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MUROJAAT UCHUN MANZIL:
Pochta manzili: 180003, Qarshi, Ko‘chabog‘,17.Qarshi davlat universiteti, Filologiya fakulteti binosi, 107-xona.
Telefon: 97-222-10-80
TelegramID:
https://t.me/Qardu_Xabarlari2024
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МЕХАНИЗМЫ ФОРМИРОВАНИЯ МЕТАЛЛИЧЕСКИХ ТОНКИХ ПЛЕНОК ПОЛУЧЕННЫХ ИОННО-ПЛАЗМЕННЫМ МЕТОДАМИ

Ташатов Алланазар
Каршинский государственный университет, профессор
ORCID 0009-0006-0164-829X
atashatov@mail.ru
Эшбобоев Сардор
Каршинский государственный университет
ORCID 0009-0006-0164-829X
atashatov@mail.ru
Нормуродов Дилшод
Каршинский государственный университет, доцент
ORCID 0009-0000-7454-5917
normurodovdilshod2110@gmail.com
Шохимардонов Жамолиддин
Каршинский государственный университет, докорант
ORCID 0009-0001-5586-3239
shjmadu@gmail.com
Бердиева Садина
Каршинский государственный университет, магистрант
ORCID 0009-0005-0133-8892
sadinaberdiyeva6@gmail.com
УДК 533.537

Аннотация. В работе проведён анализ РФЭС-спектров переходного металла в металлическом состоянии. Установлено, что для уровня 2p3/2 энергия связи составляет 852,6 эВ, а полная ширина пика на полувысоте - 1,8 эВ. Эти наблюдения показывают изменения характеристик пиков, такие как сужение ширины пика и сокращение асимметрии, что связано с процессом силицидирования. Важным инструментом для более глубокого понимания наблюдаемых сдвигов ЭС является исследование характерных РФЭС - линий для тех же самых образцов. Силицидные соединения переходных металлов были синтезированы в виде кристаллических тонких пленок, нанесенных на пластины Si с помощью распыления и последующим отжигом. Структурные, фазовые и поверхностные химические характеристики образовавшихся силицидов были проанализированы с использованием рентгеновской дифракции и РФЭС для получения атомных спектров. Химический сдвиг для состояния $2p_{3/2}$ Ni в случае перехода от Ni к $NiSi_2$ составил +2,0 эВ, что в основном обусловлено эффектами начального состояния, в то время как эффекты конечного состояния оказывают менее значительное влияние. Для других силицидных соединений сдвиг энергии связи был значительно меньшим (менее 0,3 эВ), и приводил к положительным или отрицательным химическим сдвигам, что связано с компенсационными эффектами начальных и конечных состояний.

Ключевые слова: Силицид никеля, морфология поверхности, оптическая спектроскопия, элементного состава, электронных свойств, тонкие пленки, энергия связи, рентгеновская дифракция, романовский спектр.

MECHANISMS OF FORMATION OF METALLIC THIN FILMS OBTAINED BY ION-PLASMA METHODS

Abstract. In X-ray photoelectron spectroscopy (XPS) spectra, it is shown that for the $2p_{3/2}$ level of the transition metal, the peaks in the metallic state have the following binding energy and full width at half maximum (FWHM): 852,6 eV (1,8 eV), respectively. These observations indicate changes in peak characteristics, such as peak narrowing and a reduction in asymmetry, which are associated with the silicidation process. An important tool for a deeper understanding of the observed binding energy shifts is the investigation of characteristic XPS lines for the same samples. Transition metal silicide compounds were synthesized in the form of crystalline thin films deposited on Si substrates by sputtering followed by annealing. The structural, phase, and surface chemical characteristics of the formed silicides were analyzed using X-ray diffraction and XPS to obtain atomic spectra. The chemical shift for the Ni $2p_{3/2}$ state in the transition from Ni to $NiSi_2$ was +2,0 eV, which is mainly attributed to initial-state effects, whereas final-state effects have a less significant contribution. For other silicide compounds, the binding energy shift was considerably smaller (less than 0,3 eV) and resulted in either positive or negative chemical shifts, which are associated with compensating effects of the initial and final states.

Keywords: nickel silicide, surface morphology, optical spectroscopy, elemental composition, electronic properties, thin films, binding energy, X-ray diffraction, Raman spectroscopy.

Введение. Металлические тонкие пленки являются важным классом материалов, широко применяемых в микро- и наноэлектронике, оптоэлектронике, сенсорных устройствах, энергетике и различных защитных покрытиях. Их физические свойства существенно зависят от структуры, морфологии поверхности, размеров зерен и условий формирования пленок. Поэтому изучение механизмов роста и структурообразования тонких пленок остается одной из актуальных задач физики конденсированного состояния и материаловедения.

В последние годы для получения металлических пленок все более широко используются ионно-плазменные методы осаждения, включая магнетронное распыление и вакуумно-дуговые технологии. Эти методы обеспечивают высокую чистоту покрытий, хорошую адгезию к подложке и возможность управления структурными характеристиками материала путем изменения параметров плазмы и режимов осаждения.

Процесс формирования тонких пленок включает несколько последовательных стадий: адсорбцию атомов на поверхности подложки, поверхностную диффузию, образование центров кристаллизации, рост островковых структур и формирование сплошного покрытия. Характер протекания этих процессов определяется энергией осаждаемых частиц, температурой подложки, скоростью осаждения и другими технологическими параметрами.

Целью данной работы является исследование механизмов формирования металлических тонких пленок, полученных ионно-плазменными методами, а также анализ влияния условий осаждения на процессы зарождения, роста и структурообразования пленок. Полученные результаты могут быть использованы для оптимизации технологий получения функциональных покрытий с заданными физическими свойствами.

Обзор литературы по теме. Металл и его силицидные тонкие плёнки вызывают большой интерес в наноэлектронике как материалы субмикронного уровня [1-3]. Силициды никеля используются в качестве контактов для полевых транзисторов, в преобразователях солнечно-тепловой энергии, в качестве омических контактов, а также для защиты от электромагнитного излучения и как одни из ценных электронных материалов в наноэлектронных устройствах [4-10]. Благодаря таким преимуществам, как низкотемпературная обработка, низкое потребление кремния и низкое контактное сопротивление [11], никелевые силицидные плёнки привлекли внимание как кандидаты на роль материалов наноразмерного уровня в будущем, способные заменить различные типы силицидных тонких плёнок, применяемых в настоящее время.

Образование тонких плёнок никелевого силицида в основном осуществляется через твёрдофазную реакцию никелевой плёнки с кремнием. Никель наносится на заранее подготовленную кремниевую подложку с помощью физического осаждения или химического осаждения [12, 13]. При этом формирование фаз никелевого силицида зависит от множества факторов, таких как толщина тонкой плёнки Ni, способ осаждения, ориентация подложки, условия нагрева и морфология поверхности Si. Поэтому контроль этих условий крайне важен, но затруднителен при получении единой фазы NiSi [14].

Температурно-зависимая реакция силицидирования Ni, управляемая диффузией, происходит за счёт диффузии Ni в кремниевую область. При этом возникающие вакансии Ni в основном локализуются не в слое Si, а в слое Ni [15, 16].

В данной работе использовались режимы последующего нагрева для контроля распространения низкоэнергетичных атомов Ni на поверхности Si(111) методом твердофазного ионно-плазменного осаждения и для улучшения интерфейсной структуры никелевого силицида. Это исследование предоставляет экспериментальную основу для совершенствования и оптимизации структуры металлических силицидов в интегральных схемах с целью повышения эффективности работы устройств [17].

Методология исследования. В качестве подложки использовался кремний с

ориентацией Si(111). Подложки были очищены в три этапа. С использованием режима радиочастотного магнетронного распыления (I =296 мА, U =337 В, P = 100 Вт) на подогретую поверхность Si(111) методом ионно-плазменного напыления наносился никель с чистотой 99,95%. Сначала формировался аморфный слой Ni/Si, который затем переходил в кристаллические структуры типа кубическая решётка с гранецентрированием и кубическая решётка с объёмноцентрированием. Эти кристаллические структуры определяют расположение атомов в металле.

Измерения выполняли на рентгеновском дифрактометре “D8 Discover” (Bruker-AXS, Германия) в геометрии параллельного пучка. Источник рентгеновского излучения - рентгеновская трубка с медным анодом (излучение CuK_α). Режим съемки 40 кВ - 40 мА. Для увеличения интенсивности первичного пучка и его частичной монохроматизации и коллимации в плоскости дифракции использовали зеркало Гёбеля, которое обеспечивает угловую расходимость первичного пучка 0.03°. Тестовую съемку дифракционных кривых (2θ-θ - сканирование) проводили в интервале углов 2θ от 25° до 80°. Интенсивность дифрагированного пучка измеряли с помощью 1D детектора “LynxEye” (Bruker-AXS, Германия). Съемку проводили с шагом по углу 2θ =0,02°, время накопления на точку 0,3 с.

Результаты и обсуждение. На рис 1 представлено СЭМ-изображение тонкой плёнки Ni/Si, полученной методом ионно-плазменного напыления. На изображении видно, что верхний слой (светлый оттенок) имеет толщину примерно 390 нм, что определяется по масштабной линейке.

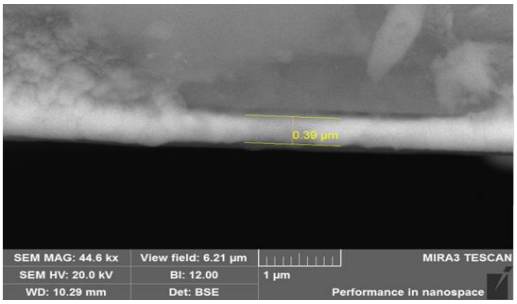

Рис 1. СЭМ-изображение тонкой плёнки Ni/Si толщиной 390 нм.

Между плёнкой и подложкой (тёмная нижняя часть) прослеживается чёткий и ровный интерфейс, что свидетельствует о хорошем сцеплении и минимальной диффузии. В верхнем слое наблюдается поликристаллическая структура — отчётливо видны зёрна различного размера и их границы. Поверхность плёнки относительно ровная, хотя в некоторых участках присутствуют незначительные вариации. Благодаря использованию детектора эластично рассеянные электроны наблюдается контраст, связанный с составом — участки с атомами тяжелее выглядят светлее, а с более лёгкими — темнее. Увеличение в 44,6 тыс. крат позволяет детально рассмотреть микроструктуру. Также видно, что процесс кристаллизации завершён полностью. Агломерация сведена к минимуму. Целостность плёнки сохранена. Эти данные имеют большое значение для оценки качества плёнки, прогнозирования её электрических свойств и оптимизации технологического процесса.

Было установлено, что энергия связи для переходного металла Ni сдвигается в положительную сторону на величину ~2,0 эВ. Напротив, соответствующие пики Si 2p не показывают значительного сдвига после этих процессов, поскольку эффекты начального и конечного состояния взаимно компенсируются, и поэтому невозможно использовать их для описания химических данных о силицидах переходных металлов. Для определения различных силицидов используется только позиция ЭС сигнала 2p

переходного металла (в данном случае, в частности, уровень $2p_{3/2}$). Следует отметить, что сдвиги ЭС для сигналов Ni, показанные на рис.2, являются представителями металлического состояния для монофазных дисилицидов $NiSi_2$, в то время как сдвиг ЭС для сигнала Ni указывает на интегральный вид фазовых смесей, таких как $NiSi_2$.

Металлические и силицидные состояния, наблюдаемые в РФЭС-спектрах, показывают, что для $2p_{3/2}$ переходного металла, пики в металлическом состоянии имеют следующие значения энергия связи полная ширина на полувысоте пика: 852,6 эВ (1,8 эВ) соответственно. Эти наблюдения показывают изменения характеристик пиков, такие как сужение ширины пика и сокращение асимметрии, что связано с процессом силицидирования. Важным инструментом для более глубокого понимания наблюдаемых сдвигов ЭС является исследование характерных РФЭС - линий для тех же самых образцов. Для данного исследования выбрана РФЭС - вершина $L_3M_{23}M_{23}$ переходного процесса.

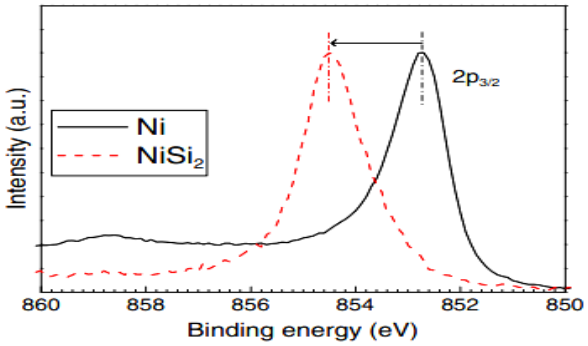

Рис. 2. Разница в спектрах основного состояния $2p_{3/2}$ силицидов никеля.

Силицидные соединения переходных металлов были синтезированы в виде кристаллических тонких пленок, нанесенных на пластины Si с помощью распыления и последующим отжигом. Структурные, фазовые и поверхностные химические характеристики образовавшихся силицидов были проанализированы с использованием рентгеновская дифракция и РФЭС для получения атомных спектров. Химический сдвиг для состояния $2p_{3/2}$ Ni в случае перехода от Ni к $NiSi_2$ составил +2,0 эВ, что в основном обусловлено эффектами начального состояния, в то время как эффекты конечного состояния оказывают менее значительное влияние. Для других силицидных соединений сдвиг энергии связи был значительно меньшим (менее 0,3 эВ), и приводил к положительным или отрицательным химическим сдвигам, что связано с компенсационными эффектами начальных и конечных состояний.

Рентгеновский фазовый анализ тонких пленок $NiSi_2$, полученных методом ионно-плазменного осаждения, показал, что в результате 10 минутного процесса магнетронного распыления в RF-режиме на кремниевой подложке образуются тонкие пленки никель силицида толщиной 420 нм.

На рис.3 показано, что NiSi относится к орторомбической структуре типа ***P***, поэтому в спектре Рамана для пленки наблюдаются активные колебания. Спектры Рамана для пленок NiSi, порошка NiSi и поликристаллического NiSi включают только часть этих режимов.

В зависимости от степени текстуры, некоторые активные колебательные режимы могут быть более выраженными в спектре тонкой пленки по сравнению с другими. Пики на 197, 216, 256, 289, 314, 332 и 362 $см^{-1}$, показанные на рис.3, были зафиксированы в спектре Рамана тонкой пленки никель силицида. Тонкие пленки никель силицида также были проанализированы с использованием угла обзора рентгеновская дифракция.

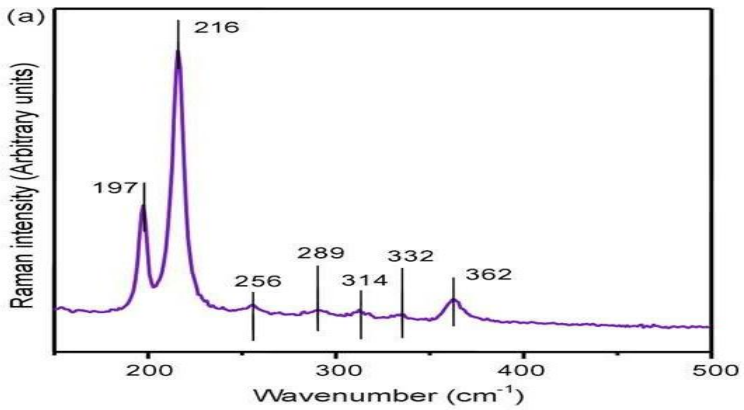

Рис.3. Рамановский спектр тонкой пленки $NiSi_2$

Выводы и предложения. На основе результатов анализа Рамана и ХРД было доказано наличие кристаллической фазы NiSi (никель-силицид) в образце. Все основные пики в спектре ХРД принадлежат фазе NiSi, что свидетельствует об отсутствии других фаз или загрязнений в образце. Это также указывает на высокую чистоту и кристаллическую структуру материала. Такие результаты имеют большое значение для использования материалов на основе NiSi в полупроводниковых компонентах, в контактных материалах и в других электронных устройствах.

