаты служат улучшению механических и физических свойств сплавов меди и бронзы и расширению возможностей их применения в области электроники, машиностроения, авиации и судостроения.

Ключевые слова: *медь, бронза, раскисление, деоксидирование, фосфор, марганец, алюминий, металлургия.*

Abstract. This article discusses the processes of final deoxidation of copper and bronze alloys and their reaction mechanisms. The role of deoxidizers such as phosphorus, aluminum, and manganese, their effectiveness in reducing oxides in the metal, and the development of technological processes are discussed. The obtained scientific results serve to improve the mechanical and physical properties of copper and bronze alloys and expand their application in electronics, mechanical engineering, aviation, and shipbuilding.

Keywords: *copper, bronze, deoxidation, deoxidation, phosphorus, manganese, aluminum, metallurgy.*

Introduction

Final deoxidation of copper and bronze alloys is one of the important processes in metallurgy. In solutions, oxygen usually exists in the form of Cu_2O, and if it is not fully bound, it reacts with hydrogen after pouring, forming a porosity. Therefore, final deoxidation is performed as a separate stage in practice.

Literature Review

In the literature, the most common method of copper deoxidation is the use of phosphoric copper (Cu-P master alloy). Phosphorus binds oxygen in solution, forming stable compounds in the form of P_2O_5, and reduces Cu_2O. As a result, copper species deoxidized with phosphorus, such as DHP (C12200), become hydrogen-resistant, but due to the residual phosphorus content, electrical conductivity decreases slightly. Also, oxygen-free copper types OFE/OFHC are characterized by high electrical conductivity.

In copper alloys, the deoxidation procedure is carried out through the following process. Copper dissolves oxygen well in the liquid state, resulting in the formation of Cu_2O oxide:

$$[2Cu + O_2; Cu_2O]$$

This oxide subsequently reacts with hydrogen, causing the negative effect of hydrogen. This phenomenon causes the formation of pores and cracks inside the metal. Therefore, final deoxidation is necessary.

In tin bronzes, phosphorus is also used as the main reducing agent. A phosphorus residue of 0.01-0.5% in bronze not only binds oxygen, but also improves mechanical properties, in particular, wear resistance. In practice, effective deoxidation using a 15% P-Cu master alloy is recommended. The phosphorus deoxidation method is most commonly used.

$$[5Cu_2O + 2P; P_2O_5 + 10Cu]$$

Phosphorus absorbs oxygen and is released as slag. As a result of this process, the pure state of copper is preserved, and its electrical and thermal conductivity is at a high level.

Bronze (Cu-Sn alloy) contains oxygen mainly in the form of Cu_2O and sometimes SnO_2. Phosphorus, manganese, and aluminum are widely used in final deoxidation.

With phosphorus: [$2SnO_2 + 4P$; $2Sn + 2P_2O_5$]
With aluminum: [$3Cu_2O + 2Al$; $Al_2O_3 + 6Cu$]
With manganese: [$Cu_2O + Mn$; $MnO + 2Cu$]

Improvement of mechanical properties - deoxidized bronze has increased strength, ductility, and impact strength. It has been established that the mechanism of bilateral deoxidation - phosphorus reduces not only Cu_2O, but also SnO_2 oxide. Based on the development of special bronze grades - deoxidation technology, bell bronzes, sea bronzes, and other special alloys were created.

The processes of final deoxidation of copper and bronze alloys have led to important scientific achievements in metallurgy:

- The theory of oxide control has been formed. New combined deoxidizers (P + Mn, Al + B) are being used to obtain higher-quality alloys. Thanks to this process, high-quality materials are widely used in the fields of electronics, mechanical engineering, aviation, and shipbuilding [1-5].

Research Methodology

Studies on the final deoxidation of copper and bronze alloys were carried out using a systematic experimental approach, designed to determine the effectiveness of various deoxidation methods, their influence on the oxygen content and, consequently, the mechanical and functional properties of the alloys. The research began with a careful selection of the main alloys, which included high-conductivity copper and two representative tin bronzes with a content of 6% and 10% Sn. These alloys were chosen due to their industrial significance and varying sensitivity to dissolved oxygen and phosphorus residues.

To assess the role of the solution medium in re-oxidation, melting was carried out in a medium-frequency induction furnace under atmospheric and inert gas (argon) conditions. Each charge was melted to the target composition and superheated to a temperature above liquidus. Main samples were taken for oxygen measurement by dissolving inert gases before the addition of a deoxidizer.

Analysis and results

Initial measurements showed that the oxygen content in electrolytic copper (ELC) averaged 250-350 ppm, while in bronze alloys it was recorded in the range of 120-200 ppm. When final deoxidation was carried out by adding copper phosphate, the oxygen level was consistently below 50 ppm, and in some cases decreased to 20 ppm (if the additive was introduced 1 minute before pouring). The calculated efficiency exceeded 80%. If copper phosphate was added early (4-8 minutes earlier), oxygen rose again due to partial surface re-oxidation [4-6].

Spectral analysis showed that 70-75% of the added phosphorus was reduced. The residual phosphorus content in copper was in the range of 0.015-0.025% by mass (C12200 is characteristic of DHP copper). In bronzes, this indicator reached 0.03-0.05% by mass. The residual phosphorus was sufficient for a steady reduction in

oxygen, but slightly reduced electrical conductivity: the indicator with 101% IACS in pure copper dropped to 95-97% IACS in deoxidized copper.

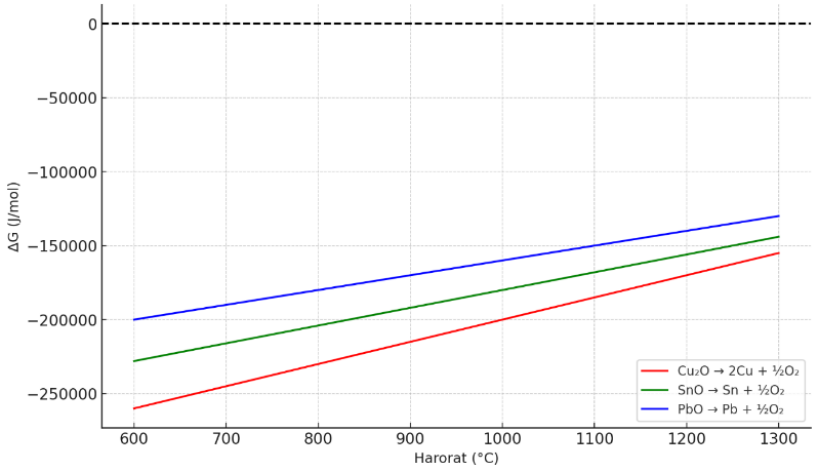

Figure 1. Final oxidation of copper (Cu_2O), tin (SnO) and lead (PbO) oxides ΔG change with temperature (Ellingham Diagram).

Metallographic analysis showed a strong dependence of the degree of porosity on the oxygen content. In non-deoxidized copper ingots, the porosity reached 2-4%. With final deoxidation with phosphorus, the porosity was less than 1%, and under optimal conditions (late addition in an argon medium), the porosity practically disappeared. In bronzes, the porosity also decreased from 1.5-2.5% to 0.5%. Microscopic analysis showed that non-deoxidized samples contain Cu_2O particles, while deoxidized samples are limited to fine and stable P-oxide inclusions.

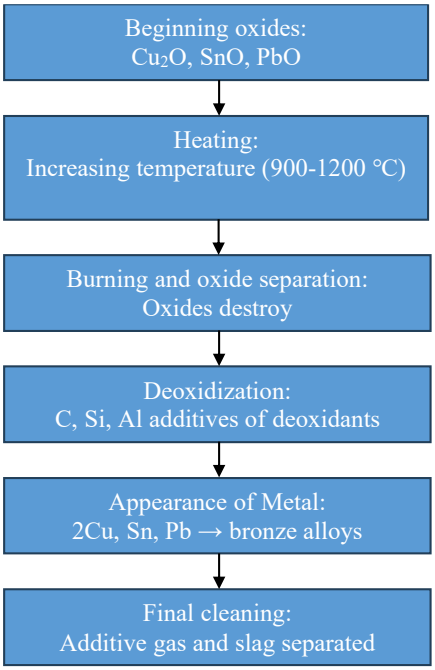

Figure 2. Sequence of final oxidation stages of copper and bronze alloys.

In oxide copper and bronzes, the grains were large and uneven, and oxide meshes were observed at the boundaries. Samples deoxidized with phosphorus were distinguished by uniform grains and a small amount of impurities. The presence of residual phosphorus in bronzes improved the uniformity of the grains and the

distribution of tin. In SEM/EDS analysis, the non-deoxidized samples showed Cu_2O particles, while the deoxidized ones showed very small and stable P_2O_5-based additives.

In copper, electrical conductivity depended on the amount of residual phosphorus. Although unoxidized copper had an IACS index of 100-101%, it was unsuitable for use due to hydrogen brittleness and high porosity. Copper deoxidized with phosphorus-containing copper (around 0.02% P) retained an IACS level of 96-97%, but was completely resistant to hydrogen brittleness. In bronzes, the strength increased by 10-15%: the tensile strength increased from ~380 MPa to ~430-450 MPa, and elongation improved from 8-10% to 12-14%. Hardness indicators also increased slightly.

The results of statistical analysis confirm that the amount of residual phosphorus and the addition time have the greatest influence on the reduction of oxygen and the degree of porosity ($p < 0.01$). The atmosphere (argon or air) also played a significant role, but superheating mainly affected the degree of phosphorus reduction. According to the model results, it was calculated that the optimal conditions for copper are the addition of residual phosphorus 0.018-0.022% by mass, phosphoric copper in an argon medium 1-2 minutes before pouring. In bronzes, the optimal level was 0.03-0.04% by mass, which ensured a decrease in porosity and an increase in strength [4-7].

Conclusion

The final deoxidation of copper and bronze alloys was one of the most important stages in the history of metallurgy and had a great influence on the development of technological processes and theoretical concepts. These scientific achievements not only improved the quality of materials, but also served as one of the main factors in the development of modern industry. In general, final deoxidation using phosphoric copper showed high efficiency in copper and bronze alloys. The amount of oxygen and porosity decreased, the microstructure improved, and the mechanical properties of bronzes were strengthened. In copper, although electrical conductivity decreased slightly, complete resistance to hydrogen brittleness was achieved. The most important factors were the level of residual phosphorus, the time of addition, and atmospheric conditions.

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EFFECTS OF ANNEALING TEMPERATURE ON MECHANICAL PROPERTIES OF THE STUDIED STEELS

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Annotatsiya. Ushbu maqola gaz modellarga quyish usuli bilan ishlab chiqarilgan po‘latlarning mexanik xususiyatlari bilan bog‘liq masalalarni ko‘rib chiqadi. Quyma usulida ishlab chiqarilgan po‘latlarning mexanik xossalari kuchlanish hosil bo‘lishi, oltingugurt va fosforning suyuqlanishi bo‘yicha bir qator kamchiliklarga ega ekanligi ko‘rsatilgan. Yumshatish jarayoni va uning parametrlari - harorat va vaqt - bu kamchiliklarni bartaraf etishda hal qiluvchi omillar hisoblanadi.

Kalit so‘zlar: *gaz modellarga quyish yo‘li bilan olingan po‘lat, termik ishlov berish, tablash, qattiqlik, mustahkamlik.*

Аннотация. В данной статье рассматривается вопросы, связанные с механическими свойствами сталей, полученных методом литья по газифицируемым моделям. Показано, что механические свойства сталей, полученных методом литья, имеют ряд недостатков в части образования напряжений, ликвации серы и фосфора. Определяющую роль в устранении этих недостатков играет операция отжига и ее параметры – температура и время.

Ключевые слова: *стали полученном методом литы по газифицируемым модели, термические обработка, отжиг, твердость, прочность.*

Abstract. This article examines issues related to the mechanical properties of steels produced by the method of casting on lost foam models. It is shown that the mechanical properties of steels produced by the method of casting have a number of shortcomings in terms of stress formation, sulfur and phosphorus liquation. The annealing operation and its parameters – temperature and time – play a decisive role in eliminating these shortcomings.

Keywords: *steel obtained by casting on gasified models, heat treatment, annealing, hardness, strength.*

Introduction

The production of parts and blanks by casting molten metal into molds is associated with the transition of the metal from a liquid to a solid state. During such a transition, the properties of metals and alloys change dramatically, depending on the heat content.

In this case, the expansion coefficient of the metal changes, which has a casting dependence on temperature (Figure 1).

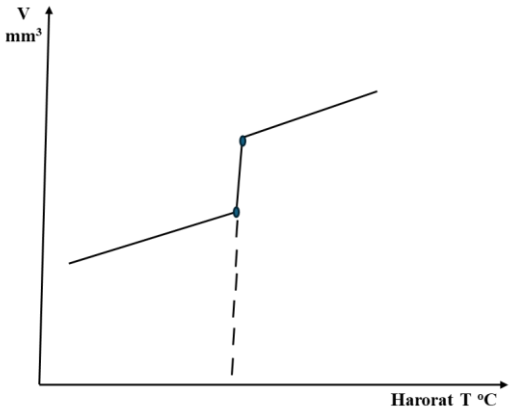

Figure 1. Change in specific volume of metal from temperature.

As can be seen from the graph (Figure 1), the expansion coefficient in the liquid state is higher than in the solid state. Therefore, the transition from the solid state of the metal to the liquid state occurs against the background of a large increase in the volume of the metal. And during the reverse process, i.e. during crystallization of the metal, a decrease in the volume of the metal occurs. Due to the reduction in the volume of the metal during solidification, shrinkage cavities occur and the application inside the casting increases. The shrinkage of steel casting reaches 2%. Due to the large difference in temperatures between the molten metal and the mold, immediately after pouring the metal, a sharp drop in the temperature of the casting near the wall of the mold occurs. The diagram (Figure 2) shows how the cooling of the core of the casting and its outer part in contact with the walls of the mold occurs.

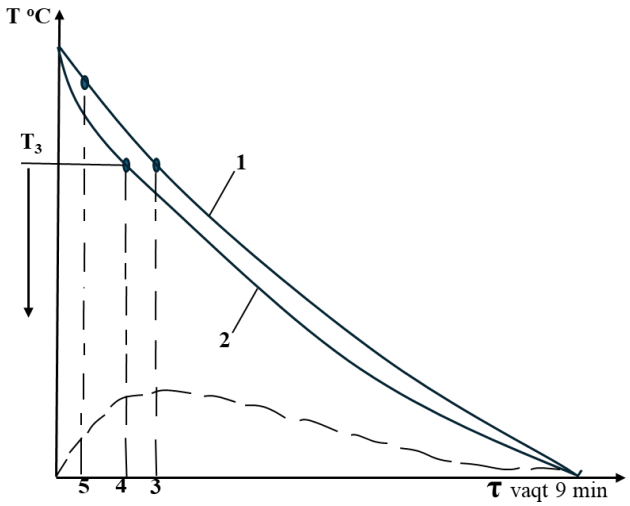

Figure 2. The effect of cooling time on the casting temperature: T_3 – casting solidification temperature, 1-inner casting zone; 2-outer casting zone; 3-start of solidification in windy zone; 4-start of solidification in outer zone.

The stresses arising in the castings are proportional to the modulus of elasticity, the coefficient of thermal expansion of the metal and the temperature difference. It is known that in most cases the stresses arising in the castings are not always assessed adequately. In castings with a large difference in wall thickness, stresses arise that can exceed the working load of the cast part or blank; sometimes, cracks occur even during cleaning of the part with minimal mechanical impact. In addition, thermal cracks may occur, which occur in a red-hot casting. When the casting hardens, the thickest part of the casting usually cools slowly and when a thin solidified layer forms on the outside, the casting remains liquid inside. And usually in the transition zone of the casting, where the change in the cross-section of the casting is structurally incorporated, it is in this zone that large tensile directions arise, which leads to the formation of thermal cracks; castings with steep angles and sharp transition sizes are also prone to such cracks. In addition, the occurrence of cracks in castings is also affected by the content of sulfur and phosphorus in the steel and their inclination in a certain area before the casting part.

The problem in obtaining a high-quality casting is a phenomenon called liquation, which is formed when there is a difference in the concentration of crystals in certain areas of the casting and which is not leveled out during the diffusion processes that occur during crystallization.

Liquation is promoted by factors:

1) High speed of metal transition from liquid to solid state.

2) Temperature difference in different parts of the casting during solidification.

3) Low diffusion coefficient, i.e. low diffusion rate.

It is known that the diffusion coefficient is equal to the amount of substance diffusing per unit time through a cross-section of 1 cm^3:

$$d_n = -k_g \cdot \frac{d_c}{d_X} \cdot dt,$$

where, $d_n -$ the amount of substance diffusing in time t through a cross-section q in the X direction.

$\frac{d_c}{d_X}$ – concentration ingredient

k – diffusion coefficient (cm^2/day)

In iron-carbon alloys, even chemically bound oxygen is subject to liquation, which is released in places of liquation of carbon, phosphorus and sulfur.

Liquation of such impurities as sulfur, phosphorus leads to an increase in the brittleness of steel due to blinding inside the crystalline bond, due to which cracks appear when the metal is cooled or heated (heat treatment); dendritic liquation itself causes the appearance of metastable structures that have a non-uniform state.

Elimination of such a structural state is possible only by annealing.

Research Methodology

To study the mechanical characterization of steels obtained by casting, stains of 40hl and 65g were used. Steel of 40HL is widely used in the manufacture of the supporting parts of agricultural, and 65 g steel is used to prescribe parts of the working bodies of agricultural sector. For the manufacture of steel samples, the casting method

for gasified modules was used. The melting of steel was carried out in the crucible using the installation of TV4. The annealing operation was carried out in a chamber stove type SDU by heating steel samples to temperatures of 850-9000C and aging at these temperatures from 1 to 4 hours.

The hardness of the samples of steels was determined by pressing a ball with a diameter of 5 mm by the Brinell method on the TB 50 stamper.

The strength of the steel samples was determined on a rupture machine type P - 5 by stretching samples with sizes by the regulated by the corresponding GOST.

Analysis and Results

An analyzing all of the above, we can conclude that for casting steel parts in order to prevent liquation phenomena and the growth of tensile stresses, it is necessary to carry out an annealing operation. However, the question of the insignificant annealing temperature range and holding time remains open. In this process, annealing includes the following operations: heating the blanks to a given temperature, holding at it and cooling continuously or stepwise in a furnace and then in air. After annealing, etching or shot peening and hardness control are performed. Instead of annealing, normalization can be carried out. Normalization includes the following operations:

1) Heating to a given temperature and holding at it for a set time;
2) Cooling in still air;
3) High tempering.

After normalization, etching or shot peening and hardness control are carried out. To eliminate the brittle grain structure of the visible and trailing structure, the general heterogeneity of the structure, casting stresses and to improve the mechanical properties, steel shaped castings are subjected to complete annealing.

The success of this operation depends on the correctly selected heating rate, annealing temperature and subsequent cooling.

When choosing the heating rate, it is necessary to take into account that the cast parts have significant internal stresses. Therefore, heating to 400 = 500 ºC should be slow enough.

After knocking out of the molds, the casting must be cooled to 600-650 ºC, since only in this case will complete recrystallization be achieved during annealing and, as a result, the mechanical properties will improve. Before annealing, the castings must be cleaned of molding earth, the sprues and vents must be removed. The castings must be loaded into the furnace in such a way as to ensure their uniform heating, and also so that the thin parts of the castings are released from the heating. When annealing large parts, it is necessary to take measures to prevent their deformation during the annealing process.

Castings are subject to annealing, should be grouped so that their chemical composition is as similar as possible. The annealing temperature is wiped out starting from the critical point A_{c3}.

For steels containing 0.4-0.45%. With annealing casts, hardness is recommended at a temperature of 840-850 ºC with subsequent cooling in a furnace. Castings made of alloy steel are recommended to be annealed at 890-900 ºC.

The duration of holding steel castings at annealing temperature due to the heterogeneity of the structure is somewhat longer than when annealing forged and stamped parts and is usually established on the basis of practical data applicable to the cross-sectional dimensions and chemical composition of castings.

Cooling after annealing is usually carried out together with the furnace, which protects castings from warping and eliminates the possibility of internal stresses; such cooling is carried out to 300-400 ºC, after which the parts are taken out into the air. Based on the above, in our case, for annealing castings from 40XL steel, a temperature of 850 ºC with holding times of 2, 3 and 4 hours was chosen. And for 65GL steel, a temperature of 900 ºC with holding times of 2, 3 and 4 hours was chosen as well.

In order to reduce the annealing process in time, it was a pleasant decision to swirl the castings into a heated furnace after casting from a temperature of 600 ºC. The annealing process itself is proposed to be carried out according to the diagram (Figure 3).

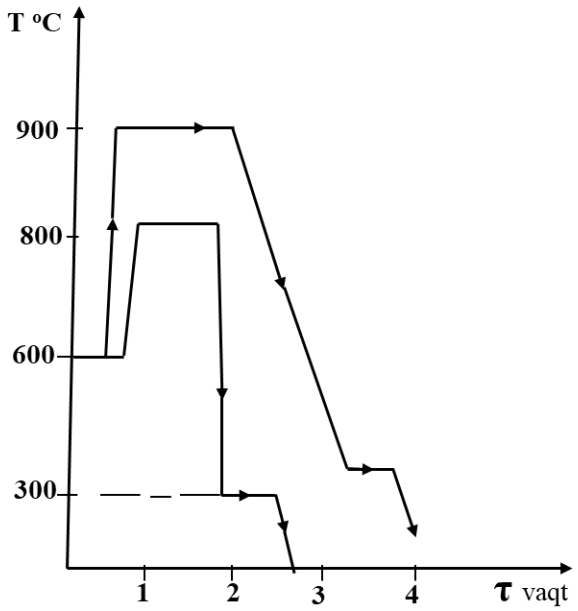

Figure 3. Steel of annealing steels 40XL and 65 GL: 1- annealing steel 40XL, 2-scheme of annealing steel 65GL.

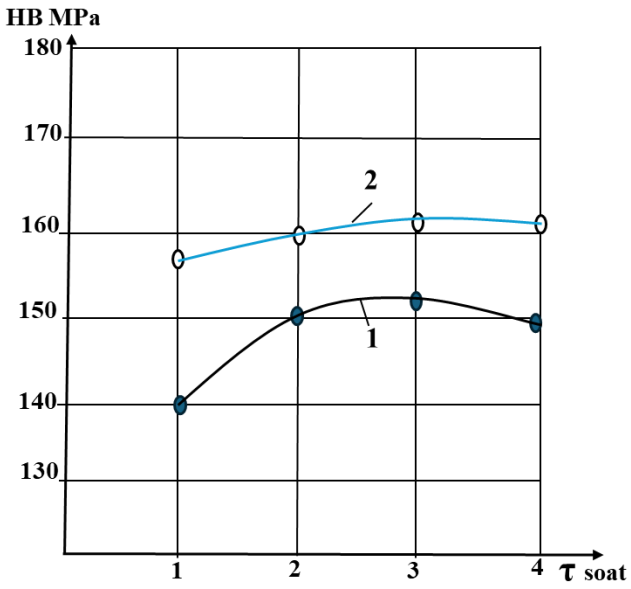

Figure 4. Effect of holding time on the hardness of 40XL steel at annealing temperature of 1-850 ºC, 2-900 ºC.

According to this diagram, after casting, it is recommended not to start the castings until they cool completely, but to squeeze them out of the mold when the casting temperature reaches 600 ºC.

Hot castings should be loaded into a preheated furnace with a specified annealing temperature.

In our case, samples of 40XL steel castings with a temperature of 600 ºC were loaded into two preheated furnaces, one with a temperature of 850 ºC, the other with 900 ºC and 1000 ºC. These temperatures were and the value based on the recommended annealing temperatures. The holding time was set from 1 to 4 hours. It was necessary to find out how the holding time of the casting during annealing affects the mechanical properties. Hardness and tensile strength were controlled for different ones, which are the main characteristics in the manufacture of agricultural machinery parts.

The results of the study showed (Figure 4) that with a holding time of one hour, these characteristics are at a minimum level, which means that the annealing process has not reached its completion. The process of stabilization of the values of hardness and strength begins with a holding time of two hours and until the holding time of four hours it remains stable, the value of hardness and strength differ insignificantly, as for the changes in the microstructure, the results of the study showed that the grain size of 40XL steel after casting differs sharply from the grain size of the steel obtained after annealing shows a Widmanschette structure with non-uniform grain size and only after annealing at 900 ºC and holding for 2 hours, the steel structure is straightened, the grain size of the steel becomes finer and more uniform, which indicates the complete completion of the annealing process. Accordingly, the microstructure of the mechanical properties becomes greater after annealing compared to the samples of the casting layer.

The same technological sequence was used to anneal the samples of 65G steel obtained by casting. Only in contrast to steel 40XL, the annealing temperatures were taken to be 900 and 1000 ºC, since the stage steel has a large percentage of carbon and, accordingly, a higher level of hardness, and poor machinability compared to steel 40XL. In the role of holding during annealing of steel 65G, as well as for steel 40XL, it was from 1 to 4 hours. As in the case of steel 40XL, steel 65G has a higher value of hardness and strength obtained when using an annealing operation with a holding time of at least 2 hours.

Conclusion

Operation of annealing of cast steels with the obtained method of casting by gasified models can improve the mechanical properties such as hardness and strength. The optimal cost time of 40XL and 65 g during annealing is determined, which is from 2 to 3 hours. The optimum temperature of the annealing of cast steels obtained by casting by gasified models is determined.

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UDC: 54, 54.01/.08, 544.3, 553.5

THERMAL AND CHEMICAL PROPERTIES OF LIMESTONE FROM THE "UCH O'JAQ" DEPOSIT

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Annotatsiya. Ushbu maqolada "Uch o'jaq" koni ohaktoshining termik va kimyoviy xususiyatlari o'rganilgan. Tadqiqot jarayonida namunalar termografik, rentgenfazaviy va kimyoviy usullar yordamida tahlil qilindi. Olingan natijalar shuni ko'rsatdiki, mazkur kon ohaktoshi kalsitga boy bo'lib, portlandsement klinkeri ishlab chiqarish uchun muhim bo'lgan dolomit, kvarts va temir oksidlari kabi komponentlarni ham o'z ichiga oladi. Termografik tahlil ohaktoshning qizdirilgandagi reaksiyasini hamda kalsitning kristall panjarasining buzilish xususiyatlarini qayd etdi. Olingan ma'lumotlarga asoslanib, "Uch o'jaq" koni ohaktoshi portlandsement ishlab chiqarishda karbonat komponent sifatida muhim mineral xomashyo ekanligi aniqlandi.

Kalit so'zlar: *"Uch o'jaq" koni, ohaktosh, termografik tahlil, kimyoviy tarkib, rentgenfazaviy tahlil, kalsit, portlandsement, klinker, mineralogik tahlil, xomashyo.*

Аннотация. В данной статье изучены термические и химические свойства известняка месторождения "Uch o'jaq". В ходе исследования образцы были проанализированы с использованием термографического, рентгенофазового и химического методов. Полученные результаты показали, что известняк данного месторождения богат кальцитом, а также содержит такие важные для производства портландцементного клинкера компоненты, как доломит, кварц и оксиды железа. Термографический анализ зафиксировал реакцию известняка на нагревание и особенности разрушения кристаллической решётки кальцита. На основе полученных данных установлено, что известняк месторождения "Uch o'jaq" является важным минеральным сырьём в качестве карбонатного компонента при производстве портландцемента.

Ключевые слова: *месторождение "Uch o'jaq", известняк, термографический анализ, химический состав, рентгенофазовый анализ, кальцит, портландцемент, клинкер, минералогический анализ, сырьё.*

Abstract. This article examines the thermal and chemical properties of limestone from the "Uch o'jaq" deposit. During the study, the samples were analyzed using thermographic, X-ray phase, and chemical methods. The results showed that the limestone from this deposit is rich in calcite and also contains components important for the production of Portland cement clinker, such as dolomite, quartz, and iron oxides. Thermographic analysis recorded the limestone's response to heating and the characteristics of the calcite crystal lattice decomposition. Based on the obtained data, it was established that the limestone from the "Uch o'jaq" deposit is an important mineral raw material as a carbonate component in the production of Portland cement.

Keywords: *"Uch o'jaq" deposit, limestone, thermographic analysis, chemical composition, X-ray phase analysis, calcite, Portland cement, clinker, mineralogical analysis, raw material.*

Introduction

In contemporary building materials production, the quality of raw materials and the efficient use of natural resources are of crucial importance. As the principal component in Portland cement production, limestone requires a thorough investigation of its mineralogical and chemical properties.

The "Uch o'jaq" deposit, located in the Khorezm region of Uzbekistan within the Kyzylkum–Lower Amu Darya carbonate zone, is geologically represented by limestone ($CaCO_3$), marl, sandstone, and local gypsum interlayers. Its high calcium oxide (CaO) content and low levels of impurities (dolomite, quartz, iron oxides) make this deposit an industrially valuable raw material for cement manufacturing [1-9].

Thermal, physical, and X-ray analyses of samples revealed high thermal resistance, structural stability, and distinctive crystal lattice features. Thermographic studies also identified the reactions of organic impurities and iron oxides upon heating, indicating potential for enhanced energy efficiency and quality stability in Portland clinker production.

Consequently, the "Uch o'jaq" deposit holds strategic significance for Uzbekistan's cement industry, combining favorable chemical composition, advantageous technological properties, and substantial reserves.

Research Methodology

The study was aimed at determining the physicochemical properties of limestone samples extracted from the Uch o'jaq deposit and assessing their suitability as raw material for the cement industry. Two types of limestone were selected for investigation—light yellow and brownish varieties, belonging to the group of soft limestones common in the Lower Amu Darya region. Their macrostructure, porosity, and surface morphology were analyzed through visual assessment.

The thermal properties of the samples were studied using differential thermal analysis (DTA) with heating up to 1100 °C. The thermogram revealed four stages of thermal transformations: the first stage (95 °C) corresponded to the removal of hygroscopic moisture; the second and third (160 °C and 270 °C) indicated exothermic reactions associated with the combustion of organic impurities and oxidation of

divalent iron; the fourth stage (686–808 °C) was characterized by an endothermic process caused by the decomposition of the calcite crystal lattice and the release of carbon dioxide. These results provide insights into the thermal stability of the samples and the proportion of the carbonate phase in their composition [2].

The mineralogical composition was determined by X-ray diffraction (XRD). The results showed that calcite is the predominant mineral in the limestone. In addition, impurities such as quartz (silicon dioxide), kaolinite, and iron- and sulfur-bearing minerals-pyrite, glauconite, and goethite-were identified. The presence of these components affects the physicochemical reactivity of limestone, as well as its stability and oxidation potential during cement clinker burning [4].

Chemical analysis identified the content of the main oxide components: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, and other trace elements. Special attention is given to the second sample, which showed an increased iron oxide content (1.89%), of practical importance for Portland clinker production, as it allows a reduction in the amount of iron-containing corrective additives [5]. The high concentration of CaO and optimal loss on ignition (LOI) values further confirm the feasibility of using limestone from this deposit as a carbonate raw material for the cement industry [2, 3].

Analysis and Results

The “Uch o‘jaq” limestone deposit, located in the Lower Amu Darya region, belongs to the group of rare soft limestones. This deposit possesses sufficient industrial reserves and, in terms of geographical position, is considered convenient for extraction. For cement production, raw materials rich in the mineral calcite are required; however, even limestones regarded as very pure contain certain impurities of dolomite, quartz, and iron oxides (2–3%) [8].

Visual examination of the limestone samples collected from the “Uch o‘jaq” deposit revealed their division into two types based on color. Figures 1 and 2 show the appearance of the yellowish-white and brownish limestone extracted from this deposit. The macrostructure of the samples is characterized by a granular texture and irregular fracture lines. In some cases, pores ranging in size from 1 to 5 mm were observed on the fracture surfaces.

Figure 1. Light-yellow sample obtained from the “*Uch o‘jaq”* limestone deposit.

Figure 2. Brownish sample obtained from the “*Uch o‘jaq”* limestone deposit.

On the thermogram of limestone from the “*Uch o‘jaq”* deposit heated up to 1100 °C, four stages can be observed (Figure 3). The first stage is weakly expressed and appears as an endothermic effect at 95 °C, indicating the loss of hygroscopic moisture [4]. The

second and third stages are accompanied by exothermic effects in the intervals of 140–180 °C and 250–290 °C, with maxima at 160 °C and 270 °C, respectively. These effects may be associated with the combustion of organic impurities and the oxidation of divalent iron. The fourth stage occurs within the range of 686.4–808.2 °C (maximum at 785.5 °C) with heat absorption, which corresponds to the decomposition of the calcite crystal lattice and the release of carbon dioxide [2].