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ОБРАЗОВАНИЯ ОКСИДНЫХ НАНОПЛЕНОК МЕДИ НА ПОВЕРХНОСТИ КРЕМНИЯ В РЕЗУЛЬТАТЕ ИОННОЙ ИМПЛАНТАЦИИ

[1]Ф. Ф. Арзикулов, [2]Ш.Т. Хожиев,
[3]И.О. Косимов, [4]Ш. К. Кучканов,
[5]Б.У. Бобомуродов, [6]Х. А. Турапова
[1]Ассистент кафедры биомедицинской инженерии, информатики и биофизикиТашкентского медицинского университета
[2]Доктор физико-математических наук, профессор кафедры биомедицинской инженерии информатики и биофизики Ташкентского медицинского университета
[3]Старший научний сотрудник института биоорганической химии им. О.С.Содикова Академия наук Республики Узбекистан,
[4]Доцент кафедры возобновляемых источников энергии, Ташкентский государственный технический университет имени Ислама Каримова
[5]Ассистент кафедры физики, Термезский государственный университет
[6]Учитель физики в средней школе № 355 Учтепского района
ORCID 0009-0004-6901-5291
УДК 621.315.592:539.216.2:621.793

Аннотация. В данной работе экспериментально обнаружены и подробно исследованы различные пики в спектре комбинационного рассеяния света (КРС), а также в спектре рентгенофазового анализа (XRD) образцов кремния, имплантированных ионами меди. Исследование направлено на изучение структурных изменений, происходящих в приповерхностных слоях кремния под воздействием ионной имплантации меди и последующего лазерного отжига. На основе полученных данных КРС и XRD, зарегистрированных для образцов с различными режимами имплантации и параметрами лазерной обработки, была проанализирована динамика трансформации микроскопической структуры кремниевого слоя. Особое внимание уделено формированию и эволюции наноразмерных включений оксида меди, возникающих в результате имплантации. Результаты исследования свидетельствуют о формировании наноструктурированных пленок оксида меди в приповерхностной области кремния. Показано, что наблюдаемые спектральные особенности могут быть объяснены присутствием локализованных атомов меди в узлах кристаллической решетки кремния, что существенно влияет на его структурные и оптические свойства.

Ключевые слова: кремний, имплантация, ионы меди, наноразмеры, кристалитов, дифрактограмма, спектр комбинационного рассеяния, микроструктура.

FORMATION OF COPPER OXIDE NANOFILMS ON THE SILICON SURFACE AS A RESULT OF ION IMPLANTATION

Abstract. In this study, various peaks in the Raman scattering (RS) spectrum as well as in the X-ray diffraction (XRD) spectrum of silicon samples implanted with copper ions were experimentally detected and analyzed in detail. The research focuses on investigating structural changes occurring in the near-surface layers of silicon under the influence of copper ion implantation and subsequent laser annealing. Based on the Raman and XRD data obtained for samples subjected to different implantation regimes and laser treatment conditions, the dynamics of the transformation of the microscopic structure of the silicon surface layer were studied. Particular attention was paid to the formation and evolution of nanoscale copper oxide inclusions formed as a result of the implantation process. The results indicate the formation of nanostructured copper oxide films in the near-surface region of silicon. It is shown that the observed spectral features can be explained by the presence of localized copper atoms occupying sites in the silicon crystal lattice, which significantly affect the structural and optical properties of the material.

Keywords: silicon, implantation, copper ions, nanosize, crystallites, diffraction pattern, Raman spectrum, microstructure.

Введение. Браттейн описал Cu_2O как полупроводник: «Оксид меди является дефектным полупроводником, основными примесными центрами, акцепторами в данном случае, вероятно, являются вакантные узлы решетки ионов меди» [1-2]. Поскольку Cu_2O является естественным полупроводником р-типа, концентрация носителей заряда в котором зависит от величины дефицита катионов. Три бинарных полупроводниковых соединения оксида меди представляют собой семейство, где только Cu_2O находится на стадии разработки и применения. Для Cu_4O_3 и CuO предстоит проделать большую работу. Оксиды меди как многофункциональные полупроводники представляют огромный интерес для современного материаловедения

и в настоящее время широко исследуются. Кроме того, эти оксиды используются в качестве фотоактивного материала. В последние годы наиболее изученным фотоактивным материалом на данный момент является диоксид титана, оксид цинка и CdSe. Однако не прекращается поиск материалов, которые могли бы составить достойную конкуренцию для TiO и TiO_2 [3]. Одним из таких материалов может являться оксид одновалентной меди. Оксид меди — это соединение меди и кислорода, которое встречается в двух формах: оксид меди (I) (Cu_2O) и оксид меди (II) (CuO). Эти соединения имеют различные цвета и химические свойства, что позволяет использовать их в различных отраслях. Оксид меди (I) - Cu_2O является p-тип полупроводником с шириной запрещенной зоны E_g ~2,0-2,2 eV. В последние годы Cu_2O интенсивно исследуется для осуществления преобразования солнечной энергии в электрическую. Теоретически эффективность этого процесса для Cu_2O составляет 9-11%. Cu_2O - перспективный материалы для создания ячеек Бозе с высокой экситонной энергией связи (~150 meV). Кроме того, Cu_2O является фотокатализатором, работающим под действием видимого света [1]. Синтезируя частицы различного размера можно управлять шириной запрещенной зоны Cu_2O создавая фотокатализаторы с чувствительностью к различным длинам волн видимого света. Оксид меди как фотокатализатор может быть использован для разложения воды и для борьбы с органическими загрязнениями, а также в медицине. Cu_2O – также является хорошим магнитным полупроводником [2]. Оксид меди является перспективным материалом современной наноэлектроники и оптоэлектроники [4]. Оксиды меди с 1D-морфологией нанопроволок, наностержней и нанолент являются объектами пристального изучения в химии и физике наноразмерных материалов, так как характеризуются уникальным набором электрофизических, оптических и каталитических свойств [5–8]. Так, было показано, что иерархические структуры 1D-наноразмерных оксидов меди являются активными катализаторами разложения озона [9], основой проводящих и прозрачных покрытий [10], электродов суперконденсаторов [11], сенсоров [12], литий-ионных аккумуляторов [13] и электрокатализаторов [14], используются в качестве фотокатализаторов [15] и т.д. При создании высокоэффективных электродных материалов особое значение имеют такие методы синтеза 1D-наноразмерных оксидов меди, которые дают возможность получить на проводящей подложке их ориентированные массивы, находящиеся с ней в электрическом контакте. Подобные массивы на поверхности меди были получены, например, в работах [5]. Данные материалы характеризуются, с одной стороны, минимальным электрическим сопротивлением, поскольку наблюдается омический контакт нанокристаллов [16] с поверхностью подложки-металла, а с другой – высокой удельной поверхностью, обусловленной их уникальными геометрическими размерами. Эти особенности задают ряд их практически важных свойств, в частности, можно ожидать, что они будут являться активными электрокатализаторами в реакции разложения воды путем электролиза вследствие сравнительно легкого удаления пузырьков газа с вершин таких нанокристаллов. При введении в кремний тяжелых элементов происходят такие интересные эффекты как: низкотемпературная рекристаллизации, с выделением газа [17] и примеси водорода [18], химическая активность инертных тяжелых газов [19], а также образование пористой структуры [20], сопровождаемое усилением КРС и люминесценции [21]. Также значительный интерес к физической природе этих эффектов наблюдается в следствии появления новых практических приложений [22-23].

Целью настоящей работы является – исследование на основе методик КРС и XRD для образцов, полученных с различными режимами имплантации Cu и лазерного отжига, динамику трансформации микроскопической структуры приповерхностного слоя кремния. А также обнаружения наноразмерности полученных структур. Методом КРС было исследовано преобразование микроскопической структуры кристаллической решетки кремния и ее динамических свойств при различных режимах имплантации и лазерного отжига.

Методы и принципы исследования. Ранее оксиды меди с подобной

морфологией получали по методике гидротермального синтеза [24], окисления меди в щелочном растворе $(NH_4)_2S_2O_8$, анодного окисления меди, восстановления соли меди(II) в щелочном растворе гидразина и окисления меди кислородом воздуха при температуре 700°C. Показано, что при осаждении катионов меди(II) в растворе NaOH образуется осадок $Cu(OH)_2$ с морфологией нанопроволоки. Известны также работы по изучению реакции гальванического замещения никеля в растворах солей меди, однако исследования первых стадий таких реакций и продуктов гидролиза и термической обработки полученных соединений не проводились. В настоящей работе на кремниевую подложку методом ионной имплантации получали оксиди меди в вакууме при температуре 500 ͦC. Исследования проводились на InVia Raman Spectrometer, производства компании «Renishaw» (Великобритания). Работа спектрометра основана на методе спектроскопии комбинационного рассеяния света, или рамановской спектроскопии. Использование данного метода обеспечивает проведение идентификации, качественного и количественного анализа органических и неорганических веществ. В качестве образцов исследовались пластины монокристаллического кремния КДБ-0.5, (кремний с дырочной электропроводностью, легированный бором, с удельным сопротивлением 0.5 Ом/см. Измерения велись при комнатной температуре. В качестве источника возбуждения использовался Cobolt CW 532 nm DPSS лазер с длиной волны излучения 532 нм и номинальной энергией 100 мВт. В процессе измерений использовалась дифракционная решётка с периодом 1800 линий/мм [24], а в качестве регистрирующего устройства – штатный детектор Renishaw CCD Camera.

Лазерный луч фокусировался на поверхность образцов в пятно диаметром 10 мкм. Мощность излучения на поверхности образца варьировалась в зависимости от величины выходного сигнала на детекторе. Объектив со 100- кратным увеличением использовался для фокусировки возбуждающего света, а также для сбора рассеянного света. Время экспозиции составляло 10 секунд, при этом измерения проводились в режиме "extended", которое позволяет проводить измерения в требуемом спектральном диапазоне длин волн.

Основные результаты и их обсуждение. Полученные спектры КРС позволили проследить трансформацию структуры приповерхностного слоя толщиной ~ 100 нм и локализацию атомов Cu в матрице Si по мере повышения дозы имплантации, а также при увеличении энергии лазерного облучения. В исходных имплантированных образцах спектр КРС соответствует в основном аморфному состоянию приповерхностного слоя Si. На рис. 2 представлено изображение исследуемого участка поверхности образца, полученное с использованием штатного микроскопа InVia Raman Spectrometer.

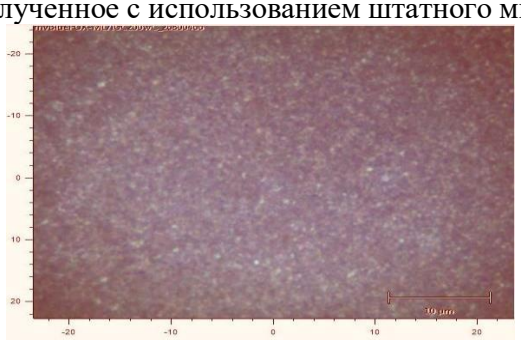

Рис. 2 – Изображение участка поверхности исследуемого образца

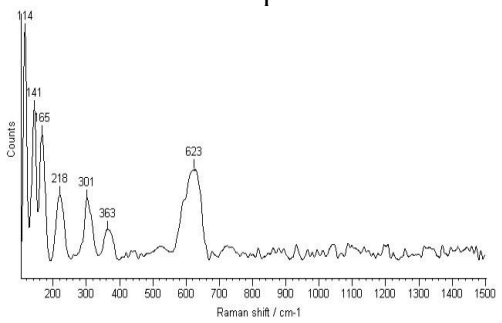

Рис. 3 – Спектр комбинационного рассеяния исследуемого образца

На рис. 3 представлен спектр комбинационного рассеяния исследуемого образца монокристаллического кремния, полученный нами с использованием InVia Raman Spectrometer в режиме, описанном ранее [22-23].

Анализируя полученный данный спектр, следует отметить, что он, наряду с другими полосами, содержит три полосы с максимумами при 301, 363 и 623 $см^{-1}$. Положения максимумов этих полос близки к соответствующим значениям для CuO, что было определено в [17]. Это позволяет предположить, что исследуемая плёнка имеет

химический состав, близкий к CuO. А появление таких полос, как (114, 141, 165, 218) $см^{-1}$, связано с несовершенством кристаллической структуры Cu_2O и наличием, наряду с кристаллической, аморфно-кристаллической структуры, что следует из результатов исследований, проведенных авторами работы [21]. Следует отметить, что для удаления пиков, ответственных за Cu_2O и образованных из-за различных точечных дефектов, возникающих в процессе ионной имплантации, применяется последующий отжиг уже имплантированных образцов в вакууме при температуре 500 ℃.

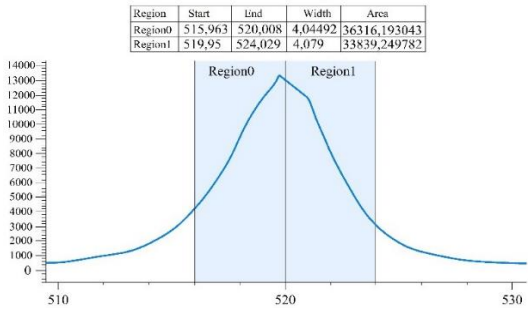

Рис. 4 – Спектры комбинационного рассеяния чистого кремния

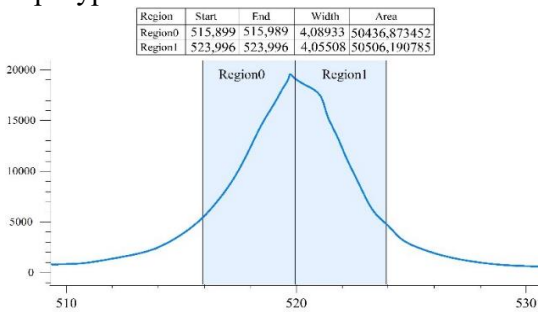

Рис. 5 – Спектры комбинационного рассеяния кремния имплантированного ионами меди

На рис. 4 и 5. показаны спектры комбинационного рассеяния чистого кремния и кремния, имплантированного ионами меди. Используя то, что при возникновении напряжений и дефектов в кристаллической решетке образца происходит соответствующее изменение положения и формы пика кремния в спектре комбинационного рассеивания, можно оценить наличие, или отсутствие таких напряжений и дефектов, исходя из изменения частоты собственных колебаний монокристаллического кремния и изменения отношения площадей левого и правого Region на соответствующих спектрах (см. рисунки 4 и 5). Также в ряде работ [17-18], [21] наблюдалось незначительное (~$3см^{-1}$) увеличение частоты собственных колебаний монокристаллического кремния. Это связывалось с наличием механических напряжений, возникающих благодаря различиям постоянных решеток эпитаксиальной пленки кремния и подложки [18], или вследствие локального лазерного отжига аморфного слоя. Кроме того, это может быть и из-за локального возмущения легирующей примесью замещения [21]. Изучение влияния легирования показало, что как диффузионное легирование, так и в еще большей мере ионная имплантация донорной примеси понижают температуру начала рекристаллизации, что хорошо объясняется повышением концентрации вакансий при таком легировании. Легирование акцепторной примесью (бором) замедляет рост зерен. Примеси никогда не ведут себя как в металлах, в которых примесь всегда тормозит рекристаллизацию. Начало рекристаллизации сопровождается изменением электрофизических свойств. В частности, в поликристаллических плёнках кремния (ППК) при этом понижается поверхностное сопротивление, что важно для ППК в металл-оксид-полупроводниковых (МОП) структурах. Кроме того, в настоящей работе нами были проведены исследования образцов оксида меди имплантированного ионной имплантации на кремниевую подложку методом рентгенофазового анализа XRD-6100 SHIMADZU. Спектры, полученные методом рентгенофазового анализа для образцов CuO и Cu_2O приведены на рисунках 6 и 7 соответственно. А также были рассчитаны размеры кристаллитов с помощью формулы Дебая-Шеррера (таб.1 и таб.2). Как показывает полученные расчетные данные размеры кристаллитов были меньше 100 нм, это подтверждает наноразмерности полученных кристаллитов. Также были определены степень кристалличности и аморфности. Для CuO аморфность составляет 81%, а кристалличность 19%, соответственно. А для Cu_2O аморфность составляет 82%, а кристалличность 18%, соответственно. Полученные данные рентгенофазового анализа подтверждает данные полученные методом комбинационного рассеяния. Эти данные являются взаимно дополняющими друг друга результатами.