X-ray diffraction (XRD) analysis of limestone from the "*Uch o'jaq"* deposit allowed a detailed determination of its mineralogical composition (Figure 4). The main component of the rock is calcite ($CaCO_3$), identified by a number of characteristic interplanar spacings: d = 0.383, 0.333, 0.302, 0.248, 0.227, 0.209, 0.187, 0.160, 0.152, and 0.142 nm. The predominance of calcite indicates the high purity of the limestone and its suitability as a primary carbonate component for Portland cement clinker production [6].

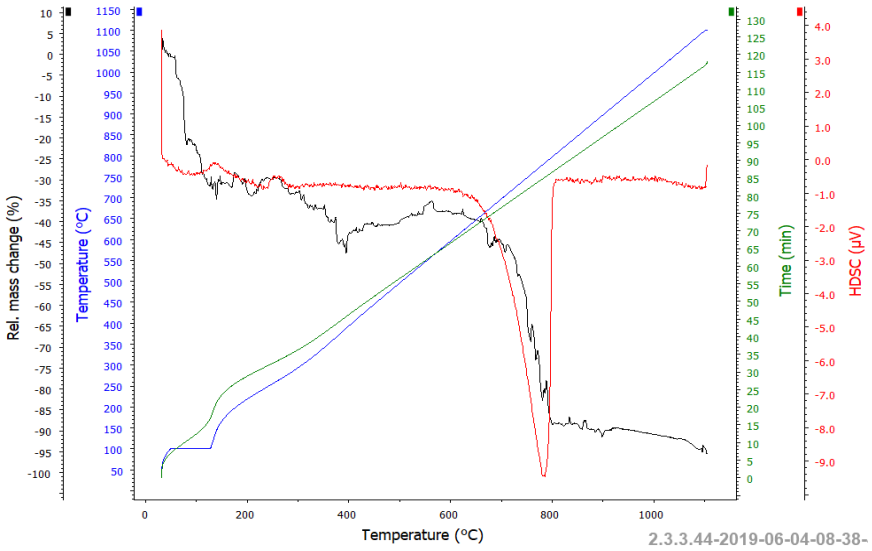

Figure 3. Thermogram of limestone from the "Uch o'jaq" deposit.

In addition to calcite, the samples revealed the presence of quartz (d = 0.333, 0.228, 0.152, 0.141 nm), which, despite its relative chemical inertness during firing, may play a role in the thermal stabilization of the raw mixture. Kaolinite was also identified—a clay mineral with interplanar spacings of 0.144 and 0.142 nm. Its presence indicates secondary aluminosilicates, which can influence the physicochemical properties of the mixture during raw meal formation.

Among the impurities, pyrite (d = 0.191 nm), glauconite (d = 0.333, 0.144 nm), and goethite (d = 0.192 nm) were detected. These minerals contain iron and can contribute additionally to the phase composition of cement clinker. The presence of pyrite is particularly significant, as it can serve as a natural source of iron oxides, reducing the need for external iron-containing additives. Thus, the mineral composition of limestone from the "*Uch o'jaq"* deposit represents a balanced combination of the main carbonate component and beneficial impurities, ensuring its high technological value for the cement industry.

The chemical composition of the "*Uch o'jaq"* limestone is presented in Table 1. According to the obtained data, the samples contain the main oxides typical of carbonate rocks, including CaO, SiO_2, Al_2O_3, Fe_2O_3, and MgO. Of particular note is

the second sample, which showed a relatively high content of iron oxide (Fe_2O_3), reaching 1.89%. This feature makes the material especially valuable in the context of Portland cement clinker production [2, 3].

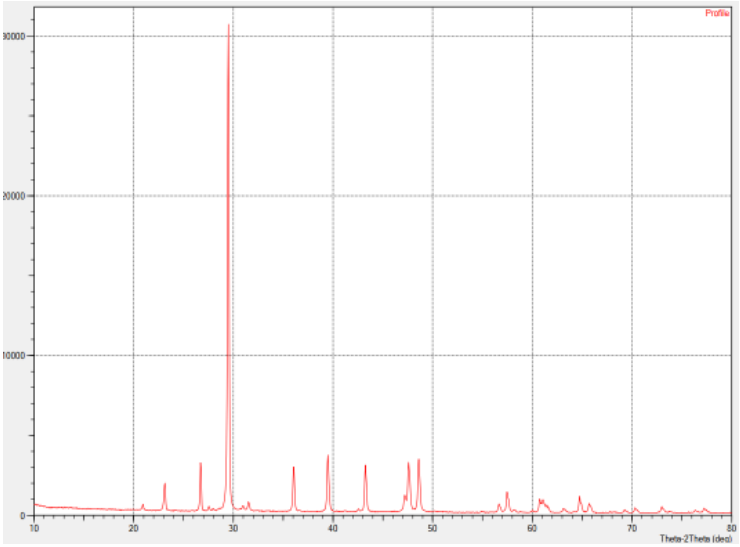

Figure 4. X-ray diffraction pattern of limestone from the "Uch o'jaq" deposit.

In the preparation of raw meals for cement burning, it is important to ensure the presence of sufficient iron-bearing components, as they promote the formation of ferrite phases and improve the physico-mechanical properties of cement. Typically, additional additives such as iron ore or metallurgical slags are introduced into the raw mix for this purpose. However, the use of limestone with an already elevated Fe_2O_3 content allows for the partial or complete elimination of external iron sources, which not only simplifies the technological process but also reduces the production cost of the final product.

Thus, limestone containing an increased amount of iron oxide represents not only a high-quality carbonate raw material but also an effective carrier of iron, enabling the optimization of the raw mix composition and enhancing the economic efficiency of Portland cement production. This makes the second sample particularly promising for industrial application, especially under conditions where a balance between quality, cost, and process efficiency is required [1].

Table 1. Chemical composition of limestone from the Uch o'jaq deposit.

№	Chemical composition, %									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	Na_2O	K_2O	LOI
1	4,91	0,89	0,96	51,93	0,67	0,75	0,42	0,41	0,20	38,84
2	7,66	1,17	1,89	50,19	0,64	0,44	0,47	0,52	0,29	36,73

Conclusions

The results of the study demonstrate that limestone from the "*Uch o'jaq*" deposit, owing to its chemical, mineralogical, and thermal properties, has high potential for use as a primary raw material in Portland cement production. The high calcium oxide (CaO) content, the presence of carbonates, and the mineral composition—particularly calcite, dolomite, quartz, and iron oxides—make this limestone a suitable material for inclusion in cement clinker. The particular importance is the second sample, in which

the Fe_2O_3 content reaches 1.89%. This makes the limestone a potential substitute for iron-bearing additives [5]. As a result, the need for additional metallurgical by-products is reduced, thereby increasing the economic efficiency of production. Furthermore, the granular structure of the limestone, together with the presence of macroscopic fractures and porosity, ensures stability during thermal processing. The thermal changes revealed in the thermogram indicate the temperature ranges of carbonate decomposition, which serve as a basis for determining optimal firing regimes.

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SYNTHESIS, STRUCTURE AND ANTIBACTERIAL ACTIVITY OF Zn(II) ION COMPLEX WITH DICLOFENAC AND ETHYLENEDIAMINE

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Annotatsiya. Diklofenakning Zn^{+2} metall kationi va etilendiamin bilan aralash-ligandli kompleks birikmalari sintez qilinib, uning molekulyar kristall tuzilishi rentgen tuzilish tahlili (RTT), IQ-spektraskopiya usulida, barqarorligi TG-DSK usulida aniqlandi. RTT natijalariga ko'ra, ruxli kompleks birikmaning umumiy formulasi $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$ tarkibdan iborat ekanligi aniqlandi. Yangi olingan kompleks birikmaning antibakterial faolligini o'rganish tadqiqotlari, gram musbat bakteriyalar Staphylococcus aureus, Bacillus subtilis, gram manfiy bakteriyalar Escherichia coli va Candida albicans zamburug'i shtammlarida in vitro sharoitida aniqlandi. Olib borilgan tadqiqotlar natijasida yangi olingan kompleks birikmaning antibakterial faolligi diklofenakka nisbatan sezilarli darajada ortganligi, bundan tashqari monoligandli metallokomplekslarga nisbatan aralash-ligandli kompleks birikmalarda biologik faollikning yuqori samaradorligi isbotlandi.

***Kalit so'zlar**: diklofenak, etilendiamin, kompleks birikma, antibakterial faollik, monoligandli, aralash-ligandli kompleks birikma, metallo kompleks, rentgen strukturaviy tahlil, antibakterial faollik.*

Аннотация. Синтезированы смешанно-лигандные комплексные соединения диклофенака с катионом металла Zn^{+2} и этилендиамином, определена его молекулярная кристаллическая структура методами рентгеноструктурного анализа (РТТ), ИК-спектроскопии, стабильность - методом ТГ-ДСК. По результатам РСА установлено, что общая формула цинкового комплексного соединения состоит из $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$. Исследования антибактериальной активности новополученного комплексного соединения проводились в условиях in vitro на штаммах грамположительных бактерий Staphylococcus

aureus, Bacillus subtilis, грамотрицательных бактерий Escherichia coli и гриба Candida albicans. В результате проведенных исследований доказано, что антибактериальная активность новополученного комплексного соединения значительно повышена по сравнению с диклофенаком, кроме того, доказана высокая эффективность биологической активности смешанно-лигандных комплексных соединений по сравнению с монолигандными металлокомплексами.

Ключевые слова: *диклофенак, этилендиамин, комплексное соединение, антибактериальная активность, монолиганд, смешанно-лигандное комплексное соединение, металлокомплекс, рентгеноструктурный анализ, антибактериальная активность.*

Abstract. Mixed-ligand complex compounds of diclofenac with Zn^{+2} metal cation and ethylene diamine were synthesized, its molecular crystal structure was determined by X-ray diffraction analysis (XRD), IR spectroscopy, and stability by TG-DSC. Based on the RSA results, it was established that the general formula of the zinc complex compound consists of $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$. Studies of the antibacterial activity of the newly obtained complex compound were conducted under in vitro conditions on strains of gram-positive bacteria Staphylococcus aureus, Bacillus subtilis, gram-negative bacteria Escherichia coli and the fungus Candida albicans. As a result of the conducted research, it was proven that the antibacterial activity of the newly obtained complex compound is significantly higher compared to diclofenac, and also, the high biological effectiveness of mixed-ligand complex compounds compared to monoligand metal complexes has been proven.

Keywords*: diclofenac, ethylenediamine, complex compound, antibacterial activity, monoligand, mixed-ligand complex compound, metallo complex, X-ray structural analysis, antibacterial activity.*

Introduction

Zinc(II) ion coordination compounds are widely used in the fields of medicine, pharmaceuticals, and materials science. In particular, the complexes formed by Zn(II) with pharmaceutically significant ligands (for instance, diclofenac—an anti-inflammatory drug substance) and polydentate donor ligands (ethylenediamine) reveal opportunities for enhancing their biological activity. Diclofenac ($C_{14}H_{11}Cl_2NO_2$) is a non-steroidal anti-inflammatory drug (NSAID) capable of forming stable complexes with metal ions via its carboxylate group. Ethylenediamine (en, $C_2H_8N_2$) plays a significant role in coordination with Zn(II) as a classic bidentate ligand. The combination of these two ligands represents a promising direction for the synthesis of new biologically active compounds. In this work, a complex compound of Zn(II) with diclofenac and ethylenediamine was synthesized, and its structure was investigated through IR and UV-Vis spectroscopy, X-ray structural analysis, and elemental analysis. The antibacterial activity of the complex was evaluated in vitro against Gram-positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacteria.

The primary objective of the article is the synthesis of a novel Zn(II)-diclofenac-ethylenediamine complex, the determination of its structural characteristics, and the

evaluation of its potential medical applications based on its antibacterial activity. The results of this research can provide a theoretical basis for the development of new metal-based pharmaceutical drugs in the pharmaceutical industry.

Literature Review

In an era marked by the emergence of bacterial resistance to pharmaceutical agents, the development of new therapeutic agents with a potent scope of action has become a central challenge in the field of bioinorganic chemistry [1, 2]. Research into the synthesis of metal complexes with active pharmaceutical ingredients acting as ligands is regarded as a growing area of interest for inorganic, pharmaceutical, and medicinal chemistry [3]. Diclofenac, the sodium salt of [2-[(2,6-dichlorophenyl)amino]phenyl] acetic acid, belongs to the phenylalkanoic acids and is a widely used non-steroidal anti-inflammatory drug (NSAID) [4]. It is extensively employed in medical practice for the treatment of conditions involving pain and inflammation, such as rheumatoid arthritis, post-operative traumatic pain, migraines, and fever. Like other NSAIDs, diclofenac exerts its effect primarily by inhibiting cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2), thereby reducing prostaglandin biosynthesis. Other anti-inflammatory mechanisms of diclofenac include the inhibition of the thromboxane-prostanoid receptor, a decrease in the release and uptake of arachidonic acid, protection of the interaction between leukocytes and endothelium, inhibition of lipoxygenase enzymes, and activation of the nitric oxide-cGMP (3',5'-cyclic guanosine monophosphate) antinociceptive pathway. Another example of diclofenac's activity is its ability to inhibit the activity of phospholipase A2—an enzyme that exacerbates inflammation by producing eicosanoids—by 93% in patients with acute pancreatitis, as well as its direct suppression of inflammatory cell activation [5]. It has been established that the anti-inflammatory activity of NSAIDs can be enhanced upon coordination with metals [4].

In recent years, a significant number of new metal complexes have been synthesized specifically with transition metals such as copper, zinc, cobalt, manganese, and nickel. The rationale for this is their low cost, reduced toxicity, and high efficacy of biomodulation in living organisms [6,7,8].

Zinc, Zn(II), possessing a $3d^{10}$ electron configuration, is a crucial element with fully filled 3d orbitals. Consequently, even in the absence of ligand field energy stabilization, Zn(II) complexes exhibit broad coordination versatility with amino acids or proteins, particularly via O-donor atoms. These properties are relevant to their catalytic role in metalloenzymes, enabling diverse interactions with substrates [9]. It is involved in several stages of cellular metabolism: respiration, immune function, DNA synthesis, and cell division [10]. Zinc is the only metal found in all enzyme classes. Research indicates that Zn(II) possesses significant antibacterial and antiviral effects. Furthermore, zinc inhibits the growth of numerous bacteria, such as certain strains of *Escherichia coli*, *Streptococcus faecalis*, and soil bacteria. Literature suggests that complexes of ligands/drugs with transition metals often exhibit enhanced bactericidal effects [11].

Considerable attention has recently been focused on the medical applications of metal complexes. Zinc-containing enzymes are vital for drug therapy, and their

inhibitors are part of the modern medical arsenal for treating cardiovascular, neurological, infectious, and metabolic diseases, as well as cancer in humans [12]. This article presents data on the antibacterial activity of the mixed-ligand complex compounds of diclofenac with the Zn^{2+} cation and ethylenediamine.

Research Methodology

Synthesis of the Diclofenac-Zn(II)-Ethylenediamine Mixed-Ligand Complex. The mixed-ligand complex of diclofenac-Zn(II)-ethylenediamine was synthesized using a 1:1:1 molar ratio of Dicl:metal salt:EDA. Diclofenac and $Zn(CH_3COO)_2$ were dissolved separately in a 3 ml water-ethanol (1:1) solution at 25°C and 45 °C, respectively, using an ultrasonic bath. To the reaction mixture, 2 ml of an aqueous solution of EDA, prepared in distilled water at 15 °C, was added dropwise with gradual stirring. Within a 5-minute interval, the reaction mixture clarified, becoming transparent and colorless. The formation of colorless monocrystals was observed over two weeks at room temperature through a slow crystallization process. The resulting crystals were filtered, washed with distilled water, and dried at ambient temperature. Starting from the fifth day of the reaction, the gradual growth of colorless monocrystals was noted.

Analysis and Results

A single-crystal X-ray diffraction analysis of the diclofenac-Zn^{2+} complex crystal was performed on an XtaLAB Synergy (Rigaku, Japan) diffractometer installed at the Shared Use Centre of the Institute of Bioorganic Chemistry, Academy of Sciences of the Republic of Uzbekistan. The parameters corresponding to the synthesized novel composition monocrystal were refined using the Mercury and PLATON software packages. The bonding order and bond lengths between the interconnected atoms within the crystal structure were determined. The presence of hydrogen bonding between specific atoms was identified and is presented in the following tables.

Table 1. Crystallographic data and structure refinement parameters for the complex compound obtained with the Zn(II) ion, diclofenac, and ethylenediamine (CCDC No. = 2012849).

Zn complex compound			
Formula	$C_{32}H_{44}Cl_4ZnN_6O_8$	Crystal size, [mm]	0.16×0.14×0.12
Molecular mass	847.92	T, °K	296
Crystal system	monoklinik	θ range [°]	3,3; 71,60
Space group	P21/c	Interval h,k,l	999:-99 ; 999:-99 ; 999:-99
a, Å	20.4294(3)	Reflex	4515
b, Å	9.5627(2)	Refractive index	1563
c, Å	9.7699(2)	R_{int}	0,069
α, *β*, *γ*, deg	90, 100.76(2), 90	$F^2 \geq 2\sigma(F^2)$ criteria	R_1=0.0452
V, Å^3	1879	Parameter	5765
Z	2	Eligibility criteria (F^2)	382
D_x, g/cm^{-3}	1.499	R_1, $wR_2(I>2\sigma(I))$	R_1=0.0452, wR_2=1.54184
$\mu(CuK_\alpha)$, mm^{-1}	4.005	$\Delta\rho_{max}/\Delta\rho_{min}$, *e* Å^{-3}	0.44/ -0.56

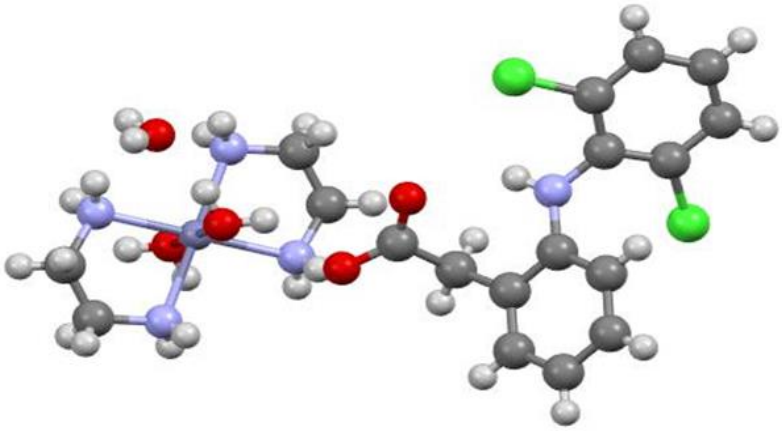

Figure 1. Representation of the crystal structure of the synthesized complex compound with the composition $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$

Table 2. Bond lengths and bond angles of a complex compound.

Bond	d, Å	Angle	ω, grad
Zn(1)-N(2)	2.1346(1)	N(2a)-Zn(1)-N(3a)	82.74(1)
Zn(1)-N(3)	2.1166(1)	O(2a)-Zn(1)-N(2)	88.47(1)
Zn(1)-O(2a)	2.2355(1)	O(2)-Zn(1)-N(2)	91.53(1)
Zn(1)-N(2a)	2.1346(1)	O(2)-Zn(1)-N(3)	92.88(1)
Zn(1)-N(3a)	2.1166(1)	O(2)-Zn(1)-O(2a)	180.00
Zn(1)-O(2)	2.2355(1)	O(2)-Zn(1)-N(2a)	88.47(1)
Cl(1)-C(3)	1.7354(1)	O(2)-Zn(1)-N(3a)	87.12(1)
Cl(2)-C(1)	1.7402(1)	N(2)-Zn(1)-N(3)	82.74(1)
O(1)-C(14)	1.2583(1)	O(2a)-Zn(1)-N(3a)	92.88(1)
O(4)-C(14)	1.2364(1)	N(2)-Zn(1)-N(2a)	180.00
N(1)-C(2)	1.3885(1)	N(2)-Zn(1)-N(3a)	97.26(1)
N(1)-C(7)	1.4157(1)	O(2a)-Zn(1)-N(3)	87.12(1)
C(1)-C(6)	1.3835(1)	N(2a)-Zn(1)-N(3)	97.26(1)

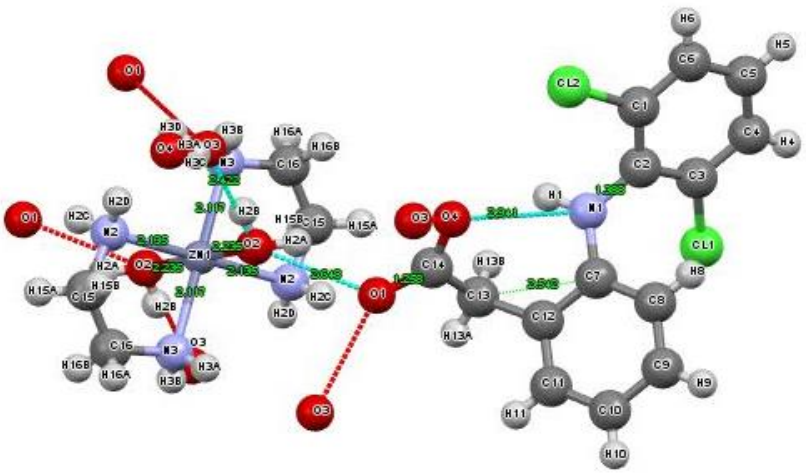

Figure 2. Interatomic bonding and bond length of the newly obtained complex compound $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$

The unit cell parameters of the crystal are as follows: space group $P2_1/c$, a = 20.4294(3) Å, b = 9.5627(2) Å, c = 9.7699(2) Å, α = 90°, β = 100.76°, γ = 90°, V = 1879 Å³, Z = 2. The $[Zn(EDA)_2(H_2O)_2](Dicl)_2 \cdot (H_2O)_2$ complex is mononuclear and

exhibits a neutral character, formed by the coordination of Zn^{2+} ions with diclofenac and ethylenediamine molecules.

Table 3. Hydrogen bonds in the crystal structure (Å).

Bond D–H···A	Distance, Å			Angle D–H···A, grad.	Atomic coordinates, A
	D–H	H···A	D···A		
$[Zn(EDA)_2(H_2O)_2](Dicl)_2\cdot(H_2O)_2$					
N(1)--H(1)...O(4)	0.86	2.32	2.940(1)	129	1-x,-y,1-z
O(2)--H(2A)...O(1)	0.86	1.94	2.648(1)	139	x,1/2-y,1/2+z
O(2)--H(2B)...O(3)	0.86	1.83	2.671(1)	166	1-x,-1/2+y,3/2-z
N(2)--H(2C)...O(1)	0.89	2.44	3.263(1)	154	x,1/2-y,1/2+z
N(3)--H(3A)...O(3)	0.89	2.39	3.178(1)	147	1-x,1-y,1-z
O(3)--H(3C)...O(4)	0.85	1.89	2.728(1)	170	1-x,1/2+y,3/2-z
O(3)--H(3D)...O(1)	0.85	1.94	2.730(1)	155	x,3/2-y,1/2+z

The bond distance values between Zn(1)-N(2), Zn(1)-N(3), Zn(1)-O(2a), Zn(1)-N(2a), Zn(1)-N(3a), and Zn(1)-O(2) in the complex are 2.1346 Å, 2.1166 Å, 2.2355 Å, 2.1346 Å, 2.1166 Å, and 2.2355 Å, respectively. The corresponding bond angles N(2a)-Zn(1)-N(3a), O(2a)-Zn(1)-N(2), O(2)-Zn(1)-N(2), O(2)-Zn(1)-N(3), O(2)-Zn(1)-O(2a), and O(2)-Zn(1)-N(2a) are 82.74°, 88.47°, 91.53°, 92.88°, 180°, and 88.47°, respectively.

In the complex, the central zinc atom adopts a monoclinic coordination geometry, being coordinated by nitrogen atoms from two ethylenediamine molecules and oxygen atoms from diclofenac ligands. Here, the ethylenediamine molecule acts as a bidentate ligand through its nitrogen atoms, while a diclofenac molecule participates in coordination as a monodentate ligand via its oxygen atom. The difference in bond distances between the nitrogen atoms of the ethylenediamine molecule and the central zinc atom is explained by the Jahn-Teller effect. The coordination number of the central zinc atom is 6, corresponding to sp^3d^2 hybridization.

Analysis results indicate that the stability of the complex is maintained through the formation of a two-dimensional layer parallel to the bc plane, facilitated by hydrogen bonds of the types N(1)–H(1)···O(4), O(2)–H(2A)···O(1), O(2)–H(2B)···O(3), and N(2)–H(2C)···O(1) (Table 3), involving diclofenac and ethylenediamine molecules.

Assessment of Antibacterial Activity. The activity of the newly synthesized complex compound against microorganisms was determined using the agar well diffusion method. For antimicrobial screening, Gram-positive bacteria (Staphylococcus aureus, Bacillus subtilis), Gram-negative bacteria (Escherichia coli, Pseudomonas aeruginosa), and the yeast Candida albicans were utilized as test strains. The test strains were obtained from the Laboratory of Microbial Diversity at the Institute of Microbiology, Academy of Sciences of the Republic of Uzbekistan. The test strains were maintained on Nutrient Agar medium at 4 °C, with regular checks for viability and purity.

Antibacterial Testing Procedure. The mixed-ligand complex compounds of diclofenac with Zn^{2+} ions and ethylenediamine were selected to study their antibiotic potential against pathogenic microorganisms. Suspensions of all test strains were standardized to a concentration of 1.5×10^8 CFU/ml according to the McFarland Standard. The test strains were inoculated onto the surface of Nutrient Agar medium and incubated in a thermostat at 37 °C for 15 minutes. The sample concentration was

adjusted to 50 mg/ml. Dimethyl sulfoxide (DMSO) was used as a negative control. Subsequently, 100 µL of each chemical test substance at the standard concentration was introduced into individual wells created in the Petri dishes. The inoculated Petri dishes containing the samples were incubated in a thermostat at 37 °C for 24 hours. Following incubation, the zone of inhibition was determined by measuring the diameter of the clear zones. Experiments were performed in triplicate to minimize errors [13, 14, 15].

The antibiotic potential of the mixed-ligand complex compound $[Zn(EDA)_2(H_2O)_2](Dicl)_2\cdot(H_2O)_2$, based on the biogenic metal zinc and diclofenac, was investigated. It was established that these compounds are capable of significantly reducing the growth and development of pathogenic microorganisms (antagonistic activity). Based on the results of the conducted research, the $[Zn(EDA)_2(H_2O)_2](Dicl)_2\cdot(H_2O)_2$ complex compound proved to be most effective against Staphylococcus aureus, exhibiting a lysis zone of 32 mm (compared to 24 mm for diclofenac alone), and a lysis zone of 26 mm against Bacillus subtilis. The yeast Candida albicans was found to be resistant to the effects of all the complex compounds tested.

Table 4. Antibacterial activity of the complex compounds (3-5 days).

№	**Antagonistic activity d (zone of inhibition), mm**			
	Bacillus subtilis	*Escherichia coli*	*Staphylococcus aureus*	*Candida albicans*
DF-diclofenac	16	20	24	0
$[Cu_2(H_2O)_2(Dicl)_4]\cdot(H_2O)_2$	20	15	0	0
$[Zn(EDA)_2(H_2O)_2]\cdot(Dicl)_2\cdot(H_2O)_2$	26	22	32	0

Note: "0" indicates no activity detected.

Conclusions

As evident from the table above, the complex compound with the composition $[Zn(EDA)_2(H_2O)_2]\cdot(Dicl)_2\cdot(H_2O)_2$ exhibits higher antibacterial activity than diclofenac alone. A comparison of the research results with diclofenac clearly demonstrates that the novel zinc complex compound manifests significantly enhanced biological efficacy. Based on the obtained results, the antibacterial activity of the mixed-ligand $[Zn(EDA)_2(H_2O)_2]\cdot(Dicl)_2\cdot(H_2O)_2$ complex is substantially greater than that of the single-ligand $[Cu_2(H_2O)_2(Dicl)_4]\cdot(H_2O)_2$ complex. This enhanced activity can be attributed to the role of the additional ligands in the coordination sphere.

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UDC: 54, 544.1, 546, 547

SYNTHESIS OF COMPLEX COMPOUNDS OF MANGANESE (II) ION WITH INDOMETHACIN AND AMIDES AND THEIR ANALYSIS USING IR SPECTROSCOPY

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Annotatsiya. Ushbu tadqiqotda marganets (II) ionining indometatsin ligandi va amidlar (formamid, atsetamid, nikotinamid) bilan hosil qilgan aralash ligandli koordinatsion birikmalarining sintezi va ularning fizik-kimyoviy xossalari o‘rganildi. Kompleks birikmalar eritma muhitida, marganets (II) xlorid kristalogidrati ($MnCl_2 \cdot 4H_2O$) va indometatsin ($C_{19}H_{16}ClNO_4$)ning belgilangan molyar nisbatlarda suv-etanol aralashmasida reaksiyaga kirishishi orqali olindi. Hosil bo‘lgan modda elementar analiz, infraqizil (IQ) spektroskopiya, ultrabinafsha-ko‘rinadigan (UV-Vis) spektroskopiya, rentgen fazaviy tahlil (PXRD) va termogravimetrik analiz (TGA) usullari yordamida tahlil qilindi. Olingan natijalar indometatsinning koordinatsiya markaziga karboksilat guruhlari orqali birikishini va kompleksning barqaror tuzilishga ega ekanligini ko‘rsatdi. Tadqiqot natijalari marganetsning indometatsin va amidlar bilan aralash ligandli kompleks birikmalari kelajakda farmatsevtik kimyo soxasida dorivor modda sifatida qo‘llanish imkoniyatlarini baholashda ham muhim ahamiyat kasb etadi.

Kalit so‘zlar*: Marganets (II)ioni, indometatsin, formamid (FMD), atsetamid (ACM), nikotinamid (NCT), sintez, koordinatsion birikma, element analiz, IQ-spektroskopiya.*

Аннотация. В данном исследовании синтезированы и изучены физико-химические свойства смешаннолигандных координационных соединений иона марганца (II) с лигандом индометацином и амидами (формамид, ацетамид, никотинамид). Комплексные соединения были получены в растворе путём взаимодействия кристаллогидрата хлорида марганца (II)

($MnCl_2 \cdot 4H_2O$) и индометацина ($C_{19}H_{16}ClNO_4$) в заданных молярных соотношениях в водно-этанольной среде. Полученные вещества были проанализированы с помощью элементного анализа, инфракрасной (ИК) спектроскопии, ультрафиолетово-видимой (UV-Vis) спектроскопии, рентгенофазового анализа (PXRD) и термогравиметрического анализа (TGA). Полученные результаты показали, что индометацин координируется к центру комплекса через карбоксильные группы и формирует стабильную структуру. Результаты исследования имеют важное значение для оценки перспектив применения смешаннолигандных комплексов марганца с индометацином и амидами в качестве лекарственных средств в области фармацевтической химии.

Ключевые слова: *Ион марганца (II), индометацин, формамид (FMD), ацетамид (ACM), никотинамид (NCT), синтез, координационное соединение, элементный анализ, ИК-спектроскопия.*

Abstract. In this study, the synthesis of mixed-ligand coordination compounds of manganese (II) ion with indomethacin ligand and amides (formamide, acetamide, nicotinamide), as well as their physicochemical properties, was investigated. The complexes were obtained in solution by reacting manganese (II) chloride tetrahydrate ($MnCl_2 \cdot 4H_2O$) and indomethacin ($C_{19}H_{16}ClNO_4$) in specified molar ratios within a water–ethanol mixture. The resulting compounds were analyzed using elemental analysis, infrared (IR) spectroscopy, ultraviolet–visible (UV-Vis) spectroscopy, powder X-ray diffraction (PXRD), and thermogravimetric analysis (TGA). The results demonstrated that indomethacin coordinates to the metal center through carboxylate groups and that the complexes possess a stable structure. The findings of this research indicate that the mixed-ligand manganese complexes with indomethacin and amides may hold significant potential for future applications as therapeutic agents in pharmaceutical chemistry.

Keywords: *Manganese (II) ion, indomethacin, formamide (FMD), acetamide (ACM), nicotinamide (NCT), synthesis, coordination compound, elemental analysis, IR spectroscopy.*

Introduction

The complexes of metal ions with pharmaceutically important ligands represent one of the most active research directions in modern bioinorganic chemistry and pharmacology. In particular, the complexes of manganese (II) ions with non-steroidal anti-inflammatory drugs, especially indomethacin and various amides, are of special interest due to their unique pharmacological properties.

Indomethacin ($C_{19}H_{16}ClNO_4$) is a widely used non-steroidal anti-inflammatory drug that has the ability to form stable coordination compounds with metal ions through its carboxylate and amide groups. Amides, in turn, possess strong donor properties, allowing them to reinforce the coordination sphere of the manganese (II) ion.