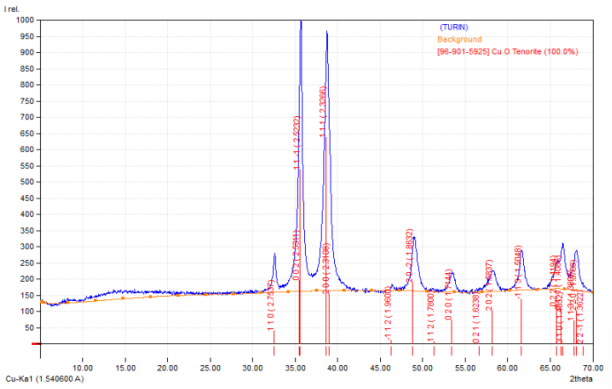

Рис-6. Дифрактограмма полученная методом рентгенофазового анализа для пленки CuO.

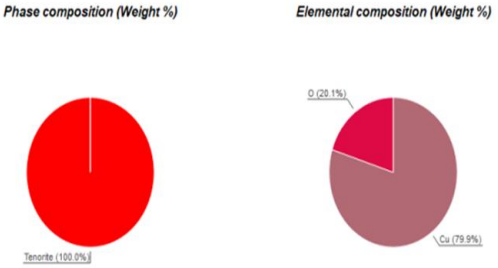

Рис-7 Диаграммы фазового и элементного анализа для CuO полученного по данным XRD

Таблица 1. Размеры наночастиц определенная по формуле Дебая-Шеррера для CuO.

№	2θ	d	I/I_1	Ширина на половине высоты (FWHM)	Размер кристаллитов	Средний размер кристаллитов
1	35.6570	2.51593	100	0.51070	17,07nm	14,77 nm
2	38.7684	2.32087	97	0.73620	12 nm	
3	49.0413	1.85605	22	0.72050	12,66 nm	
4	66.4723	1.40542	19	0.57120	17,38 nm	

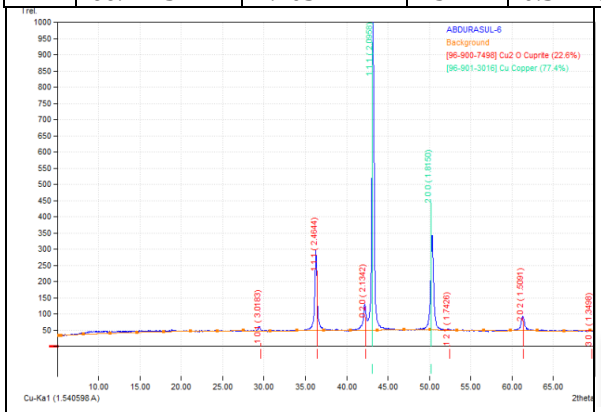

Рис-8 . Дифрактограмма полученная методом рентгенофазового анализа для пленки Cu_2O.

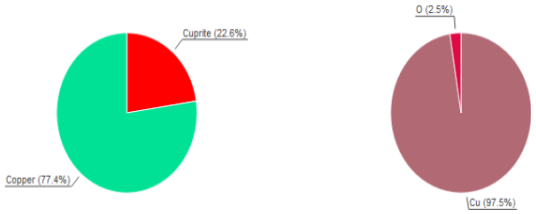

Рис-9 Диаграммы фазового и элементного анализа для Cu_2O полученного по данным XRD

Таблица 2 Размеры наночастиц определенная по формуле Дебая-Шеррера для тонкой пленки Cu_2O

№	2θ	d	I/I_1	Ширина на половине высоты (FWHM)	Размер кристаллитов	Средний размер кристаллитов
1	36.3	2,47	30	0.27	32,35nm	28,28 nm
2	43.2081	2.09212	100	0.30450	29,32 nm	
3	50.3264	1.81163	39	0.33300	27,54 nm	
4	42.2006	2.13971	10	0.33070	26,91 nm	

Кроме того, нами были получены диаграммы фазового и элементного анализа для оксидов меди CuO и Cu_2O полученного по данным XRD приведенные на рис.7 и 9. Как показывают полученные диаграммы это являются прямым подтверждением о кристаллизации аморфного кремния и его полным покрытием оксида меди. Наибольший интерес представляет изучение влияния кислорода на структуру ППК, поскольку кислород практически всегда присутствует в пленках кремния. Источником кислорода в пленках являются атмосфера отжига и изолирующие слои SiO2. Кислородные включения резко повышают термическую стабильность пленок, особенно аморфных [21]. Можно отметить, что природа и механизм низкотемпературной рекристаллизации с газовыделением остаются еще недостаточно изученными, однако на основании полученных в настоящей работе экспериментальных данных можно

предположить, что процесс рекристаллизации стимулируется локальными напряжениями. Этот вывод подкрепляется экспериментально проверенными результатами о процессе кристаллизации аморфного кремния. Полученные экспериментальные данные хорошо объясняются наличием локальных атомов Cu в узлах кристаллической решетки.

Заключение. По результатам наших исследований можно сделать вывод о том, что спектры комбинационного рассеяния образцов монокристаллического кремния, имплантированного ионами меди, могут быть использованы в качестве инструмента для проведения оценки их структурного совершенства и содержания собственных и примесных дефектов, а также присутствия в кристаллах неконтролируемых примесей и кислорода. На основе данных КРС и XRD полученных для образцов с различными режимами имплантации Cu и лазерного отжига, получена динамика трансформации микроскопической структуры приповерхностного слоя кремния. Показаны наноразмерность имплантированных пленок оксида меди. Экспериментальные данные хорошо объясняются наличием локальных атомов Cu в узлах кристаллической решетки. Полученные результаты представляют существенный интерес для исследований в области микроэлектроники, дефектообразовании, а также при создании материалов для оптоэлектроники и нанотехнологии.

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SUV CHIQARUVCHI FOTOELEKTRIK/ISSIQLIK QURILMANING ASOSIY ELEKTROFIZIK PARAMETRLARINI SINOVDAN O‘TKAZISH

Eshmatov Mansur Mamayusupovich
Turon universiteti, Tabiiy fanlar kafedrasi dotsenti
meshmatov2811@mail.ru
ORCID 0009-0004-1097-8579
Xolov Uyg‘un Raufovich
Qarshi davlat texnika universiteti, Tabiiy fanlar kafedrasi mudiri, dotsent
uygunshams@mail.ru
ORCID 0000-0002-6675-5479
Eshmuratov Muhiddin Rizamatovich
Turon universiteti, Iqtisodiyot kafedrasi asistenti
muhiddin0174645@gmail.com
ORCID 0009-0006-4894-9946
Meyliyev Elbek Mahmud o‘g‘li
Qarshi davlat universiteti
meyliyev.elbek@mail.ru
ORCID 0009-0006-6568-7132
UDK 621.311.243:620.1

Annotatsiya. Ushbu maqolada issiq va quruq iqlimli chekka hududlarda joylashgan qishloqlarda quduqlardan suv chiqarish va maishiy iste’molchilarni energiya bilan ta’minlashda foydalanish uchun ishlab chiqilgan sovitishda qo‘shimcha quvvat talab qilmasdan o‘zini o‘zi sovitish tizimi bilan jihozlangan yangi reflektorli fotoissiqlik batareya asosidagi mobil qurilmaning asosiy elektrofizik parametrlari sinovdan o‘tkazilgan va bir xil quvvatdagi an’anaviy mobil fotoelektrik qurilma ko‘rsatkichlari bilan taqqoslangan. Fotoelektrik batareya va fotoissiqlik batareyasi asosidagi qurilmalarning salt yurish kuchlanishi mos ravishda 20,5 V va 25 V qiymatni, Qisqa tutashuv toklari esa mos ravishda 33 A va 44 A ni tashkil qilgan. Qurilmaning chiqish quvvati esa mos ravishda 520 W va 885 W qiymatlarni ko‘rsatgan.

Kalit so‘zlar: Fotoelektrik batareya, fotoissiqlik batareya, invertor, salt yurish kuchlanishi, qisqa tutashuv toki, quvvat, elektr energiya, quyosh nurlanish oqim zichligi.

TESTING OF THE MAIN ELECTROPHYSICAL PARAMETERS OF A PHOTOVOLTAIC/THERMAL WATER EXTRACTION DEVICE

Abstract. This paper investigates a new mobile device designed for water extraction from wells and

supplying electricity to household consumers in remote areas with hot and dry climates. The device is based on a reflector-type photo-thermal battery and is equipped with a self-cooling system that operates without additional power consumption. The main electophysical parameters of the device were tested and compared with those of a conventional mobile photovoltaic device of the same power. The results showed that the open-circuit voltage of the photovoltaic and photo-thermal batteries was 20.5 V and 25 V, respectively, while the short-circuit current was 33 A and 44 A. The output power of the devices was 520 W and 885 W, respectively.

Keywords: photovoltaic battery, photo-thermal battery, inverter, open-circuit voltage, short-circuit current, power, electric energy, solar irradiance.

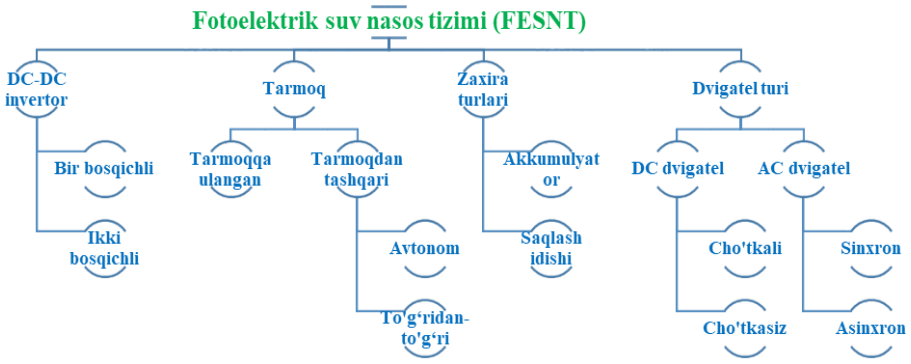
Kirish. Bugungi kunda respublikada qishloq xo‘jaligini suv bilan ta’minlashga bo‘lgan talab oshib bormoqda. Shu bilan bir qatorda O‘zbekiston Respublikasi quruq iqlim mamlakati hisoblanib, katta qismi cho‘l va yarim cho‘l hududlarini tashkil qiladi. Intensiv sug‘oriladigan hududlar esa 4,3 mln gektarni tashkil etadi. Yerdan foydalanish bo‘yicha islohotlar asosan qishloq xo‘jaligida sug‘oriladigan yerlarga ko‘proq yo‘naltirilib, uning maydoni jami hududning 9.7 % ga yaqinini egallaydi. [1]

Nasoslarni elektr energiyasi bilan ta’minlash tarmoq mavjud joylarda tarmoqdan, tarmoq mavjud bo‘lmagan va tarmoqda uzilishlar sodir bo‘lganda suyuq yonilg‘i bilan ishlovchi generatorlar yoki fotoelektrik batareyalardan foydalaniladi. Qishloq va chekka hududlarga elektr tarmoqlari tizimini ishlab chiqish ko‘pincha juda qimmatga tushadi, chunki bu hududlar ko‘pincha mavjud tarmoq liniyalaridan juda uzoqda joylashadi. Mamlakat ichida yoqilg‘i mavjud bo‘lsa ham yonilg‘i narxining qimmatligi yoki yoqilg‘ini olis, qishloq joylariga tashish qiyin bo‘lishi mumkin. Ko‘pgina chekka hududlarda yo‘llar yoki yordamchi infratuzilma mavjud emas. Shunday qilib, chekka hududlardagi suv nasoslarini qayta tiklanadigan energiya manbalari bilan birlashtirish maqsadga muvofiq[2].

Biroq FEB larning asosiy kamchiligi nisbatan yuqori harorat, quyosh nurlanishi va changlanish ta’sirida quvvatning yo‘qotilishi bo‘lib bu suv chiqaruvchi tizimlarning samaradorligini pasaytiradi. Shu sababli harorat, quyosh nurlanishi, havoning changlanganlik darajasini hisobga olib suv chiqaruvchi fotoelektrik qurilmalarni cho‘l va yarim cho‘l hududlarning iqlimiga moslashtirish, suv chiqarish ishlari mavsumiy bo‘lganligi uchun suv chiqaruvchi qurilmalarni boshqa xo‘jalik iste’moli uchun ishlatish imkoniyatini yaratish va yil davomida foydalanish yo‘llarini ishlab chiqishni talab qiladi.

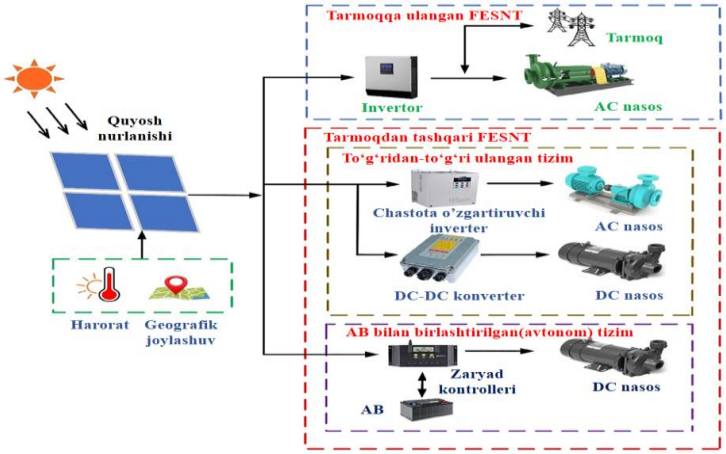
Tadqiqotning maqsadi chekka qishloq hududlari iqlim sharoitini hisobga olib yaratilgan FIB asosidagi suv chiqaruvchi qurilmaning elektrofizik parametrlarini sinovdan o‘tkazish va ularni an’anaviy fotoelektrik qurilma ko‘rsatkichlari bilan taqqoslashdan iborat.

Materiallar va metodlar. Maishiy suv iste’moli uchun fotoelektrik batareyalar suv chiqaruvchi nasoslarni energiya bilan ta’minlash uchun ishlatiladi. Fotoelektrik suv chiqaruvchi tizimlar (FESChT), fotoelektrik batareya (FEB), suv nasosi, zaryadlash regulyatorlari, akkumulyatorlar, invertor yoki to‘g‘ridan to‘g‘ri invertor kabi aksessuarlar, kabellar, quvurlar va nazorat klapanlaridan tuzilgan[3]. Fotoelektrik suv chiqaruvchi tizimining umumiy tasnifi 1- rasmda keltirilgan[4].



1- rasm. FESChT ning umumlashtirilgan tasnifi

Fotoelektrik massividan, nasosga birlashtirilgan dvigateldan va quvvat elektron interfeysidan iborat fotoelektrik suv chiqarish tizimining (FESChT) ning umumlashtirilgan tuzilishi 2 -rasmda ko‘rsatilgan[5].



2-rasm. FESChT ning umumlashtirilgan tuzilishi

Suvni uzatish uchun zarur bo‘lgan fotoelektrik massivining o‘lchami bir nechta omillarni hisobga olgan holda aniqlanadi: joylashuv, harorat, quyosh nurlanishi, kuniga talab qilinadigan suv miqdori, oqim tezligi, quvvat va boshqalar. Umuman olganda, fotoelektrik suv nasos tizimini (FESNT), tarmoqqa ulangan va tarmoqdan tashqari ulangan tizimlarga bo‘lish mumkin. Tarmoqdan tashqari tizimlar, akkumulyatorli va to‘g‘ridan to‘g‘ri boshqariladigan tizimlarga bo‘linadi.

1. Tarmoqqa ulangan FESNT. Tarmoqqa ulangan fotoelektrik tizimi 5 ta asosiy komponentdan iborat: FEM, invertor, asosiy xizmat ko‘rsatish bloki, xavfsizlik tizimi va elektr hisoblagich. Tarmoqqa ulangan tizim elektr tarmog‘iga ulangan holatda ishlaydi.