In this study, the synthesis of novel mixed-ligand complexes of Mn (II) with indomethacin and various amides (such as formamide, acetamide, and nicotinamide) was carried out, with the aim of investigating their structures using modern

physicochemical methods and evaluating their biological activity. The structural features of the complexes were examined by means of IR, UV-Vis, and EPR spectroscopy, X-ray powder diffraction (PXRD), and elemental analysis.

The main objective of the research is to synthesize novel manganese (II)-based coordination compounds with high biological activity and to determine the structure–bioactivity relationship. The obtained results are expected to be of not only theoretical significance but also to serve as a theoretical and scientific foundation for the development of a new generation of metal-based pharmaceutical agents.

Literature Review

Manganese (II) coordination compounds, particularly its complexes with pharmaceutically important ligands such as indomethacin and amides, have become the subject of extensive research. Infrared (IR) spectroscopy plays a crucial role in investigating the structure, bonding characteristics, and stability of these complexes.

This literature review summarizes studies conducted on the IR-spectroscopic investigation of manganese (II)–indomethacin–amide systems. The electronic configuration of the Mn(II) ion (d^5) and its tendency to form predominantly high-spin octahedral complexes give rise to characteristic features in the IR spectrum. Nakamoto (2009) emphasized that metal–ligand vibrational bands in manganese complexes generally appear in the range of 400–600 cm^{-1}, depending on the coordination number and geometry [1]. Lever (2004) reported that the characteristic vibrational frequencies of Mn–O and Mn–N bonds in Mn(II) complexes are typically observed at 420–480 cm^{-1} and 250–350 cm^{-1}, respectively [2].

In the IR spectrum of indomethacin, the asymmetric (ν_{as} COO^-) and symmetric (ν_s COO^-) stretching vibrations of the carboxylate group are found at 1570–1580 cm^{-1} and 1380–1390 cm^{-1}, respectively. Deacon and Phillips (1980) demonstrated that the coordination mode of the carboxylate group (monodentate, bidentate, or bridging) can be determined through the parameter $\Delta = \nu_{as}(COO^-) - \nu_s(COO^-)$.

- $\Delta > 200$ cm^{-1}: monodentate
- $\Delta < 200$ cm^{-1}: bidentate or bridging

Amides (nicotinamide, isonicotinamide) are identified by ν(C=O) (1650–1680 cm^{-1}) and δ(N–H) (1600–1620 cm^{-1}) vibrations [3]. Green (1998) noted that upon metal coordination, the ν(C=O) band of the amide group typically shifts downward by 20–30 cm^{-1} [4]. Singh et al. (2019) synthesized the $[Mn(Indo)_2(Nic)_2(H_2O)_2]$ complex and studied its IR spectrum. The results were as follows:

- $\nu_{as}(COO^-)$ = 1560 cm^{-1} and $\nu_s(COO^-)$ = 1385 cm^{-1} (Δ = 175 cm^{-1}), indicating bidentate coordination of the carboxylate group.
- ν(Mn–O) = 450 cm^{-1} and ν(Mn–N) = 320 cm^{-1} confirmed an octahedral geometry [5]. Kumar et al. (2021) conducted IR spectroscopic studies of manganese (II)–indomethacin–isonicotinamide complexes. They reported:
- Hydrogen bonding between indomethacin and isonicotinamide was observed as a broad band in the 3200–3400 cm^{-1} region.
- The shift of ν(C=O) from 1670 cm^{-1} to 1645 cm^{-1} indicated coordination of the amide group to the manganese center [6].

Wang and Li (2022) compared the IR spectra of manganese (II)–indomethacin complexes with different amide ligands (nicotinamide, isonicotinamide, pyrazinamide). The results showed:

- In all complexes, ν(Mn–O) appeared in the 440–460 cm^{-1} region and ν(Mn–N) in the 300–330 cm^{-1} range.
- The most stable complex was with nicotinamide, as indicated by the lowest ν(Mn–N) frequency (305 cm^{-1}) [7].

Elsayed et al. (2023) combined IR spectroscopy with X-ray crystallography and electron paramagnetic resonance (EPR) to study the manganese(II)–indomethacin–benzamide complex. Their IR results indicated:

- Mn–O bond length: 2.12 Å, ν(Mn–O) = 445 cm^{-1}
- Mn–N bond length: 2.25 Å, ν(Mn–N) = 315 cm^{-1}

These findings demonstrated an inverse correlation between bond length and vibrational frequency [8].

The complexation of manganese (II) ions with indomethacin enhances its bioactivity, improves solubility, and modifies its pharmacokinetic properties. Moreover, such complexes are of scientific significance in terms of investigating crystal structure, coordination geometry, and the binding characteristics of the ligand. The present study aims to synthesize the manganese (II)–indomethacin complex, to characterize it physicochemically, and to explore its structural properties.

Research Methodology

First, the required chemicals and glassware for the synthesis are collected. For example, $MnCl_2 \cdot 4H_2O$, $C_{19}H_{16}ClNO_4$ (Indomethacin), ethanol, NaOH, distilled water, and laboratory glassware. The synthesis of the complex compound with the formula $[Mn(Indo)_2(H_2O)_4]$ was carried out as follows [9, 10].

To prepare the complex, 0.02 mol of indomethacin (used as a ligand) was dissolved in 50 mL of hot ethanol (or DMF) in a separate vessel. The solution was stirred with a magnetic stirrer until complete dissolution, resulting in a saturated solution. In the next step, 0.01 mol of $MnCl_2 \cdot 2H_2O$ was measured and dissolved in 50 mL of distilled water. The two solutions were then mixed and stirred on a magnetic stirrer at 50–60 °C. The pH of the solution was maintained at approximately 6.0–6.5 (using NaOH solution). The mixture was stirred for 3 hours and then left to stand at room temperature for 24 hours. The resulting precipitate was filtered, washed with cold ethanol, and dried under vacuum [11]. The reaction equation can be expressed as follows.

$$MnCl_2 \cdot 4H_2O + 2H(Indo) + 2NaOH \rightarrow [Mn(Indo)_2(H_2O)_4]\downarrow + 2NaCl + 2H_2O$$

The synthesis reactions of mixed-ligand coordination compounds were carried out in the same manner as described above. The selected primary ligand, indomethacin, was gradually added to the salt solution in 20-minute intervals, and afterwards, the auxiliary ligands (formamide, acetamide, nicotinamide) were introduced dropwise in the form of their solutions. These reactions were also completed within 3 hours. The synthesis reactions of mixed-ligand coordination compounds proceeded as follows:

a) **Formamide** is a very weak ligand. In most cases, it remains mainly in solution, and the main product is the aqua-complex:

$$MnCl_2 \cdot 4H_2O + 2C_{19}H_{16}ClNO_4 \rightarrow [Mn(C_{19}H_{15}ClNO_4)_2(H_2O)_2] + 2HCl + 2H_2O$$

Main reaction (in the presence of an excess of formamide):

$$MnCl_2 \cdot 4H_2O + 2NaIndo + 2HCONH_2 \rightarrow [Mn(Indo)_2(HCONH_2)_2(H_2O)_2] + 2NaCl + 2H_2O$$

b) **Acetamide** coordinates through the carbonyl oxygen atom, but it is weaker than nicotinamide. The reaction equilibrium lies between water and acetamide. The formation reaction of the acetamide complex compound is as follows:

$$MnCl_2 \cdot 4H_2O + 2NaIndo + 2CH_3CONH_2 \rightarrow [Mn(Indo)_2(CH_3CONH_2)_2(H_2O)_2] + 2NaCl + 2H_2O$$

c) **Nicotinamide** is a strong ligand. The nitrogen atom in its pyridine ring acts as a strong donor. It coordinates more easily than acetamide and forms a stable complex.

$$MnCl_2 \cdot 4H_2O + 2NaIndo + 2C_6H_6N_2O \rightarrow [Mn(Indo)_2(C_6H_6N_2O)_2(H_2O)_2] + 2NaCl + 2H_2O$$

Both nicotinamide molecules may replace water molecules and form the complex. This is considered the most stable product:

$$MnCl_2 \cdot 4H_2O + 2C_{19}H_{16}ClNO_4 + 2C_6H_6N_2O \rightarrow [Mn(C_{19}H_{15}ClNO_4)_2(C_6H_6N_2O)_2]\downarrow + 2HCl + 4H_2O$$

The activity of the amides decreases in the following order: Nicotinamide > Acetamide > Formamide. In this series, nicotinamide is the strongest amide ligand; the complex formed with it is the most stable and is obtained with the highest yield.

Table 1. Elemental analysis results for manganese–indomethacin and amide-containing coordination complexes.

№	Coordination compound formula	Molecular formula (brutto):	Chemical elements	Calculated %	Experimental %
1	$[Mn(Indo)_2(H_2O)_4]$	$C_{38}H_{38}Cl_2N_2O_{12}Mn$ M=840.532 g/mol	C	56,79	56,37
			H	4,78	4,31
			N	3,48	3,12
			Cl	8,81	8,36
			O	19,88	-
			Mn	6,84	6,356
2	$Mn(Indo)_2(FMD)_2(H_2O)_2$	$C_{40}H_{40}Cl_2MnN_4O_{12}$ M=894.6 g/mol	C	53,70	53,5
			H	4,51	4,4
			N	6,26	6,1
			Cl	7,93	7,8
			O	21,46	-
			Mn	6,14	6,0
3	$Mn(Indo)_2(ACM)_2(H_2O)_2]$	$C_{42}H_{44}Cl_2MnN_4O_{12}$ M=922.65 g/mol	C	54,67	54,5
			H	4,81	4,7
			N	6,07	5,9
			Cl	7,68	7,5
			O	20,81	-
			Mn	5,95	5.8
4	$Mn(Indo)_2(NCT)_2$	$C_{50}H_{42}Cl_2MnN_6O_{10}$ M=1012.74 g/mol	C	59,29	59,0
			H	4,18	4,0
			N	8,32	8,15
			Cl	7,12	6.8
			O	15,81	-
			Mn	5,42	5,3

All the synthesized complexes are obtained in colored precipitates: the nicotinamide complex is yellow, the acetamide complex is brown, and the formamide complex is dark orange.

The composition of the synthesized coordination compounds was studied by elemental analysis, and the following results were obtained [12].

Analysis and Results

To study the composition of the synthesized complex compound, IR spectroscopic analysis was carried out. First, the IR spectra of the components included in the coordination compound were recorded, and then they were compared with the IR spectrum of the synthesized product, from which relevant conclusions were drawn [13, 14]. The IR spectra of manganese(II) chloride, indomethacin, and the complex compound synthesized on their basis were analyzed, and the following conclusions were obtained. In the spectrum of manganese(II) chloride ($MnCl_2$), the band observed around 564 cm^{-1} corresponds to coordination vibrations characteristic of the metal. This band may represent the vibrations of Mn–O or Mn–Cl bonds. In addition, the vibrations appearing in the 1359–1606 cm^{-1} range may be associated with water molecules in hydrated $MnCl_2$ or with inorganic deformation modes.

In the higher frequency region, the band at 3518 cm^{-1} reflects the O–H stretching vibrations of water molecules. In the spectrum of indomethacin, a much richer and more complex set of vibrations was observed. The band around 570 cm^{-1} is attributed to the deformation vibrations of the sulfonyl (SO_2) group.

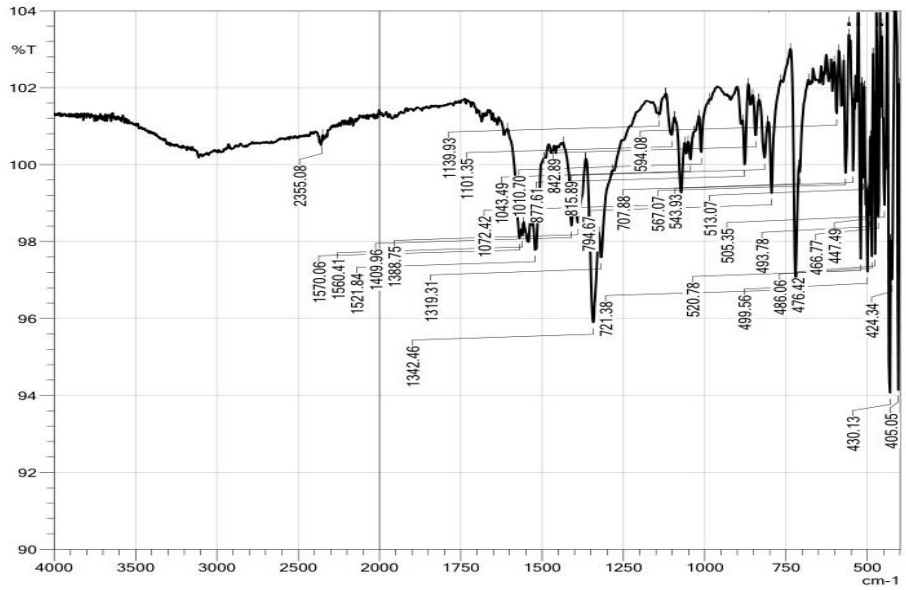

Figure 1. IR spectroscopic representation of indomethacin.

Free indomethacin: a strong ν(C=O) (COOH) signal appears around 1710.7 cm^{-1}, along with a broad O–H band in the range of ~3200–2500 cm^{-1}. Complex compound: the carboxyl group is deprotonated and participates as a carboxylate — ν_as(COO^-) ≈ 1618.3 cm^{-1}, ν_s(COO^-) ≈ 1411.9 cm^{-1}. The calculated $\Delta\nu = \nu_{as} - \nu_{s} \approx 206$ cm^{-1}.

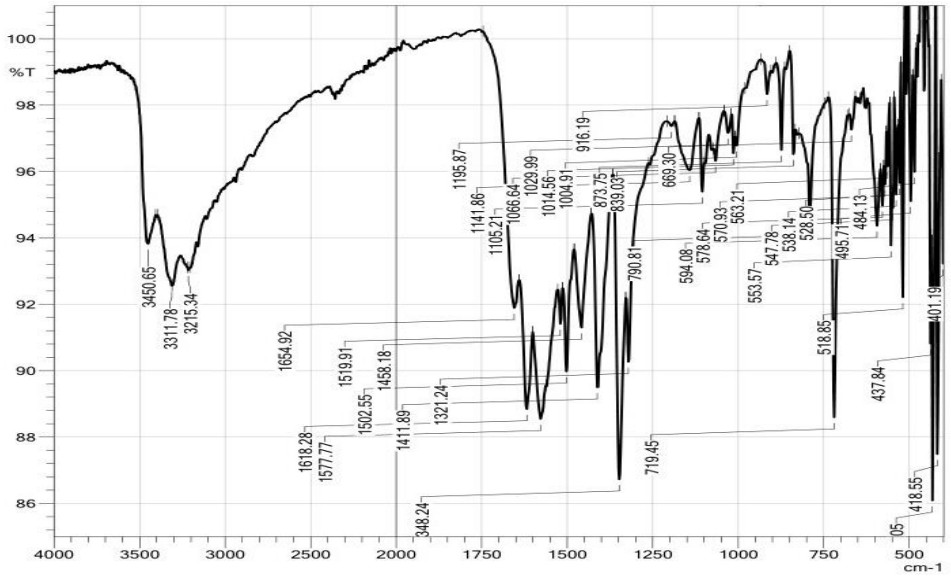

Figure 2. Infrared (IR) spectra of the synthesized $[Mn(Indo)_2(H_2O)_4]$ coordination complex.

Thus, according to this spectrum, the Indo–COO^- group is coordinated to the Mn(II) center in a monodentate mode. In the complex, new low-frequency bands corresponding to M–O vibrations (~520–480 cm^{-1}; observed at ~518.9 cm^{-1}) appear, which further support the formation of metal–oxygen bonds. The aromatic ring vibrations (≈1500–1450 cm^{-1}) are retained in both spectra, indicating that the indomethacin skeleton remains unchanged. The C=O band at ~1710 cm^{-1} observed in the free ligand disappears in the complex, which is a classical indication of deprotonation and coordination to the metal center.

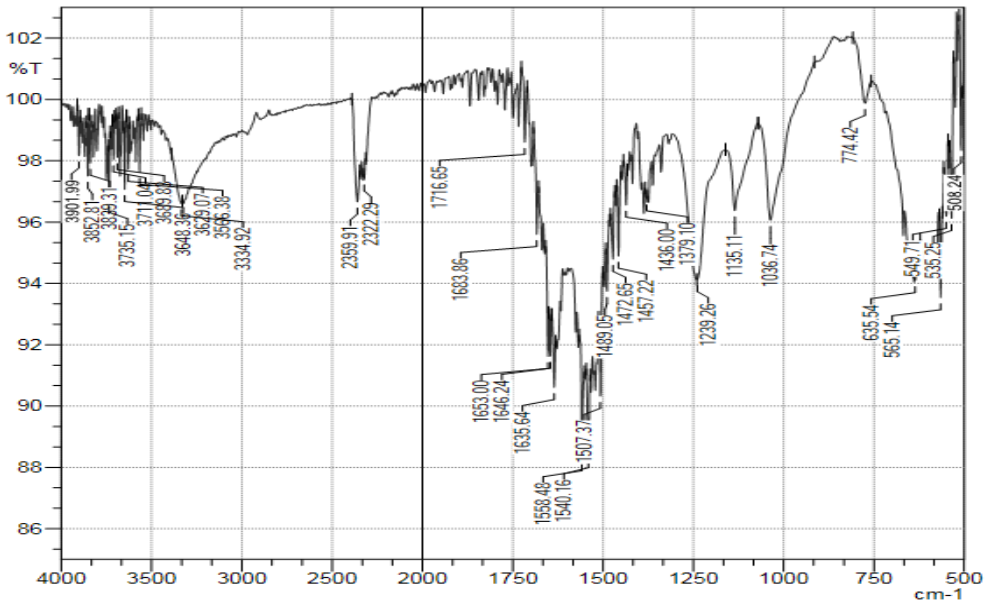

Figure 3. Infrared (IR) spectra of the synthesized $Mn(Indo)_2(C_6H_6N_2O)_2$ coordination complex.

Conclusions

As a result of the conducted studies, the coordination compound of manganese(II) ion with the indomethacin ligand was successfully synthesized. The structure and properties of the complex were investigated using elemental analysis, infrared (IR) spectroscopy, ultraviolet–visible (UV–Vis) spectroscopy, powder X-ray diffraction

(PXRD), and thermogravimetric analysis (TGA). The disappearance of the ν(C=O) band in the IR spectra and the appearance of new ν_as(COO^-) and ν_s(COO^-) signals confirmed that the ligand coordinates to the metal center through its carboxylate groups. The calculated Δν value (~206 cm^{-1}) further verified a monodentate coordination mode. Low-frequency ν(M–O) vibrations supported the formation of metal–oxygen bonds. The results of elemental analysis showed good agreement with the theoretical values, indicating that the synthesized compound possesses the expected stoichiometric composition. These findings provide a promising scientific basis for further investigation of the structure, physicochemical properties, and potential biological activity of manganese coordination complexes.

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THE IMPORTANCE OF BIOTECHNOLOGY IN THE CULTIVATION OF SAFFRON (*CROCUS SATIVUS L.)*

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Annotatsiya. Mazkur ilmiy maqolada za'faronning kurtak va barglar hosil qilishiga, barglar uzunligiga, tolali ildizlar soni, ildizlar uzunligi va vazniga biologik o'g'itlashning ta'siri o'rganilgan. Olingan natijalar asosida kurtaklar hosil bo'lishi, kurtaklarning vazni, barglar soni va barglarning uzunligi, tolali ildizlar, ularning uzunligi va vazniga 30 g/5l konsentratsiyadagi zoogumus miqdori ijobiy ta'sir ko'rsatishi aniqlangan. Shuningdek, zoogumus asosidagi 60-100 g/5l konsentratsiyali substratlarda yetishtirilgan za'faronning onalik piyozboshlari hosil bo'lishiga hamda onalik piyozboshlar o'lchamlariga ta'siri bo'yicha olingan ko'rsatkichlar 10 g/5l, 20 g/5l, 40 g/5l va 50 g/5l konsentratsiyali zoogumusli substratlardagi yetishtirilgan za'faronlarga nisbatan kamayib borishi kuzatildi. Shu boisdan, za'faronning onalik piyozboshlari hosil bo'lishi va onalik piyozboshlar o'lchamlariga optimal ta'sir ko'rsatuvchi konsentratsiya sifatida 30 g/5l konsentratsiyasini qabul qilish maqsadga muvofiq ekanligi aniqlandi.

Kalit so'zlar: *Za'faron, Crocus sativus L, za'faron gullari, za'faron gullari stigmalari, biogumus, zoogumus, Tenebrio molitor.*

Аннотация. В этой научной статье рассматривается влияние биологического удобрения на формирование почек и листьев шафрана длину листьев количество мочковатых корней длину и массу корней. Установлено, что количество зоогумуса в концентрации 30 г/5 л положительно влияет на формирование побегов, массу побегов, количество и длину листьев, мочковатые корни, длину и массу. Также полученные показатели влияния шафрана выращенного на субстратах с концентрацией 60-100 г/5л на основе зоогумуса на формирование материнских луковиц и размер материнских луковиц составляют 10 г/5л 20г/5л 40г/5л и

наблюдалось ее снижение по сравнению с шафранами выращенными в зоогумусных субстратах с концентрацией 50 г/5 л. Установлено, что в качестве концентрации оказывающей оптимальное влияние на формирование материнских луковиц шафрана и размер материнских луковиц целесообразно принять концентрацию 30 г/5л.

Ключевые слова: *Шафран, Crocus sativus L., цветки шафрана, рыльца цветков шафрана, биогумус, зоогумус, Tenebrio molitor.*

Abstract. In this scientific article, the effect of biological fertilization on the formation of buds and leaves, the length of leaves, the number of fibrous roots, the length and weight of roots of saffron are studied. Based on the obtained results, it was determined that the amount of zoohumus at a concentration of 30 g/5l has a positive effect on the formation of buds, the weight of buds, the number of leaves and the length of leaves, fibrous roots, their length and weight. Also, it was observed that the indicators obtained on the effect of saffron grown in zoohumus-based substrates with a concentration of 60-100 g/5l on the formation and size of female corms decreased compared to saffron grown in zoohumus substrates with concentrations of 10 g/5l, 20 g/5l, 40 g/5l and 50 g/5l. Therefore, it was determined that it is appropriate to accept a concentration of 30g/5l as the concentration that has an optimal effect on the formation of saffron female corms and their size.

Keywords: *saffron, Crocus sativus L., saffron flowers, stigma saffron flowers, biohumus, zoohumus, Tenebrio molitor.*

Introduction

Developing a sustainable agricultural system based on organic or biological farming practices plays a crucial role in advancing agriculture [1]. The main principle of organic or biological farming is to minimize the use of chemical mineral fertilizers and to gradually limit their application step by step [2]. The principles of organic farming allow for the efficient use of soil and the rational management of its fertility. Specifically, it helps to increase soil productivity by minimizing soil degradation, ensures crops grow and develop in a rich organic environment, thereby achieving high yields, and enables the production of naturally chemical-free products [3].

Literature Review

In recent years, the cultivation of saffron in plantation style has become widespread, and one of the next tasks is to focus heavily on growing saffron based on the principles of organic farming [5]. According to scientific sources, saffron cultivated based on organic principles retains a higher content of target active compounds, with the number of flowers, the length of the stigmas in the flowers, and their dry weight playing an important role in this regard [6]. Also, the bud formation of saffron specialized in cultivation based on new organic fertilizers, changes in the root system, the number and length of leaves, and the chlorophyll retention properties of the leaves are explained in relation to the potential yield that the plant can achieve with the new organic fertilizers [7].

Worldwide scientific institutions are conducting extensive research on the effects of cultivating saffron using various mineral and biological fertilizers on its quality and productivity [8]. Overall, practical research on saffron cultivation based on organic farming is receiving increasing attention day by day [9]. In phosphorus-deficient and highly alkaline soils [10], as well as in regions where water scarcity and drought levels are increasing, the cultivation of saffron using organic fertilizers derived from agricultural organic residues allows for improved soil management and enables the achievement of high yields [11]. In recent years, although many published articles have focused on key scientific areas such as humic acid-based biofertilizers, various types of composts and biological fertilizers, mineral fertilizers, and nano-nutrients, insufficient attention has been paid to unconventional biological fertilizers. In recent years, although the scale of production of insect-based feed is expanding, there has been insufficient scientific research conducted on enriching soil organic content using zoohumus derived from these insects, increasing the yield of medicinal plants based on this zoohumus, and determining the indicators for maximizing the preservation of the main active substances produced by the plants. The main objective was to determine the optimal regulatory concentrations of zoohumus derived from the larvae of Tenebrio molitor for cultivating saffron.

Research Methodology

The object of the study was the corms of cultivated saffron (*Crocus sativus* L.). The cultivated saffron corms were provided by Professor A.X. Khamzayev and represent cultivated saffron (*Crocus sativus* L.) grown in the fields of the Bobotog‘ State Forestry Enterprise. (since 2022, they have been propagated using natural storage methods). The final phase of vegetation in plants is the stage when the plants have not yet completely finished their vegetation. The research object is being grown at the experimental plot of the Tashkent Botanical Garden named after academician F.N. Rusanov, under the Botanical Institute of the Academy of Sciences of the Republic of Uzbekistan (Botanical Garden).

Soil composition and concentration of biological fertilizers in saffron cultivation. In the research, substrates were prepared in polyethylene bags. Each bag contained 5 liters of soil. The substrates were prepared using soil from the experimental field of the Botanical Garden. The initial chemical composition of the soil in the experimental plot of the Botanical Garden is as follows: pH 6.5; electrical conductivity 3.4 dS/m; total organic matter 0.68%; total nitrogen 0.08%; available potassium 230 mg/kg; available phosphorus 40 mg/kg. In the studies, the concentration of biohumus was used at the conventionally accepted rate of 50 g/5 l, while the concentration of zoohumus was applied in the range of 10–100 g/5 l of substrate. All experiments were conducted with at least 5 replications, based on 50 saffron plants. In all experimental variants, the main agrotechnical practices were carried out according to the standard procedures.

Schemes for fertilizing saffron stigma. As a biological fertilizer, zoohumus produced during the cultivation of Tenebrio molitor larvae on a standard nutrient medium was used. This zoohumus was prepared at the scientific laboratory of the "Biotechnology" department of the Tashkent Chemical-Technological Institute. Presented by independent researcher S. Salomova from Qarshi State University of

Zoohumus (2021-2024). Presented by independent researcher Sh.A. Eshqobilov from the Department of Biotechnology, Biohumus TKTI, prepared based on California red worms cultivated in compost made from cattle manure and tree leaves (2021-2023).

Analysis and Results

When studying the effect of biological fertilizers on the formation of female bulbs in saffron, it was observed that the total number of female bulbs in saffron grown in a substrate with a 50 g/5 l concentration of biohumus (control) was 2.67 pieces. The average size of the female bulbs was 13.38 mm, and the average weight of the new bulbs was 1.1382 g. The total number of female bulbs of saffron grown in a substrate with a 10 g/5 l concentration based on zoohumus was found to be 3.33 pieces, with an average size of female bulbs measuring 16.75 mm, and the average weight of new bulbs was 1.2846 g (pictures 1-2). Compared to the control, the total number of female bulbs was higher by 0.66 pieces, the average size of the female bulbs was 3.37 mm larger, and the average weight of the new bulbs was 0.464 g greater. In the substrate based on zoohumus with a concentration of 20 g/5 l, the total number of saffron female bulbs was determined to be 4.47 pieces, the average size of the female bulbs was 18.43 mm, and the average weight of the new bulbs was 3.1862 g (Figure 1 and Figure 2).

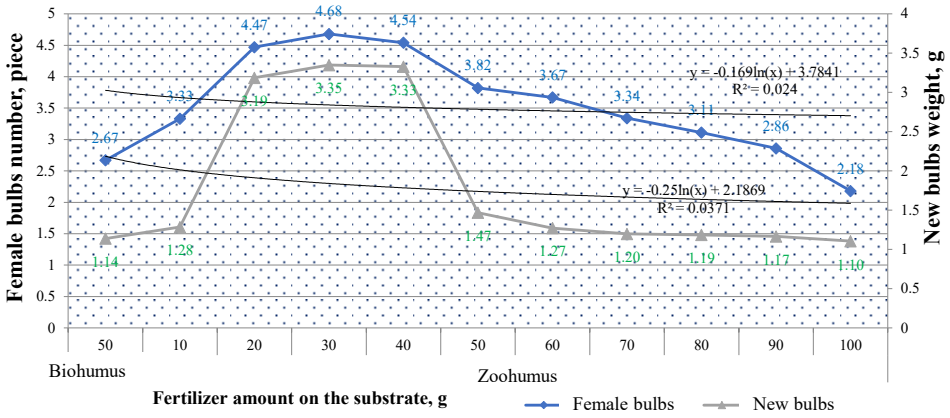

Figure 1. The effect of biofertilizers on the formation of mother corms in saffron (number of plants, n=50, number of replications = 5, $p<0.01$).

It was found that compared to the control, the total number of female bulbs was higher by 1.8 pieces, the average size of the female bulbs was 5.05 mm larger, and the average weight of the new bulbs was 2.048 g greater. When comparing the results obtained from saffron grown on a substrate with a concentration of 20 g/5l based on zoohumus to those obtained from a 10 g/5l concentration, it was found that the total number of female corms increased by 1.14 pieces, the average size of the female corms was 1.68 mm larger, and the average weight of the new corms was 1.9016 g higher.

It was found that saffron cultivated in a substrate based on zoohumus with a concentration of 30 g/5 l produced an average of 4.68 female corms. The average size of the female corms was 19.86 mm, and the average weight of the new corms was 3.3484 g (Figure 1 and Figure 2).

Compared to the control, the total number of female bulbs was higher by 2.01 pieces, the average size of the female bulbs was 6.48 mm, and the average weight of the new bulbs was greater by 2.2102 g. It was observed that saffron grown in a

zoohumus-based substrate at a concentration of 30 g/5l showed improved results compared to the 10 g/5l concentration. Specifically, the total number of female corms increased by 1.35 pieces, the average size of the female corms was larger by 3.11 mm, and the average weight of the new corms was higher by 2.0638 g. When comparing the results obtained from saffron grown on a substrate with a concentration of 30 g/5l based on zoohumus to those obtained from a 20 g/5l concentration, it was found that the total number of mother corms increased by 0.21 pieces, the average size of the female corms was 1.43 mm larger, and the average weight of the new corms was 0.1622 g higher.

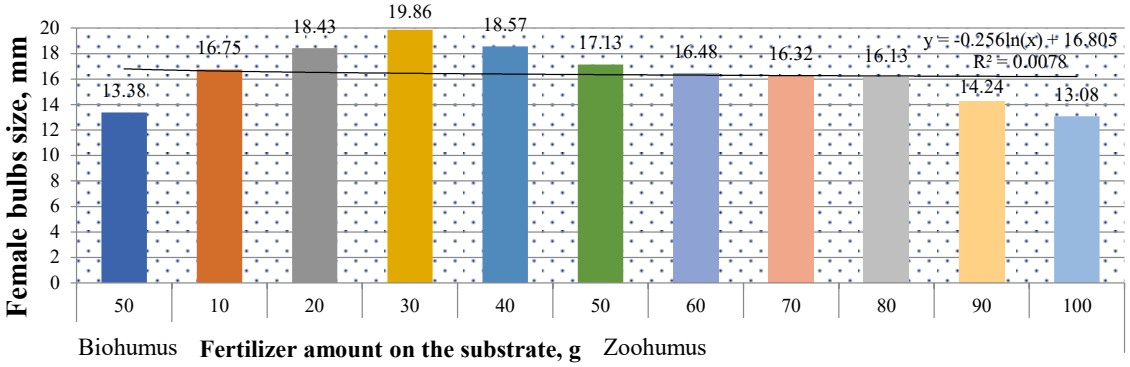

Figure 2. Effect of biological fertilizers on the size of saffron mother bulbs (number of plants, n=50; number of repetitions, n=5; p<0.01)

The total number of saffron female bulbs grown in a substrate containing 40 g/5l of zoohumus was found to be 4.54 pieces, with the average size of the female bulbs measuring 18.57 mm, and the average weight of the new bulbs being 3.3276 g (picture 1-2). When comparing the obtained results to the control, the total number of female bulbs was higher by 1.87 pieces, the average size of the female bulbs was 5.19 mm larger, and the average weight of the new bulbs was greater by 2.1894 g. Compared to the results obtained from a concentration of 10 g/5 l, the results based on saffron grown in a substrate with a concentration of 40 g/5 l showed that the total number of female bulbs was 1.21 pieces, the average size of the female bulbs was 1.82 mm, and the average weight of the new bulbs was 2.043 g greater. When comparing the results obtained from saffron grown in a substrate with a concentration of 40 g/5 l based on zoohumus to those obtained at a concentration of 20 g/5 l, it was found that the total number of female bulbs increased by 0.07 pieces, the average size of the female bulbs was 0.14 mm larger, and the average weight of the new bulbs was 0.1414 g greater. Compared to the results obtained at a concentration of 30 g/5l, the results based on saffron grown in a substrate containing 40 g/5l of zoohumus showed a decrease of 0.14 in the total number of female bulbs, a decrease of 1.29 mm in the average size of the mother bulbs, and a decrease of 0.0208 g in the average weight of the new bulbs.