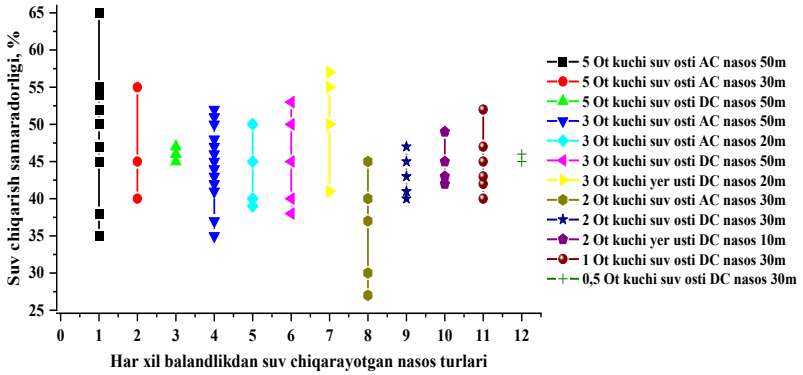
2. Tarmoqdan tashqari FESNT. Bu tizimda tarmoqqa ulanish bo‘lmaydi faqat stansiyaning o‘zida generatsiya qilingan quvvat hisobiga ishlaydi. Tarmoqdan tashqari tizimlar ikki xil FESNT larga bo‘linadi, yani to‘g‘ridan to‘g‘ri ulangan FESNT va akkumulyator bilan jihozlangan (Avtonom) FESNT.

2.1. To‘g‘ridan to‘g‘ri ulangan FESNT. Ushbu tizimda FEB lar tomonidan ishlab chiqarilgan elektr energiyasi to‘g‘ridan to‘g‘ri suv chiqaruvchi nasosga yetkazib beriladi. Ushbu tizimda FEB lar tomonidan ishlab chiqarilgan elektr energiyasi to‘g‘ridan to‘g‘ri suv chiqaruvchi nasosga yetkazib beriladi. Nasos suvni chiqarish uchun elektr quvvatini FEB lar ishlab chiqargan quvvatdan foydalanadi. Zaxira quvvat mavjud emasligi sababli, tizim kunduzi faqat quyosh energiyasi mavjud bo‘lganda suvni chiqaradi. FEB sirtiga tushuvchi quyosh nurlanishining intensivligi bu vaqt davomida chiqariladigan suv miqdorini belgilaydi. Ushbu tizimning afzalligi shundaki, u batareyaga ulangan FESNT bilan solishtirganda, sodda va arzon. Biroq uni tungi vaqtda suv chiqarish uchun ishlatish imkoniyati mavjud emas.

2.2. Akkumulyator bilan jihozlangan (avtonom) fotoelektrik suv nasos tizimi. Akkumulyatorlar bilan bog‘langan FESNT FEB lar, zaryad boshqaruvchisi, akkumulyatorlar, nasos boshqaruvchisi, bosim o‘tkazgich, doimiy suv nasosidan iborat. Kunduzgi soatlarda FEB lar tomonidan ishlab chiqarilgan elektr toki batareyalarni zaryad qiladi va akkumulyatorlar o‘z navbatida suv nasosni elektr quvvati bilan ta’minlaydi. Akkumulyatorlardan foydalanish nasosning dvigatelida barqaror ish kuchlanishini ta’minlash orqali nasosni uzoqroq vaqt davomida ishlatadi. Shunday qilib, tungi va kam yorug‘lik davrlarida ham tizim iste’mol uchun zarur bo‘lgan suvga bo‘lgan talabni doimiy ta’minlashi mumkin. Akkumulyatorlardan foydalanish o‘zining kamchiliklariga ega. Birinchidan, batareyalar umumiy tizimning samaradorligini kamaytirishi mumkin, chunki ishchi kuchlanishni FEB lardan emas, balki akkumulyatorlar tomonidan belgilanadi. Ularning haroratiga va batareyalar qanchalik yaxshi zaryadlanganligiga qarab akkumulyator kuchlanishi, maksimal quyosh nurlanish intensivligi sharoitida FEB lar tomonidan ishlab chiqarilgan kuchlanishdan birdan to‘rt voltgacha past bo‘lishi mumkin. Ushbu pasaytirilgan samaradorlikni nasosga yetkazib beriladigan akkumulyator kuchlanishini oshiradigan tegishli nasos boshqaruvchisidan foydalanish bilan kamaytirish mumkin [6-8].

Yuqorida keltirilgan fotoelektrik suv chiqarish tizimlarida asosan o‘zgarmas va o‘zgaruvchan tokka ishlovchi suv nasoslaridan foydalaniladi. Fotoelektrik suv nasoslarining

suv chiqarishiga nurlanish va harorat o‘zgarishining ta’siri tahlil qilinganda suv sathining balandligi va nasosning ish nuqtasiga qarab, dasturning eng ko‘p uchraydigan sharoitlaridan foydalangan holda fotoelektrik suv nasoslarining ishlashini optimallashtirish metodologiyasi taklif qilingan. Nasos uchun optimal massiv o‘lchamlarini tanlashda kerakli kirish quvvati va quyi tizim samaradorligini hisobga olgan holda amalga oshirildi. PV-syst dasturi yordamida suv nasosining ishlashiga turli massiv konfiguratsiyalarining ta’siri ham o‘rganildi. O‘rganilgan nasoslarning aksariyatida quyi tizimning o‘rtacha samaradorligi (nasos samaradorligi) 40-50% oralig‘ida ishlashi ma’lum bo‘ldi. O‘zgaruvchan tokka ishlovchi (AC) suvosti nasoslari doimiy tok(DC) nasosiga qaraganda samaraliroq ishlashi va 50 m balandlikda yuqori suv oqimini ta’minlashi ma’lum bo‘ldi. AC nasoslar quyi tizim samaradorligi 28-65% oralig‘ini, sirt suv nasoslarining samaradorligi esa 38-60% oralig‘ini ko‘rsatdi(3-rasm)[9].



3-rasm. O‘zgarmas va o‘zgaruvchan tokka ishlovchi suv nasoslarining samaradorligini taqqoslash

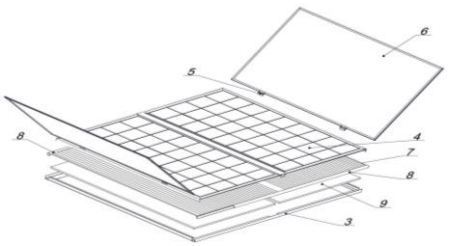
Fotoelektrik stansiyalar (FES)ning ishlash samaradorligiga asosan quyidagi omillar ta’sir ko‘rsatadi: quyosh nurlanishi oqimining zichligi, atrof-muhit harorati, changlanish darajasi hamda fotoelektrik massivlarning quyoshga nisbatan optimal orientatsiya qilinmaganligi.

Yuqoridagi tahlillarni umumlashtirish asosida mualliflar tomonidan suv chiqarish jarayonlarida samaradorlikni oshirish maqsadida avtonom mobil fotoissiqlik qurilmasi ishlab chiqildi [10–11].

Mahalliy iqlim sharoitlarini hisobga olgan holda ishlab chiqilgan, fotoissiqlik batareyasi asosidagi reflektorli mobil fotoelektrik qurilmaning issiq va quruq iqlim sharoitlarida suv chiqarish uchun mo‘ljallangan konstruksiyasi 4-rasmda keltirilgan. Qurilma quyidagi asosiy tarkibiy qismlardan tashkil topgan. Issiqlik kollektori (IK) va reflektorlar bilan jihozlangan fotoissiqlik batareyasining tarkibi aksonometrik proyeksiya ko‘rinishida 5-rasmda tasvirlangan. Qurilma: 3 – to‘g‘ri burchakli metall ramka; 4 – fotoelektrik batareyalar (2 dona); 5 – reflektorlarning ochilib-yopilishini ta’minlovchi sharnirlar; 6 – reflektor; 7 – polikarbonat kollektor; 8 – polikarbonat kollektorlarning ikki uchini birlashtiruvchi polimer quvurlardan iborat.

Issiqlik kollektori (IK) va reflektorlar bilan jihozlangan fotoelektrik batareyasining tarkibi aksonometrik proyeksiya ko‘rinishida 5-rasmda tasvirlangan. 3-to‘g‘ri burchakli metal ramka, 4- FEB lar (2 dona), 5- reflektorlarni ochilib yopilishini ta’minlovchi sharnirlar, 6-reflektor, 7- polikarbonat kollektor, polikarbonat kollektorlarning ikki uchi biriktiriladigan 8-polimer quvurlardan iborat.

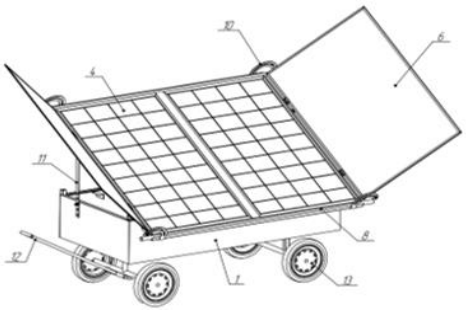
4-rasm. FIB asosidagi mobil suv chiqaruvchi qurilmaning sinov jarayonida olingan tasviri.



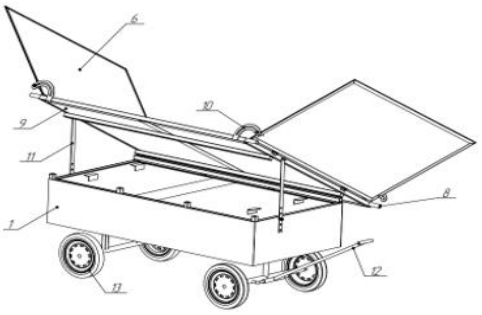
5-rasm. IK va reflektorlar bilan jihozlangan fotoissiqlik batareyasi tarkibining aksonometrik proeksiyasi

Mobil tayanch konstruksiyaga mahkamlangan issiqlik kollektori va reflektorlar bilan

jihozlangan qurilmaning old tomondan ko‘rinishi 6-rasmda, orqa tomondan ko‘rinishi 7-rasmda tasvirlangan.

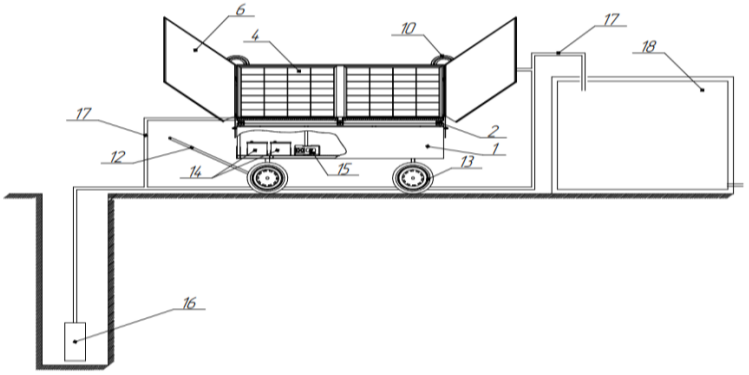


6-rasm. Mobil tayanch konstruksiyaga mahkamlangan IK va reflektorlar bilan jihozlangan qurilmaning old tomondan ko‘rinishi



7-rasm. Mobil tayanch konstruksiyaga mahkamlangan IK va reflektorlar bilan jihozlangan qurilmaning orqa tomondan ko‘rinishi

1. mobil qurilmaning kuzovi, 2. FIB si joylashtirilgan to‘g‘ri burchakli metall ramka va kuzovni birlashtirish uchun sharnirlar, 9 orqa qopqoq, 10 kronshteyn, 11 metall planka, mobil tayanch konstruksiyasi va fotoelektrik batareyalarni tutib turuvchi metall ramkaga o‘zgartiriladigan holatda mahkamlangan, mobil tayanch konstruksiyasi old qismi o‘rtasiga 12 biriktirish qismi mahkamlangan. 1 mobil tayanch konstruksiyasi kuzovi 13 g‘ildiraklarga mahkamlangan.Mobil tayanch konstruksiyasi kuzovi ichiga 14 akkumulyator va 15 invertor joylashtirilgan. 8-rasmda o‘zini-o‘zi sovitish tizimi bilan jihozlangan mobil tayanch konstruksiyaga ega suv chiqaruvchi FIB ososidagi qurilmaning aksonometrik proyeksiyasi tasvirlangan. Rasmda 16-chuqurlikdan suv chiqaruvchi nasos, 17- rezina shlang va 18-zaxira suv idishi. Mazkur qurilma issiq va quruq iqlim sharoitlarida suv chiqarish uchun moslashtirilgan bo‘lib o‘zini o‘zi sovutish tizimi bilan jihozlangan, FEB larni sovitishda qo‘shimcha quvvat talab qilinmaydi. Suv chiqarish ishlari mavsumiy (Iyun, iyul, avgust, sentyabr oylari) bo‘lganligi uchun, suv chiqarishdan tashqari boshqa ehtiyojlar uchun foydalanish maqsadida harakatlanuvchi tirkamaga ega. Tirkama 2 x 1,5 m o‘lchamdagi kuzovga ega bo‘lib kuzov ichida uskunalar bloki (Invertorlar, akkumulyatorlar, o‘lchov anjomlari va kerakli buyumlarni saqlash uchun) joylashtirilgan.



8-rasm. FIB ososidagi qurilmaning aksonometrik proyeksiyasi

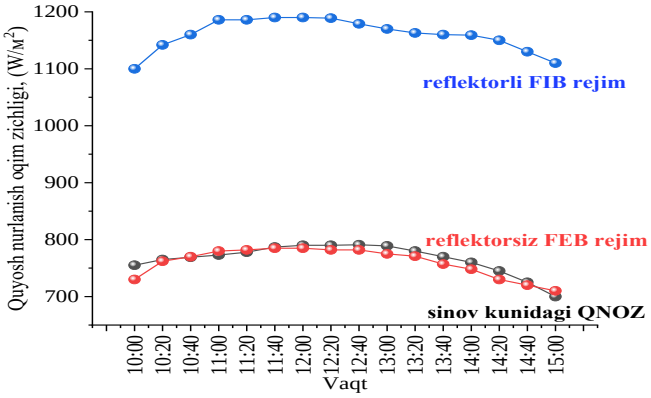
FIB larning gorizontga nisbatan joylashuvini o‘zgartirish maqsadida to‘g‘ri burchakli metall konstruksiya ishlab chiqilgan bo‘lib kuzov bilan sharnirlar orqali biriktirilgan. FIB lar to‘g‘ri burchakli metall konstruksiya(ramka) ichiga oson o‘rnatiladi. Sharnirlar erkin harakatlanish imkoniyatiga ega bo‘lib FIB larning gorizontga nisbatan joylashuv burchagini o‘zgartirish orqali QN ning FIB sirtiga perpendikulyar tushishi ta’minlaydi. Gorizontal yo‘nalishda quyosh harakatini kuzatish tirkamani burish orqali amalga oshiriladi natijada QN ning FIB sirtiga kun davomida maksimal tushishi ikki o‘q bo‘yicha harakat orqali ta’minlanadi.

Ikki o‘qli trekkerlar bilan jihozlangan FES larningning kun davomida ishlab chiqargan quvvati an’anaviy statsionar holatda o‘rnatilgan FES larga qaraganda ko‘proq energiya ishlab chiqarish imkoniyatiga ega[12].

FIQ ni bir xil quvvatdagi an’anaviy FEQ bilan taqqoslandi va qurilmalarning potensial

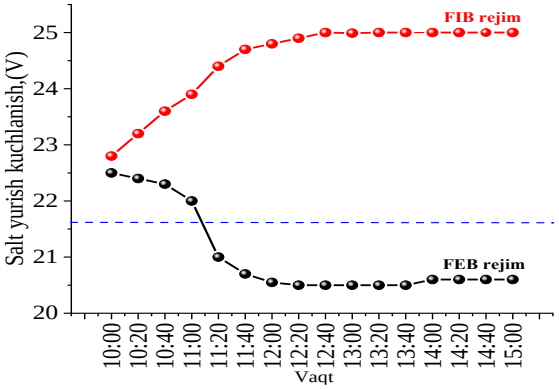
imkoniyatlarini aniqlash uchun tabiiy sharoitlarda bir vaqtda o‘lchash amalga oshirildi. QN oqim zichligi, salt yurish kuchlanishi, qisqa tutashuv toki kabi asosiy kattaliklar maxsus o‘lchov asboblarida o‘lchandi va qurilmalarning elektr quvvati hisoblab chiqildi. QN oqim zichligi kristalli kremniydan tayyorlangan etalon QE yordamida aniqlandi.

Natijalar va muhokamalar: Tajriba sinov ishlari 2025 yil 5-6 sentyabr kunlari Fizika texnika instituti geliopoligonida olib borildi. Sinov kunida havo harorati 22-28ºC oralig‘ini tashkil qildi Yon qaytaruvchi reflektorlar FEB frontal sirtiga tushuvchi QN oqim zichligini 1,5-1.6 marta oshirishga erishgan. FEB va FIB si sirtiga tushuvchi QN oqim zichliklarini taqqoslash natijalari 9-rasmda keltirilgan.



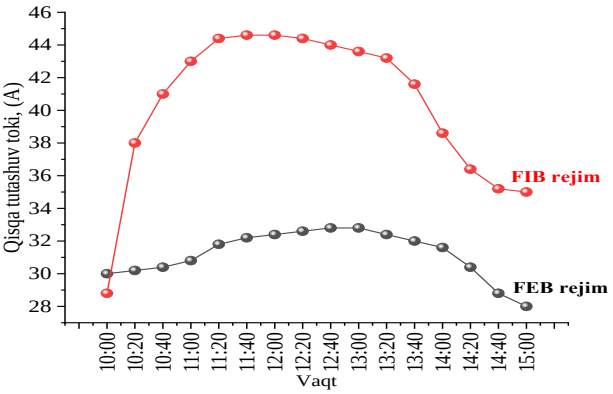
9-rasm. Tajriba sinov kunidagi FEB va FIB asosidagi mobil qurilmalarning frontal sirtiga tushayotgan QN oqim zichliklarini taqqoslash. 1,2-sinov kunidagi QN oqim zichliklari, 3-reflektorli FIB frontal sirtiga tushayotgan QN oqim zichligi.

10-rasmda Qurilmada foydalanilgan FEB va FIB salt yurish kuchlanishlarining qiymatlari taqqoslash natijalari keltirilgan. FEB lar parallel holatda ulanganligan. Agar bir qancha FEB parallel holatda ulansa, ularda chiqish kuchlanishi o‘zgarmaydi, aksincha tok kuchi ortadi[14].



10-rasm. Qurilmada foydalanilgan FEB va FIB salt yurish kuchlanishlarining qiymatlari va taqqoslash natijalari.

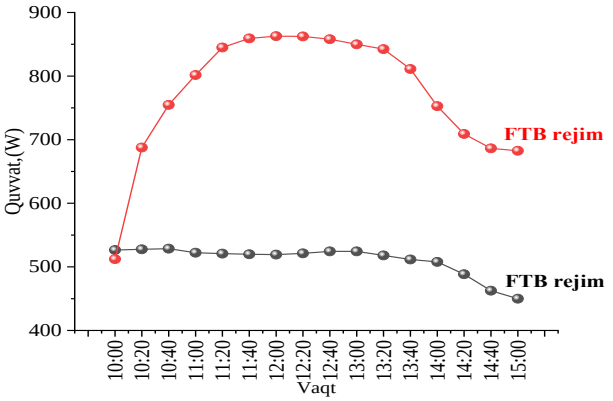
FEB rejimida tajriba boshlangan paytda FEB ning salt yurish kuchlanishi 22,5 V ni ko‘rsatgan va soat 12:20 ga qadar pasayib 20,5 V ni ko‘rsatgan va tajriba davomida o‘zgarmagan (5a-rasm). Reflektorli FIB rejimida ishlaganda esa salt yurish kuchlanishi 22,7 V dan 25 V gacha ko‘tarilgan va shundan keyin o‘zgarishsiz saqlangan(10-rasm). Taqqoslash natijalaridan ko‘rish mumkinki, FIB rejimida salt yurish kuchlanishi FEB ning standart sinov sharoitida olingan ma’lumotlar yorlig‘idagi qiymatidan (rasmda uzlukli to‘g‘ri chiziq bilan ko‘rsatilgan) 1,1 V gacha kamaygan. FIB rejimida ishlaganda esa ma’lumotlar yorlig‘idagi qiymatidan 3.4 V yuqori, FEB rejimidagi qiymatidan esa 4,5 V ga yuqori qiymatlarni ko‘rsatgan. FEB va FIB rejimida parallel ulangan holatda qurilmaning qisqa tutashuv toklari 11-rasmda keltirilgan.



11-rasm. Qurilmaning FIB va FEB rejimidagi qisqa tutashuv toklarining vaqt davomida o‘zgarishini taqqoslash.

FEB asosidagi mobil qurilmada qisqa tutashuv toki 30 A dan 33 A gacha, FIB asosidagi mobil qurilmada 24 A dan 44 A gacha ko‘tarilgan. Bundan ko‘rinadiki FIB asosidagi qurilmaning qisqa tutashuv toki, FEB asosidagi qurilma qisqa tutashuv tokidan 11A ga ko‘p (11-rasmga qarang)

Qurilmalar quvvatining vaqt davomida o‘zgarish grafigi 12-rasmda keltirilgan.



12-rasm. Qurilma FEB va FIB rejimida ishlaganda quvatlarini taqqoslash

Quvvat grafigidan aniqlandiki, FEB asosidagi qurilma tajriba boshlangan vaqtda maksimalquvvatga erishgan 530 W ya’ni bu paytda FEB qizishga ulgurmagan. Kunning QN oqim zichligi katta va harorat yuqori vaqtlarida o‘rtacha quvvati 520 W ni tashkil qilgan. Reflektorli FIB asosidagi qurilmada quvvatining maksimal qiymati 885 W ni tashkil qilgan. Kunning QN oqim zichligi katta va harorat yuqori vaqtlarida o‘rtacha quvvati 880 W ni tashkil qildi. Qurilmaning FEB va FIB rejimidagi o‘tracha quvvatlari natijalaridan shu narsa ma’lum bo‘ldiki FIB rejimidagi quvvat FEB rejimidagi quvvatdan 1,7 marta katta.

Xulosa. Suv chiqarishda samaradorlikni oshirish maqsadida 600 W quvvatdagi FIB asosidagi suv chiqarish uchun mobil qurilma ishlab chiqildi. Qurilmaning elektrofizik parametrlari bir xil 600 W quvvatdagi an’anaviy FEB asosidagi mobil qurilmaning elektrofizik ko‘rsatkichlari bilan taqqoslandi. Reflektorlar hisobiga qurilmaga tushayotgan quyosh nurlanish oqim zichligi 1,5-1.6 marta oshirishga erishildi. Qurilmalarning salt yurish kuchlanishi an’anaviy qurilmanikiga qaraganda kollektorda suv o‘tkazib sovitish hisobiga 4,5 V ga oshgani, ya’ni an’anaviy qurilma ko‘rsatkichidan 1,22 marta yuqori ekanligi aniqlandi. Yon reflektorlar hisobiga qurilmaning qisqa tutashuv toki an’anaviy FEB asosidagi qurilmaga nisbatan 1,33 marta yuqori ekanligi va FIB mos ravishda chiqish quvvati 1,6 marta yuqori ekanligi aniqlangan.

Shuni ta’kidlash kerakki, qurilmalar quyoshga nisbatan oriyentatsiya qilingan holatda natijalar olingan.

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ИЗМЕНЕНИЯ ОПТИЧЕСКИХ СВОЙСТВ ПЛЕНОК ZnO, ЛЕГИРОВАННЫХ АЛЮМИНИЕМ, В РЕЗУЛЬТАТЕ ТЕРМИЧЕСКОЙ ОБРАБОТКИ

Бобоев Акрамжон Юлдашбоевич
Андижанский государственный университет
доктор физико-математических наук (DSc), доцент
ORCID 0000-0002-3963-708X
Гуламов Бахтиёрджон Дилмуроджон оглы
Андижанский государственный университет, доктор философии (PhD) по физико-математическим наукам, старший преподаватель
ORCID 0009-0005-8614-6311
Акбаров Ахмаджон Иномжон оглы
Андижанский государственный университет, студент магистратуры
Иброхимов Сарварбек Хамзали оглы
Андижанский государственный университет, студент
UDK 621.315.592.4

Аннотация. В данной статье представлены результаты исследования тонких пленок ZnO, полученных методом золь-гель осаждения на стеклянных подложках. В качестве исходного вещества использовался ацетат цинка, растворителем служил изопропиловый спирт, стабилизатором — диэтиламин, а в качестве легирующей примеси применялся нитрат алюминия. Соотношение массы атомов Al к массе атомов Zn составляло 3 %. Тонкие пленки ZnO подвергались термической обработке при различных температурах, после чего их оптические свойства исследовались с использованием спектрометра Perkin Elmer Instruments Lambda 35 UV/VIS. Установлено, что наибольшую оптическую прозрачность (84 %) в видимом и ближнем инфракрасном диапазонах излучения продемонстрировали пленки, отожжённые при температуре 550 °C. С помощью прибора HMS-7000 Hall определено, что основными носителями заряда в пленках ZnO являются носители n-типа проводимости.

Ключевые слова: нанесение покрытия погружением, тонкие пленки ZnO:Al, золь-гель метод, оптическое пропускание, температура сушки, эффект Холла, проводимость n-типа, прозрачный проводящий оксид, легирующая добавка алюминия.

CHANGES IN OPTICAL PROPERTIES OF ALUMINUM-DOPED ZnO FILMS AS A RESULT OF HEAT TREATMENT

Absract. ZnO:Al thin films were grown on glass substrates by sol-gel deposition. Zinc acetate was used as the main element, isopropyl alcohol as the solvent, diethylamine as the stabilizer, and aluminum nitrate as the dopant. The ratio of the mass of Al atoms to the mass of Zn atoms was chosen to be 3%. The ZnO thin films with Al atoms were thermally treated at different temperatures and their optical transmittance was analyzed using a Perkin Elmer Instruments lambda 35 UV/VIS spectrometer. The results showed that among the samples, the ZnO:Al films heat-treated at 550 °C exhibited the highest (84 %) optical transmittance in the visible and near-infrared radiation range. The fact that the main charge carriers in the ZnO:Al films have a type of conductivity was determined using the HMS-7000-Hall device.

Keywords: dip coating, ZnO:Al thin films, sol–gel method; optical transmittance, annealing temperature, Holl effect, n-type conductivity, transparent conducting oxide (TCO), aluminum doping.

Введение. В настоящее время требования к прозрачным и оптоэлектронным материалам возрастают с точки зрения их оптической прозрачности, долговременной стабильности и высокой электропроводности. Среди таких перспективных материалов важное место занимают тонкие пленки полупроводников на основе оксида цинка (ZnO). Благодаря своим уникальным оптическим и электрофизическим параметрам эти слои широко используются в различных оптоэлектронных устройствах, фотодетекторах и сенсорных технологиях.

Оксид цинка (ZnO) имеет большое значение благодаря своим полупроводниковым свойствам [1]. Полупроводниковые тонкие пленки ZnO прозрачны в видимом диапазоне света, имеют ширину запрещенной зоны 3,37 эВ и широко используются в качестве проводящего материала в современной электронике [2,3]. Путем введения различных легирующих примесей можно контролировать оптические и электрофизические свойства пленок ZnO. Существуют различные методы получения тонких пленок оксидов металлов, такие как молекулярно-лучевая эпитаксия [4], золь-гель центрифугирование [5], распылительный пиролиз [6,7,8], радиочастотное магнетронное распыление [9], золь-гель погружное нанесение [10].

В зависимости от атомов легирующей примеси, пленки ZnO могут широко использоваться в газовых датчиках [11], фотокатализаторах [12], пьезоэлектрических материалах [13], прозрачных проводящих электродах [14], оптоэлектронике [15] и других областях науки и техники.

Несмотря на проведение обширных научных исследований в области тонких пленок оксидов металлов, существует недостаток исследований, посвященных углубленному изучению влияния температур термической обработки, применяемых к выращенным тонким пленкам ZnO, на их оптические и электрофизические свойства. Это может негативно сказаться на стабильной работе устройств, чувствительных к внешним воздействиям, разработанных на основе таких пленок.

В связи с этим в данной работе было изучено влияние температуры термической обработки на оптические свойства тонких пленок ZnO:Al, выращенных методом золь-гель осаждения.

Материалы и методы. В данной исследовательской работе для получения тонких пленок оксидов металлов использовался метод золь-гель осаждения. Сначала был приготовлен необходимый для эксперимента золь-раствор из определенного соотношения исходных веществ.

В эксперименте в качестве основного прекурсора использовали дигидрат ацетата цинка ($Zn(CH_3COO)_2 \cdot 2H_2O$), в качестве растворителя — изопропиловый спирт ($CH_3CH(OH)CH_3$), в качестве стабилизатора — диэтиламин ($C_4H_{11}N$), а в качестве исходного элемента — нонагидрат нитрата алюминия ($Al(NO_3)_3 \cdot 9H_2O$). Ацетат цинка и нитрат алюминия (масса атомов Al составляла 3% от атомной массы Zn) взвешивали на аналитических весах и последовательно помещали в лабораторный стакан, заполненный 100 мл изопропилового спирта. После включения магнитной мешалки диэтиламин добавляли по каплям (~1 минуту) для повышения растворимости раствора. Полученную смесь перемешивали при 60 °C магнитной мешалкой со скоростью 1500 рад/с до тех

пор, пока она не стала прозрачной. Золь хранили в специальных контейнерах до тех пор, пока он не превратился в гель.

В качестве подложек для выращивания пленок использовались стеклянные предметные стекла, очищенные от механических и химических загрязнений в ультразвуковой ванне в дистиллированной воде, затем промытые спиртом и высушенные. Такая обработка обеспечивает чистоту поверхности подложки и улучшает однородность и адгезию получаемой пленки.

Для выращивания пленок ZnO:Al из приготовленного геля на стеклянные подложки использовалось оптимизированное устройство осаждения. Частота повторения процессов выращивания пленок ZnO:Al в оптимизированном устройстве осаждения составляла приблизительно 40 раз. Выращенные пленки подвергались термической обработке при различных температурах (450-650 °C) в течение 30 минут с использованием многокамерной печи.

Оптические свойства выращенных пленок изучались с помощью УФ/видимого спектрометра Perkin Elmer Instruments lambda 35, работающего в спектральном диапазоне 190–1100 нм. Этот прибор является удобным и современным устройством, предназначенным для высокоточного измерения оптических свойств в диапазоне 190–1100 нм, что позволяет анализировать оптические свойства образцов.

Тип носителей заряда определяли с помощью прибора Холла HMS-7000. Прибор Ecopia HMS-7000 — это современная система физических измерений, отличающаяся высокой точностью и эффективностью. Этот прибор предназначен для измерения магнитных полей и электрических свойств (концентрации, типа и подвижности носителей заряда) на основе эффекта Холла.

Результаты и их обсуждение. Первоначально были изучены оптические свойства стекла, используемого в качестве подложки. Результаты измерений показали, что стекло начинает проявлять высокое оптическое пропускание, начиная с длины волны 352 нм (рис. 1). Затем на этих стеклянных подложках были выращены тонкие пленки ZnO:Al, которые подверглись термической обработке в диапазоне температур 450–650 °C. Были подробно проанализированы оптические и электрофизические свойства выращенных образцов, а также определено влияние процесса термической обработки на их физическое состояние.

На рисунке 2 показаны графики оптического пропускания пленок ZnO, легированных Al, в зависимости от длины волны. Как видно из рисунка, все приготовленные полупроводниковые тонкие пленки демонстрировали высокое оптическое пропускание в видимом (400–700 нм) и ближнем инфракрасном (700–800 нм) диапазонах излучения. Согласно анализу графика, пропускание постепенно увеличивается с повышением температуры, что объясняется улучшением кристаллической структуры материала в результате термической обработки, уменьшением количества дефектов и увеличением размера зерен. В частности, максимальное оптическое пропускание около 84% было достигнуто в образце, термически обработанном при 550 °C. Это значение указывает на высокую оптическую прозрачность и улучшенное качество поверхности.

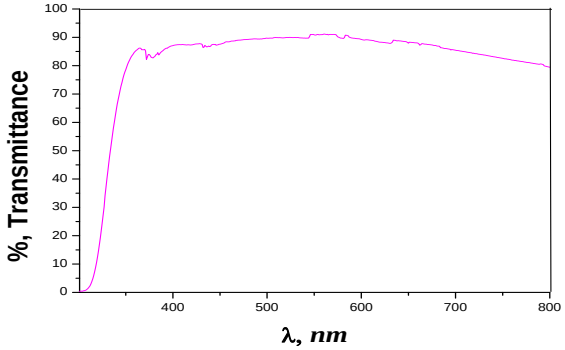

Рисунок 1. Спектры оптического пропускания стеклянной подложки.