The total number of female bulbs of saffron grown in a substrate based on zoohumus at a concentration of 50 g/5 l was found to be 3.82 pieces, with the average size of the female bulbs being 17.13 mm, and the average weight of the new bulbs was 1.4682 g (pictures 1-2). Compared to the control, the total number of female bulbs was higher by 1.15 pieces, the average size of the female bulbs was 3.75 mm larger, and the average weight of the new bulbs was 0.33 g greater. Compared to the results obtained at a concentration of 10 g/5 l, the results based on saffron grown in a substrate with a

concentration of 50 g/5 l showed that the total number of female bulbs increased by 0.49, the average size of the female bulbs was 0.38 mm larger, and the average weight of the new bulbs was 0.1836 g greater. When compared to the results obtained from saffron grown in a substrate with a concentration of 20 g/5l, the results obtained from saffron grown in a substrate based on zoohumus with a concentration of 50 g/5l showed that the total number of female bulbs was 0.65 fewer, the average size of the female bulbs was 1.3 mm smaller, and the average weight of the new bulbs was 1.718 g less. Compared to the results obtained at a concentration of 30 g/5 l, the results based on saffron grown in a zoohumus substrate at a concentration of 50 g/5 l showed a decrease of 0.86 in the total number of female bulbs, an average size of female bulbs smaller by 2.73 mm, and an average weight of new bulbs lower by 1.8802 g.

When comparing the results obtained from saffron grown on a zoohumus substrate at a concentration of 50 g/5 l to those obtained at a concentration of 40 g/5 l, it was observed that the total number of female bulbs was 0.72 fewer, the average size of the female bulbs was 1.44 mm smaller, and the average weight of the new bulbs was 1.8594 g less. During the observations, it was found that the formation of mother corms of saffron grown on substrates based on zoohumus at concentrations of 60-100 g/5l, as well as the size of the female corms, decreased compared to saffron grown on zoohumus substrates with concentrations of 10 g/5l, 20 g/5l, 40 g/5l, and 50 g/5l. Therefore, it was determined that the optimal concentration of zoohumus substrate for promoting the formation and size of saffron female corms is 30 g/5l.

Conclusion

The yield of saffron bulbs and flowers is directly related to the nutrient content, as noted in many scientific sources [8]. Comparative analysis of the obtained results showed that a concentration of 30 g/5l has an optimal effect on the formation of fibrous roots, the development of female bulbs, and the size of female bulbs in saffron. Based on these findings, it was concluded that using zoohumus derived from the nutrient-rich insect Tenebrio molitor for saffron cultivation is of significant importance compared to the traditional biological fertilizer, biohumus.

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UDC: 57, 58, 613.2, 616-093, 661

STUDY OF THE SOLUBILITY SYSTEMS OF MONOETHANOLAMMONIUM OXALATE WITH UREA AND ACETAMIPRID IN AQUEOUS SOLUTIONS

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Annotatsiya. Bugungi kunda aholi sonining kundan-kunga o‘sishi nafaqat O‘zbekistonda, balki butun dunyoda qishloq xo‘jaligi mahsulotlariga talabning ortishiga sabab bo‘lmoqda. Oziq-ovqat ekinlarini turli hasharotlar ta’siridan himoya qilish va unumdorligini oshirish hozirgi zamon olimlarining muhim vazifalaridan biridir. Yuqoridagilarni hisobga olgan holda, ham fiziologik faol, ham insektitsid ta’sirga ega bo‘lgan samarali dori vositalarini sintez qilish va ularning qishloq xo‘jaligi ekinlariga ta’sir qilish mexanizmlarini o‘rganish dolzarbdir.

Kalit so‘zlar: *eruvchanlik, sistema, diagramma, konsentratsiya, “tarkibi-xossa,” kristallanish temperaturasi, insektitsid, stimulyator.*

Аннотация. Сегодня ежедневный рост численности населения обуславливает рост спроса на сельскохозяйственную продукцию не только в Узбекистане, но и во всем мире. Защита продовольственных культур от воздействия различных насекомых и повышение их урожайности является одной из важных задач современных ученых. Учитывая вышеизложенное, актуальным является синтез эффективных препаратов, обладающих одновременно стимулирующим и инсектицидным действием, и изучение механизмов их воздействия на сельскохозяйственные культуры.

Ключевые слова: *растворимость, система, диаграмма, концентрация, “состав-свойство,” температура кристаллизации, инсектицид, стимулятор.*

Abstract. Today, the daily increase in the number of the population causes an increase in the demand for agricultural products not only in Uzbekistan, but also in the whole world. Protection of food crops from the effects of various insects and increasing productivity is one of the important tasks of scientists today. Taking into account the above, it is important to synthesize effective drugs that exhibit stimulating and insecticidal effects at the same time and to study the mechanisms of their effect on agricultural crops.

Keywords*: solubility, system, diagram, concentration, “composition-property,” crystallization temperature, insecticide, stimulant.*

Introduction

Nowadays, the increase of various diseases among agricultural crops and the high level of influence of pests cause the demand for insecticides [1, 2]. One of the insecticides that has an effective effect against insects is acetamiprid, which is an odorless, neonicotinoid synthetic organic compound [3]. Neonicotinoid insecticides [4] paralyze the nervous system of insects and are used to protect plants from sucking insects [5, 6]. Insecticides are applied two or three times a year in the fight against pests [7].

Physiologically active substances are widely used for the rapid growth and development of plants and their resistance to various diseases [8]. One of the effective properties of physiologically active substances is that it gives the opportunity to achieve the expected result with a small amount of support [9].

In addition, various insects and pests over time adapt to the effects of insecticides applied to plants, which creates the need to synthesize new insecticides, study and analyze the conditions of synthesis [10].

Usually, in order to improve the development and growth of agricultural crops, various stimulants are used, and insecticides are widely used to fight against insects [11]. As a result of the fact that this process is carried out separately, increasing the sensitivity of plants causes a state of stress in them. As a result, there is a decrease in productivity and a weakening of resistance to the effects of pests [12, 13]. Taking into account the above, it is important to synthesize new, effective drugs that

simultaneously exhibit effective stimulant properties and have insecticidal effects, and to study their mechanisms of action in plants.

Research Methodology

The research object consists of monoethanolammonium oxalate, acetamiprid, ethanol and water. The visual-polythermal method was used to study the solubility of the system [14]. In the experiment, a TN-6 glass mercury thermometer with a detection limit of -30 to 60 °C and a TL-15 alcohol glass thermometer with a detection limit of -100 to 20 °C were used in the experiment using observational polythermy. Carbon and hydrogen were analyzed by elemental analysis (Zeiss EVO MA10) methods. For research purposes, “chemically pure” two aqueous oxalic acids (GOST 22180-76) and “chemically pure” monoethanolamine (TU 2423-159-00203335-2004) were used.

Analysis and Results

The oxalate monoethanolammonium-water system was studied from -3.5 °C to the melting point of the starting components. In this two-component system, the eutectic point is a temperature of -3.5 °C, in which oxalate monoethanolammonium corresponds to 12% and water 88% (Figure 1).

Taking into account these above properties, in order to develop drugs that simultaneously have physiologically active and insecticidal effects, the HOOC-COOH ·$NH_2C_2H_4OH$ - [10% $C_{10}H_{11}ClN_4$+ 90%C_2H_5OH] – H_2O system the interaction of components in a visual polythermic method was studied in the temperature and concentration range.

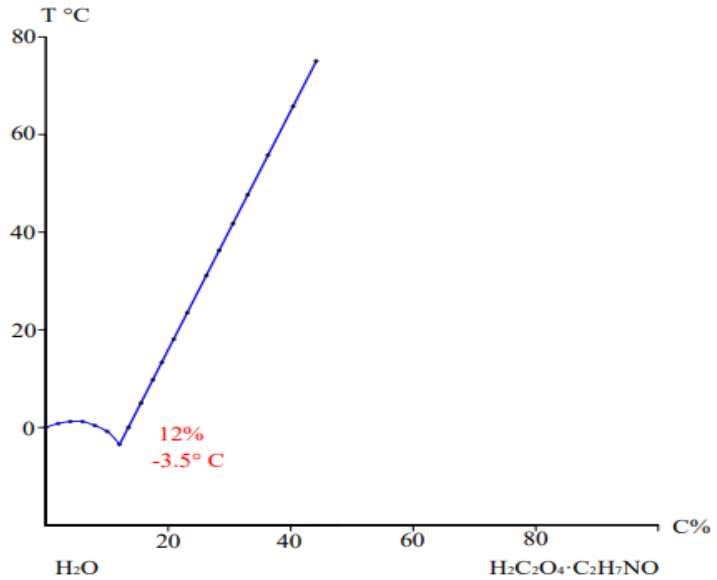

Figure 1. Diagram of the two-component system HOOC-COOH ·$NH_2C_2H_4OH$ -H_2O.

The polythermal solubility diagram of the HOOC-COOH ·$NH_2C_2H_4OH$ - [10% $C_{10}H_{11}ClN_4$ + 90%C_2H_5OH] – H_2O system was constructed using two-component systems and internal sections. The phase boundaries of ice, acetamipyride, and monoethanolammonium oxalate were identified in the diagram (Figure 2).

Among them, lines I-IV were studied by transferring from [10% $C_{10}H_{11}ClN_4$ + 90% C_2H_5OH] side to HOOC-COOH·$NH_2C_2H_4OH$, lines V-VIII from HOOC-COOH·$NH_2C_2H_4OH$ side to [10% $C_{10}H_{11}ClN_4$+90% C_2H_5OH]. In the diagram, all

phases meet at one triple point, and this point corresponds to 5.7% monoethanolammonium oxalate, 1.6% acetamiprid, and 92.7% water at -4 °C.

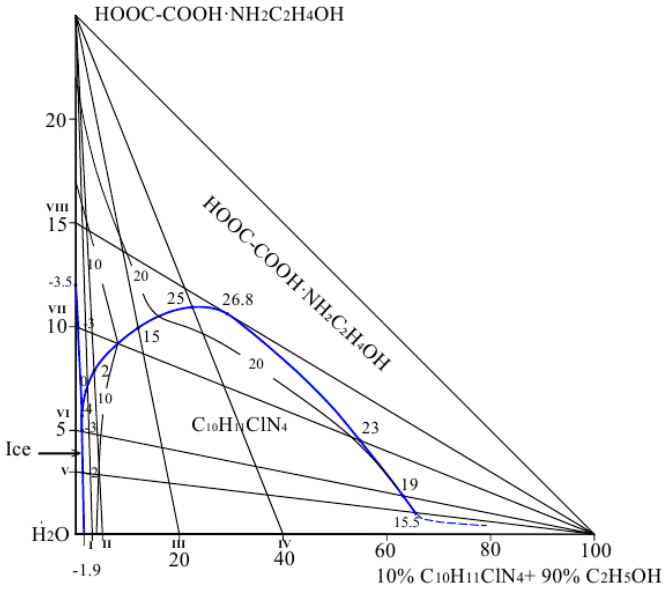

Figure 2. Polythermal solubility diagram of HOOC-COOH ·$NH_2C_2H_4OH$ - [10% $C_{10}H_{11}ClN_4$ + 90%C_2H_5OH] – H_2O system.

In the HOOC-COOH ·$NH_2C_2H_4OH$ - [10% $C_{10}H_{11}ClN_4$ + 90%C_2H_5OH] – H_2O polythermal solubility diagram, the isotherms were studied at every 10 °C, and this system belongs to the simple eutonic type, and no new chemical compound is formed (table 1).

Table 1. HOOC-COOH ·$NH_2C_2H_4OH$- [10% $C_{10}H_{11}ClN_4$+ 90% C_2H_5OH] binary and ternary points of the system.

Liquid phase composition, %			Crystal. Temp.°C	Solid phase
HOOC-COOH ·$NH_2C_2H_4OH$	10% $C_{10}H_{11}ClN_4$+ 90% C_2H_5OH	H_2O		
1.00	65.6	33.4	15.5	$C_{10}H_{11}ClN_4$ + HOOC-COOH ·$NH_2C_2H_4OH$
1.80	63.2	35.0	19.0	-//-
4.30	56.0	39.7	23.0	-//-
10.9	22.4	66.7	25.0	-//-
9.90	12.0	12.0	15.0	-//-
7.50	3.60	88.9	2.00	-//-
7.00	2.00	91.0	0.00	-//-
5.70	1.60	92.7	-4.00	$C_{10}H_{11}ClN_4$ + ice + HOOC-COOH·$NH_2C_2H_4OH$
5.00	1.60	93.4	-3.00	$C_{10}H_{11}ClN_4$ + ice
3.00	1.60	95.4	-2.00	-//-
	1.60	98.4	-1.90	-//-
10.0	0.40	89.6	3.00	HOOC-COOH ·$NH_2C_2H_4OH$ + ice
12.0	---	88.0	3.50	-//-

The polythermal solubility diagram of the system $CO(NH_2)_2$ - HOOC - $COOH \cdot NH_2C_2H_4OH$ - H_2O was constructed between - 11.2 and 61°C temperature using seven internal cuts and binary systems (Figure 2). Internal lines I-IV are directed from HOOC - $COOH \cdot NH_2C_2H_4OH$ side to the $CO(NH_2)_2$ side, and lines V-VII are directed to the HOOC - $COOH \cdot NH_2C_2H_4OH$ side from $CO(NH_2)_2$ side.

During the study of the system, the phase boundaries of ice, urea, monoethanolammonium oxalate, and ureamonoethanolammonium oxalate were identified in the diagram. In the diagram, all phases combine at two ternary point. In this case, the first ternary point corresponds to the temperature of - 16.0°C, the composition of the liquid phase is 16 % monoethanolammonium oxalate, 26 % urea and 58 % water, and this point is limited by the crystallization areas of urea, ureamonoethanolammonium oxalate and water.

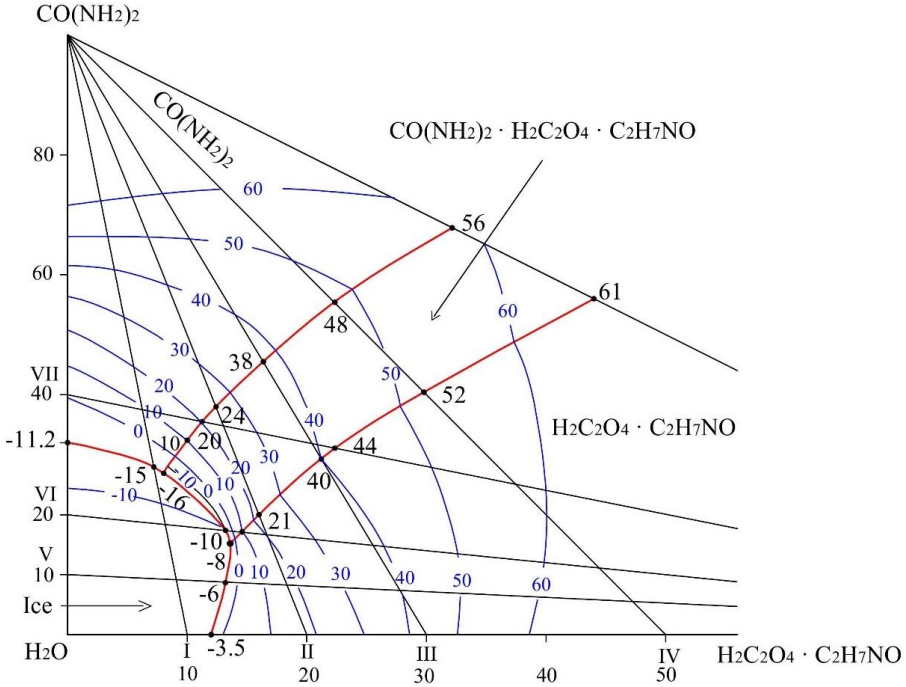

Figure 3. Solubility diagram of the system $CO(NH_2)_2$ - HOOC - $COOH \cdot NH_2C_2H_4OH$ - H_2O.

The next ternary point corresponds to 13.4 % monoethanolammonium oxalate, 14.6% urea and 82% water at a temperature of – 8 °C and consists of monoethanolammonium oxalate, ureamonoethanolammonium oxalate and water according to the composition of the solid phase.

The new phase formed in the diagram, ureamonoethanolammonium oxalate, was synthesized based on the solubility diagram, and its composition was determined using chemical and physical-chemical research methods.

Conclusion

HOOC-$COOH \cdot NH_2C_2H_4OH$ - [10% $C_{10}H_{11}ClN_4$ + 90%C_2H_5OH] – H_2O system belongs to the simple eutonic type, it was found that the components retain their individuality and no new chemical compounds are formed. $CO(NH_2)_2$ - HOOC - $COOH \cdot NH_2C_2H_4OH$ - H_2O polythermal solubility system was studied by the authors for the first time and a solubility diagram was constructed. The phase boundaries of the components were determined in the diagram and the composition of the new phase

ureamonoethanolammonium oxalate was analyzed by chemical and physicochemical methods. The scientific information obtained on the interaction of components in this system serves as the basis for the creation of the technology of obtaining physiologically active substances with insecticidal properties.

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NEURODIDACTIC APPROACHES TO UNDERSTANDING AND ENHANCING TEACHERS' PROFESSIONAL DEVELOPMENT

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Annotatsiya. Ushbu maqolada o‘qituvchilarning kasbiy o‘sish dinamikasi uzluksiz magistratura ta’limi doirasida ko‘rib chiqiladi. Neyrodidaktikaning — neyrobiologiya, psixologiya va pedagogikani birlashtiruvchi multidissiplinar sohaning — ahamiyati ortib borar ekan, miyadagi neyrofiziologik mexanizmlar bo‘yicha yangi tadqiqotlar muhim nazariy qarashlarni taqdim etmoqda. Ushbu natijalarni tahlil qilish, nazariy integratsiyasi va sintezi ularni qayta ko‘rib chiqish hamda o‘qituvchilarning kasbiy rivojlanish tizimini takomillashtirish uchun konseptual asos yaratadi.

Kalit so‘zlar: *Neyrodidaktika, professional o‘sish, neyrobiologiya, psixologiya, pedagogika, neyrofiziologik mexanizmlar, professional rivojlanish, ta’lim jarayoni.*

Аннотация. В данной статье рассматривается динамика профессионального роста учителей в контексте непрерывного послевузовского образования. С возрастанием значимости нейродидактики — междисциплинарной области, объединяющей нейробиологию, психологию и педагогику — новые исследования нейрофизиологических механизмов мозга предоставляют ценные перспективы. Анализ, теоретическая интеграция и синтез этих результатов формируют концептуальную основу для переосмысления и совершенствования системы профессионального развития учителей.

Ключевые слова: *Нейродидактика, профессиональный рост, нейробиология, психология, педагогика, нейрофизиологические механизмы, профессиональное развитие, образовательный процесс.*

Abstract. This paper examines the dynamics of teachers' professional growth within the context of ongoing postgraduate education. With the increasing prominence of neurodidactics—an interdisciplinary domain integrating neurobiology, psychology, and pedagogy—emerging findings on the brain's

neurophysiological mechanisms offer valuable perspectives. The analysis, theoretical integration, and synthesis of these findings provide a conceptual foundation for rethinking and enhancing the framework of teachers' professional development.

Keywords: *Neurodidactics, professional growth, neurobiology, psychology, pedagogy, neurophysiological mechanisms, professional development, educational process.*

Introduction

In contemporary scientific discourse, encompassing specialized and popular science literature, as well as international symposia and conferences, considerable attention is devoted to neurocognitive sciences. The number of publications presenting new findings on human brain functioning is rapidly increasing. Of particular interest to us, for evident reasons, are studies exploring the application of knowledge about the patterns and mechanisms of brain function to achieve specific didactic objectives, with a primary focus on works in the field of neurodidactics.

Promising research directions in neurodidactics include the following:
• Development of learning models that account for the lateral asymmetry of brain hemispheres;
• Validation of the effectiveness of gender-based learning based on neurophysiological studies of learners' brain functions;
• The influence of learners' psychodynamic and/or sensory-perceptual characteristics on a teacher's selection of specific, including individualized, teaching strategies;
• Consideration of the individual dynamics of psychological process development in the educational process;
• Alignment of neurotransmitter characteristics between learners and educators (Malsagov, Lezina, 2021).

The last of these directions directly intersects with our research interests, namely the investigation of the specifics of teachers' professional development. Contemporary scholars incorporate the management of the neurodidactic subsystem into the framework of teacher competency, associating this phenomenon—cleansed of accompanying "neuromyths" (Kostromina, Gnedykh, 2021)—with the psychological and pedagogical conditions that enhance the effectiveness of educational practices (Alekseeva, 2023). The primary motivations for teachers to acquire this competency may include the pursuit of prestige or self-affirmation, professional motivation expressed through a desire to integrate innovations into their practice, and the motivation for personal self-realization and self-actualization (Emets, 2022). Thus, mastering the theoretical foundations and practical outcomes of neurodidactic research, which are utilized in this study to elucidate the phenomenon of teachers' professional development, can itself serve as an effective tool for their professional growth.

Research Methodology

The theoretical foundation of the study is based on the core principles of the andragogical approach (S. I. Zmeev, E. A. Klimov, et al.), theories of professional development (N. S. Glukhanyuk, E. F. Zeer, L. M. Mitina, C. R. Rogers), as well as recent research in the fields of neurophysiology (Yu. D. Kropotov, T. V.

Chernigovskaya, I. Berkovich, R. A. Bjork, et al.) and neurodidactics (N. O. Verbitskaya, S. N. Kostromina, et al.).

The primary research methods employed include an analysis of scientific literature, with a search depth spanning 65 years across international and Russian scientometric databases, focusing on issues of neurodidactics and the neurophysiological aspects of teachers' professional development.

Analysis and Results

As a starting point for our discussion, let us consider the definition of the phenomenon of teachers' professional development. According to E. A. Klimov, it entails the continuous enhancement of professional competencies and personal qualities, striving toward their optimal integration—namely, professional-pedagogical mastery, which ensures the effective implementation of professional teaching activities (Klimov, 1996). A key element here is the issue of actualizing the process of professional development of the individual as such.

Soviet psychologist A.V. Petrovsky argued that the transition to a new stage of personal and professional development is externally determined by social factors, implying that it must be prepared within the preceding period (Petrovsky, 1984). Today, the prevailing perspective posits that the driving force behind the phenomenon of professional development is the principle of self-development (Mitina, 2021) or the "tendency toward self-actualization" (Rogers, 1959). It can be hypothesized that the process of professional development should be driven by the teacher through the identification of a certain dissatisfaction with the progression and effectiveness of their pedagogical work (Konovalov, 2024).

One of the challenges complicating the study of the phenomenon of professional development within the framework of postgraduate continuous education is the lack of clearly defined stages within the continuous education system. Glukhanyuk N.S. distinguishes the following stages of teacher professionalization based on the dominant type of activity:

- Academic-professional orientation, characterized by academic-professional or quasi-professional activities;
- Professional adaptation, during which psychological readiness for professional-pedagogical activity is formed, its initial implementation begins, and integration into new socio-professional groups occurs;
- Professional career and mastery attainment, during which an expansion of psychological knowledge about the interaction between the individual and the profession takes place (Glukhanyuk, 2005).

The most comprehensive periodization, which accounts for the specifics of professional-pedagogical growth, can be attributed to E.F. Zeer, who identifies the following stages in the continuous process of teachers' professional formation and development: professional potation; professional adaptation; primary professionalization; secondary professionalization; acmeprofessionalism (or professional mastery); and mentorship (Zeer, 2013).

Next, let us consider the periodization of adult age groups proposed by M.E. Vaindorf-Sysoeva and E.O. Vorobchikova (2023), which is based on the characteristics of

neurophysiological processes and structural changes in the brain during different periods of adulthood. The researchers categorize the first age group as learners aged 23–30 years, whose frontal lobe is fully developed, enabling reflection on life and professional experiences but often accompanied by heightened anxiety regarding their mistakes and professional deficiencies. The second group includes learners aged 31–45 years, who experience a slowdown in the speed of processing educational information due to partial loss of hypothalamic sensitivity.

Deterioration in memory, attention, and reaction speed, attributed to the complexity of occipital and temporal lobe functions, characterizes the third age group of adult learners (46–60 years). Finally, although significant cognitive decline is not observed in individuals over 61 years (the fourth group), memory capacity and verbal fluency decrease, and acquiring fundamentally new competencies becomes considerably more challenging, while learning applied (routine) tasks proceeds without significant effort.

It is crucial to highlight the following point. Until recently, it was believed that a critical brain property such as plasticity—the ability to form synaptic connections as a result of acquiring new cognitive knowledge and experience—diminishes with age. However, contemporary research findings confirm that plasticity, or the capacity for neurogenesis, is inherent to the human brain at any age. Consequently, at the stages of enhancing teachers' qualifications, this brain property (neuroplasticity) serves as an essential process supporting both personal and professional development.

In the process of adult education, several key brain properties significantly influence the effectiveness of perceiving, memorizing, and applying new information. Khramova M.V. and co-authors (2023), discussing the interplay between neuroscience and education, highlight the substantial benefits of understanding brain function patterns for designing and refining pedagogical conditions to enhance the educational process. Addressing the integration of neuroscience and the theory of lifelong learning, N. O. Verbitskaya (2022) identifies the following interrelated patterns:

• The necessity of continuous learning and professional development in postgraduate education is mediated by a fundamental brain property—neuroplasticity—which facilitates the restoration of lost synaptic connections through the acquisition of new, including cognitive, experiences.

• Emotions, motivation, stress, and multisensory stimuli serve as predictors of acquiring such experiences. Additionally, according to findings from Canadian researchers, emotional workloads independently impact teachers' well-being in terms of stress management (Zito et al., 2024). This underscores the critical importance of emotional-volitional regulation in educational activities, including for adults.

This list can be supplemented by the correlation between the use of language (as a leading role) in adult education through communication and the productivity or effectiveness of forming and developing higher mental functions during learning (Solovyova, 2018). E.F. Zeer (2021) elucidates the educational potential of neurodidactics in the context of personalized education, where the learner acts as an active subject in both the learning process and the selection of educational content directly relevant to addressing pressing personal, social, and professional challenges. This perspective aligns with the principles of the andragogical approach to education (Zmeev, 2015). Language, therefore, not only serves as the primary mode of

communication but also functions as the main tool of thought (Chernigovskaya et al., 2020).

Another critical neurophysiological aspect to consider in organizing education, including for adults, is memory—both short-term and long-term (Miller, 2015). Without delving into the specifics of neurophysiological processes, but noting the activation of sensory systems, enhanced responses at the hippocampal level, and increased amplitude of theta rhythms (Kropotov, 2010), it can be inferred that incorporating emotional context is essential for the memorization process.

Equally important is the cognitive flexibility of the teacher, another neurophysiological property of the brain that enables the teacher to regulate their own behavior and that of learners, adapt thinking to changes in the educational environment, and simultaneously consider various aspects of a pedagogical situation. This flexibility allows the application of diverse teaching approaches and methods, thereby enhancing the quality of education. This aspect is thoroughly explored in the context of teachers' educational activities in the work of A.V. Savchenkov and N.V. Uvarina (2019).

Finally, the overall neural activity of the brain contributes to improving the quality of the educational process and fostering better interactions with all participants in educational relationships, particularly learners. The prefrontal cortex, responsible for complex cognitive processes, and the temporal lobes, involved in processing verbal information and understanding social contexts, are activated during critical thinking (Kostromina, 2019). The subject of a teacher's analytical activity encompasses both the educational situation as a whole and their own behavior, thus involving the evaluation of their actions through pedagogical reflection. We concur with V.A. Chupina and O.A. Fedorenko (2019) that the procedural complexity of reflection serves as a condition for the development of a professional teacher and their progression to the level of creative activity.

The table below comprehensively presents the process of teachers' professional development, incorporating the neurodidactic perspective.

Table 1. The Process of Teachers' Professional Development with Consideration of the Neurodidactic Perspective.

Brain Property	Characteristic	Neurodidactic Commentary
Neuroplasticity	Although plasticity decreases with age, it remains sufficiently high to enable the brain to adapt to new conditions and learn. This property allows adults to acquire new skills, languages, and knowledge even after the primary period of brain development has concluded (Verbitskaya, 2022; Kostromina, 2019).	In addition to universal or metacognitive competencies, which are currently receiving significant emphasis, it is crucial for teachers to continuously update and deepen their knowledge in specific subject areas, as well as to develop and refine academic skills. This necessitates active engagement with new research, methodological materials, and technologies related to the taught subject or training profile.
Cognitive Flexibility	In adults, this skill may be more developed than in children due to accumulated experience and the	Educators must be prepared to adopt and apply rapidly evolving modern educational technologies,

Brain Property	Characteristic	Neurodidactic Commentary
	ability to quickly assess situations. In the learning process, cognitive flexibility facilitates faster problem-solving of complex tasks and the selection of the most effective strategies for assimilating new material (Savchenkov, Uvarina, 2019; Khramova, 2023).	including digital ones, in their professional and pedagogical practice. Cognitive flexibility contributes to the enhancement of pedagogical creativity, particularly in combining various ideas and implementing them in educational contexts
Working memory	Plays a key role in learning, as it allows for maintaining attention on new material and linking it with existing knowledge. With age, the capacity of working memory may decline, but training can help maintain a high level of efficiency (Miller, Buschman, 2015; Kropotov, 2010).	Working memory helps the teacher, especially during a lesson, to simultaneously manage several elements of the educational process (conducting the lesson itself, maintaining discipline, responding to questions) and to promptly react to changes (adjusting the course of the lesson and selecting methods based on students' responses).
Long-term memory	In the learning process, it is important that new information is transferred from short-term memory to long-term memory, where it will be available for future use. Adults can utilize their life experience and previously acquired knowledge to better consolidate new information (Kropotov, 2010; Kostromina, 2019).	Teachers need to retain a large volume of information. This includes not only knowledge from their subject (disciplinary) field, but also theories, pedagogical concepts and methods of teaching and upbringing, as well as individual characteristics of students, colleagues, and more.
Emotions and Motivation. Stress Management	Positive emotions contribute to better perception and retention of information, while high motivation helps maintain interest in learning and overcome difficulties. Adults often have clearly defined goals and motives, which makes the learning process more purposeful (Verbitskaya, 2022; S. Zito et al., 2024).	The teaching profession, being socio-nomic in nature (type “human–human”), is associated with a high level of stress. The ability to cope with emotional pressure, maintain calmness and concentration is an essential quality for a teacher. Effective stress management helps prevent burnout and sustain high productivity in professional and pedagogical activities.
Speech Function (Communication Skills)	Effective communication is the foundation of successful professional and pedagogical activity. Teachers need to be able to explain material clearly and accessibly, listen to and understand their students, and provide constructive feedback. (Zeer, 2021; Solovyova, 2018; Chernigovskaya et al., 2020)	Improving communication skills helps teachers interact more effectively with students, colleagues, and parents. A teacher must also be able to collaborate, participate in joint projects, share experiences, and adopt best practices. Moreover, in the process of professional development, a teacher often needs a teacher as well. One-on-one learning with an

Brain Property	Characteristic	Neurodidactic Commentary
		online course today raises many concerns and cannot be used as the sole tool.
Critical Thinking. Reflection and Self-Regulation	The ability to analyze one's progress, adjust learning methods, and manage emotions is a crucial aspect of successfully acquiring new knowledge. Adults find it easier to reflect on their experiences and make changes to their learning strategies based on their needs and goals (Karpov & Karpov, 2022; Kostromina, 2019; Chupina & Fedorenko, 2019; Bjork et al., 2012).	For teachers, critical thinking is essential for evaluating curricula and syllabi, selecting teaching methods and pedagogical technologies, as well as educational resources, including digital ones. In the process of analyzing their own teaching practices and seeking ways to improve, teachers develop self-analysis skills, enhance their readiness for objective evaluation of their successes and failures, and make necessary adjustments to their work.
Social Context – Empathy and Social Intuition	Learning occurs not only individually, but also within a social context. Adults can learn through interaction with others—exchanging ideas, discussing complex issues, and receiving feedback. Social connections also help provide emotional support and motivation (Zeer, 2021; Zmeev, 2015; Berkovich, 2018).	For teachers, empathy—the ability to understand and share the feelings of learners—is of great importance, as they work with diverse students, each with unique needs and experiences. Through professional development, teachers enhance their ability to recognize students' emotional states, which helps them interact more effectively and improve the learning process.

As a result of the analysis of the teacher's professional development process from the standpoint of andragogy, as well as considering the neurophysiological characteristics of brain function, the following directions for enhancing professional and pedagogical qualifications can be formulated:

1. Updating academic knowledge in the subject (specialized) area, including regular participation in scientific and methodological seminars, conferences, and webinars dedicated to the latest research and developments in the taught subject or related fields of professional activity (educational, methodological, etc.).

2. Mastering modern educational technologies and integrating them into professional pedagogical practice, including through professional development courses—not only in the format of online learning, but primarily through traditional, face-to-face formats that involve pedagogical communication and exchange of experience with colleagues, thereby also enhancing communication skills.

3. Developing cognitive flexibility and creative thinking by participating in various workshops and training sessions.

4. Developing critical thinking, empathy, and emotional intelligence through various reflective methodologies (such as the analysis of educational situations, solving didactic cases, polylogue, didactic games, and more).

5. Enhancing working memory and increasing long-term memory capacity, including through maintaining a healthy lifestyle that incorporates physical activity and a balanced diet.

Conclusion

The process of professional development for a teacher—as the most prominent representative of a socio-nomic profession—is complex and encompasses all key aspects of professional activity. The analysis of this process through the lens of neurodidactics has made it possible to identify several areas in which teachers' professional qualifications should be enhanced. An important place in this development process is occupied not only (and perhaps not primarily) by the advancement of academic skills, but also by personal growth and the development of universal or metacognitive competencies. Future research should focus on the development of a scientific pedagogical framework for supporting the professional development of educators. Such a framework would enable the design and implementation of targeted and well-grounded initiatives—also from the perspective of neurodidactics—aimed at improving the qualifications of teachers in areas most relevant to their professional needs.

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PSYCHOPEDAGOGICAL APPROACHES TO FORMING SOCIAL COMPETENCE AND COMMUNICATION SKILLS FOR IT PROFESSIONALS IN THE ENVIRONMENT OF DIGITAL EDUCATION

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Annotatsiya. Ushbu maqola raqamli ta’lim kontekstida axborot texnologiyalari (AT) mutaxassislari o‘rtasida ijtimoiy kompetentsiyani, xususan, aloqa ko‘nikmalarini rivojlantirish zarurligini ko‘rib chiqadi. Tadqiqot ushbu ko‘nikmalarni rivojlantirishda psixo-pedagogik yondashuvlarning rolini ta’kidlaydi. Aralash metodli tadqiqot natijalari shuni ko‘rsatdiki, diagnostika testlari, o‘quv mashg‘ulotlari va interfaol texnikalar IT mutaxassislari o‘rtasida onlayn muloqot, jamoada ishlash va empatiya kabi yumshoq ko‘nikmalarni sezilarli darajada yaxshilagan. Psixologik va pedagogik usullarning integratsiyasi zamonaviy raqamli muhitda kasbiy tayyorgarlik va o‘qitish samaradorligini oshirishning samarali omili sifatida e’tirof etildi.

Kalit so‘zlar: *Raqamli ta’lim, AT mutaxassislari, ijtimoiy kompetentsiya, muloqot qobiliyatlari, psixo-pedagogik yondashuv, yumshoq ko‘nikmalar, masofaviy ta’lim, jamoaviy ish, hissiy intellekt, onlayn muloqot.*

Аннотация. В данной статье рассматривается необходимость развития социальной компетентности, в частности коммуникативных навыков, у специалистов в области информационных технологий (ИТ) в контексте цифрового образования. В исследовании подчеркивается роль психолого-педагогических подходов в развитии этих навыков. Результаты исследования, проведенного с использованием смешанных методов, показывают, что диагностические тесты, тренинги и интерактивные методики значительно улучшили такие гибкие навыки, как онлайн-коммуникация, командная работа и эмпатия, у ИТ-специалистов. Интеграция психолого-педагогических методов признана эффективным фактором повышения эффективности профессиональной подготовки и преподавания в современной цифровой среде.

Ключевые слова: *Цифровое образование, ИТ-специалисты, социальная компетентность, коммуникативные навыки, психолого-педагогический подход, гибкие навыки, дистанционное обучение, командная работа, эмоциональный интеллект, онлайн-коммуникация.*

Abstract. This article examines the necessity of developing social competence, particularly communication skills, among information technology (IT) professionals in the context of digital education. The research highlights the role of psycho-pedagogical approaches in fostering these skills. The results of a mixed-method study reveal that diagnostic tests, training sessions, and interactive techniques significantly improved soft skills such as online communication, teamwork, and empathy among IT specialists. The integration of psychological

and pedagogical methods has been recognized as an effective factor in enhancing professional training and teaching efficiency in modern digital environments.

Keywords: *Digital education, IT professionals, social competence, communication skills, psycho-pedagogical approach, soft skills, distance learning, teamwork, emotional intelligence, online communication.*

Introduction

Modern information - communication technologies intense development digital education system formation and to the expansion ground created. Especially, information in the field of information technology (IT) activity running experts for digital in the environment effective communication to do, team with work and social competence manifestation to grow necessity sharp increasing is going on. Because technician knowledge and skills has to be with together, digital collaboration, remote collective in projects participation to grow and communicative problems solution enough to take such as soft skills (soft skills) today on the day IT field of experts professional in success important to the factor has become [1]. This in the article digital education under the circumstances IT field representatives social competence, especially communicative skills formation necessity and this in process psychopedagogical approaches caught place analysis Psychopedagogical approaches, that is psychology and pedagogy sectors intersected on point formed scientific - practical methods, interpersonal relationships develop oneself understanding and others with effective communication installation opportunity gives.

The research main purpose - IT field experts digital education in the context of communicative in terms of support, their social competence in formation effective psychopedagogical approaches determination and from justification consists of. This topic not only professional education quality to increase, maybe digital economy under the circumstances competitive experts to prepare also service does.

Literature Review

In recent years, the rapid development of digital educational technologies has made the development of professional competencies, in particular soft skills, an integral part of educational strategies. International and local research shows that, along with technical knowledge, social competence and communicative skills play an important role in the activities of IT professionals (Robles, 2012; Sidorova et al., 2019) [2].

Social competence in psychology includes such qualities of a person as establishing effective and positive relationships with other people, working in a group, empathy, and expressing one's thoughts clearly (Goleman, 1995; Bar-On, 2006) [3]. For IT professionals, these skills are of incomparable importance in the processes of remote collaboration, communication with customers, and participation in team projects.

Psychopedagogical approaches are understood as the harmonious use of psychological and pedagogical methods in the upbringing and teaching of the individual. These approaches are aimed at developing students' competencies such as self-awareness, expressing their own opinions, understanding social roles, and overcoming barriers in communication (Vygotsky, 1978; Rogers, 1983) [4]. For example, cooperative learning**,** interactive training**,** problem-based learning (PBL), and methods aimed at developing emotional intelligence are among the effective

psychopedagogical approaches. These approaches are particularly important in a digital learning environment, where students may be deprived of face-to-face interaction in distance learning settings. Research suggests that digital platforms can foster a culture of communication through the inclusion of social-emotional learning elements, virtual team assignments, and online discussion forums (Anderson, 2008; Hrastinski, 2009) [5]. Also, advanced methodologies aimed at developing personal and social skills, along with digital competencies, are being introduced in the higher education system of Uzbekistan. In particular, special attention is paid to the development of communicative competence in bachelor's and master's degree programs in the field of ICT (Resolution of the President of the Republic of Uzbekistan № PQ-4954, 2021) [1].

The literature review shows that psychopedagogical approaches to effectively developing social competence and communicative skills in the IT field in digital learning environments have an important scientific and theoretical basis. These approaches directly affect not only personal development, but also the effectiveness of professional activities.

Research Methodology

Our research was conducted to determine the effectiveness of psychopedagogical approaches in developing social competence and communicative skills for IT professionals in digital learning environments [6]. The research used a mixed methodology, that is, a combination of qualitative and quantitative approaches.

Represent the research methodology in a model, we present the following table:

1	Research object	Studying in IT field	University students
			Digital learning platform participants
			Current IT professionals
2	Research subject	The content and effectiveness of psychopedagogical approaches in the formation of social competence and communicative skills in digital education	
3	Research participants	90 respondents	30 university IT students
			30 digital learning platform users
			30 IT professionals (remote and office-based)
4	Research methods	Questionnaire (closed/open questions)	Interview (semi-structured)
		Diagnostic tests (Bar-On EQ, communication, teamwork)	Experimental sessions (training and seminars)
5	Experiment object	Tashkent universities	Online platforms (Coursera, Udemy, Programming Schools)
6	Experiment stages	Initial diagnosis – determination of baseline indicators	
		Impact stage – conducting training and exercises	
		Final diagnosis – identification of final changes	
7	Methods for analyzing results	Quantitative analysis	percentages, averages, T-test
		Qualitative analysis	thematic analysis, content analysis

Analysis and Results

The study analyzed the effectiveness of psychopedagogical approaches in developing social competence and communicative skills of IT professionals in digital learning environments. A total of 90 participants were involved in the study - students of higher education institutions (HEIs), independent learners studying on digital platforms, and current IT professionals.

The results of the study were analyzed by grouping as follows:

1. Initial diagnostic results. In the initial stage, the level of social competence and communicative skills of the respondents was assessed as follows:

Average rating results (on a 5-point scale):

- For university students – 2.9 points
- Independent learners on a digital platform – 2.6 points
- In practical IT specialists – 3.2 points

The assessment results showed that while all groups had high technical knowledge, their communication and social skills were low to moderate. It was found that professionals working remotely, in particular, had problems with interpersonal communication.

2. Results of the experimental phase (intervention). Training and seminar sessions (8-week program) based on psychopedagogical approaches were organized in the following areas: teamwork and role- playing games; virtual group projects; emotional intelligence exercises (based on Bar-On EQ); online problem-solving exercises.

Results of the re-diagnostics after training:

- University students – average score 4.1
- Digital platform readers – 3.9
- IT professionals – 4.3

These results indicate a significant increase in the participants' communicative skills and social competence. Qualitative analysis based on interviews and open-ended questions also showed that the participants: to express one's opinion clearly; integration into online teamwork; who have noticed improvements in listening skills and empathy.

3. Qualitative analysis results (Based on interviews and observation). Many participants reported that during the trainings they learned to express themselves freely and began to actively participate in situations where they were previously shy or passive. Communication skills in digital environments have grown significantly, especially in online presentations and group forums. IT professionals noted that collaboration efficiency at work increased after the training.

4. Quantitative analysis results (statistical calculation). T-test results (difference between pre- and post-training scores):

- $p < 0.05$ – meaning the changes are statistically significant.

Skills growth:

- 41% increase in university students.
- Digital learners – 50% increase.
- IT professionals – 34% growth.

Conclusion

The modern education system, especially the transition to a digital environment, has made it necessary for specialists working in the field of information technology to have not only technical knowledge, but also a high level of social competence and developed communicative skills. Such activities as working in digital teams, remote communication, and teamwork on online platforms have become professional tasks of today's IT specialist. In such conditions, communicative and social competencies formed on the basis of psycho-pedagogical approaches serve as an important factor ensuring the professional success of representatives of the IT sector.

The results of the study showed that in the context of digital education, an integrated approach is required to effectively develop communicative skills and social competence in IT professionals [7]. In particular, psychopedagogical approaches that combine psychological and pedagogical methods, such as diagnostic tests, training sessions, interactive methods, and experimental training based on person-centered communication, have yielded positive results.

As part of the study, the communicative and social competencies of 90 participants (higher education students, independent learners, and practical specialists) were diagnosed. The results of the experiment showed that after trainings organized on the basis of psychopedagogical approaches, a significant increase in these skills was observed. In particular, positive changes were noted in such components as teamwork, empathy, clear expression of thoughts, and online communication culture.

The study also found that approaches that address the socio-emotional needs of students and professionals in digital learning environments increase their self-confidence and encourage active communication even in remote environments. This not only improves the effectiveness of the learning process, but also increases productivity in real professional environments.

In general, the following main conclusions were reached based on the research: the formation of communicative and social competence of IT specialists in digital education is of strategic importance in their professional development; psychopedagogical approaches are highly effective in developing personal and collective competencies in digital learning; experimental training, showed positive dynamics and proved the practical value of this methodology.

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TEACHING PROFESSIONAL FOREIGN LANGUAGE TO STUDENTS IN THE FIELD OF FOOD TECHNOLOGY

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Annotatsiya. Zamonaviy dunyoda oziq-ovqat sanoati tez rivojlanayotgan va globallashtiruvchi soha hisoblanadi. Shu sababli, oziq-ovqat texnologiyasi mutaxassislari xorijiy tillarni, xususan ingliz tilini yaxshi bilishlari zarur. Bu esa o‘z navbatida, ta'lim tizimida yangi pedagogik yondashuvlar va innovatsion o‘qitish texnologiyalarini joriy etishni talab qiladi. Talabalar kasbiy faoliyatlari davomida xorijiy tilni bilish orqali xalqaro standartlarga mos keluvchi bilim va ko‘nikmalarga ega bo‘lishlari lozim. Oziq-ovqat texnologiyasi sohasida talabalarning kasbiy tilni o‘rganish jarayoni ko‘plab omillarga bog‘liq: o‘quv materiallari sifatiga, o‘qituvchilarning malakasiga va ta’lim muassasasining infratuzilmasiga. Ushbu maqolada oziq-ovqat texnologiyasi yo‘nalishida tahsil oluvchi talabalar uchun xorijiy tilni o‘qitishning samarali usullari va metodologiyalari tahlil qilinadi.

Kalit so‘zlar: *oziq-ovqat texnologiyasi, kasbiy xorijiy til, o‘qitish texnologiyalari, fanlararo bog‘liqlik, kommunikativ kompetentlik, interaktiv metodlar, multimedia, loyihalash, simulatsiya va rol o‘ynash, aralash o‘qitish modeli, VR va AR texnologiyalari*

Аннотация. В современном мире пищевая промышленность является быстро развивающейся и глобализирующейся сферой. Поэтому специалистам в области пищевых технологий необходимо хорошо владеть иностранными языками, особенно английским. Это, в свою очередь, требует внедрения новых педагогических подходов и инновационных технологий обучения в образовательную систему. Студенты должны обладать знаниями и навыками, соответствующими международным стандартам, через знание иностранного языка в процессе своей профессиональной деятельности. Процесс изучения профессионального языка студентами в области пищевых технологий зависит от множества факторов: качества учебных материалов, квалификации преподавателей и инфраструктуры образовательного учреждения. В данной статье анализируются эффективные методы и методологии преподавания иностранного языка для студентов, обучающихся по направлению пищевых технологий.

Ключевые слова: *пищевая технология, профессиональный иностранный язык, технологии обучения, междисциплинарная связь, коммуникативная компетентность, интерактивные методы, мультимедиа, проектирование, моделирование и ролевые игры, смешанная модель обучения, технологии VR и AR.*

Abstract. In the modern world, the food industry is a rapidly developing and globalizing sector. Therefore, food technology specialists need to have a good command of foreign languages, particularly English. This, in turn, requires the introduction of new pedagogical approaches and innovative teaching technologies in the education system. Students must acquire knowledge and skills that meet international standards through their knowledge of foreign languages during their professional activities. The process of learning a professional language in the field of food technology depends on many factors: the quality of educational materials, the qualifications of teachers, and the infrastructure of educational institutions. This article analyzes effective methods and methodologies for teaching foreign languages to students majoring in food technology.

Keywords: *Food technology, professional foreign language, teaching technologies, interdisciplinary connections, communicative competence, interactive methods, multimedia, project-based learning, simulation and role-playing, blended learning model, VR and AR technologies.*

Introduction

The 21st century is characterized by the rapid development of the food industry and the expansion of international cooperation. In conditions of globalization, food technology specialists are required not only to have deep professional knowledge but also to be proficient in foreign languages, especially English. Since international companies, technological innovations, and scientific research are primarily conducted in English, language proficiency is a decisive factor in the professional development of specialists. Developing the professional foreign language competencies of students in the field of food technology is one of the priority tasks of the modern education system. Traditional language teaching methods today do not fully meet professional needs, as they often focus on general language skills and do not adequately cover specialized terminology and professional context. The approach of teaching English for Specific Purposes (ESP) is aimed at developing students' language skills relevant to their fields. This approach assists food technology students in reading technical documents, participating in international conferences, communicating with foreign colleagues, and conducting scientific research. The development of modern educational technologies creates new opportunities for teaching professional foreign languages. Virtual reality, artificial intelligence, mobile applications, and multimedia resources make the teaching process more effective and engaging.

Literature Review

The issues of teaching professional foreign languages have been studied by many foreign and local researchers. Their research mainly focuses on teaching methodologies, educational materials, interactive methods, and the application of modern technologies in the educational process. The importance of learning a foreign language in a professional context, specially designed programs and curricula for students, as well as the challenges that arise in the language learning process, have also been investigated. Many researchers emphasize the effectiveness of applying an interdisciplinary approach in teaching foreign languages. According to P.C. Robinson,

the interdisciplinary approach not only facilitates language learning but also deepens professional knowledge [1].

According to F. Stoller, the interdisciplinary approach in language teaching aims to ensure the unity of language and content, directing the learning process towards contextual understanding [2]. In J. Biggs's interpretation, "Interdisciplinary integration in the educational process helps students engage in deep learning and develop professional skills" [3]. M. Jo'rayev also presents the interdisciplinary approach in teaching professional English as an effective method that allows the application of language in real professional situations. According to him, interdisciplinary integration plays a crucial role in preparing students for a professional environment [4].

A.D. Zubkov notes that interdisciplinary connections represent the concept of the integrity of knowledge that allows students to transfer the knowledge, skills, and competencies acquired in one subject to other subjects during the teaching process. In this process, students can expand their learning experiences, understand the connections between various subjects, and have the opportunity to apply their knowledge in practice [5]. D. Karimova emphasizes that by teaching professional subjects alongside language in ESP (English for Specific Purposes) classes, students are prepared for communication and assimilate the language in a practical context [6]. D. Isroilova also believes that based on her research, teaching professional foreign languages with consideration of the specific aspects of the specialty should be directed according to the following strategies [7]:

- Working with specialized texts;
- Developing communicative competence;
- Teaching new vocational terminology;
- Working on educational materials related to actively applying grammar and lexical materials.

Thus, ensuring interdisciplinary connections while providing education in professional foreign languages in non-philological fields yields effective results when selecting authentic materials relevant to professional activities. It is advisable for teachers to use effective strategies and methods to teach terminology related to the field in order to develop high knowledge and skills among students in the food technology discipline.

Research Methodology

Using various pedagogical technologies and modern teaching methods in the classroom helps facilitate the quick understanding of new material. Today, the application of innovative approaches and methods in the education system enhances student motivation and expands their opportunities for self-development. The use of modern pedagogical technologies by teachers makes lessons more engaging and interactive, ensuring active participation from students. Additionally, different teaching methods take into account the individual needs of each student, personalizing the learning process and enabling deeper knowledge acquisition. In this way, modern educational methods not only provide knowledge but also prepare students for critical thinking, creativity, and problem-solving skills.

M. Jo‘rayev’s views on the interdisciplinary approach to teaching professional English hold significant importance in the modern educational process. The interdisciplinary approach is recognized as an effective method that allows students to see connections between various subjects and apply them in real professional situations. The main methods of this approach include:

1. Project work	Students can work on projects related to food products or restaurants. For example, they might develop a project for creating a new menu or marketing food products. In this process, they communicate in English while solving professional tasks.
2. Simulation and role-playing	By simulating situations in the food sector, students prepare for real-life scenarios such as restaurant environments or food events. For instance, they might role-play discussions with customers about food choices or restaurant services.
3. Problem solving	Assigning tasks to students that require them to solve problems in the food industry. For example, conducting research on food safety or sustainability issues allows them to practice thinking and communicating in English.
4. Interdisciplinary activities:	Learning by integrating knowledge from various fields such as food technology, nutrition, marketing, and economics. This teaches students to think in a broader context within the food sector and to apply language in various domains.
5. Group work	Students can collaborate in groups to analyze food products or develop new recipes, exchanging ideas with one another. In this process, they communicate in English and develop teamwork skills.
6. Use of technology	Making the process of learning English engaging and effective through online platforms, video lessons, and interactive materials related to the food field. For example, watching video tutorials on food preparation.
7. Research	Engaging students in research related to the food industry. They can conduct scientific analyses and investigations on topics such as food safety, healthy eating, or sustainability.

Through these methods, students in the food field not only learn English but also prepare for a professional environment. The interdisciplinary connection emphasizes the unique significance of studying individual subjects in the educational process since this approach helps deepen knowledge within each subject while also understanding their interrelations and interactions [8].

Blended Learning Model. The blended learning model incorporates traditional classroom activities along with online lessons. This approach is crucial for enhancing the effectiveness of education in the field of food technology and equipping students with modern knowledge. Classes conducted through platforms like Moodle, Google Classroom, and Coursera enable students to independently develop their knowledge, use their time outside of class effectively, and automate the assessment system. [9]

1. Independent work:

In the field of food technology, students have the opportunity to work independently through online platforms. For example:

• Video tutorials: Students can watch video tutorials on processes of food product preparation, their chemical composition, and quality control. This allows them to learn at their own pace and convenience.

• Interactive quizzes: Students can use interactive quizzes to assess their acquired knowledge independently. These quizzes help in mastering the terminology and key concepts of food technology.

2. Effective use of extracurricular time:

The blended learning model creates opportunities for effective use of extracurricular time:

• Reviewing: Students can revisit the material learned in class on online platforms. This is especially useful for complex processes or topics that are difficult to understand.

• Research projects: Students can independently conduct research projects in the field of food technology and present their findings on online platforms. This helps them develop practical skills.

3. Automation of the assessment system:

Online platforms allow for the automation of the assessment process:

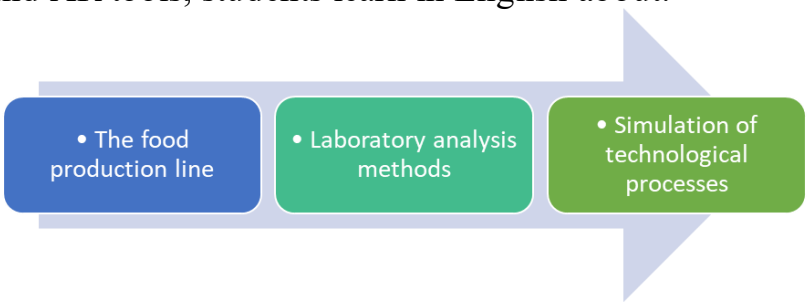
• Automatic grading: Tests and assignments completed by students are graded automatically, helping teachers save time and providing students with quick feedback.

• Statistical analysis: There is the possibility to monitor student performance and conduct statistical analysis through online platforms. This allows teachers to assess each student individually and provide necessary support.

The blended learning model plays a significant role in equipping students in the field of food technology with modern knowledge, developing practical skills, and making the educational process more effective. By utilizing online platforms, students can independently expand their knowledge, organize their extracurricular time effectively, and make the assessment process more convenient. This approach offers innovative solutions for preparing future specialists in the field of food technology.

Virtual Reality (VR) and Augmented Reality (AR) technologies:

Through VR and AR tools, students learn in English about:



Virtual Reality (VR) and Augmented Reality (AR) technologies provide innovative approaches in food technology education. With these technologies, students have the opportunity to simulate the food production line, laboratory analysis methods, and technological processes. This not only expands their knowledge but also helps them understand industry terminology visually. As a result, students are equipped with modern knowledge and practical skills, preparing them for successful careers as future specialists [10].

Conclusion

The process of teaching a foreign language for specific purposes is of great importance for students studying in the field of food technology, as confirmed by the results of this research. The application of modern pedagogical technologies and

interactive methods makes the knowledge acquisition process more effective for students. Specially designed curricula and materials play a crucial role in developing their professional skills. Therefore, the widespread implementation of new methods for teaching foreign languages in higher education is a significant factor in preparing competitive and modern specialists.

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LINGUISTIC CHARACTERISTICS AND TRANSLATION APPROACHES OF UZBEK PHRASEOLOGICAL UNITS

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Annotatsiya. Frazeologik birliklar har bir tilning muhim tarkibiy qismi bo'lib, ular nutqni obrazli, ifodali va madaniy jihatdan boyitadi. Ushbu maqolada o'zbek tilidagi frazeologik birliklarning umumiy nazariy tushunchalardan tortib, o'zbek frazeologiyasining o'ziga xos lingvistik va madaniy xususiyatlarigacha bo'lgan jihatlari yoritilgan. O'zbek tilshunoslik tadqiqotlariga asoslanib, maqolada o'zbek frazeologiyasi ma'no va vazifasiga ko'ra tasniflanadi, hamda o'zbek xalqining urf-odatlarini aks ettirishdagi muhim roli aks etgan. Shuningdek, maqolada o'zbek tilidagi turg'un birliklarning boshqa tillarga, xususan ingliz tiliga tarjima qilishdagi ayrim muommolar ham ko'rib chiqiladi.

Kalit so'zlar: *frazeologik birliklar, so'z birikmalari, ko'chma ma'no, tushunchalar, tarjima.*

Аннотация. В данной статье рассматриваются фразеологические единицы как важные компоненты любого языка, которые обогащают коммуникацию за счет образного, экспрессивного и культурно нагруженного значения. Анализируется природа фразеологических единиц в узбекском языке — от общетеоретических концепций до специфических лингвистических и культурных особенностей узбекской фразеологии. В исследовании рассматривается классификация узбекской фразеологии на основе её семантических и функциональных характеристик, а также прослеживаются её истоки и подчеркивается её роль в отражении культурных и традиционных ценностей узбекского народа. Дополнительно исследуются трудности, связанные с переводом узбекских идиоматических выражений на другие языки, в частности на английский.

Ключевые слова: *фразеологические единицы, словосочетания, переносное значение, концепты, перевод.*

Abstract. This article discusses the phraseological units as important components of each language that enrich communication through figurative, expressive, and culturally loaded meanings. It explores the nature of phraseological units in the Uzbek language from general theoretical concepts to the specific linguistic and cultural features of Uzbek phraseology. This study examines the classification of Uzbek phraseology based on its semantic and functional features, while also tracing its origins and emphasizing its importance in reflecting the cultural and traditional values of the Uzbek people. The research

further explores the challenges associated with translating Uzbek idiomatic expressions into other languages, with particular focus on English.

Keywords: *phraseological units, word combinations, figurative meaning, concepts, translation.*

Introduction

Phraseological units are conventionalized multi-word expressions that function as single semantic entities within a language. These units include idioms, proverbs, clichés, and other fixed or semi-fixed phrases that often carry meanings not deducible from the individual words composing them. Their study is crucial for understanding language complexity, figurative language, and cultural specificity. Phraseological units enrich communication by conveying emotions, attitudes, and culturally nuanced concepts, thereby extending beyond the referential scope of literal language.

Literature Review

The phraseological units present in our speech are stable word combinations that play an important role in enhancing communication by adding imagery and emotional depth to the speech process. Although phraseological research has long been established in Western and Russian linguistics, interest in the scientific study of Uzbek phraseological units emerged after our country gained independence, as part of efforts aimed at preserving linguistic and cultural identity. Mamatov A.E. (2019) noted that phraseological units reflect national culture through their prototypes, as free word combinations that have become fixed expressions often depict certain customs, traditions, details of everyday life and culture, historical events, and many other objects and phenomena [1]. For example, expressions such as *qosh quyaman deb ko‘z chiqarmoq* (to make something worse while trying to improve it), *hovuridan tushmoq* (to calm down), and *kovushini tog‘irlab quymoq* (to leave quietly/avoid responsibility) are phraseological units. As a linguistic phenomenon, a phraseologism is a unit related to both language and speech. It is formed by the combination of more than one independent lexeme and represents a linguistic unit with an imaginative and figurative semantic nature [2].

In phraseology, there are two important aspects: the object of expression and the object of content, both of which are of great significance. The object of expression studies the material side of phraseological units, i.e., their structure, form, and lexical-phonetic composition, while the plane of content analyzes their semantic components that convey stylistic coloring. The object of expression refers to the sound form, lexical structure, and construction equivalent to a phrase or sentence, whereas the plane of content refers to its denotative meaning and what it expresses or signifies. For instance, in the phrase *og‘zi-qulog‘ida* (“mouth to ear”), the object of content expresses the meaning “to be very happy” [3].

Research Methodology

Translating phraseological units poses significant challenges due to their semantic capacity and cultural specificity. Direct, literal translation typically fails to capture the intended meaning and stylistic effect. Translators must employ strategies such as finding functional equivalents, paraphrasing, or adapting cultural references to the

target audience. There are several approaches and methods to translate the context meaningfully such as full equivalent, partial equivalent, contextual, situational, and literal translation. Based on the object of research, they can be opted for translation.

Uzbek phraseological units possess figurative meanings and culturally specific features, which often cause numerous challenges when translating them from one language to another. In other words, finding their exact equivalents can be quite difficult. Therefore, using a literal translation is generally not advisable when dealing with such units. This is because every fixed expression is the product of a particular nation's social and cultural way of life.

Bakieva M. (2022) explains this national colorfulness as follows: when studying phraseological units, it is essential to approach them from the perspective of Uzbek national culture, national color, and lifestyle. Issues such as their linguo-cultural and cognitive interpretation belong to the most pressing problems in modern linguistics, and for this reason, the topic remains consistently relevant (p. 651).

Based on the above, it can be said that in translating fixed expressions, it is necessary to pay attention to the original text while also capturing the national values and cultural uniqueness of the people. Otherwise, such units may lose their expressiveness and intended meaning during the translation process. Therefore, this process requires translators to study the beliefs and traditions related to the spiritual and cultural life of each nation.

An effective translation often requires either finding equivalent idioms or using explanatory paraphrasing, depending on the context and target audience. For example, in Uzbek phraseology, the expression "*qo'li uzun odam*" loses its meaning if it is translated literally as "*a person with a long hand*." In English, there is the equivalent "*Jack of all trades*," but this unit usually carries only a negative connotation. Therefore, if the intended meaning in context is positive, it would be more appropriate to use the English idiom "*can move mountains."*

Analysis and Results

Uzbek phraseological units, according to their degree of imagery and grammatical function, have been classified into several groups by various linguists. Some scholars divide them into three groups, while others classify them into four or more groups. However, among these, the classification that divides and defines these units into three groups is the most commonly encountered.

Phraseological units exhibit several defining features. First, their lexical and syntactic fixedness ranges from completely fixed (e.g., idioms) to partially variable (e.g., collocations). Second, semantic opacity varies: some units possess transparent meanings, while others are entirely idiomatic and non-compositional. Third, these units often involve metaphorical or metonymic mechanisms, linking linguistic form to cognitive and cultural patterns.

Uzbek phraseological units may be categorized according to the semantic content and meanings they express.

1. **Phraseological fusions** (Frazeologik chatishmalar) — idiomatic fixed expressions in which the words within the fusion are not related to the literal meaning of the phrase. The overall meaning of the phrase is revealed based on the figurative

meaning it conveys. For example: "*temirni qizig'ida bosmoq*" ("to take action at the right moment"), "*tegirmonga tushsa butun chiqmoq*" ("to remain unharmed in a difficult situation"), "*boshi ko'kka yetmoq*" ("to be extremely happy") — in these expressions, the meanings of the individual words are not connected to the meaning understood from the fixed phrase.

2. **Phraseological unities** (Frazeologik birlashmalar) — in these unities, one word is used in its literal meaning while another is interpreted figuratively. For example, "*ko'zini ochmoq*" can mean "*to open one's eyes*" in the literal sense, but its actual figurative meaning is equivalent to "*to realize or understand something*."

3. **Phraseological combinations** (Frazeologik birikmalar) — in most cases, the meanings and grammatical features of the words in these combinations merge and are used in a figurative sense. For example, "*achchiq so'z aytmoq*" means "*to insult someone with harsh words*." The expression "*tishini oqini ko'rsatmoq*" conveys the meaning of "*to smile or grin*" in a negative or sarcastic sense.

Other examples include: *"hayot yo'li*" — lifestyle, "*yuragi keng*" — generous, "*oq suyak*" — a noble person

According to the function of phraseological units in a sentence, they can be classified into several types.

Nominal units — the characteristics of a noun are expressed through other parts of speech, and the main emphasis depends on how the subject is named. For example:

- "*O'q yutgan odam*" – used to praise a brave and courageous person; its English equivalent is "*a man of great courage*."
- "*Qo'li gul*" – conveys the meaning of being skillful or talented; its English equivalent is "*to have green fingers*."
- "*Ishtahasi ochiq*" – expresses the idea of eating a lot of food; its English equivalent is "*to eat like a horse*."

Verbal units — contain a verb as part of their structure, and their main meaning is conveyed through words that express an action or state. For example:

- "*Boshi osmonga yetmoq*" – expresses the meaning "to be very happy," and its English equivalent is "*over the moon*."
- "*Tagiga suv quymoq*" – means "to stop or ruin someone's activity," and its English equivalent is "*to burn one's boats*."
- "*Ko'kka ko'tarmoq*" – means "to praise," and its English equivalent is "*the apple of one's eye.*"

Adverbial units — are phraseological units in which an adverb serves as the main meaning-bearing element. Such words can express concepts of time or quantity.