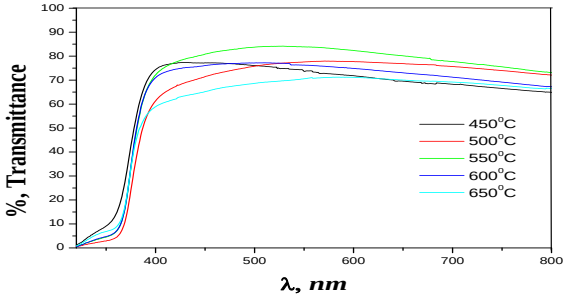

Рисунок 2. Спектры оптического пропускания пленок ZnO, легированных атомами Al и подвергнутых термической обработке при различных температурах.

Из графика видно, что оптическое пропускание пленки ZnO:Al уменьшается при температурах выше 550 °C, то есть в диапазоне 600–650 °C. Это может быть связано с тем, что при высоких температурах увеличивается количество кислородных вакансий, что приводит к увеличению числа свободных электронов. По мере увеличения числа электронов они поглощают больше световых лучей, особенно в инфракрасной области. Это, в свою очередь, указывает на то, что полученные образцы потенциально могут быть использованы в качестве прозрачных электропроводящих материалов в оптоэлектронных устройствах.

Измерения эффекта Холла на выращенных пленках легированного алюминием ZnO (AZO) показали, что основными носителями заряда являются электроны, подтверждая полупроводниковую природу n-типа этого материала. Это объясняется тем, что атомы Al замещают ионы Zn^{2+} в кристаллической решетке. То есть, в результате замещения ионов Zn^{2+} ионами Al^{3+} в решетке образуется один дополнительный электрон [16,17,18].

Эти электроны имеют донорную природу и перемещаются в зону проводимости, увеличивая количество свободных носителей заряда. Таким образом, в процессе замещения $Al^{3+}Zn^{2+}$ каждый атом алюминия участвует в качестве дополнительного донора электронов. Это приводит к увеличению концентрации свободных электронов в пленке и, как следствие, к увеличению электропроводности. Проводимость n-типа, определенная измерениями эффекта Холла, указывает на образование донорных дефектов, связанных с внедрением ионов Al в кристаллическую решетку.

Выводы. В данном исследовании был проанализирован эффект температуры термической обработки на оптические и электрические свойства тонких пленок ZnO, легированных алюминием. Эксперименты показали, что тонкие пленки ZnO:Al были успешно получены методом золь-геля, и их свойства существенно зависели от режима термической обработки. В частности, термическая обработка в диапазоне 450–650 °C оказывала значительное влияние на оптическое пропускание пленок. Анализ показал, что, хотя все образцы имели высокое оптическое пропускание в видимом и ближнем инфракрасном диапазонах, наилучший результат наблюдался у образца, термически обработанного при 550 °C. Значение оптического пропускания этого образца достигло 84%, что указывает на высокую прозрачность материала. Это объясняется улучшением кристаллической структуры, уменьшением количества дефектов и повышением качества пленки в результате термической обработки. При повышении температуры до 600–650 °C наблюдалось снижение оптической проводимости, что связано с увеличением количества кислородных вакансий и свободных электронов. Измерения эффекта Холла показали, что основными носителями заряда в пленках ZnO:Al являются электроны, что подтверждает их проводимость n-типа. Это объясняется образованием дополнительных свободных электронов в результате замещения ионов Zn^{2+} ионами Al^{3+}. В целом, результаты исследования показали, что тонкие пленки ZnO:Al перспективны для использования в оптоэлектронных устройствах в качестве прозрачных проводящих материалов с высокой оптической прозрачностью и подходящими электрическими свойствами. Также было установлено, что функциональные свойства этого материала можно эффективно контролировать, выбирая оптимальную температуру термической обработки.

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CAF_2 ASOSIDA A^3B^5 PLYONKALAR UCHUN MOSLASHTIRUVCHI QATLAMLAR HOSIL QILISH

G.M. Shirinov
Islom Karimov nomidagi Toshkent davlat texnika universiteti
Radiotexnik qurilmalar va tizimlar kafedrasi katta o‘qituvchisi
fizika-matematika fanlari bo‘yicha falsafa doktori (PhD)
ganjimurod777@gmail.com
ORCID 0000-0002-7188-2560
УДК 533.537

Annotatsiya. Ushbu ishda CaF_2 asosida A^3B^5 (GaAs, GaP) yarimo‘tkazgich tizimlarida moslashtiruvchi o‘tish qatlamlarini shakllantirish jarayonlari kompleks ravishda o‘rganildi. Tadqiqotda past energiyali ion implantatsiyasi hamda keyingi termik ishlovning sirt va interfeys xossalariga ta’siri tahlil qilindi. Oje-elektron spektroskopiyasi yordamida atomlarning chuqurlik bo‘yicha taqsimlanish profillari aniqlanib, o‘tish qatlamlarining hosil bo‘lish mexanizmlari baholandi. Natijalar shuni ko‘rsatdiki, Sr^+ ionlari bilan implantatsiya qilish va T ≈ 900 K da tavlash natijasida panjara parametrlari bosqichma-bosqich

moslashuvchi, yuqori sifatli epitaksial qatlam hosil bo‘ladi. Hosil bo‘lgan $Ca_{1-x}Sr_xF_2$ qatlam GaAs bilan yaxshi mos keluvchi panjara parametrlariga ega bo‘lib, geterotuzilmalarda mexanik kuchlanishlarni sezilarli darajada kamaytiradi. Olingan natijalar zamonaviy optoelektron qurilmalar uchun samarali geterostrukturalar yaratishda muhim ahamiyat kasb etadi.

Kalit so‘zlar: moslashtiruvchi o‘tish qatlamlari, interfeys, taqsimlanish profili, nanoplyonkalar, atom konsentratsiyasi, ion implantatsiyasi, o‘zaro diffuziya.

FORMATION OF MATCHING INTERFACIAL LAYERS FOR A^3B^5 FILMS BASED ON CaF_2

Abstract. In this study, the processes of forming matching interfacial layers in A^3B^5 (GaAs, GaP) semiconductor systems based on CaF_2 were comprehensively investigated. The effect of low-energy ion implantation and subsequent thermal treatment on the surface and interface properties was analyzed. The depth distribution profiles of atoms were determined using Auger electron spectroscopy, and the mechanisms of transition layer formation were evaluated. The results show that implantation with Sr^+ ions followed by annealing at T ≈ 900 K leads to the formation of a high-quality epitaxial layer with gradually matched lattice parameters. The formed $Ca_{1-x}Sr_xF_2$ layer exhibits good lattice matching with GaAs, significantly reducing mechanical stress in heterostructures. The obtained results are of great importance for the development of efficient heterostructures for modern optoelectronic devices.

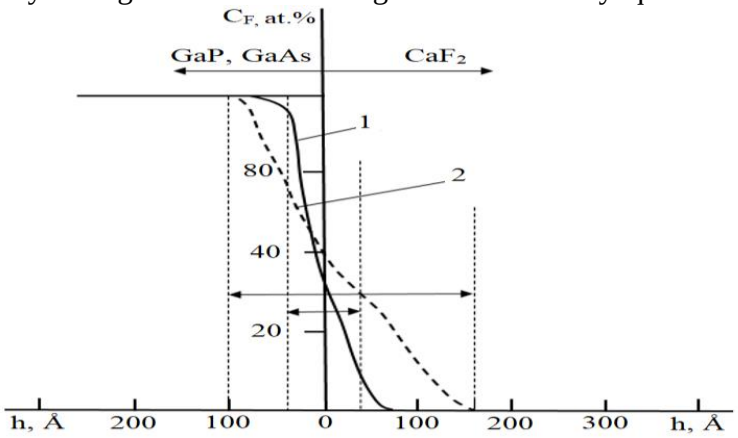
Keywords: matching interfacial layers, interface, depth distribution profile, nanofilms, atomic concentration, ion implantation, interdiffusion.

Kirish. Ma’lumki, epitaksial MDYa (metal-dielektrik-yarimo‘tkazgich) va YaDYa (yarimo‘tkazgich-dielektrik-yarimo‘tkazgich) tipidagi strukturalar mikro-, nano- hamda optoelektronika sohasida keng qo‘llanilib, yuqori istiqbolga ega hisoblanadi (SVCh tranzistorlar, integral sxemalar, rezonatorlar, optoelektron qurilmalar, xotira tizimlari, quyosh elementlari va boshqalar). Bunday tizimlarda plyonkalar chegaralari, xususan, “yarimo‘tkazgich-dielektrik” interfeysi o‘ziga xos fizik-kimyoviy xususiyatlarga ega bo‘lib, ularni maqsadli boshqarish va foydalanish yangi avlod elektron qurilmalarini ishlab chiqish imkonini yaratadi [1-5]. Shu bilan birga, ko‘p qatlamli zamonaviy strukturalarni yaratishda panjara parametrlari o‘zaro mos keladigan yarimo‘tkazgich va dielektrik materiallarni tanlash har doim ham imkonli bo‘lavermaydi. Natijada, bunday tizimlarda maxsus o‘tish (moslashtiruvchi) qatlamlarni shakllantirish zarurati yuzaga keladi. Nanoplyonkali strukturalar tayyorlash jarayonida ko‘pincha kubik panjara tuzilishiga ega bo‘lgan materiallar qo‘llaniladi. Jumladan, Si, Ge, GaAs, GaP, CdTe yarimo‘tkazgichlari; CaF_2, BaF_2, SrF_2 dielektriklari hamda metall xossalariga ega bo‘lgan yarimo‘tkazgichlar — $NiSi_2$ va $CoSi_2$ keng ishlatiladi [6-9]. Bunday holatlarda plyonkalarni o‘stirish uchun kristall tuzilmaning mosligi, panjara parametrlari o‘rtasidagi yaqinlik, shuningdek, issiqlik kengayish koeffitsiyentlarining uyg‘unligi muhim omillar sifatida qaraladi. Panjara parametrlari o‘rtasida sezilarli nomutanosiblik mavjud bo‘lgan hollarda moslashtiruvchi (o‘tish) qatlamlarni hosil qilish zarurati yuzaga keladi. Hozirgi vaqtgacha MDYa va YaDYa tipidagi strukturalar sifatida asosan $NiSi_2/CaF_2/Si$ hamda $CoSi_2/CaF_2/Si$ ko‘rinishidagi epitaksial tizimlardan keng foydalanib kelinmoqda [9-12]. Ushbu materiallarning panjara parametrlari o‘zaro deyarli mos keladi. Shu bilan birga, zaryad tashuvchilarning konsentratsiyasi va ularning harakatchanligi bilan bog‘liq xususiyatlar sababli Si o‘rniga GaAs, GaP, InP kabi ikki komponentli (binar) yarimo‘tkazgichlarni qo‘llash maqsadga muvofiq hisoblanadi. Amaliy nuqtayi nazardan CaF_2/GaP va CaF_2/GaAs geterostrukturalari alohida qiziqish uyg‘otadi. CaF_2 ning panjara parametri (a ≈ 5,39 Å) GaP (a ≈ 5,45 Å) ga yaqin bo‘lsa-da, GaAs (a ≈ 5,65 Å) bilan taqqoslaganda sezilarli tafovut kuzatiladi. Panjara doimiylarining mos kelmasligi natijasida atomlarning o‘zaro diffuziyasi kuchayadi va bu holat plyonka-taglik interfeysida o‘tish qatlamlari qalinligining ortishiga olib keladi [13-15]. Ushbu ishning asosiy maqsadi A^3B^5-CaF_2(111) tizimi uchun ion implantatsiyasi usulini keyingi termik ishlov bilan uyg‘unlashtirgan holda moslashtiruvchi o‘tish qatlamlarini shakllantirishdan iborat.

Eksperiment metodikasi. Qalinligi taxminan ~600 Å bo‘lgan GaAs va GaP plyonkalari CaF_2(111) sirtining oldindan puxta tozalangan yuzasiga MNE (molekulyar nur epitaksiyasi) usuli orqali xona haroratida cho‘ktirildi. Hosil qilingan plyonkalar amorf holatga ega bo‘ldi. Tadqiqot obyekti sifatida diametri ≈ 10 mm va qalinligi 1 mm bo‘lgan GaP(111) monokristall namunalari tanlab olindi. Eksperimental tadqiqotlar bir qator zamonaviy usullar

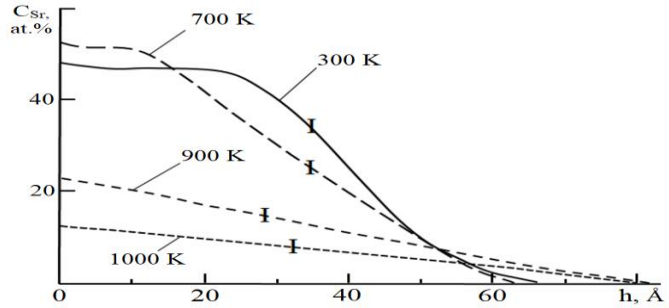
asosida olib borildi: Oje-elektron spektroskopiyasi (OES), tez elektronlar difraksiyasi (TED), ultrabinafsha fotoelektron spektroskopiyasi (UFES), shuningdek, ikkilamchi elektron emissiya koeffitsiyentining (IEEK) energiya va burchakka bog‘liqliklarini aniqlash. Atomlarning chuqurlik bo‘yicha taqsimlanishini aniqlash maqsadida namuna sirtiga Ar^+ ionlari (E = 1 keV, tushish burchagi ~80-85°) bilan ta’sir ettirilib, bosqichma-bosqich Oje-tahlil amalga oshirildi. Jarayon davomida yemirish tezligi ~(5±1) Å/min ni tashkil etdi. Ultrabinafsha fotoelektron spektrlari foton energiyasi hν ≈ 10,8 eV qiymatda qayd qilindi. Nurlanish manbayi sifatida standart gaz razryadli vodorod lampasidan foydalanildi.

Eksperimental natijalar. 1-rasmda GaP/CaF_2 va $GaAs/CaF_2$ tizimlari uchun F atomlarining chuqurlik bo‘yicha taqsimlanish profillari, ya’ni tavlash (annealing) dan oldingi va keyingi holatlar keltirilgan. Rasm tahlili shuni ko‘rsatadiki, hatto xona haroratida ham plyonka-taglik interfeysida GaP (yoki GaAs) va CaF_2 birikmalarining qisman parchalanishi hamda ular orasida atomlarning o‘zaro diffuziyasi yuz beradi. Bunda P (yoki As) hamda F atomlarining diffuziya tezligi Ga va Ca atomlariga nisbatan ancha yuqori ekanligi aniqlanadi.



1-rasm. $GaP/CaF_2(111)$ va $GaAs/CaF_2$ tizimlarida F atomlarining chuqurlik bo‘yicha taqsimlanish profillari: 1 - $GaP/CaF_2(111)$, 2 - $GaAs/CaF_2$.

Tavlashdan oldingi holatda GaP/CaF_2 tizimida o‘tish qatlamining qalinligi taxminan ~100 Å ni, $GaAs/CaF_2$ tizimida esa ~250 Å ni tashkil etadi. Epitaksial plyonkalarni shakllantirish maqsadida $GaAs/CaF_2$ va GaP/CaF_2 tizimlari mos ravishda T = 850 K va 900 K haroratgacha qizdirildi. Tavlash jarayonining davomiyligi ~25-30 minutni tashkil etdi. Tavlashdan keyin o‘tish qatlamining kengligi GaP/CaF_2 tizimida ~150 Å gacha, $GaAs/CaF_2$ tizimida esa ~400 Å gacha ortgani kuzatildi [5]. Natijada, o‘tish qatlamining qalinligi hamda o‘zaro diffuziyalanuvchi atomlar konsentratsiyasi GaP/CaF_2 tizimida $GaAs/CaF_2$ tizimiga nisbatan kamida ikki baravar kichik ekanligi aniqlandi. Tahlillar shuni ko‘rsatadiki, $GaAs/CaF_2$ interfeysida o‘tish qatlamining katta qalinlikka ega bo‘lishi, asosan, panjara parametrlari o‘rtasidagi sezilarli nomutanosiblik natijasida tutashuvchi yuzalar orasida yuqori darajadagi mexanik kuchlanishlarning paydo bo‘lishi bilan izohlanadi. Shu bois, $GaAs/CaF_2$ tizimida maxsus moslashtiruvchi o‘tish qatlamini shakllantirish zarurati yuzaga keladi. Bunda CaF_2 ning panjara parametri “a” ni ~5,46 Å dan ~5,65 Å gacha bosqichma-bosqich oshirish talab etiladi. Ushbu natijaga ion implantatsiyasi usulini keyingi termik ishlov bilan birgalikda qo‘llash orqali erishish mumkin [NIM B – 2000, UPE]. Implantatsiya jarayoni Mg^+, Ba^+ va Sr^+ ionlari yordamida E_0 = 0,5-3 keV energiya oralig‘ida hamda to‘yinish dozasi $D = D_H$ sharoitida amalga oshirildi. Keyinchalik namunalar uch komponentli monokristall birikma qatlamlari hosil bo‘ladigan haroratgacha tavlandi. Tadqiqotlar shuni ko‘rsatdiki, eng barqaror va samarali o‘tish qatlami aynan Sr^+ ionlari implantatsiyasi natijasida shakllanadi. 2-rasmda E_0 = 1 keV energiyada va $D = 6 \cdot 10^{16}$ sm^{-2} dozada Sr^+ ionlari bilan implantatsiya qilingan CaF_2 namunalarida turli tavlash haroratlaridan so‘ng olingan Sr atomlari konsentratsiyasining (C_{sr}) chuqurlikka (h) bog‘liqligi tasvirlangan. Har bir haroratda tavlash davomiyligi 30 minutni tashkil etgan. Natijalardan ko‘rinadiki, tavlashdan oldin implantatsiya qilingan Sr atomlarining asosiy qismi sirtga yaqin qatlamda, taxminan 40-45 Å chuqurlikkacha joylashadi. Shu bilan birga, Sr atomlarining barchasi ham matritsa atomlari bilan to‘liq kimyoviy bog‘lanishga kirishmaydi.



2-rasm. E_0 = 1 keV energiya va D = 6·10^{16} sm^{-2} dozada Sr^+ ionlari bilan implantatsiya qilingan CaF_2 da tavlashning Sr atomlari konsentratsiyasining chuqurlik bo‘yicha taqsimlanishiga ta’siri.

T = 600 K gacha bo‘lgan harorat oralig‘ida Sr atomlarining chuqurlik bo‘yicha taqsimlanish profili deyarli o‘zgarmaydi. T = 700 K da amalga oshirilgan tavlash jarayoni esa sirt qatlamida Sr atomlari konsentratsiyasining biroz ortishiga olib keladi, bu holat bog‘lanmagan Sr atomlarining sirtga yo‘nalgan diffuziyasi bilan tushuntiriladi. Harorat yanada oshirilganda Sr atomlarining nafaqat sirtga, balki nishon ichkarisiga diffuziyasi ham kuchayadi. Natijada Ga-Sr-As tipidagi birikmalar shakllanadi, strukturadagi nuqsonlar kamayadi va ionlar bilan legirlangan qatlamlarning kristallanish jarayoni yuz beradi. Shu bilan bir vaqtda implantatsiya hududidan Sr atomlarining intensiv desorbsiyasi kuzatilib, $C_{sr}(h)$ bog‘liqligi pasayuvchi egri chiziq ko‘rinishini oladi. Natijada sirtga yaqin qatlamda Sr atomlarining umumiy konsentratsiyasi kamayadi, bu esa $C_{sr}(h)$ egri chizig‘i ostidagi maydonning qisqarishi orqali tasdiqlanadi. T = 900 K haroratda Sr atomlarining barchasi matritsa atomlari bilan kimyoviy bog‘lanishga kirishib, epitaksial monokristall plyonka shakllanadi. Sirt qatlamining taxminiy tarkibi $Ga_{0,6}Sr_{0,4}F_2$ ko‘rinishida ifodalanadi. Chuqurlik ortishi bilan Sr atomlari konsentratsiyasi muntazam kamayib boradi, aksincha Ca atomlari konsentratsiyasi ortadi. d ≈ 75-80 Å chuqurlikda Sr miqdori deyarli nol darajagacha kamayadi. Sirt sohasida hosil bo‘lgan $Ca_{0,6}Sr_{0,4}F_2$ strukturasi uchun panjara parametri a ≈ 5,71 Å ni tashkil etib, bu qiymat GaAs plyonkasining panjara parametriga yaqin keladi. Shu bois, CaF_2 yuzasida Sr^+ ionlarini implantatsiya qilish orqali hosil qilingan o‘tish qatlami GaAs/CaF_2 tizimi uchun eng samarali yechim hisoblanadi. Haroratni 1000 K gacha oshirish orqali $Ca_{0,7}Sr_{0,3}F_2$ turidagi birikmani shakllantirish mumkin [13-15].

Xulosa. GaAs/CaF_2 tizimi uchun CaF_2 yuzasida $Ca_{1-x}Sr_xF_2$ tarkibli nanometr diapazondagi moslashtiruvchi o‘tish qatlamlari shakllantirildi. Chuqurlik bo‘yicha “x” parametrining chiziqli o‘zgarishi bilan tavsiflanadigan eng optimal qatlamlar E_0 = 1 keV energiyada Sr^+ ionlari bilan implantatsiya qilingan CaF_2 namunalarini T = 900 K da tavlash natijasida hosil qilindi. Mazkur holatda o‘tish qatlamining qalinligi taxminan ~ 80 Å ni tashkil etdi.

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ZNO+C_{60} NANOKOMPOZIT YUPQA PLYONKALARINING LAZER QUVVATIGA BOG‘LIQ RAMAN TAHLILI

M.A. Zaxidova
Mirzo Ulug‘bek nomidagi O‘zbekiston Milliy universiteti
Fizika fakulteti Prof. v.b.
mzakhidova@yahoo.com
S.E. Abdurashidova
Mirzo Ulug‘bek nomidagi O‘zbekiston Milliy universiteti
Fizika fakulteti magistratura talabasi
sabdurashidova89@gmail.com
ORCID 0000-0002-5749-1870
UDK 535.375.5

Annotatsiya. Ushbu maqolada ZnO va ZnO+C_{60} yupqa plyonkalarining turli lazer quvvatlari ostida olingan Raman spektrlari tahlil qilindi. Tadqiqotda lazer nurlanishi ta’sirida yuzaga keladigan issiqlik effektlarining namunalar strukturasi va vibratsion xossalariga ta’siri o‘rganildi. Natijalar o‘rtacha lazer quvvati spektral aniqlik hamda pik intensivligini optimal darajada ta’minlashini ko‘rsatdi. Yuqori quvvatlarda esa spektral piklarning kengayishi, fon signalining ortishi va kristall panjaradagi strukturaviy buzilishlar kuzatildi. ZnO+C_{60} kompozit tizimiga xos fonon modlari hamda ichki atom tebranishlarining aniqlanishi kompozitning muvaffaqiyatli shakllanganligini tasdiqlaydi. Olingan natijalar ushbu tizimlarning optoelektronika, sensorika va nanofotonika qurilmalarida qo‘llanish istiqbollarini ko‘rsatadi. Shuningdek, Raman spektroskopiyasi yordamida lazer quvvatining material morfologiyasi va kristall sifati bilan bog‘liqligi aniqlandi hamda termik degradatsiya jarayonlari baholandi.

Kalit so‘zlar: Raman spektroskopiya, ZnO, C_{60}, nanokompozit, lazer quvvati, yupqa plyonkalar, optoelektronika.

LASER POWER-RELATED RAMAN ANALYSIS OF ZNO+C_{60} NANOCOMPOSITE THIN FILMS

Abstract. In this study, the Raman spectra of ZnO and ZnO+C_{60} thin films obtained under different laser power conditions were analyzed. The influence of laser-induced thermal effects on the structural and vibrational properties of the samples was investigated. The results demonstrated that moderate laser power provides optimal spectral resolution and peak intensity. At higher laser powers, spectral peak broadening, an increase in the background signal, and structural disorder in the crystal lattice were observed. The identification of phonon modes and intrinsic atomic vibrational modes characteristic of the ZnO+C_{60}

composite system confirms the successful formation of the nanocomposite structure. The obtained results indicate the potential applications of these systems in optoelectronic, sensing, and nanophotonic devices. Furthermore, Raman spectroscopy revealed the correlation between laser power, material morphology, and crystal quality, as well as thermally induced degradation processes.

Keywords: Raman spectroscopy, ZnO, C_{60}, nanocomposite, laser power, thin films, optoelectronics.

Kirish. So‘nggi yillarda nanostrukturalangan materiallarning fizik va optoelektron xossalarini o‘rganish zamonaviy ilm-fanning dolzarb yo‘nalishlaridan biriga aylandi. Ayniqsa, metall oksidlari va uglerod asosidagi nanostrukturalardan tashkil topgan kompozit tizimlar yangi funksional materiallar yaratishda muhim ilmiy va amaliy ahamiyat kasb etmoqda.

ZnO keng taqiqlangan zonaga ega yarimo‘tkazgich material bo‘lib, yuqori optik shaffoflik, katta eksiton bog‘lanish energiyasi va kuchli lyuminestsensiya xossalari bilan ajralib turadi. C_{60} fullerene esa yuqori elektron qabul qilish qobiliyati hamda o‘ziga xos vibratsion modlari bilan xarakterlanadi, bu esa zaryad almashinuvi va molekulyar o‘zaro ta’sirlar uchun muhimdir[3, 450–490].

ZnO va C_{60} ni kompozit tuzilma sifatida birlashtirish energiya konversiyasi samaradorligini oshirish hamda sirt hodisalarini boshqarish uchun yangi imkoniyatlar yaratadi. Bunday tizimlarni tadqiq qilish yuqori aniqlikdagi spektroskopik usullarni talab qiladi. Raman spektroskopiyasi panjara dinamikasi, fonon modlari va molekulyar o‘zaro ta’sirlarni o‘rganishda samarali usullardan biri hisoblanadi. Shu bilan birga, lazer quvvati, issiqlik effektlari va nuqsonlar hosil bo‘lishi spektral natijalarga sezilarli ta’sir ko‘rsatishi mumkin. [1, 214–230]

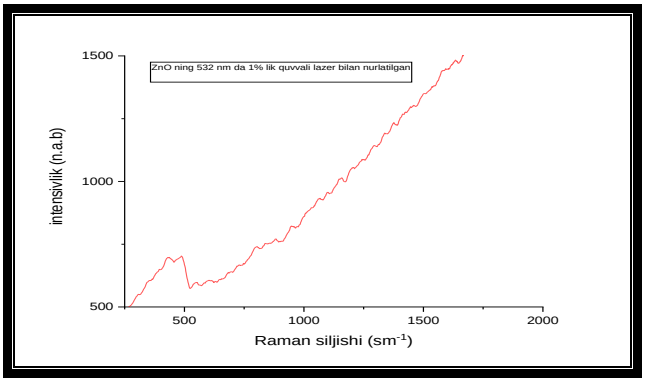
ZnO + C_{60} kompozit tizimi fotokataliz, sensorika va optoelektron qurilmalarda qo‘llash uchun istiqbolli material hisoblanadi. Mazkur ishning asosiy maqsadi ZnO va ZnO + C_{60} yupqa plyonkalarining turli lazer quvvatlarida olingan Raman spektrlari asosida ularning strukturaviy va optik xossalarini tahlil qilish hamda optimal o‘lchash parametrlarini aniqlashdan iborat[10, 55–110].

Tadqiqot metadologiyasi. ZnO va ZnO+C_{60} yupqa plyonkalari standart cho‘ktirish texnologiyalari yordamida tayyorlandi. C_{60} qatlami bir tekis va barqaror qoplam hosil qilish maqsadida spin-coating usuli orqali yotqizildi.

Raman spektrlari laboratoriya sharoitida Raman spektrometri (Renishaw) yordamida o‘lchandi. O‘lchovlar 532 nm to‘lqin uzunlikdagi qo‘zg‘atuvchi lazer nurlanishi quvvatining maksimal qiymatining turli quvvat darajalarida (1%, 10% va 50%) o‘tkazildi[6, 55–98].

Spektrlarni yozib olishda 200–3200 sm^{-1} spektral diapazonda, ~1–2 sm^{-1} spektral aniqlik va natijalarning ishonchliligini ta’minlash uchun 5–6 marotaba takroriy o‘lchashlar olib borildi. O‘lchashlar davomida namunalarni ortiqcha qizib ketishdan saqlash maqsadida lazer nurlanishining har bir spektr uchun alohida optimal fokuslab olindi[4, 25–56].

Natijalar va muhokama. ZnO namunasini 532 nm to‘lqin uzunlikdagi qo‘zg‘atuvchi lazer nurlanishi quvvatining maksimal qiymatining 1% quvvat darajasida lazer nurlanishi ta’siri ostida olingan Raman spektrlari 1-rasmda tasvirlangan. Spektr 250–2000 cm^{-1} oralig‘ida olingan bo‘lib, intensivlik qiymatlari taxminan 500 dan 1500 nisbiy birlikkacha ortib boruvchi qiymatlarda olingan. Grafikda Raman sochilish spektri fon signalining ortishi kuzatiladi[2, 3–7].

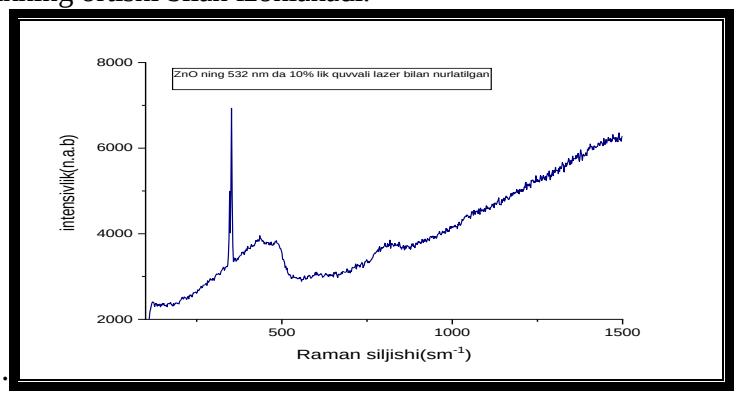


1-rasm. ZnO plyonkasining 532 nm lazer (1% quvvat) ta’sirida olingan Raman spektri

Bunday holat ko‘pincha fon lyuminessensiyasi yoki ZnO materialining optik xususiyatlari va lazer nuri bilan o‘zaro ta’siriga bog‘liq bo‘lishi mumkin.

Lazer quvvatining ortishi bilan fon signal va lyuminessensiya hissasi sezilarli darajada ortadi. Raman spektrining past chastota sohasida (~437 sm^{-1}) kichik intensivlik o‘zgarishlari kuzatiladi (1-rasm), bu o‘zgarishlar ZnO ga xos E_2 (high) fonon modasi bilan bog‘liq bo‘lib, u asosan kristall panjaradagi kislorod atomlarining tebranishlari bilan bog‘liq[11, 3027–3073].

Bu holat ZnO ning vurtzit kristall tuzilmasiga ega ekanligini hamda materialning yuqori kristall sifati va yaxshi tartiblanganligini tasdiqlaydi. Olingan natijalar Cuscó va boshqalar [2] ishlaridagi ma’lumotlar bilan mos keladi. Lazer quvvati ortishi bilan pikning kengayishi va intensivligining kamayishi kuzatildi, bu fononlar sochilishi hamda kristall panjaradagi tartibsizlikning ortishi bilan izohlanadi.



2-rasm. ZnO plyonkasining 532 nm lazer (10% quvvat) ta’sirida olingan Raman spektri

Raman siljishi ortishi bilan fon signalining kuchayishi fotolyuminessensiya hissasi bilan bog‘liq bo‘lib, ayniqsa 532 nm lazer bilan nurlantirilgan yarimo‘tkazgich materiallarda kuzatiladi. Shuningdek, sirt holati, zarracha o‘lchami va kislorod bo‘shliqlari kabi defekt markazlari ham fon signalining ortishiga sabab bo‘lishi mumkin.