For example: *bir zumda* (immediately), *tong sahar* (small hours), *zudlik bilan* (at a fast pace).

Conclusion

Uzbek phraseological units are an essential part of the language's expressive power and cultural heritage. Their study not only reveals aspects of linguistic structure but also provides insights into the values, humor, and worldview of the Uzbek people. Preserving the values embedded in the language and passing them on to future generations is of great importance. In this respect, the research of phraseological units

will continue to enhance their role in education, translation, and intercultural communication.

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LINGUOCULTURAL FEATURES OF LEXICAL UNITS IN KHOREZM FOLK TALES

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Annotatsiya. Ushbu maqolada Xorazm xalq ertaklari, xususan "Apandi" obraziga oid ertaklar tahlil markaziga olingan bo'lib, ular tarkibidagi Xorazm shevasiga xos leksik birliklarning lingvokulturologik xususiyatlari yoritilgan. So'zlarning fonetik, morfologik, semantik va madaniy konnotatsiyalari xalqning mentaliteti, ijtimoiy qadriyatlari va milliy tafakkuri bilan uzviy bog'liq ekani asoslangan. Tahlil natijasida xalq tilining emotsional, obrazli va muloqotdagi ahamiyati ochib berilgan. Bu esa sheva va folklor o'rtasidagi uzviy bog'liqlikni hamda tilning madaniyat ifodasidagi rolini ko'rsatadi.

Kalit so‘zlar: *Xorazm shevasi, xalq ertagi, Apandi, lingvokulturologiya, leksik birlik, og‘zaki ijod, madaniy kod, milliy tafakkur.*

Аннотация. В данной статье рассматриваются лексические особенности сказок Хорезма, в частности, народных сказок с образом Апанди. Анализируются региональные лексические единицы хорезмского диалекта с точки зрения их лингвокультурологических характеристик. Выявлено, что фонетические, морфологические, семантические и культурные аспекты этих слов напрямую связаны с менталитетом, социальной памятью и национальным мировоззрением народа. Работа подчеркивает значение диалекта как носителя культурных кодов в фольклорных текстах.

Ключевые слова: *Хорезмский диалект, народная сказка, Апанди, лингвокультурология, лексическая единица, устное народное творчество, культурный код, национальное мышление.*

Abstract. This article explores the linguistic and cultural characteristics of lexical units found in Khorezm folk tales, particularly those featuring the character “Apandi.” The analysis focuses on dialectal expressions specific to the Khorezm region, examining them through phonetic, morphological, semantic, and cultural lenses. The findings reveal the deep connection between language and national mentality, traditional values, and cultural worldview. The study highlights the role of dialectal vocabulary as a cultural code and a means of expression in oral folklore narratives.

Keywords: *Khorezm dialect, folk tale, Apandi, linguoculturology, lexical unit, oral folklore, cultural code, national mentality.*

Introduction

In modern world linguistics, the expression of national mentality through cultural components of language, conceptual perception of the world, and naming processes of reality are being extensively studied [1]. Language, throughout its historical development, reflects social changes in society and serves as a tool for preserving the cultural and social memory of a people [2]. Analyzing the linguistic picture of the world provides deeper insight into a nation's living environment, lifestyle, ethnocultural values, and national character. In this process, the study of cultural-ethical norms expressed through language, social relationships, and the pragmatic aspects of intercultural communication gains particular importance [3]. Therefore, the investigation of the relationship between language and culture, the identification of the national-cultural content of linguistic units, and their role in reflecting cultural values and traditions are among the most pressing issues in the era of globalization.

Folk tales, as a product of oral speech, reflect the natural and living form of popular language. Particularly in traditional oral narratives, such as those of the Khorezm region, the presence of dialectal elements carries significant weight. These elements reflect the naturalness of the tale, its national spirit, and its close connection with the people's way of life. Over time, however, as tales have been transcribed, elements of literary language have intermingled, leading to the coexistence of literary and dialectal features in Khorezm folk tales.

The Khorezm dialect, as one of the regional variants of the Uzbek language, embodies the worldview, mentality, cultural values, lifestyle, and historical memory of its speakers. This dialect is among the ancient and rich forms of the Uzbek language, particularly notable in oral literature, especially in folk tales, for its linguistic richness, emotional expressiveness, and cultural semantics. For centuries, folk tales have served as a unique reflection of people's worldview, beliefs, ethical-aesthetic values, and way of life. This article focuses on a linguocultural analysis of several lexical units found in the Khorezm tale of "Apandi" [4].

Literature Review

The lexical features of Khorezm folk tales, when studied through the lens of linguoculturology, represent a significant area at the intersection of philology, linguistics, and folklore studies. Central to this research is the intrinsic connection between the spoken language of the people and oral folklore texts, which are viewed as natural expressions of collective identity. One of the most authoritative and up-to-date sources on the Khorezm dialect is the "Dictionary of Khorezm Dialects" by Norboyeva, Sadullayeva, and Atabayeva (2024). This work systematically classifies and explains lexical units used across the Khorezm region, considering their semantic, phonetic, and morphological properties. It serves as a foundational resource for the analysis of dialectal units in this study.

The theoretical underpinnings of the link between folklore and dialectal vocabulary are discussed in I. Qodirov's "Khorezm Folklore School" (2012) [5] and A. Madrahimov's "Typology of Khorezm Tales" (2007) [6]. These works explore the development, genre structure, and social relevance of Khorezm folk narratives, emphasizing the role of regional dialects in shaping their linguistic identity.

F. Abdurahmonov's "Oral Folk Literature: Genres and Types" (2008) offers a detailed overview of Uzbek folklore, including the linguistic structure and communicative function of folk tales [7]. The author frames folk narratives as reflections of national consciousness, aligning well with the linguocultural approach adopted in the present article.

The structural and semantic analysis of tale elements draws from V. Propp's "Morphology of the Folktale" (1998), which introduces a functionalist method for examining recurring motifs and narrative functions. Propp's framework underpins the interpretation of the Apandi character and his culturally embedded linguistic expressions [8]. The mutual influence of literary language and dialect, as well as their phonetic and lexical distinctions, are elaborated in K. Imomov's "Lexicon of Uzbek Dialects" (1990) [9]. This work provides crucial insight into the phonological and morphological variations characteristic of Khorezm speech, supporting the analysis of regional features in folk texts. Modern interpretations of the "Apandi" character as a culturally symbolic figure are further elaborated in M. Usmanova's article "The Role of Afandi in Reflecting Social Life" (2025). The article focuses on the communicative and cultural function of the Apandi figure, enriching the linguocultural analysis in this study [10].

Overall, the literature cited in this research provides a solid theoretical foundation for analyzing the lexical richness of Khorezm dialects and their cultural implications

in folk narratives. These sources highlight the deep interrelation between language and culture and support a multidimensional approach to the study of folk texts as both linguistic and sociocultural artifacts.

Research Methodology

This study employs a qualitative research design grounded in the principles of linguocultural analysis. The primary objective is to investigate the interplay between linguistic form and cultural content within specific lexical units drawn from Khorezm folk tales. The methodology is structured to facilitate a multi-dimensional analysis, encompassing phonetic, morphological, semantic, and pragmatic levels.

Analysis and Results

The lexical units analyzed in this study were extracted from Khorezm folk tales collected in the districts of Gurlan, Yangibozor, and Bog‘ot. These units were analyzed from phonetic, morphological, semantic, and pragmatic perspectives. In the Khorezm dialect, the pronunciation of words often differs from their standard literary forms. For instance:

- “ajab” instead of “ho‘p bo‘ladi” (it’s okay),
- “akan” instead of “ekan” (was),
- “ertang” or “artang” instead of “ertaga” (tomorrow),
- “Inshollo” instead of “Xudo xohlasa” (God willing).

These phonetic shifts, typical of oral speech, help preserve the natural and sincere tone of the tale. The distinctiveness of these pronunciations plays a vital role in conveying the lively spirit of folk narratives.

This study adopts a linguocultural approach, analyzing not only the lexical meanings of the words but also their cultural connotations. The primary source used for the analysis is the “Dictionary of Khorezm Dialects” (Norboyeva, Sadullayeva, Atabayeva, 2024) [11].

Apandi – (Afandi) A wise and humorous hero character in folk tales [1]. Derived from the Persian-Tajik word “afandi.” An anthroponym, figurative name. In oral folklore, Apandi symbolizes a wise hero who exposes social truths through humor and satire [10]. Through him, the people express their beliefs, moral norms, and aesthetic views. The variant “apandi” in the Khorezm dialect is a regional modification of this image and is perceived as a cultural code.

Ulim – “My son” (a form of address to a close person). Found in the dialects of Gurlan, Yangibozor, and Bog‘ot. Noun, form of address. This is the Khorezm dialectal variant of the word “o‘g‘lim,” expressing closeness, affection, and family relationships. The word reflects the culture of sincerity, warmth, and care.

Ko‘vningizdegidiy – Means “as you wish,” “as you like.” A very positive, approving expression. An attributive phraseological unit. This phrase conveys the people’s aspirations, consent, and states of the heart. In Uzbek culture, “ko‘ngil” (heart, spirit) holds an important place as a moral and aesthetic concept.

Angqayib – To be astonished, to be surprised due to not understanding. Derived from the word “anqov” [onqov] [11]. Verb (adverbial form). Used in folk speech to describe astonishment, naivety, or lack of understanding in response to unexpected

situations. It reflects the linguistic expression of the people's simplicity and sincere attitude towards natural occurrences.

Y'lav – Derived from "yig'i" (crying, weeping) or "yig'lamoq" (to cry). A unit with emotional significance. Functions as either a noun or a verb expressing a state. Denotes an intense expression of emotion, especially grief or distress. Often found in oral speeches within dramatic contexts. Considered a means of emotional richness in folk language.

Bayatir akan – Means "was going" or "is on the way" (in the past continuous sense). Used in oral narrative style. An analytic verb phrase. In Khorezm oral storytelling, it conveys continuity and the uninterrupted flow of action within the plot. Serves as an important tool for transmitting reality through the language of narration.

Muning – Dialectal pronunciation of "uning" (his/her). Possessive form. A personal pronoun in the possessive case. An example of regional pronunciation. As a unit expressing possession towards a person, it reflects the simplicity of folk language and oral speech.

Tushunavalmin – Means "I don't understand" (I'm not grasping it). A simplified oral variant. A reduced verb phrase. Used in everyday speech to express misunderstanding or confusion in complex situations. Viewed as an example of the simplified style of speech typical of folk thinking.

The above-analyzed lexical units specific to the Khorezm dialect have been studied as a direct linguistic expression of oral folk creativity. Language is the mirror of culture, reflecting not only the real environment surrounding a person and their actual living conditions, but also the people's self-awareness of their social role, their mentality, national character, lifestyle, traditions, customs, morals, a set of values, and worldview. Language is the treasury, the repository, and the entirety of culture. Through its vocabulary, grammar, idioms, proverbs and sayings, folklore, literary and scientific works, as well as oral and written speech, it preserves cultural values. These units encapsulate not only the richness of the language, but also the cultural mindset of the people, their social values, and the culture of communication. The lexical elements found in tales about the "Apandi" character serve as an important source in the linguocultural analysis of folklore texts. The relationship between dialect and literary language, particularly in terms of imagery and emotional expression, enables an in-depth study of the people's culture and linguistic thinking [9].

Conclusion

The lexical units found in the vocabulary of Khorezm folk tales reveal not only the regional distinctiveness of the language but also the people's mental worldview, moral-aesthetic values, and cultural codes. These words serve as both communicative and poetic tools in oral folk literature. The research has shown that such words possess specific phonetic, morphological, semantic, and pragmatic features, forming the direct lexical layer of oral folklore. Each lexical item embodies cultural semantics such as simplicity, emotionality, humor, compassion, consent, and amazement—characteristics intrinsic to the daily life of the people. Furthermore, the lexical richness of the Khorezm dialect, particularly in tales featuring the "Apandi" character, vividly manifests as an expression of popular thought. Thus, Khorezm dialect tales are not only

of artistic and aesthetic significance but are also of great importance from a linguocultural perspective. Therefore, studying the vocabulary of Khorezm tales in terms of linguocultural features provides a valuable theoretical basis for Uzbek dialectology, folklore studies, and cultural studies.

Recommendations. It is recommended to systematically study the lexical features of the Khorezm dialect on the basis of folk tales, to scientifically catalogue them, and to publish them in the form of annotated dictionaries.

Dialect-specific expressions, phraseological units, inversions, and poetic devices in folk tales should be analyzed separately and enriched with linguocultural commentary. It is necessary to create a regional language model based on tales featuring the "Apandi" character and, through this model, to explore the people's communicative culture, moral norms, and aesthetic tastes. Developing a digitized corpus of Khorezm folk tale texts and designing automated linguistic analysis tools based on this corpus is of particular importance. Through comparative analysis with other regional dialects of Uzbekistan, the linguistic and cultural position of the Khorezm dialect can be identified, which in turn will contribute to a deeper understanding of the national language as a whole.

Finally, it is proposed to incorporate the lexical units used in Khorezm folk tales into educational curricula (at both school and university levels) and to employ them as cultural and educational tools.

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GENDER-SPECIFIC APPROACHES IN THE MEDIA

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Annotatsiya. Mazkur maqolada zamonaviy jamiyatda shakllanayotgan kommunikativ-axborot makonining xususiyatlari, ommaviy axborot vositalarining (OAV) roli hamda gender stereotiplarini shakllantirish va transformatsiya qilishdagi o‘rni tahlil qilinadi. Medialingvistika nuqtai nazaridan mediamatn va mediadiskurs tushunchalarining ilmiy talqinlari, jumladan T.G. Dobrosklonskaya, Teun van Deyk, Alan Bell, Norman Feyerklaff va boshqa olimlarning qarashlari ko‘rib chiqiladi. Shuningdek, ingliz tilidagi genderga yo‘naltirilgan nashrlarda (masalan, *Vogue*, *Gentlemen’s Quarterly*) hamda o‘zbek kontekstida shakllanayotgan gender stereotiplari sotsiologik va lingvistik jihatdan tahlil qilinadi. O‘zbek jamiyatida patriarxal qadriyatlarning saqlanib qolishi, OAV orqali gender stereotiplarining mustahkamlanishi yoki transformatsiya qilinishi jarayonlari yoritiladi. Maqola gender va mediamatn o‘zaro ta’sirini chuqurroq anglashga yordam beradi.

Kalit so‘zlar: *Gender, mediamatn, kommunikativ-axborot, OAV, yondashuv, medialingvistika.*

Аннотация. В статье анализируются особенности формирующегося в современном обществе коммуникативно-информационного пространства, роль средств массовой информации (СМИ) и их роль в формировании и трансформации гендерных стереотипов. С позиции медиалингвистики рассматриваются научные интерпретации понятий “медиатекст” и “медиадискурс,” включая взгляды Т.Г. Добросклонской, Тьюна ван Дейка, Алана Белла, Нормана Фойерклаффа и других учёных. Также с социологической и лингвистической точки зрения анализируются гендерные стереотипы, формирующиеся в гендерно-ориентированных изданиях на английском языке (например, Vogue, Gentlemen’s Quarterly) и в узбекском контексте. Освещаются процессы сохранения патриархальных ценностей в узбекском обществе, укрепления или трансформации гендерных стереотипов посредством СМИ. Статья способствует лучшему пониманию взаимодействия гендера и медиатекста.

Ключевые слова: *Гендер, медиатекст, коммуникативно-информационный, медиа, подход, медиалингвистика.*

Abstract. This article analyzes the characteristics of the communicative and information space being formed in modern society, the role of the media (mass media), and their role in the formation and transformation of gender stereotypes. From the perspective of media linguistics, scientific interpretations of the concepts of media text and media discourse are considered, including the views of Dobrosklonskaya T.G., Teun van Dijk, Alan Bell, Norman Feuerklaff and

other scholars. Also, gender stereotypes being formed in gender-oriented publications in English (for example, Vogue, Gentlemen's Quarterly) and in the Uzbek context are analyzed from a sociological and linguistic perspective. The processes of the preservation of patriarchal values in Uzbek society, the strengthening or transformation of gender stereotypes through the media are highlighted. The article helps to better understand the interaction between gender and media text.

Keywords: *Gender, media text, communicative-information, media, approach, media linguistics.*

Introduction

The communicative and information situation in modern society is characterized by the active use of all media (radio, television, press). The media are becoming more and more fast, mobile, the speed of response to events is increasing several times. All this has a significant impact on the process of creating and distributing information. This situation cannot but attract the attention of scientists studying the language of the media, that is, media linguistics.

Literature Review

Among the famous scientists who paid special attention to this issue are such researchers as Theun van Dijk, Martin Montgomery, Alan Bell, Norman Feuerklaff, Robert Fowler, who analyzed mass media texts from the point of view of various scientific schools and approaches. These include determining the functional-stylistic status of the language of the media, methods for describing various types of media texts, the influence of sociocultural factors on media speech, and the study of technologies of linguo-media influence [1-5]. Dobrosklonskaya T.G. notes that media texts or media texts (Latin media textus – "means, intermediaries," "fabric, wrapping") are one of the most widespread forms of language today, their total volume far exceeds the volume of speech in other areas of human activity [5]. The scientist distinguishes between the concepts of "text," "mediatext," and "media discourse." In his opinion, "text is the message, mediatext is the message and the channel, and media discourse is the message and all other components of communication" [4].

The concept of media text is based on the harmonious unity of verbal and media layer units. This feature, which is characteristic of mass information texts, is especially emphasized by English authors. They describe media text as a set of verbal and media signs. For example, Alan Bell, a well-known scholar studying the language of the media, in his work "Approaches to Media Discourse," emphasizes that "the definition of media text is much broader than the traditional concept of text, that is, a sequence of words written or printed on paper. The concept of media text is even broader. It also includes sound features, music and sound effects, visual images. That is, media texts reflect the technologies used to create and distribute them in practice" [1, 3].

Research Methodology

In the analysis of contemporary linguistics and media texts, the famous Dutch scholar Theun van Dijk places special emphasis on the broad interpretation of this discourse from a contextual point of view.

Another important factor that distinguishes media linguistics as an independent discipline is its internal structural structure. Although this structure is still in the process of formation, it currently demonstrates a stable system of components. Currently, the following six main sections are distinguished in media linguistics, the content of which is structured around the following central themes:

1. Determining the internal status of the media language, describing it within the framework of the main paradigms of "language-speech", "text-discourse";
2. The possibilities of identifying functional-stylistic differences in media discourse, classifying texts based on the main functions of the language and their distribution channels (press, radio, television, Internet);
3. Types of media discourse, classification of media texts by genre and type characteristics, distinction of main text types: news, analytical and commentarial information, journalism (features), advertising;
4. Linguistic-stylistic characteristics of the main types of media texts;
5. Extralinguistic components of media discourse: production, distribution and perception of media texts, socio-cultural and ideological context;
6. Technologies of linguomedia influence: language tools of propaganda, manipulation, information policy, information management and PR.

These sections constitute the main theoretical and practical directions that serve to form media linguistics as an independent discipline.

Analysis and Results

The interpretation of the concept of media text as a complex, multi-level phenomenon is supplemented by a system of parameters that allow us to determine the features of production, distribution and linguistic-format features of this text. This system of parameters allows us to comprehensively and accurately characterize the media text. This system includes the following important parameters:

1. Method of text production (authorship - collective);
2. Form of creation (oral - written);
3. Form of processing (oral - written);
4. Distribution channel (media - print, radio, television, Internet);
5. Functional-genre type of the text (news, commentary, journalism (features), advertising);
6. Thematic dominance or belonging to one or another stable media theme.

In understanding the socio-psychological processes and approved behavioral strategies taking shape in modern society, the psychological aspects of male and female socialization and their cultures are of great importance. The materials collected by historians, ethnographers, and cultural scientists show how various specific aspects of men and women have changed, how kinesthetic means of expressing their social status and essence - actions, gestures - have been formed, how the corresponding behavioral stereotypes have been strengthened in games and rituals. These signs illuminate the specific aspects of male and female behavior as an integral part of the process of preparing for and confirming social roles. They are explained by the specific functionality of the "masculine" and "feminine" mentalities, their semiotic resource, that is, the system of gender concepts. Because the mega-opposition "masculinity -

femininity" as one of the ancient cultural binary pairs was an archaic way of organizing the world. Therefore, these concepts exist in the mental space of both sexes, but are differentiated differently by men and women as symbols that build a macro-level system [6].

The study of gender relations is gradually becoming an integral part of modern research on journalism. In the issues of gender relations, discussions about the social status of men and women, the struggle of women to achieve harmonious relations with men, and, in general, gender inequality, the media are the main means of reflecting the reality created by gender norms. According to the definition of E.S. Zinovyeva, media discourse is a text that takes place in real communication situations, takes into account a set of psychological, social and cultural factors and is intended for a specific audience [8]. One of the most obvious factors that reflects the expression of gender differences is gender-oriented publications, that is, media that classify their audience based on gender. Such periodicals, addressing an audience of a specific gender, form a unique identification system. Through this system, readers can feel themselves to belong to a certain social group, lifestyle, model of femininity or masculinity [2].

Gender-oriented media is a special type of media discourse that is aimed at covering various areas of social life. In general, the topics of such publications are focused on issues of work, fashion, health, relationships with the opposite sex, sports and nutrition. The main goal of such publications is to form a certain lifestyle among the target audience, emphasizing gender relations. In order to establish contact with the target audience and ensure the effective perception of the text taking into account gender, the selection of lexical units, emotional-evaluative means or grammatical construction features is of great importance. Nowadays, gender-oriented publications in the English language are dominated by lexical units characteristic of femininity or masculinity, depending on their orientation. At the same time, the use of gender-neutral units is increasing. For example, neutral lexemes such as person (person), anybody (someone), someone (someone) are increasingly used to represent a woman or a man. Another innovation is the formation of new images of femininity and masculinity, that is, the transformation of gender categories. This phenomenon can be observed at the lexical level through the increased occurrence of stylistically inferior units in women's speech, as well as in the content of publications. In magazines aimed at a male audience, articles on fashion and self-care topics appear, and in magazines aimed at a female audience, articles about successful women in business and politics appear [5].

Vogue magazine promotes the image of a successful woman, for whom it is also important to have her place in the family. Independence, self-sufficiency, personal and physical perfection are the goals of a woman who embodies modern femininity. The magazine is divided into the following main sections: "News", "Fashion", "Catwalk", "Beauty", "Arts & Lifestyle", "People & Parties". Each of them participates in the process of popularizing global values, advertising famous brand products and forming gender stereotypes.

Gentlemen's Quarterly magazine presents a unique monthly publication in a unique format. Its main audience is self-confident and successful business people who understand modern culture, politics and business.

In general, based on the diversity of the magazine's sections ("Fashion," "Watches," "Culture," "Grooming," "Lifestyle," "Women," "Sport," "Politics," "Fitness," "Food and Drink," "Catwalk"), the magazine creates the image of a modern, purposeful male leader who works on himself in various fields. Gender-oriented publications are aimed at a gender-based audience and become an important tool in shaping social roles and lifestyles.

Conclusion

From a sociological perspective, it can be seen that these stereotypes are collective social constructions and therefore can be reconstructed. In this regard, it is necessary to develop new studies to determine how far the arguments and examples discussed in the media have come and how far they still need to go, to monitor changes in gender norms and to evaluate their effectiveness. Breaking or eliminating gender stereotypes is not an easy process, but it is an important step for the development of the country, a step towards a just and modern society.

The media is not only a means of disseminating information, but also an important social space for the formation and transformation of gender stereotypes. Analyzing the complex nature of media texts based on verbal and media units allows for a deeper understanding of the interaction of gender and culture. Despite the persistence of patriarchal values in Uzbekistan, the media serve as an effective tool for transforming gender stereotypes. Therefore, the rational use of media texts to ensure gender equality is an important condition for the development of modern society.

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CENTRAL ASIAN CERAMIC CRAFTSMANSHIP TREASURES AND THEIR SIGNIFICANCE

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Annotatsiya. Mazkur maqolada Markaziy Osiyo hunarmandchiligining asosiy manbasi hisoblangan risolalar, xususan, kulolchlik risolasi, uning mazmuni, mohiyati hamda turli davrlarda hunarmandlarning risolalarga bo'lgan munosabatlari haqida ma'lumot beradi. Shuningdek, bugungi kunda Markaziy Osiyoda kulolchilikning markaziga aylanib borayotgan Farg'ona vodiysidagi Rishton kulolchiligi haqida fikr yuritiladi.

Kalit so'zlar: *Said Amir Kulol, Bahouddin Naqshbandiy, Rishton, Risola, pir, oqsoqol.*

Аннотация. В статье представлена информация о трактатах, считающихся основным источником знаний о среднеазиатских ремёслах, в частности, о трактате о гончарном деле, его содержании, сути и отнешении к ним мастеров в разные периоды. Также рассматривается гончарное дело Риштана в Ферганской долине, в которое в наши дни становится центром гончарного искусства Средней Азии.

Ключевые слова: *Саид Амир Кулал, Бахауддин Накшбанди, Риштан, трактат, пир, старейшина.*

Abstract. This article provides information about the treatises, which are considered the main source of Central Asian crafts, in particular the treatise on pottery, its content, essence, and the attitude of craftsmen to the treatises in different periods. It also discusses the Rishton pottery in the Fergana Valley, which is becoming the center of pottery in Central Asia today.

Keywords: *Said Amir Kulal, Bahauddin Naqshbandi, Rishton, treatise, pir, elder.*

Introduction

In the crafts of Central Asia, each craft has its own procedures, requirements, customs. Pottery from the oldest craft species of humanity is no exception. Through the sources created to this day as well as mainly oral narratives, we can learn about the traditions and values in pottery. Also, in Central Asian crafts, each profession had its own treatise, which provided information about the history of a particular craft, its patron, procedures, customs, and rituals, and these treatises were considered a kind of constitution of the craft. Brochure means in Arabic "letter," "revealed propaganda," "work dedicated to the craft" [1].

Literature Review

The field of crafts has always been one of the main topics of researchers. After all, the socio-economic life of peoples depends on this area. Treatises devoted to Central Asian crafts were studied in the 19th -20th centuries by Russian researchers Razvadovsky V.N., Gavrilov M.F., Pesherova Ye.M., Nalivkin V.P. To date, this issue is being studied by many domestic researchers.

Sadriddin Aini wrote the following about the treatises of Bukhara crafts in his memoirs. The clergy wrote down rules and regulations for the craftsmen of each craft, calling them “Brochure”. Brochures were short books, and the introduction to all craft treatises was the same - first of all, they began with praise to Allah, the Prophet, and their companions. Then, the narrations of the truthful Imam Ja’far [2]. The treatise on pottery lists the gurus who were engaged in pottery after the narrations of Abu Ja'far, and the names of Said Amir Kulal, Bahauddin Naqshbandi, and Sheikh Hasan Basri are listed as the most perfect of them. In the question-and-answer part of the treatise, the first potters are mentioned as Adam, Noah, Abraham, and the Prophet Muhammad. In addition, various prayers are written for each type of craft, which the craftsman was required to recite before starting work, during work, and at the end of work. The Brochure also contains the laws, regulations, traditions, and punishments for violating the rules of each craft. In addition, the relationship of the craftsman to the elder, master and owner, and the relationship between master and disciple were also the main themes of the treatises.

There is no clear written source about when and by whom the Brochures were written. Most often, the hypothesis that they were created in the first centuries of the spread of Islam in Asia prevails. After the Russian Empire occupied Central Asia, in the second half of the 19th century and the beginning of the 20th century, Russian researchers and scientists began to study the peoples of the colonial territory - to collect and compile information about the culture and customs of the colonial peoples.

In particular, this was directly facilitated by the colonial policy carried out around the world during this period, which required a full understanding of the culture, lifestyle, and national characteristics of the colonial countries in general. After a certain amount of factual information was collected by researchers, the process of generalizing the materials collected in ethnological studies and analyzing them based on a certain theoretical and methodological concept began. The first Russian researcher to pay attention to handicraft Brochures was A.F. Middendorf [3]. The issue of studying Brochures during the authoritarian regime and the Soviet era was repeatedly raised. One of the Russian researchers, P.A. Kamarov, compiled a short list of Brochure collectors in the newspaper “Туркестанскихъ Ведомост” [4]. According to him, the first person to collect the Brochures is the Kashgar kosul Petrovsky N.O. He studies the Brochure of the silk workers. The next person who became interested in the treatises is the orientalist V.P. Nalivkin, who wrote numerous works on the history, ethnography, and Islamic culture of the Turkestan region, and created manuals on the Uzbek and Persian languages. He lives with his family in the Fergana Valley and studies the customs and culture of the local people. Nalivkin finds and examines the Brochure of the peasants, and later sends it to Ostrumov. In 1885, Ostrumov published this treatise in 50 copies. The work of collecting Brochures continued, and a total of twenty-three Brochures on various crafts were collected. In general, the question arises

as to why Russian researchers searched for Brochures, why there were so few of them. Ethnographers who studied Central Asia in the 19th century had difficulty finding them. Even the Nalivkins, who were close to the local population, had difficulty finding them.

Research Methodology

This study employs a qualitative historical-ethnographic approach to investigate the role of treatises (Brochures) in Central Asian pottery, with a specific focus on the Rishton school.

Analysis and Results

As a result of research, it was found that by the 20th century, such Brochures existed in some households. This situation requires two different reactions. It can be concluded that at that time, manuscripts written or printed in the Arabic alphabet were treated with respect, so they were preserved in some households. On the other hand, because the need for the Brochure arose again, people who knew about it rewrote it. It is possible that the elders wrote the Brochure out of their own interests when rewriting it. Therefore, some people who knew about the Brochure did not trust the copies of the treatise. In the course of research, Russian scientists also observed that the attitude of the population towards the Brochures, that is, the loss of trust in them, was also the reason for the non-preservability of the Brochures. According to Nalivkin V.P., who studied the local people, by this time it can be observed that the trust in the Brochures among the population was decreasing day by day. It was believed that only people who could not see far would believe in the Brochures. At that time, in the last quarter of the 19th century, the number of Brochures also decreased, and even the elders did not have them [5].

According to the information in the Brochures, the village blacksmiths of the Fergana Valley recognize the Prophet Davud, The Carpenters the Prophet Noah, the silkworkers the Prophet Job, the builders Abraham or the Prophet Muhammad, the Lord of the mahsidoots The Righteous, and the Barber Salman the pure as their pirs [6]. Pir means “elder” or “old man” in Persian, and in Sufi tradition, the supreme leaders or supreme leader of the tariqa each murid referred to his Murshid as pir. In addition, among people, the word pear is also used in the sense of a saint, the founder of a particular craft [6]. The main pirs in pottery were Sheikh Bahauddin Naqshbandi and Said Amir Kulol. Said Amir was used with the word “kalon” in relation to the pir. This means “big” in Tajik and means the greatest of the pirs. Naqshbandi Hazrats are especially revered by masters who decorate dishes. The reason is that it is believed that putting flowers and decorating dishes is inherited from Naqshbandi. Every year, potters from different regions sent seven dishes from each pot to Bukhara as an offering, as a tribute to Bahauddin Naqshbandi or Said Amir Kulol, and these offerings were the main source of income for the pirs. In the 19th century, Rishton pottery became such a large center that the “descendants of the pirs” turned this place into the main center of livelihood. Even in the 70s of the 19th centuries, Said Akbar, a 20-year-old “descendant” of Said Amir Kulol, moved to Rishton with his family. After this incident, the potters of Rishton no longer needed to go to Bukhara and began to pay their vows to Said Akbar right there [8]. But within some masters, distrust, discontent

with the chops was moving, and it was concluded that the questions of the piers and the brochure should be re-examined. Such opposition is largely attributed to Russian propaganda coming to Central Asia against religious rites, customs and traditions as well as the October Revolution. While local potters argue that there is no Russian involvement in this, such a policy was also pursued by Russians. The main reason for the emergence of distrust among the Masters was the increased costs of craft ceremonies as well as the various bidiates. It is also the echo of Mahmudkhoja Behbudiy's 1903 appeal to the Central Asian jadids regarding the need to pay attention to pamphlets that distort sharia rules. In this way, distrust of the rituals and treatises of pottery increased, and now local craftsmen were not afraid to practice it. Such circumstances did not fail to affect the situation of elders who had no profession and religious representatives who made a living from donations.

According to many master potters, until the time of Amir Temur, each mullah had his own profession and made a living from it. After Amir Temur established a centralized state, due to increased attention to religious representatives, endowment properties expanded, and religious scholars abandoned their professions and began to make a living from these endowment properties. Gradually, religious representatives stopped engaging in crafts or additional work.

Conclusion

In conclusion, it can be said that by the beginning of the 20th century, despite the growing distrust of the Brochures, mainly their rewritten copies and the proliferation of bid'ahs related to their implementation, and the "generations of the pirs," local craftsmen always treated the authentic Brochures, the procedures and customs and traditions contained in them, and the leaders of pottery with respect. Also, Rishton potters always show respect and honor to older masters, considering them as *ustoz* (masters). Today, any ceremonies and gatherings of potters do not take place without the presence of older master potters of the region. This, in turn, is the result of the master-student tradition, which is considered a national value. It is precisely because of this relationship that Rishton is now recognized as the center of Central Asian pottery.

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HISTORY OF RISHTON POTTERY SCHOOL

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Annotatsiya. Ushbu maqolada Markaziy Osiyo kulolchilik maktablaridan biri bo'lgan Rishton kulolchilik maktabi tarixi, u yerda faoliyat yuritgan hunarmand ustalar hamda mazkur hududda hozirgi kundagi ishlab chiqarilayotgan sopol mahsulotlari haqida ma'lumot berilgan. Shuningdek, Rishton kulolchiligining bugungi kundagi rivojlanish omillari haqida fikr yuritiladi.

Kalit so'zlar: *Rishton, neolit, rivoyat, hoki surx, zardpaz, safedpaz, kavudpaz, harjakipaz.*

Аннотация. статье представлена информация об истории Риштанской гончарной школы, одной из среднеазиатских гончарных школ, о работавших мастерах и о керамических изделиях, производимых в регионе в настоящее время. Также рассматриваются причины развития Риштанского гончарного искусства в наши дни.

Ключевые слова: *Риштан, неолит, легенда, хоки сурх, зардпаз, сафедпаз, кавудпаз, харжакипаз.*

Abstract. This article provides information about the history of the Rishton pottery school, one of the Central Asian pottery schools, the craftsman who worked there, and the ceramic products produced in the region today. It also discusses the reasons for the development of Rishton pottery today.

Keywords: *Rishton, Neolitthic, legend hoki surkh, zardpaz, safedpaz, kavudpaz, kharjakipaz.*

Introduction

Crafts are an important and valued field in the life of the peoples of the world. Because their way of life was closely related to crafts. Handicrafts were a field of human production and were originally part of Agriculture and animal husbandry. Throughout the development of the community, it gradually separated from farming and animal husbandry to become a separate sector. Rafts are an important and valued field in the life of the peoples of the world. Because their way of life was closely related to crafts. Handicrafts were a field of human production and were originally part of Agriculture and animal husbandry. Throughout the development of the community, it gradually separated from farming and animal husbandry to become a separate sector. At the same time, handicrafts did not develop evenly everywhere, progressing depending on the availability of natural resources necessary to carry out activities. For example, where there was good quality soil, pottery, wool and leather became abundant, textiles and tanning, and shipbuilding developed along the river banks. The hom-material needed for the development of a particular craft was obtained pure from

the territories themselves. Thus, as the craft improved, it was broken into separate branches such as weaving, tanning, pottery, blacksmithing.

Uzbek pottery is one of the most ancient and developed types of crafts. This is also confirmed by numerous archaeological finds from the territory of this region. In particular, in the southern regions of Uzbekistan in the 2nd half of the 20th century, under the leadership of Askarov A., a very large-scale archaeological investigation was carried out and a large number of scientific works were created [1].

Literature Review

Many sources have been created on Central Asian crafts. To date, a number of studies and research have been conducted on the study of Rishton pottery, and these studies are mainly dominated by art history and ethnographic studies. Through them, we gain information about the pottery of the region. In the study of Rishton pottery, the books "The Miracle of Rishton" by Burkhonov X., "Гончарное производство Средней Азии" by Pesherova Ye.M., and "Central Asian Pottery" by Rahimov M. serve as important sources. Aliyeva S., Gyul E., and Kodzayeva L. also conducted research on the pottery of this region.

Among the schools of Fergana pottery, Rishton pottery is distinguished by its distinctive aspects. The town of Rishton is considered to be one of the oldest towns in the Great Silk Road section of the Fergana Valley. All the pottery centers in the Fergana Valley – Ghurumsaroy, Chorku, Konibodom and others-were influenced by Rishton pottery [2]. The city is known as one of the largest shopping centers in Central Asia for the production of unique glazed pottery. The word Rishton is derived from the old Sogdian word "Rash" ("Rush", "Rushi") meaning "Red Land" meaning soil with a reddish tint. The yellowish-reddish soil is laid out in layers at a depth of 1-1.5 m in almost all places of the area. The city is known as one of the largest shopping centers in Central Asia for the production of unique glazed pottery. The word Risht.

The history of Rishton pottery from its inception to the mid-19th century has not been well studied. Due to the lack of research on this area and the lack of reliable information, there are different opinions about the period when Rishton artistic glazed dishes began to be produced. According to the legend, which has been told by masters until now, the foundation of the ancient city of potters was in the Chinnigaron neighborhood, located near the Sohibi Hidoya cemetery, one of the ancient villages of the modern city of Rishton. Some legends indicate its emergence in the 9th and early 12th centuries. Others attribute it to the early 14th -15th centuries [3]. Lyudmila Kodzayeva, who studied the history of Rishton pottery, claims that in both cases the founders of this craft are masters from Bukhara and Samarkand. Kodzayeva believed that the rishtanians considered themselves to be descendants of immigrants from Samarkand and O'ratepa. This may have been due to the fact that some masters thought so. Lyudmila Kodzayeva, who studied the history of Rishton pottery, claims that in both cases the founders of this craft are masters from Bukhara and Samarkand. Kodzayeva believed that the rishtonians considered themselves to be descendants of immigrants from Samarkand and O'ratepa. This may have been due to the fact that some masters thought so. However, other accounts, on the contrary, say that the Potters of Rishton moved to Samarkand and Bukhara, where they founded pottery. In

particular, they attribute this to the period of the reign of Amir Temur. It is known that when Amir Temur founded a centralized state, he gathered Masters and artisans from different regions to Samarkand. During the reign of Amir Temur, great works were carried out in the field of construction. The importance of koshinpasis in architecture was high in the decoration of the exterior facade of mosques and madrasas. It is known that when Amir Temur founded a centralized state, he gathered Masters and artisans from different regions to Samarkand. During the reign of Amir Temur, great works were carried out in the field of construction. The importance of koshinpasis in architecture was high in the decoration of the exterior facade of mosques and madrasas. In Rishton, however, it was also during this period that koshinpazism was well-riveted that the Masters living in the Dahbed neighborhood of Rishton moved to Samarkand with their families, where they initially practiced primarily koshinpazism. There are also two different views among master potters in this regard. While some of them consider Rishton pottery to be a descendant of Samarkand pottery, most Masters instead believe that pottery has existed in Rishton for a long time.

Research Methodology

This study employs a multidisciplinary methodology integrating historical, archaeological, and art historical approaches to investigate the origins, development, and enduring significance of the Rishton pottery school.

A comprehensive analysis of existing scholarly works, including ethnographic studies (e.g., Peshereva, Burkhonov), archaeological reports, and historical texts, was conducted to establish the current state of knowledge and identify contested narratives regarding the school's origins.

The core of the historical investigation relies on the critical examination of archaeological findings from the Fergana Valley (e.g., Chust culture, Akhsikent) and specific excavations in Rishton (e.g., by G. Ivanov, V.D. Zhukov). This evidence is used to empirically test and challenge established legends and oral histories about the antiquity of pottery in the region.

The evolution of Rishton pottery is situated within broader socio-economic and political contexts, including its position on the Silk Road, the impact of the Mongol invasion, the cultural policies of Amir Temur, and 19th-century colonial economic dynamics (e.g., the introduction of the railway and Russian porcelain).

The study analyzes the unique material practices of Rishton potters, including the classification of local clay types (*hoki surkh*, *hoki siyo*, *reghok*) and the technical terminology for specialized artisans (*zardpaz*, *safedpaz*, *kavudpaz*, *xarjakipaz*) to define the school's distinctive characteristics.

Analysis and Results

The fact that pottery originated in Rishton itself is evidenced by the presence of clay in the Rishton area, which is suitable for pottery production. It is said that there are three types of soil in Rishton.

1. hoki siyo (black soil),
2. Reghok (flax sand),
3. hoki surkh (red soil).

According to the information of old masters, Rishton was located in a depression, and floods often came from the mountains. The floods brought with them bentonite, field sphagnum, and various rocks. As a result, a special soil layer was formed to make the soil juicy. Rishton soil is reddish in color due to the high content of iron oxide. Soil of this color is mainly found in the central regions of Rishton. Based on this, it can be assumed that Rishton pottery was not influenced by Samarkand pottery. In addition, excavations carried out at monuments of the Fergana Valley region such as the Chust culture, Eylaton, Akhsikent, Mingtepa, and the ceramic layers found in them indicate that pottery was formed in the Fergana Valley itself, and there was no need for potters from the distant Samarkand region to come to Rishton to establish this type of craft.

There are other narratives regarding the emergence of Rishton pottery and the long-standing composition of Rishton pottery, which are mainly given a proportion to the presence of this area pottery for more than 800 years. In fact, the emergence of pottery in this region dates back at least to the beginning of the ad period. Several archaeological studies have been conducted with the aim of determining when the Rishton pottery originated. Archaeologist Gennady Ivanov conducted a search in the Rishton district in 1998, 2010, 2011, with the support of the request of the townspeople [5]. Ivanov noted that all ancient layers are now covered with modern buildings or plowed as a result of agricultural work. This made it very difficult and laborious to search for the remains of ancient settlements. There were no archaeological layers in the territory of the modern city and its surroundings. Earlier than Ivanov, in 1939, in connection with the construction of the Great Fergana Canal, Zhukov V.D. conducted archaeological excavations in the Rishton area [6]. He showed in his diagram that there was a mound about 2 meters high in the Sohibi Khidoya cemetery. However, since this mound has not been preserved, Ivanov mainly carried out excavations in and near the Sohibi Khidoya cemetery on the northern outskirts of modern Rishton. The reason for Ivanov's decision was the discovery of many archaeological artifacts in this area and the protection of this place as an archaeological site. According to the results of the excavations, finds were found mainly from the 10^{th} -12^{th} centuries. However, the objects found belonged to a small circle, and the settlement was not very large. According to information provided by Arab geographers of the 10^{th} century, the city of Rishton was described as a large city. The city could not have become so small in such a short time. That is why Ivanov continued additional exploration in 2011 in the northern part of the city of Rishton. As a result, he excavated the Khoja Asror cemetery in the present-day village of Toda, northeast of modern Rishton. The cemetery covered an area of about 3 hectares. Its surface is mostly flat, but in the western part there is a small hill about 40 m high and about 40 m in diameter. Ivanov's research shows that the hill was the site of an ancient settlement. Ivanov did not conduct excavations in this hill area. Because the entire area of the hill has been covered with several layers of graves for more than one hundred and fifty years. They excavated two parts of the cemetery, in the northern and southern parts, where no traces of burials are visible from the surface. In both areas, the layers are 150 cm deep. Among the finds were fragments of pottery that may date back to the first century BC. Ivanov then concluded that the settlement in the Rishton area had occurred no later than the beginning of the AD. This

proves that Rishton pottery was not 800 years old, as is reported in the legends, but much older.

The assumption that the emergence and development of Rishton pottery existed before the Middle Ages is based on many economic and political reasons. This can be attributed to the fact that in the 6th century there was a direct access to the Great Silk Road, which moved northward to the areas inhabited by nomadic tribes. The main trade routes connecting Fergana with Chach (Shosh), Old Asia and the eastern borders of the Caliphate passed through the ancient cities of the Fergana Valley - Kuva, Akhsikent and other places. Fergana was included in the framework of extensive international trade, economic and cultural relations. Since the period of stabilization after the Arab conquest - from the 9th century, the cultural integration of the peoples living in Central Asia, the Near East and the Middle East began to intensify. The integration process, which was generally shaped by the influence of Islam, the Arabic language, and later the Persian language, was accompanied by the rapid growth of cities, the widespread development of science and culture, trade and crafts, and the migration of master craftsmen throughout the Transoxiana region [7]. During the Mongol invasion in the 13th century, these processes stopped. By the time of Amir Temur, the traditions of craftsmanship were not only restored, but also raised to a high level. In particular, due to the development of the architectural sphere, the production of various decorative tiles for mosques and madrasas increased. At the same time, the demand for ceramic products increased. As a result, new centers of pottery appeared during this period. Since there is no information about pottery from the period after Amir Temur to the 18th century, these periods have hardly been studied. Therefore, Rishton pottery from this period is problematic.

By the 19th century, the pottery of this region had developed and continued to produce valuable dishes. At a time when other pottery schools were disappearing, Rishton pottery continued to develop. This is because Russian porcelain products dominated the markets of Bukhara and Samarkand, while such a process did not occur in Fergana. Because the railway entered Fergana only in 1899, 11 years after Bukhara and Samarkand. This, in turn, was the basis for the preservation of the Rishton pottery school. In addition, the unrest in Chinese Turkestan at that time prevented the entry of Chinese porcelain into this region [8]. These factors contributed to the preservation of the pottery of the Fergana Valley, at least for a certain period. Also, potters from Rishton tried to learn the secret of producing Chinese porcelain and established porcelain production in Rishton. The common people could not afford to buy Russian porcelain. This also served to preserve local products. At the end of the 19th century, 10 workshops operated in Rishton. In addition to the workshops, there were mainly three neighborhoods - Chinnigaron, Dukchiyon, and the upper Kulolon neighborhoods - families engaged in pottery in their homes. Almost the entire Rishton neighborhood engaged in pottery was engaged in this craft. Chinnigaran neighborhood was called Kulibegon until the 19th century. “Qulibegon” – “Slave of the Beks” according to the old masters, when the peasants and artisans fell into the hands of the wealthy and beks, the kullos of this area were also under the influence of the beks and worked only for the beks. Other masters interpret this toponym differently. That is, they believe that it was named so because it was the area where the descendants of Master Qulibek lived.

Later, this neighborhood began to be called Chinnigaran. This is due to the establishment of porcelain production in Rishton. The area that has been engaged in pottery since ancient times is the Dukchiyon neighborhood. The most famous master of this neighborhood was Master Abdusattor [9]. The master was also called a zardpaz master. In the Rishton pottery of the 19th-20th centuries, the terms “safedpaz”, “zardpaz”, “kavudpaz” and “xarjakipaz” are found. This product is related to the color of the background. “Xarjakipaz” is mainly red, produced for weddings and ceremonies, and was inexpensive because it was simply decorated.

Conclusion

In conclusion, it can be said that at a time when most of the existing pottery schools in the world were disappearing, Rishton pottery production was not only preserved, but today it is recognized as the center of Central Asian pottery art. Even in the second half of the 19th century, when cheap factory products made in Russia entered our country and Chinese porcelain products occupied the Asian markets, the Rishton pottery school was not only preserved, but is developing and progressing in all respects to this day. True, at some times the industry faced difficulties, but even then, despite various problems, Rishton potters fought to preserve their craft. They created innovations in the field of pottery and put forward new ideas. At a time when attention is increasing worldwide to national traditions and values, nationalism and traditions are being restored in pottery within the framework of craftsmanship in Rishton. At the same time, modern tones are being added to nationality, and the types of pottery products are increasing and developing.

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THE IMPORTANCE OF PHYSICAL MODELS IN SIMULATING DEGRADATION EFFECTS IN GaN NANOWIRE FETS

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Annotatsiya. Mazkur maqolada GaN nanotolali maydoniy tranzistorlarda degradatsion effektlarni modellashtirishda fizik modellarni tanlashning ahamiyati yoritiladi. Nanoo'lchamli qurilmalar texnologiyasining jadal rivojlanishi sharoitida elektr va radiochastotali xususiyatlarni stress holatlarida aniq prognoz qilish ilg'or fizik modellashtirishni talab etadi. Issiq tashuvchilar injeksiyasi, o'z-o'zini qizish effekti, nuqsonlardagi tuzoqlar dinamikasi va polarizatsiya effektlari qurilmaning ishonchliligi va ishlashiga kuchli ta'sir ko'rsatadi. Sentaurus TCAD dasturida ushbu mexanizmlarni tahlil qilish asosida tadqiqot shuni ko'rsatadiki, fizik modellarni to'g'ri tanlash va kalibrovka qilish natijasida simulyatsiya tajriba natijalari bilan yuqori darajada mos keladi. Asosiy modellarning e'tiborsiz qoldirilishi esa ishonchlilikni noto'g'ri prognozlashga olib kelishi mumkin. Bu esa, to'g'ri model tanlashning ilmiy tadqiqotlar va sanoatda ishlab chiqarish amaliyoti uchun zarurligini ta'kidlaydi.

***Kalit so'zlar**: GaN nanotolali MET, degradatsiya effektlari, fizik modellar, Sentaurus TCAD, zatvor kuchlanishini kechikish effekti, stok kuchlanishini kechikish effekti, o'z-o'zini qizdirish effekti, tuzoqlar dinamikasi, ishonchlilik.*

Аннотация. В данной статье рассматривается ключевая роль физических моделей при моделировании деградационных эффектов в нановолоконных полевых транзисторах на основе GaN (NW-FET). С быстрым развитием наноэлектроники точное прогнозирование электрических и радиочастотных (RF) характеристик в условиях нагрузок требует применения продвинутых физических моделей. Такие явления, как инжекция горячих носителей, саморазогрев, динамика ловушек и поляризационные эффекты, существенно влияют на надежность и производительность устройств. Анализ этих механизмов в Sentaurus TCAD показывает, что правильный выбор и калибровка моделей обеспечивает высокую степень соответствия симуляции экспериментальным результатам. Игнорирование ключевых моделей приводит к серьезным ошибкам при прогнозировании gate/drain lag, current collapse и долговременной надежности. Таким образом, корректный выбор

физических моделей является необходимым условием как для научных исследований, так и для промышленных приложений.

Ключевые слова: *GaN нановолоконный ПЭТ, деградационные эффекты, физические модели, Sentaurus TCAD, эффект задержки по затвору, эффект задержки по стоку, эффект саморазогрев, динамика ловушек, надежность.*

Abstract. This article explores the critical role of physical models in simulating degradation effects in GaN nanowire field-effect transistors (NW-FETs). With the rapid advancement of nanoscale device technology, accurate prediction of electrical and radio-frequency (RF) characteristics under stress conditions requires advanced physical modeling. Phenomena such as hot-carrier injection, self-heating, trap dynamics, and polarization effects strongly influence device reliability and performance. By analyzing these mechanisms within Sentaurus TCAD, the study demonstrates how proper selection and calibration of physical models enable simulations to closely correspond to experimental results. The findings highlight that neglecting key models can lead to significant errors in predicting gate/drain lag, current collapse, and long-term reliability, underlining the necessity of precise model choice for both academic research and industrial applications.

Keywords: *GaN nanowire FET, degradation effects, physical models, Sentaurus TCAD, gate lag effect, drain lag effect, self-heating effect, trap dynamics, reliability.*

Introduction

The rapid progress in semiconductor device technology has been driven by the continuous demand for higher performance, miniaturization, and reliability in modern electronic and communication systems. Gallium Nitride (GaN) has emerged as one of the most promising wide bandgap semiconductors owing to its superior material properties, including a wide energy bandgap (~3.4 eV), high breakdown electric field, high electron saturation velocity, and strong thermal stability. These attributes make GaN a leading candidate for high-power, high-frequency, and high-temperature electronic applications, particularly in power electronics, radio frequency (RF) amplifiers, and next-generation wireless communication systems. Among the various device architectures developed using GaN, the nanowire field-effect transistor (GaN-NW FET) has attracted significant attention due to its ability to enhance electrostatic gate control, suppress short-channel effects, and provide a large surface-to-volume ratio that can be exploited for novel functionalities [1-3].

Despite the remarkable advantages offered by GaN nanowire transistors, one of the most critical challenges hindering their commercialization and integration into advanced circuits is the problem of device degradation. Device degradation manifests itself in the form of threshold voltage instability, transconductance reduction, current collapse, gate-lag, drain-lag, and reduced reliability under long-term bias and thermal stress. The underlying mechanisms of such degradations are complex and typically involve surface states, bulk and interface traps, hot-carrier injection, self-heating effects, and defect generation. In particular, the large surface-to-volume ratio of GaN

nanowires, while beneficial for gate controllability, also makes them extremely sensitive to surface defects and trap states. These effects, if not properly understood and mitigated, can severely compromise the performance and long-term reliability of GaN-NW FETs, thereby limiting their usefulness in practical high-frequency and power applications.

The accurate understanding of degradation phenomena in GaN nanowire FETs requires robust experimental characterization and theoretical modeling. However, experimental investigations alone are often limited by complexity, cost, and the difficulty of isolating individual physical mechanisms that contribute to degradation. This is where device simulation, and in particular physics-based Technology Computer-Aided Design (TCAD), becomes indispensable. Through the use of physical models that capture the transport, thermal, and trap-related phenomena, simulations can provide deep insight into the degradation dynamics, enabling the prediction of device behavior under stress conditions and guiding the design of more reliable device architectures. Nevertheless, the accuracy of such simulations is highly dependent on the choice and implementation of physical models. Simplified or incomplete models may lead to misleading predictions, while comprehensive and calibrated models can faithfully reproduce experimental observations and even reveal new insights not easily accessible in the laboratory [4, 5].

Narrowing the focus to GaN nanowire FETs, the critical role of physical models becomes even more evident. Unlike conventional planar GaN HEMTs or MOSFETs, nanowire-based devices exhibit unique transport and degradation characteristics due to their three-dimensional geometry, enhanced quantum confinement, and strong influence of surface and interface trap states. For instance, self-heating is more pronounced in nanowire channels because of limited thermal dissipation pathways, while hot-carrier degradation can be exacerbated due to high electric field concentrations at the nanowire surface. In addition, dynamic trapping and detrapping processes at the nanowire/oxide or nanowire/passivation interface can lead to pronounced gate-lag and drain-lag phenomena, directly affecting RF performance. These unique features underscore the necessity of carefully selecting physical models that account for quantum confinement, trap-assisted tunneling, nonlocal carrier transport, and thermal effects when simulating GaN-NW FET degradation.

Despite the growing research interest in GaN electronics, there remains a notable research gap in the comprehensive simulation of degradation effects in GaN nanowire FETs. Most existing simulation studies on GaN devices focus predominantly on planar HEMTs, where models for trapping, hot carriers, and self-heating are relatively mature. In contrast, the modeling of nanowire-based devices is still at an early stage, and the available studies often simplify or neglect crucial degradation mechanisms. For example, some works consider only static trap models without including the time-dependent capture and emission processes that are essential to describe gate-lag and drain-lag accurately. Others focus mainly on electrical characteristics without properly incorporating self-heating and thermal degradation models. Moreover, very few studies combine multiple degradation mechanisms within a unified framework that can reproduce both the DC and RF characteristics of GaN-NW FETs under stress conditions. This lack of comprehensive and physically accurate models hampers the

ability to predict device lifetime, optimize geometries, and propose strategies for mitigating reliability issues.

Therefore, the objective of this study is to emphasize and analyze the importance of physical models in simulating degradation effects in GaN nanowire FETs [6, 7].

Specifically, this work highlights how various physical mechanisms such as trap-assisted recombination, Shockley–Read–Hall (SRH) statistics, hot-carrier effects, self-heating models, and quantum confinement must be carefully implemented to capture the true behavior of GaN-NW devices [8, 9]. By systematically reviewing and applying these models within TCAD simulations, this study aims to bridge the gap between experimental observations and theoretical predictions. The contribution of this research lies in demonstrating that only through the appropriate integration of advanced physical models can simulation results reliably reproduce degradation-induced phenomena such as current collapse, threshold voltage shift, transconductance degradation, and dynamic RF instabilities. Furthermore, the findings are expected to provide guidelines for researchers and engineers in selecting suitable physical models, thereby accelerating the design of more reliable GaN nanowire FETs for next-generation power and RF applications.

Research Methodology

Simulation and Conditions for Reliable Results

The use of Sentaurus TCAD has become an indispensable approach for modeling the performance and degradation effects in advanced semiconductor devices, particularly GaN nanowire field-effect transistors (NW-FETs). However, obtaining simulation outcomes that can be regarded as both accurate and reliable requires strict adherence to certain methodological and physical principles. Merely running the simulator with default settings may produce results that look consistent but fail to reflect experimental behavior. This section outlines the essential conditions under which simulations in Sentaurus TCAD can lead to scientifically valid predictions.

1. *Accurate Geometry and Meshing Strategy*

The first prerequisite for trustworthy simulations is the correct definition of the device geometry. GaN nanowires often operate at diameters in the range of a few nanometers to several tens of nanometers, where quantum confinement effects become significant. In Sentaurus, constructing the nanowire geometry must be complemented by a well-optimized meshing scheme. A mesh that is too coarse will smooth out steep gradients in potential and carrier concentration, while an excessively fine mesh can lead to unnecessary computational expense without improved accuracy. Adaptive meshing that refines near interfaces, gate edges, and trap-rich regions is usually necessary.

2. *Proper Selection of Physical Models*

Reliable results are heavily dependent on the physical models employed. For GaN NW-FETs, this includes: Carrier transport: Classical drift–diffusion models may underestimate high-field transport effects; hence, hydrodynamic or energy balance models are preferred.

Polarization effects: GaN materials exhibit both spontaneous and piezoelectric polarization. Ignoring polarization or approximating it with fixed charges leads to significant errors in threshold voltage and channel formation.

Quantum corrections: One-dimensional confinement in nanowires requires incorporation of Density Gradient (DG) corrections or Schrödinger–Poisson solvers.

Defect and trap models: Shockley-Read-Hall recombination, trap-assisted tunneling, and surface state models are critical to reproduce degradation effects such as gate lag and drain lag.

Thermal effects: Electrothermal simulations, incorporating lattice heat flow and self-heating models, are essential for predicting current collapse and RF degradation.

3. *Parameter Calibration Against Experimental Data*

Even when all relevant models are selected, parameter calibration remains central. Trap densities, capture cross-sections, mobility degradation coefficients, and thermal conductivity values must be adjusted in line with measured data from fabricated GaN NW-FETs. Without calibration, results may be qualitatively correct but quantitatively inaccurate, reducing their predictive power. Calibration typically involves iterative tuning against transfer and output characteristics, small-signal parameters, and degradation measurements.

4. *Boundary Conditions and Biasing Schemes*

The accuracy of simulation also depends on applying physically meaningful boundary conditions. Contact definitions (Ohmic vs. Schottky), gate dielectric interfaces, and work function choices all influence charge distribution and device threshold. In addition, the simulation should replicate realistic stress conditions used in reliability experiments, such as pulsed biasing for gate/drain lag or constant stress for hot-carrier degradation studies.

5. *Convergence and Stability Considerations*

Numerical convergence can strongly affect the reliability of TCAD results. Failure to converge or oscillations during iterative solutions may indicate poor meshing, unrealistic physical parameters, or incompatible model combinations. Monitoring residual errors and ensuring solution stability under parameter sweeps is essential before interpreting the results.

6. *Sensitivity and Variability Analysis*

For simulations to be considered reliable, it is important to assess sensitivity—that is, how variations in model parameters influence the results. Given the variability of nanowire fabrication, sensitivity analysis helps distinguish between genuine physical trends and simulation artifacts. Monte Carlo or parametric sweeps in Sentaurus can provide insight into robustness.

7. *Documentation and Reproducibility*

Finally, reliable simulations must be transparent and reproducible. Each simulation step, including geometry definitions, physical model selection, parameter calibration, and boundary conditions, should be documented in detail. This ensures that results are not only reliable for one study but can also be compared across different research groups.

Analysis and Results

Accurate and Purposeful Selection of Physical Models

The reliability and predictive power of technology computer-aided design (TCAD) simulations critically depend on the appropriate choice of physical models. When simulating degradation effects in GaN nanowire field-effect transistors (NW-FETs), the problem becomes especially demanding because of the inherent complexity of wide band-gap semiconductors, their susceptibility to trapping phenomena, and the nanoscale geometrical confinement that alters transport mechanisms. An accurate and purposeful selection of physical models is not merely a technical necessity but a central scientific decision that defines the relevance, credibility, and applicability of the obtained results. In this section, we examine the reasoning, criteria, and methodological steps involved in choosing physical models for GaN NW-FET degradation studies.

1. *Fundamental Considerations:*

Before delving into specific models, it is essential to recognize the guiding principles:

Device geometry and dimensionality - Nanowire FETs exhibit quasi-one-dimensional electron transport. Carrier confinement in the radial direction modifies the density of states, scattering processes, and mobility models. Thus, models developed for planar GaN HEMTs or bulk devices cannot be directly transplanted.

Material properties of GaN - GaN is a wide band-gap semiconductor (Eg ≈ 3.4 eV) with strong polarization effects, high critical electric field (>3 MV/cm), and pronounced hot carrier behavior. These properties necessitate models for polarization charges, high-field transport, and defect-mediated degradation.

Timescale of degradation - Degradation may manifest in microseconds (gate/drain lag), milliseconds (trap charging), or long-term device aging (bias-temperature instability). Physical models must capture both short-term dynamic response and cumulative degradation.

2. *Key Physical Effects Relevant to GaN NW-FETs*

2.1 *Carrier Transport Models* - At the heart of any TCAD simulation lies the carrier transport formulation. Three levels are generally considered:

Drift–diffusion (DD) model - Simplest approach, solving Poisson's and continuity equations. While adequate for low-field regions, it fails to capture hot carrier and velocity saturation effects that dominate GaN NW-FETs.

Hydrodynamic (HD) model - Incorporates carrier temperature equations, enabling simulation of hot-electron phenomena, energy relaxation, and self-heating. This is crucial for degradation studies where high electric fields accelerate carriers, producing interface states.

Monte Carlo (MC) simulation - Considered the most accurate for GaN transport, it solves the Boltzmann transport equation stochastically. However, it is computationally expensive and impractical for full-device transient degradation studies. A calibrated HD model often offers a good compromise.

2.2 *Polarization Effects* - GaN and its alloys exhibit spontaneous and piezoelectric polarization, leading to built-in charges at heterointerfaces. In nanowire geometries, the surface-to-volume ratio amplifies polarization effects, which significantly influence threshold voltage stability. A reliable simulation must include polarization charge models consistent with crystallographic orientation and strain.

2.3 *Trap and Defect Models* - Degradation in GaN NW-FETs is intimately tied to traps:

Shockley–Read–Hall (SRH) recombination: Basic framework for trap-assisted recombination.

Trap-assisted tunneling (TAT): Important under high electric field, allowing carriers to tunnel via defect states.

Surface traps and border traps - Particularly significant in nanowires because of the large surface area. Surface states are a primary cause of current collapse, gate lag, and dynamic on-resistance increase.

Accurate modeling requires specifying trap energy levels, capture cross-sections, and spatial distributions. Experimental calibration (e.g., deep-level transient spectroscopy data) is often indispensable.

2.4 *Self-Heating and Thermal Transport* - GaN devices operate at high power densities. In NW-FETs, the confined geometry reduces thermal dissipation, exacerbating self-heating. Degradation accelerates due to elevated channel temperature, which modifies carrier mobility and enhances trap activation. Thus, lattice heat flow equations and temperature-dependent material parameters are mandatory.

2.5 *Reliability-Oriented Effects* - Several degradation pathways have been identified in GaN devices:

Hot carrier degradation (HCD): energetic electrons create interface states or displace atoms.

Bias temperature instability (BTI): threshold voltage shifts due to long-term trap charging.

Electrothermal degradation: progressive reduction of mobility and breakdown strength due to cumulative heating.

Purposeful physical model selection must ensure that each of these mechanisms is represented.

3. *Criteria for Purposeful Model Selection* - The term “purposeful” highlights that model choice must be aligned with the research objectives. Four primary criteria can be identified:

Accuracy vs. computational efficiency: For exploratory device design, simplified DD models may suffice. For degradation analysis, however, at least HD transport is essential, with selective MC validation.

Relevance to degradation mechanism: If gate lag is the focus, surface trap models are indispensable. If hot carrier degradation is under study, energy-dependent impact ionization models become central.

Calibration feasibility: A model must be parameterized against experimental data. Overly complex models without measurable parameters risk producing unreliable predictions.

Scalability and transferability: Models should remain valid across device sizes, bias conditions, and timescales of interest.

4. *Methodological Steps in Model Selection* - A systematic methodology can be outlined:

Problem Definition: Identify the degradation phenomenon: e.g., current collapse, drain lag, threshold shift.

Phenomenological Mapping: Relate the degradation effect to underlying physics: traps, heating, hot carriers.

Model Inventory: Enumerate available physical models in TCAD libraries (drift–diffusion, hydrodynamic, SRH, etc.).

Prioritization: Choose the minimum model set that captures the relevant physics without unnecessary overhead.

Calibration: Fit model parameters to experimental data: DC I–V, pulsed I–V, capacitance–voltage, or RF S-parameters.

Validation: Compare model predictions against independent degradation metrics, such as threshold voltage shift under stress.

5. *Case Study: Gate Lag in GaN NW-FETs* - To illustrate purposeful model selection, consider gate lag— a transient reduction of drain current after pulsed gate bias.

Physics involved: surface/border traps, trap charging/discharging dynamics.

Required models: SRH recombination, trap-assisted tunneling, surface recombination velocity, and transient simulation capability.

Complementary models: thermal coupling if lag is temperature dependent.

Validation metrics: pulsed I–V measurements showing drain current recovery.

Here, using a full hydrodynamic transport model may not be necessary; instead, precise trap modeling and transient simulation are more critical. This demonstrates how purposeful selection avoids unnecessary complexity while capturing essential physics.

6. *Common Pitfalls in Model Selection* - Several errors frequently compromise TCAD degradation simulations:

Overgeneralization: applying planar GaN HEMT models to nanowires without modification.

Neglect of calibration: relying on default trap parameters not anchored in experimental data.

Ignoring surface effects: underestimating surface trap dominance in NW devices.

Overcomplication: deploying all possible models simultaneously, leading to numerical instability without added insight.

Recognizing these pitfalls helps refine purposeful modeling strategies.

7. *Towards Multiscale and Hybrid Modeling* - Future progress in GaN NW-FET degradation simulation will increasingly rely on multiscale approaches:

Atomistic input: density functional theory (DFT) for defect levels.

Device-scale TCAD: hydrodynamic models incorporating trap dynamics.

Circuit-level compact models: extracting degradation parameters for RF circuit reliability. Purposeful model selection must therefore consider not only device-level accuracy but also compatibility with higher-level modeling frameworks.

8. *Contribution of Purposeful Model Selection to Scientific Progress* - The careful choice of physical models contributes in several ways:

Improved predictive accuracy: reliable estimation of lifetime and RF performance.

Efficient computation: focusing resources on relevant mechanisms.

Clarity of interpretation: isolating causal mechanisms of degradation.

Transferability: generating insights applicable to broader classes of GaN devices.

Thus, accurate and purposeful selection of models transforms TCAD from a descriptive tool into a predictive and explanatory scientific instrument.

Conclusion

In this study, the importance of accurate and purposeful selection of physical models in simulating degradation effects in GaN nanowire field-effect transistors (NW-FETs) has been emphasized. Through a systematic review of transport, polarization, quantum confinement, defect/trap, and thermal models, it has been shown that the fidelity of Sentaurus TCAD simulations strongly depends on how carefully these models are chosen and calibrated against experimental data. Neglecting key effects such as self-heating, surface traps, or piezoelectric polarization inevitably leads to discrepancies between simulations and real measurements, particularly when predicting gate/drain lag, current collapse, or RF performance degradation.

Furthermore, the discussion on simulation reliability highlighted that mesh design, boundary conditions, biasing schemes, and numerical convergence are equally critical in ensuring meaningful results. Without considering these methodological aspects, even advanced physical models cannot guarantee predictive accuracy. Importantly, calibration with experimental benchmarks remains the cornerstone of bridging simulation and practice, transforming numerical results into physically interpretable and reliable insights.

Overall, this research underscores that TCAD-based modeling of GaN NW-FETs is not merely a numerical exercise but a physics-driven methodology. By properly integrating physical models, ensuring calibration, and adopting best practices in simulation setup, researchers can achieve reliable predictions that advance both the fundamental understanding of degradation mechanisms and the practical development of robust GaN nanodevices for high-power and high-frequency applications.

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UDC: 53, 537, 539

STUDY OF THE PROCESSES OF TEMPERATURE MIGRATION OF IRON EXOATOM ON THE SURFACE OF FULLERENE C_{60} BY MOLECULAR DYNAMICS METHODS

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Annotatsiya. Maqola molekulyar dinamika usullari (LAMMPS) yordamida erkin fulleren C_{60} yuzasida temir ekzoatomining dinamik migratsiya jarayonini o‘rganadi. Temir ekzoatomining aniq migratsiyasi 1000K dan yuqori haroratlarda sodir bo‘lishi aniqlandi. 1100K haroratda, asosan, ekzoatomning sakrashlari, dastlabki holatiga qaytishi kuzatiladi. Ekzoedral fullerenlarning sintezi va kimyosi sohalari uchun amaliy ahamiyatga ega bo‘lishi mumkin bo‘lgan xarakterli o‘tish vaqtlari diapazoni belgilanadi.
Kalit so‘zlar: *temir atomi, fulleren, ekzoatom, modellashtirish, migratsiya, qirralar, harorat, energiya.*

Аннотация. В работе исследован динамический процесс миграции экзоатома железа по поверхности свободного фуллерена C_{60}, методами молекулярной динамики (LAMMPS). Получено, что выраженная миграция экзоатома железа происходит при температурах выше 1000К. При температуре 1100К, наблюдаются в основном перескоки экзоатома, с возвратом в исходное положение. Установлен диапазон характерных времен переходов, что может представлять практический интерес для областей синтеза и химии экзоэдральных фуллеренов.
Ключевые слова: *атом железа, фуллерен, экзоатом, моделирования, миграция, ребра, температура, энергия.*

Abstract. The paper studies the dynamic process of migration of iron exoatom on the surface of free fullerene C_{60} using molecular dynamics methods (LAMMPS). It is found that pronounced migration of iron exoatom occurs at temperatures above 1000K. At a temperature of 1100K, jumps of the exoatom are

mainly observed, with a return to the initial position. The range of characteristic transition times is established, which may be of practical interest for the areas of synthesis and chemistry of exohedral fullerenes.

Keyword: *iron atom, fullerene, exoatom, modeling, migration, edges, temperature, energy.*

Introduction

Iron and fullerene derivatives attract the attention of researchers due to the possibility of synthesizing new magnetic materials, catalysts, and biologically active compounds based on them. The characteristics of iron fulleride FeC_{60} and organometallic complexes of fullerene C_{60} with ferrocene and iron carbonyls have been studied in most detail [1–6]. Organometallic complexes of iron and fullerene are synthesized by exchange reactions in organic solutions [5, 6]. Iron fullerene can be obtained by chemical methods, such as the decomposition of ferrocene and fullerene complexes [1], gas-phase reactions [7], or direct synthesis of fullerene in an arc discharge using iron-containing graphite electrodes or a Fe $(CO)_5$ medium [8].

Literature Review

Crystalline FeC_{60} has superparamagnetic properties [1]. In [9], iron complexes with fullerene were obtained in a flow of iron-doped carbon-helium plasma formed by a high-frequency electric arc of alternating current. Iron powder or wire was placed in the hole of one of the electrodes. Iron-containing mixtures of fullerenes, isolated from fullerene soot by organic solvents, were used to synthesize water-soluble iron-fullerene products with biological activity [10]. In [11, 12], the possibility of synthesizing derivatives of d-transition metal fullerenes by the reaction of fullerenes with metal acetylacetonates, occurring in the combustion mode, was shown.

The existence of FeC_{60} complexes in the gas phase was detected by mass spectroscopy [13], thereby experimentally demonstrating that the binding energy of Fe to C_{60} is quite high. The Fe–C bond lengths were determined for both endohedral $Fe@C_{60}$ and external FeC60 complexes using EXAFS [14]. In other experiments, iron was introduced into the fullerene matrix either by implantation of Fe ions [15], deposition of metal vapor [16], or diffusion of FeCIl4− ions [17]. In the present work, migration of iron exoatom on the surface of fullerene C_{60} was studied using mathematical modeling methods.

Research Methodology

This study employed molecular dynamics (MD) simulations using the LAMMPS software package to investigate the thermal migration of an iron (Fe) atom on the surface of a C_{60} fullerene. A stable geometric model of a C_{60} fullerene was created and its energy was minimized. An iron atom was then randomly placed near the fullerene surface. Further energy minimization procedure was performed to identify the most stable initial configurations for the Fe–C_{60} system, where the exohedral iron atom typically localized on the edges between carbon atoms. The system was heated within an NVT (canonical) ensemble thermostat across a temperature range of 800–1500 K (in 100 K increments). Each simulation ran for 2000 picoseconds (ps) with a time step of 0.001 ps. The migration of the iron atom was tracked by analyzing the time-

dependent series of its binding energy to the fullerene, recorded every 0.1 ps. Changes in this energy signature were used to identify atomic jumps between local minima on the fullerene surface. The process was also visually monitored.

Analysis and Results

The model experiment was constructed as follows. A geometric model of the C_{60} fullerene was created, which was minimized to obtain a stable configuration. Then, an iron atom was randomly placed above the stable configuration of the fullerene. The minimization procedure (of energy) was carried out, which allowed us to establish the most stable configurations of the fullerene with an iron exoatom. Within the framework of the potential used, it was found that the iron atom can be localized both in the center of the fullerene faces (a small part), between the edges (with a deviation from the center, on the edges), between carbon atoms, and most of the localization occurs on the edges or between them (Figure 1).

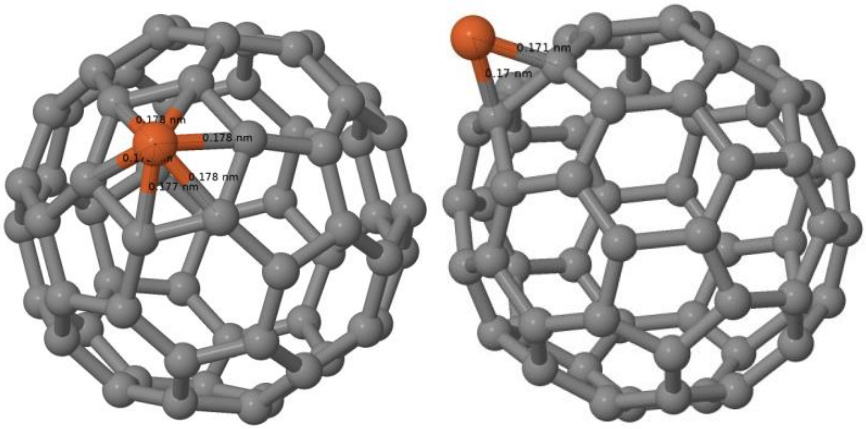

Figure 1. Examples of localization of iron exoatom on the fullerene surface after the energy minimization procedure.

Then, the fullerene was heated in the NVT thermostat, the process duration was 2000 ps, the time step was 0.001 ps (temperatures were 800-1500 K with a step of 100 K). To track the migration of the iron exoatom, time series of the binding energy of the iron exoatom with the fullerene were derived (with a step of 0.1 ps). The migration of the exoatom will be noticeable by the time dynamics of the binding energy. Figure 2 shows an example of exoatom migration at different moments in time.

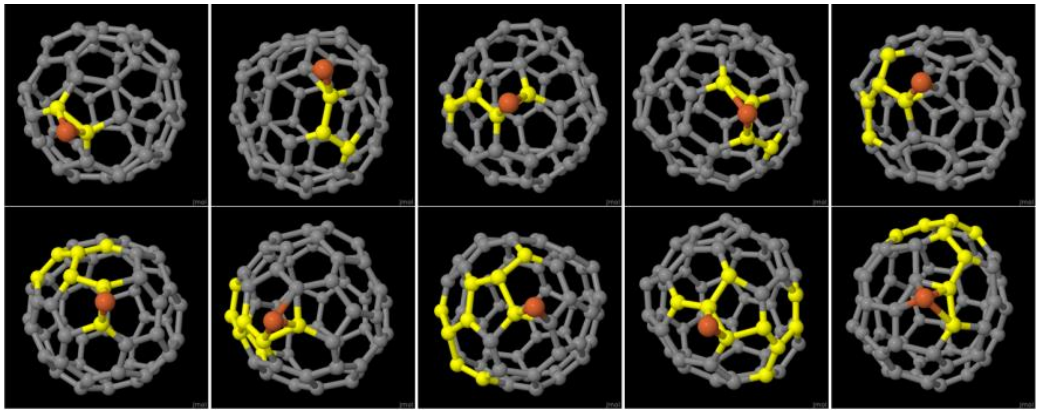

Figure 2. Migration of an iron atom on the surface of a fullerene, process time -2000 ps.

The simulation results show that at temperatures below 1000K, migration of the iron atom is not observed. At temperatures of 1100K and above, jumps of the iron exoatom between local minima are observed. At a temperature of 1100K, jumps of the exoatom are mainly observed, with a return to the original position.

An example of a time series for a temperature of 1300K is shown in the graph, Figure 3.

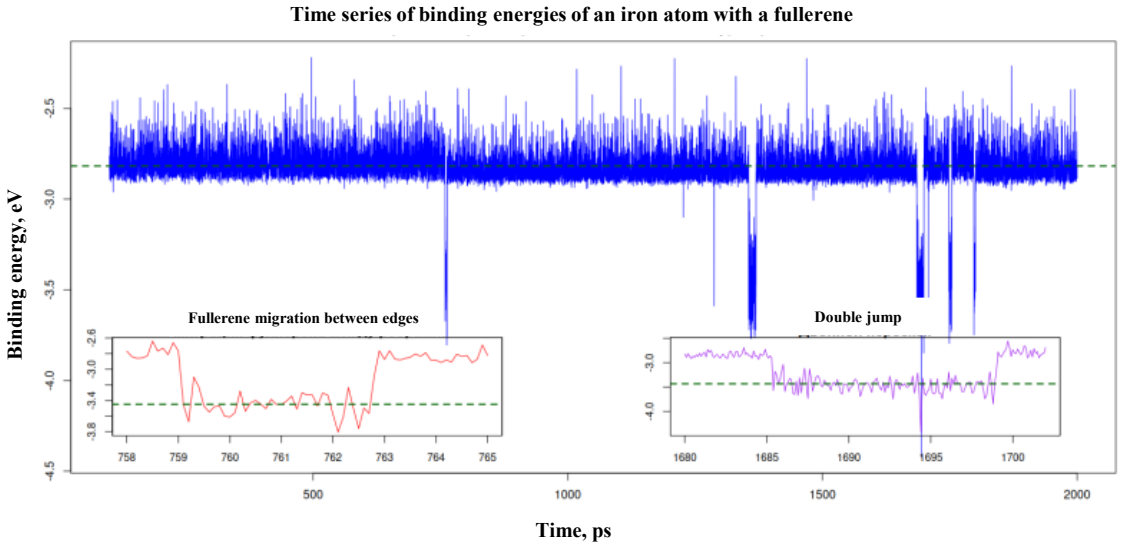

Figure 3. Time series of exoatom binding energy.

As can be seen from the graph, peaks with a depth of 0.6 eV can be distinguished by the amplitude. Also, relatively "narrow" peaks can be seen on the graph. Peaks with a larger amplitude can correspond to the migration of the exoatom from edge to edge along the trajectory closer to the center of the fullerene face, which is qualitatively explained by the increase in the contribution of attractive forces when the exoatom moves closer to the center of the face. Relatively narrow peaks correspond to the case when the exoatom did not jump from edge to edge. The characteristic times of the exoatom migration process between local minima, as can be seen from the graph, are 3-15 ps. Consideration of the dynamics of the process allows us to assume that the migration of the exoatom is mainly due to temperature deformations of the fullerene.

Conclusion

In this work, the process of temperature migration of an exo-atom on the surface of a fullerene is estimated using molecular dynamics methods. Within the framework of the potential used, a threshold temperature is established, starting from which migration of an exo-atom can be observed. A range of characteristic transition times is established, which may be of practical interest for the areas of synthesis and chemistry of exohedral fullerenes.

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NUMERICAL CALCULATION OF OPTIMAL DURATION AND TEMPERATURE OF DIFFUSION OF IMPURITY ATOMS OF SULFUR AND MANGANESE

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Annotatsiya. Maqolada diffuziya jarayonini hisoblashning raqamli usuli keltirilgan bo‘lib, unda diffuziyaning davomiyligi va harorat sharoitlari oldindan belgilanishi mumkin. Tadqiqot ob’ektlari sifatida oltingugurtning nopoklik atomlari va monokristalli kremniy tarkibidagi marganetsning o‘tish elementi tanlangan. Oltingugurt va marganets bir kristalli kremniyga ketma-ket tarqaladi deb taxmin qilinadi, oltingugurtning diffuziya harorati mos ravishda 1250 °C, marganetsniki esa 1200 °C deb tanlangan. Diffuziya oltingugurt uchun 10 minut, 30 minut, 1 soat, 3 soat, 5 soat, 10 soat, 15 soat va 20 soat oraliqlar uchun raqamli hisoblangan. Barcha holatlar uchun marganetsning diffuziya davomiyligi 30 minut qilib tanlangan. Raqamli hisob-kitoblar natijalariga ko‘ra, oltingugurt va marganets aralashmalarining kontsentratsiyasini tenglashtirishni ta’minlaydigan 1250 °C oltingugurt diffuziya haroratida 140 μm gacha bo‘lgan chuqurliklar uchun optimal diffuziya davomiyligi 5 soatni tashkil qiladi deb taxmin qilish mumkin.

Kalit so‘zlar: *sonli xisoblash modeli, kremniy, gibrid tuzilma, yarimo‘tkazgich, diffuziya, konsentratsiya, diffuzion profil.*

Аннотация. В работе представлен численный метод расчета процесса диффузии, при котором длительность и температурные условия диффузии могут быть заданы заранее. В качестве объектов исследования были выбраны примесные атомы серы и переходного элемента марганца в монокристаллическом кремнии. Предполагается, что сера и марганец диффундируют в монокристаллический кремний последовательно, при этом температура диффузии серы была выбрана равной 1250 °C, а марганца

– 1200 °C соответственно. Диффузия численно рассчитывалась для интервалов 10 минут, 30 минут, 1 час, 3 час, 5 час, 10 час, 15 час и 20 час для серы. Для всех случаев длительность диффузии марганца была выбрана равной 30 минут. На основании результатов численных расчетов можно предположить, что для глубин до 140 мкм при температуре диффузии серы 1250 °C оптимальной продолжительностью диффузии, обеспечивающей выравнивание концентраций примесных атомов серы и марганца, оказалось 5 часов.

Ключевые слова: *численная модель, кремний, гибридная структура, полупроводник, диффузия, концентрация, профиль диффузии.*

Abstract. The paper presents a numerical method of the diffusion process whereas duration and temperature conditions of the diffusion could be set finetuned in advance. Impurity atoms of sulfur and the transition element manganese in single-crystal silicon were selected as objects of study. Sulfur and manganese were supposed to be diffused into single crystalline silicon in sequence while the diffusion temperature of sulfur was chosen to be 1250 °C and of manganese 1200 °C, respectively. Diffusion was numerically calculated for intervals 10 minute, 30 minute, 1 hour, 3 hours, 5 hours, 10 hours, 15 hours and 20 hours for sulfur. For all cases, the duration of diffusion of manganese diffusion was chosen as 30 minutes. Based on the numerical calculation results, it can be assumed that for depths up to 140 μm at a diffusion temperature of 1250 °C for sulfur, the optimal diffusion duration to ensure that concentrations of impurity atoms of sulfur and manganese would equal to each other, was revealed to be 5 hours.

Keywords: *numerical model, silicon, hybrid structure, semiconductor, diffusion, concentration, diffusion profile.*

Introduction

The issue of formation of compounds between elements of groups III, V and II, VII and monocrystalline silicon has recently been the subject of a number of interesting scientific investigations [1].

In this paper, the objects of study were sulfur and transition element manganese impurity atoms in single-crystal silicon. The problem of ensuring interaction between sulfur and manganese impurity atoms in the bulk of single-crystal silicon in order to build Si_2MnS-type hybrid phases in the course of diffusion doping could be solved within the framework of appropriate technological process. Often, due to different diffusion coefficients and evaporation temperatures, technological options for implementing the diffusion process (combined or sequential processes, duration, etc.) it becomes frantic experience to find and ensure such interaction by constant trial and error and numerous experiments and checking facts whether such structures form locally in the bulk of silicon by implementing electrophysical and optical experiments, XRD analysis. Such an approach is characterized by enormous waste of time, resources and energy.

Numerical modeling the diffusion process with a preliminary option that envisages flexible setting of duration and temperature conditions would, in part, help to simplify

and rationalize the process of searching for optimal technological conditions to ensure that concentrations of dopants in the bulk of silicon would equal to each other, compare the results and develop a prognosis mechanism that would enable the "only" appropriate method.

Literature Review

In [2, 3] the authors give a thorough information on thermodynamic conditions and technological stages of formation of ZnS-type binary unit cells in single-crystal silicon with the participation of impurity atoms of elements of groups II and VI – zinc (Zn) and sulfur (S).

A number of literature sources [4, 5] have suggested that silicon-carbon and silicon-oxygen complexes might form in the bulk of single crystal silicon during cooling and $SiA_{II}^{2-}B_{VI}^{2+}$ type complexes alike. In particular impurity atoms of manganese and sulfur might also be players in forming such complexes, which puts forward the idea of the formation of electrically neutral molecules $S^{++}Mn^{--}$), [$S(s^2p^4)$-$2e$=$S^{++}(s^2p^2)$ and $Mn(d^5s^2)$+$2e$=Mn^{--} (s^2p^2)] between these impurity atoms.

The paper [6] reports that sulfur impurity centers actively interact with transition metal impurity centers to form electrically neutral chemically bonded complexes.

Buildup of electrically neutral chemically bonded complexes in the bulk of silicon could improve the functional parameters of semiconductor structures [7-9].

In particular, one could harness the functional properties of single crystalline silicon by embedding non-isovalent compounds in the crystal lattice ($Si_2A_{II}B_{VI}$ -type), which would represent a hybrid of the cubic lattice of silicon *Si* and sphalerite *ZnS* (cubic modification) [10].

In [11-15] the investigators have proposed that hybrid phases of Si_2AlP (or Si_2ZnS) with lattice constants close to the lattice constant of the base matrix could become the right materials with fine tunable local chemical order in the vicinity Si atoms. In the above-mentioned studies, using the first-principles calculation methods, the authors discuss the impact of chemical order on electronic and optical properties of non-isovalent solid solutions.

Research Methodology

To study the diffusion profile (across depth) in silicon samples doped with manganese and sulfur atoms based on the developed technology, the silicon sample was successively doped with sulfur and manganese impurity atoms. The doping of impurities into silicon samples was carried out by implementing diffusion from the gaseous phase in vacuumed quartz ampoules. Samples of single-crystal silicon of the boron-doped-silicon - 3 with an initial specific resistance of ρ = 3 Ohm·cm were used as initial ingots.

Thus, alloying with sulfur and manganese was carried out by diffusion process in the sealed quartz ampoules pre-evacuated (10^{-4} mm Hg) at a temperature of 1260 °C and 1200 °C, respectively for a duration sufficient for ensuring uniform alloying. Numerical calculation was performed for diffusion durations for sulfur of 10 minute, 30-minute, 1 hour, 3 hours, 5 hours, 10 hours, 15 hours and 20 hours. For all cases, duration of diffusion of manganese was 30 min.

To simulate the diffusion profile of Mn and S impurity atoms into silicon at different temperatures and diffusion times, the Mathcad software suite was used. During the calculations, the diffusion distribution of impurity atoms was determined using the diffusion equations from infinite and finite sources and the Arrhenius diffusion equation alike:

$$D = D_0 \exp\left(\frac{-Q_d}{kT}\right) \quad (1)$$

For the case of sequential diffusion, the model was considered for diffusion temperatures of 1250 °C for sulfur and 1200 °C for manganese, respectively.

Analysis and Results

It was revealed that as the diffusion time of impurity S atoms into silicon increased, so the depth of their penetration into the samples increased significantly. Also, we had observed a tendency of the increase of concentration of impurity sulfur atoms across the depth.

Thus, as a result of diffusion carried out for 10 min S atoms penetrated to a depth of about 380 μm, and at this depth their concentration was equal to 10^{14} cm^{-3}. On the surface, the concentration of sulfur atoms was 9.5×10^{15} cm^{-3}. At 10 minutes, first to a depth of 100 μm, the concentration decreased from 9.5×10^{15} cm^{-3} down to 9.3×10^{15} cm^{-3}. From 100 μm to 380 μm, a sharp decrease in concentration was observed and at a depth of 290 μm, the concentration decreased by an order of magnitude, while at depth of 380, the concentration decreased almost 100 times and was 10^{14} cm^{-3} (Figure 1 (a)).

With the increase in diffusion time the penetration depth increased and at 30 min it was 520 μm (Figure 1 (b)), 1 hour. – 660 μm (Figure 1 (c)), and after 3-hour diffusion the penetration depth of atoms reached 900 μm (Figure 1 (d)). Theoretical calculation shows that starting from the duration of 10 minutes the surface concentration of the diffusant gradually begins to increase and at the duration of 20 hours it is approximately 2.3×10^{16} cm^{-3} (Figure 1 (k)).

Simultaneously with the increase of the duration of diffusion the curve becomes less sloped, which indicates the dynamics of a sharp increase in the concentration over cross-section. For example, with a diffusion duration of 5 hours, the concentration at a depth of almost 900 μm and above decreases by only an order of magnitude and tends to be 2.3×10^{15} cm^{-3} (Figure 1 (e)). With a further increase in the diffusion duration, starting from 5 hours to 20 hours, the penetration depth of atoms also reached and exceeded 900 μm, and the concentration at a depth of 900 μm was 5.8×10^{15} cm^{-3}, whereas the concentration on the surface of a millimeter sample was approximately 2.4×10^{16} cm^{-3} (Figure 1 (j, k)). Thus, within 20 hours the penetration depth of atoms reached 900 μm, the surface concentration increased from 9.5×10^{15} cm^{-3} to 2.4×10^{16} cm^{-3}, and the concentration of sulfur atoms along the cross section showed a dynamic of sharp growth.

As it is seen from graphs the concentration of both sulfur and manganese impurity atoms equal to each other at a diffusion duration of 5 hours and then with increasing diffusion time the concentrations began to be equalized by the sample depth. However, starting with a diffusion duration of 5 hours, a slight excess in the concentration of

sulfur impurity atoms over manganese impurity atoms was revealed in the range from 50 μm to 630 μm. After crossing the penetration depth of 630 μm, the concentration of sulfur impurity atoms began to decrease and the concentration of manganese impurity atoms prevailed (by an order of magnitude, Figure 1 (e)).

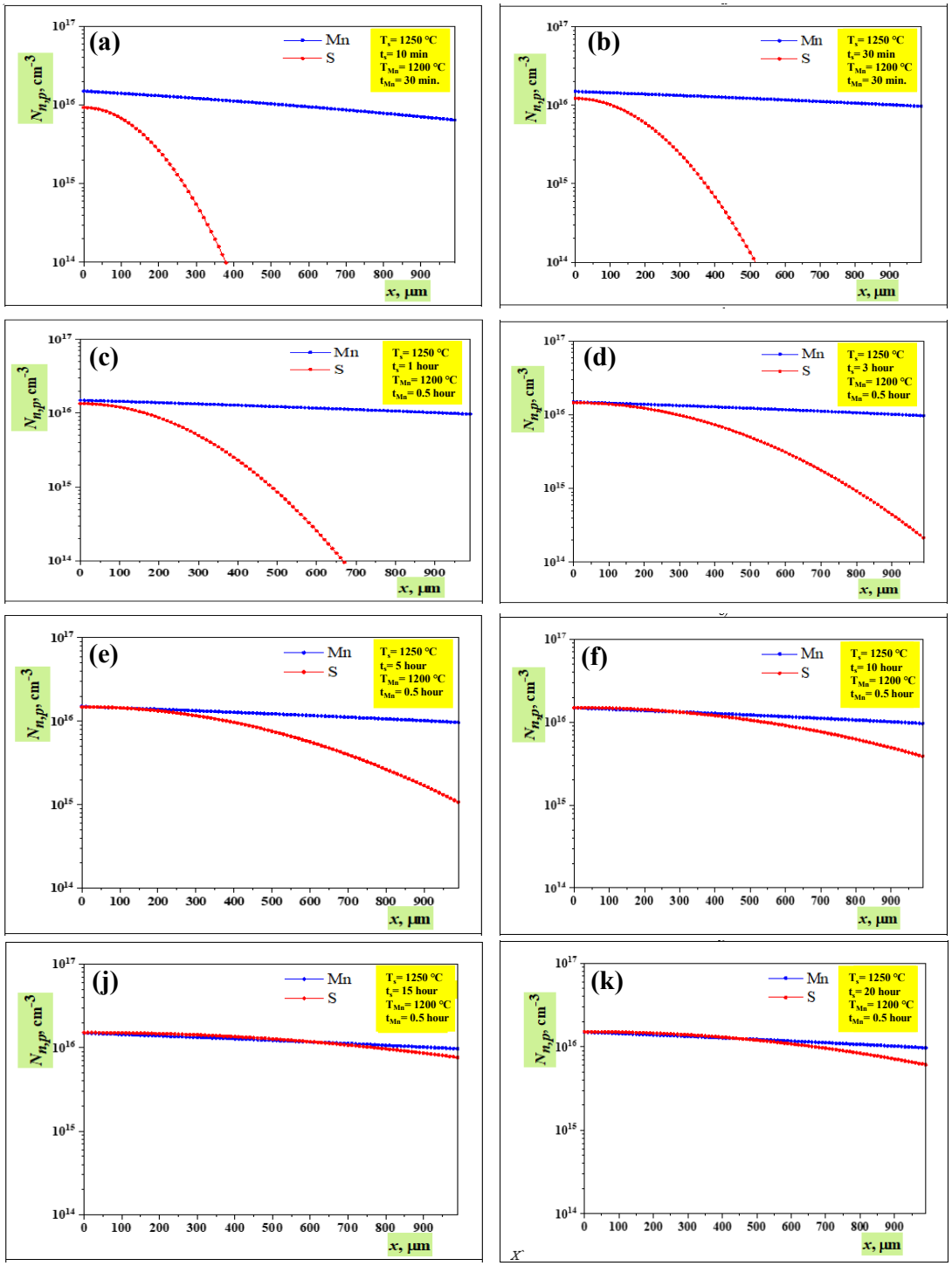

Figure 1. Numerical modelling results of the penetration depth of impurities and the concentration of sulfur and manganese atoms in silicon (time duration-breakdown) during sequential diffusion.

Thus, based on the results of the theoretical calculation, it can be assumed that for depths up to 140 μm at a diffusion temperature of 1250 °C for sulfur, the optimal diffusion duration to ensure that the concentrations of impurity atoms of sulfur and

manganese would equal to each other tends to be 5 hours (Figure 1 (e)). A further increase in the diffusion time of sulfur leads to non-uniformities in the concentration and penetration depth of impurity atoms of sulfur, is well seen in sections where either is an excess or a slight decrease in the concentration of impurity atoms of sulfur and the sections of a sharp decrease in the penetration depth of sulfur atoms. For example, at a depth of 900 μm, the concentration of impurity atoms of sulfur is an order of magnitude lower than the concentration of manganese atoms with a diffusion duration of 5 hours.

With increasing diffusion time of Mn atoms into silicon, no significant changes in their distribution vs depth were observed. Initially, as a result of diffusion carried out for 10 minutes, Mn atoms were distributed according to the law of 2.4×10^{16} cm^{-3} on the surface and (2.4×10^{16} - 20% (of the surface concentration)) cm^{-3} at a depth of 900 μm. However, with increasing diffusion time, this difference was negligent, and the concentration became the same throughout the depth of the silicon crystal and fluctuated within 2.4×10^{16} cm^{-3} (Figure 1 (c-k)). Even with a diffusion duration of 10 and 20 hours, the concentration of Mn atoms with depth remained virtually unchanged and always remained stable ≈ 2.4×10^{16} cm^{-3}.

Conclusion

Thus, based on the results of theoretical calculations, it can be assumed that for depths up to 160-170 μm at a diffusion temperature of 1250 °C for sulfur, the optimal diffusion duration to ensure that the concentrations of impurity atoms of sulfur and manganese would equal to each other, tends to be 5 hours. A further increase in the diffusion time of sulfur leads to unevenness in the concentration and penetration depth of impurity atoms of sulfur, expressed in sections where either there is an excess or a sharp decrease in the concentration of impurity atoms of sulfur and also in sections of a sharp decrease in the penetration depth of sulfur atoms.

While analyzing the dynamics whereby the concentration of S and Mn impurities ($N_{n,p,}$ cm^{-3}) get closer with increasing diffusion time, it was noted that their concentrations ($N_{n,p,}$ cm^{-3}) became closer with increasing diffusion time starting from 1 hour (the dynamics noticeably accelerates) and optimally from 3 to 10 hours. As the diffusion time increased, the difference between the concentrations of S and Mn impurities in silicon steadily decreased. In general, it can be stated that the solubility limit of interstitial S atoms increased with increasing diffusion time.

Numerical modeling of the diffusion process with an option of preliminary flexible fine-tuning of duration and temperature conditions would, in part, help to simplify and rationalize the process of searching for optimal technological conditions to ensure that the concentrations of doped impurities in the volume of silicon would equal to each other, as well as compare the results and develop a predictive mechanism for choosing the “only” right method of diffusion.

The formation of Si_2MnS-type hybrid silicon structures in the matrix or on the surface layers of silicon will most likely be translated in the expansion of the absorption range in certain regions of the spectrum. Experiments on measuring the photoconductivity spectrum could incidentally help to prove or disapprove this assumption.

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