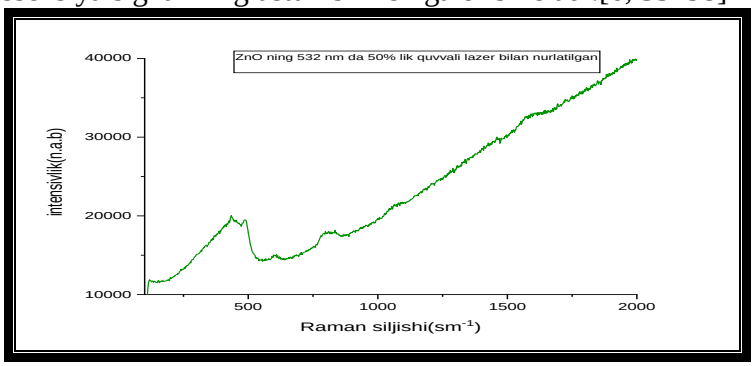
Lazer quvvatining 10% qiymatida olingan spektrning (2-rasm) past chastota sohasida (≈300–450 sm^{-1}) keskin va aniq pik kuzatildi. Ushbu pik ZnO ning wurtzit strukturasi uchun xarakterli E_2(high) fonon modasiga mos kelib, materialning yuqori kristallik darajasini ko‘rsatadi. Spektrda 400–600 sm^{-1} oralig‘idagi kichik tebranishlar panjara nuqsonlari yoki ikkilamchi fonon jarayonlari bilan bog‘liq bo‘lishi mumkin. 600 sm^{-1} dan keyin intensivlikning pasayib, keyinchalik ortib borishi fon signali va lyuminessensiya hissasi bilan izohlanadi. 1000 sm^{-1} dan yuqori sohada intensivlikning monoton ortishi esa defekt holatlari va lyuminessensiya hissasi bilan bog‘liq bo‘lib, yuqori energiyali elektron-o‘tish jarayonlarini aks ettiradi [4, 25–56].

Tadqiqot natijalari lazer quvvatining 10% qiymati spektrlarni qayd etish uchun optimal rejim ekanligini ko‘rsatdi, chunki bu holatda signal intensivligi hamda namunaning strukturaviy va fizik-kimyoviy barqarorligi o‘rtasida maqbul muvozanat ta’minlanadi. Ushbu rejimda spektral chiziqlar aniq, fon signali past va termik ta’sir minimal bo‘lib, natijalar ishonchliligi hamda takrorlanuvchanligini oshiradi. Bu ayniqsa sezgir nanostrukturali materiallarni tadqiq etishda muhim ahamiyatga ega.

Aksincha, lazer quvvatining 50% qiymatida (3-rasm) spektral piklarning kengayishi va deformatsiyalanishi kuzatildi, bu esa kristall panjaradagi nuqsonlar ortishi hamda issiqlik effektlari bilan izohlanadi.

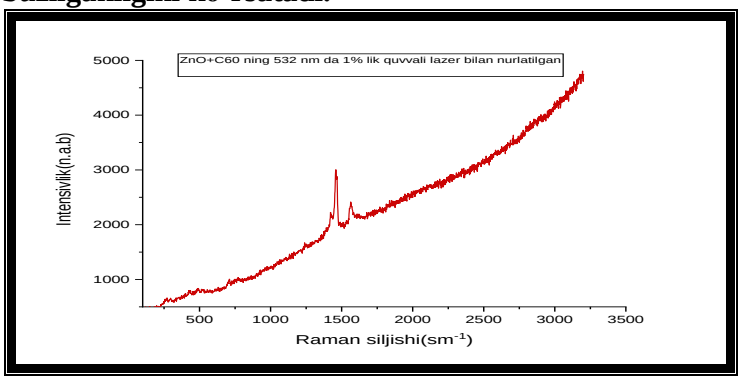
Mazkur spektrda intensivlikning Raman siljishiga bog‘liqligi yuqori lazer quvvatida sezilarli o‘zgarishlarga uchraganligi kuzatiladi. Past chastota sohasida (≈300–500 sm^{-1}) kengaygan va nisbatan yoyilgan piklar mavjud bo‘lib, ular ZnO kristall panjarasining asosiy fonon modalariga tegishlidir. Biroq, 10% quvvat bilan olingan spektrga nisbatan bu piklar ancha keng va deformatsiyalangan bo‘lib, bu kristall panjarada issiqlik ta’siri yoki nuqsonlar ortganligini ko‘rsatadi. ≈450–550 sm^{-1} oralig‘ida kuzatiladigan maksimum qiymatlar E_2 (high) modasining susaygan va kengaygan shakliga mos keladi. Pikning aniqligi pasaygani yuqori quvvatli lazer ta’sirida fononlarning tarqalishi va panjara tartibining buzilishi bilan izohlanadi. 600–900 sm^{-1} oralig‘ida bir nechta kichik tebranishlar mavjud bo‘lib, ular ko‘p fononli

jarayonlar yoki strukturaviy nuqsonlar bilan bog‘liq. Ushbu sohada signalning notekisligi va shovqinning ortishi lazer nurlanishining kuchayishi bilan bog‘liq termik effektlarni ko‘rsatadi.1000 sm^{-1} dan yuqori sohada lyuminessensiya fonining keskin va deyarli chiziqli ortishi kuzatiladi. Yuqori quvvatli lazer elektronlarning yuqori energiyali holatlarga o‘tishini kuchaytirib, lyuminessensiya signalining ustun bo‘lishiga olib keladi.[6, 55–98]



3-rasm. ZnO plyonkasining 532 nm lazer (50% quvvat) ta’sirida olingan Raman spektri

50% quvvatdagi lazer bilan olingan Raman spektr ZnO namunada **E_2 (high) modasining susayishi va kengaygan shaklga o‘tishi fononlarning tarqalishi hamda panjara tartibining buzilganligini ko‘rsatadi.**



4-rasm. ZnO + C_{60} kompozitining 1% quvvatdagi lazer (532 nm) ta’sirida olingan Raman spektri

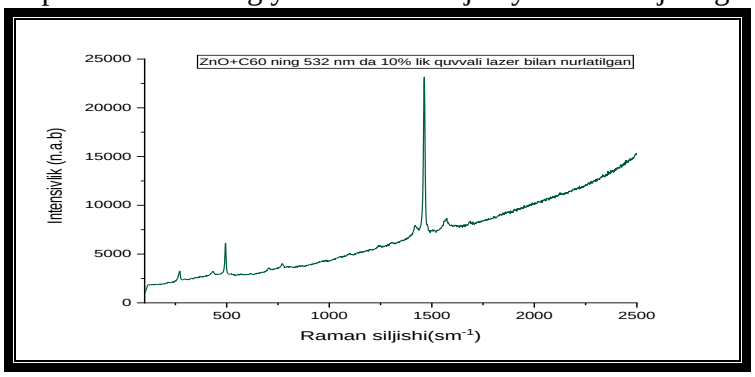
Shuningdek, spektrda shovqin va **lyuminestsensiya**ning ortishi yuqori quvvatli lazer ta’sirida yuzaga keladigan termik jarayonlar bilan bog‘liq bo‘lib, bu holat kristall tuzilmaning qisman buzilganligini va material sifatining pasayganligini bildiradi. Olingan natijalar Banwell va Mc Cash tomonidan tavsiflangan [4] Raman signal sifatiga ta’sir etuvchi issiqlik effektlari nazariyasi bilan mos keladi.

Lazer nurlanishi quvvatining maksimal qiymatining 1% darajasidan foydalangan holda olingan ZnO + C_{60} kompozit tizimining Raman spektrida (4-rasm) har ikkala komponentga xos vibratsion xususiyatlar 1400–1500 sm^{-1} oralig‘ida joylashgan kuchli va aniq piklar paydo bo‘lishi bilan harakterlanadi va bu holat kompozit tuzilmaning muvaffaqiyatli shakllanganligini ko‘rsatadi.

ZnO+C_{60} kompozit tuzilmaning muvaffaqiyatli shakllanganligini 5-rasmdagi lazer nurlanishi quvvatining maksimal qiymatining 10% darajasidan foydalangan holda olingan Raman spektrida yaqqol namoyon bo ‘ladi. Spektrning past chastotali sohasida, taxminan 300–500 sm^{-1} oralig‘ida, ZnO kristall panjarasiga xos fonon modalar kuzatiladi. Xususan, ~437 sm^{-1} atrofidagi pik ZnO uchun xarakterli bo‘lgan E_2 (high) fonon modasiga mos kelishini va bu ZnO tarkibiy qismida wurtzit kristall tuzilmasi kompozitda ham saqlanganini va materialning yetarli darajada yaxshi kristallanganligini bildiradi, biroq ushbu modalar intensivligining nisbatan pasayishi ZnO yuzasiga C_{60} qatlamining joylashishi hamda komponentlar o‘rtasidagi interfeys o‘zaro ta’siri natijasida ZnO signalining qisman susayganligini ko‘rsatadi[3, 450–490].

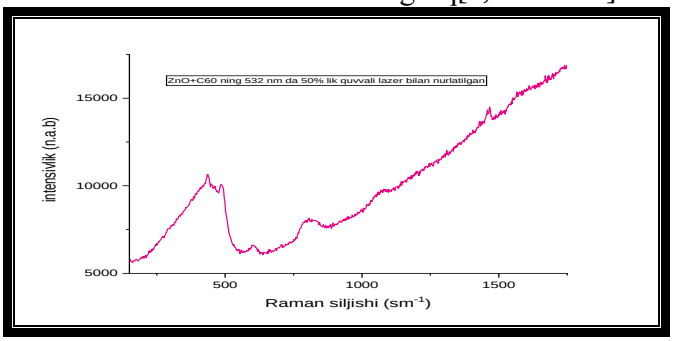
Spektrning eng informativ sohasi 1400–1500 sm^{-1} oralig‘ida joylashgan yuqori intensivlikdagi piklar bilan xarakterlanadi. Xususan, ~1460 sm^{-1} atrofidagi kuchli pik C_{60} molekulasiga xos Ag(2) simmetrik (“pentagonal pinch”) vibratsion modaga mos keladi. Ushbu moda fullerene C_{60} dagi pentagon halqalarning radial tebranishlari bilan bog‘liq bo‘lib, C_{60}

tuzilmasining saqlanganligini tasdiqlaydi. Pikning yuqori intensivlik va aniqlik bilan namoyon bo‘lishi fullerene C_{60} ning kompozit tarkibiga samarali integratsiyalashganini hamda kompozit shakllanish jarayonining muvaffaqiyatli amalga oshganini ko‘rsatadi. Shu sababli mazkur pik C_{60} mavjudligining eng ishonchli spektral belgilaridan biri hisoblanadi[9, 201–240]. Spektrdagi ~1550 sm^{-1} yaqinidagi kichikroq pik C_{60} yoki qisman grafitlashgan uglerod tuzilmalariga xos vibratsion modalar bilan bog‘liq bo‘lib, lazer nurlanishi ta’sirida yuzaga kelgan qisman strukturaviy o‘zgarishlarni ko‘rsatadi. Shuningdek, 1500–2500 sm^{-1} oralig‘ida fon signalining ortishi fluoresensiya effektlari yoki amorf uglerod komponentlari mavjudligi bilan izohlanadi va kompozit ichida energiya almashinuvi jarayonlari mavjudligini bildiradi.



5-rasm. ZnO + C_{60} kompozitining 10% quvvatdagi lazer (532 nm) ta’sirida olingan Raman spektri.

ZnO va C_{60} o‘rtasidagi o‘zaro ta’sir piklarning shakli, intensivligi va siljishida namoyon bo‘ladi. ZnO ga tegishli fonon modalarining susayishi hamda C_{60} ga xos piklarning ustunligi komponentlar o‘rtasida zaryad almashinuvi va interfeysdagi fizik-kimyoviy bog‘lanishlar mavjudligini ko‘rsatadi. Bu esa kompozitning oddiy mexanik aralashma emas, balki funksional geterotuzilma ekanligini tasdiqlaydi. ZnO + C_{60} kompozitining 50% quvvatdagi lazer (532 nm) ta’sirida olingan Raman spektrida (6-rasm) ~500–600 sm^{-1} oralig‘ida kuzatilgan kengaygan piklar ZnO panjarasidagi kislorod vakansiyalari, lokal nuqsonlar yoki C_{60} bilan o‘zaro ta’sir natijasida yuzaga kelgan panjara buzilishlari bilan bog‘liq bo‘lishi mumkin. Bu holat interfeys hududida ma’lum strukturaviy o‘zgarishlar mavjudligini ko‘rsatadi. Bunday nuqsonlar ayrim hollarda materialning optik va elektron xossalariga ijobiy ta’sir ko‘rsatishi mumkin. 1500 sm^{-1} dan yuqori sohada fon signalining asta-sekin ortishi lyuminestsensiya hissasi, amorf uglerod komponentlari yoki lazer ta’siridagi energiya almashinuvi jarayonlari bilan izohlanadi. Lyuminestsensiyaning kuchayishi C_{60} ning qisman buzilishi, grafitlashishi yoki amorf uglerod hosil bo‘lishini ham ko‘rsatishi mumkin. 1400–1600 sm^{-1} oralig‘idagi kichik piklar uglerodga xos D va G bantlari bilan bog‘liq bo‘lib, C_{60} ning qisman amorf holatga o‘tganini bildiradi. Umumiy fon signalining ortishi esa asosan fotolyuminestsensiya hissasi va termik effektlar bilan bog‘liq[5, 110–145]



6-rasm. ZnO + C_{60} kompozitining 50% quvvatdagi lazer (532 nm) ta’sirida olingan Raman spektri

Lazer quvvatining ta’siri Raman spektrlarini tahlil qilishda muhim omil hisoblanadi. Tajriba natijalari 10% lazer quvvatida olingan spektr optimal ekanligini ko‘rsatdi, bunda ZnO ga xos fonon modalar va C_{60} ning Ag(2) vibratsion modasi aniq kuzatiladi. Ushbu rejim signal aniqligi yuqori, fon signali past va termik ta’sir minimal bo‘lishi bilan xarakterlanadi. Aksincha, 50% quvvatda spektral piklarning kengayishi, intensivlikning pasayishi va fon

signalining ortishi kuzatilib, bu termik effektlar hamda kristall panjaradagi tartibsizlikning kuchayishi bilan izohlanadi[4, 25–56]

Xulosa va takliflar. ZnO + C_{60} kompozit tizimining Raman spektri ZnO ning wurtzit kristall tuzilmasi saqlanganligini, C_{60} molekulalari muvaffaqiyatli integratsiyalashganligini hamda komponentlar o‘rtasida sezilarli interfeys o‘zaro ta’siri mavjudligini tasdiqlaydi. Spektrdagi asosiy markerlar sifatida ~437 sm^{-1} dagi ZnO E_2 (high) fonon modasi va ~1460 sm^{-1} dagi C_{60} Ag(2) vibratsion modasi xizmat qiladi. Ushbu tadqiqot natijalari Raman spektroskopiya ZnO va ZnO+C_{60} yupqa plyonka tizimlarining strukturaviy va vibratsion xossalarini tahlil qilishda samarali usul ekanligini ko‘rsatdi. Olingan natijalar lazer quvvati spektr sifati va aniqligini belgilashda hal qiluvchi ahamiyatga ega ekanligini yaqqol namoyon qildi. Mazkur natijalar ZnO + C_{60} kompozit materiallarining optoelektronika, fotonika va sensor texnologiyalarida qo‘llash istiqbollarini kengaytiradi. Kelgusi tadqiqotlarda interfeys xususiyatlarini chuqurroq o‘rganish va tayyorlash texnologiyalarini optimallashtirish orqali bunday gibrid nanomateriallarning samaradorligini yanada oshirish mumkin.

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NUMERICAL METHODS FOR SOLVING SAINT-VENANT-TYPE HYPERBOLIC SYSTEMS: ANALYSIS AND EXPERIMENTS

Aziza Abdukhakimovna Akbarova
Kokand University Andijan Branch. Senior Lecturer
Department of Physics and Mathematics.
Doctor of Philosophy (PhD) in Physics and Mathematics
aziza_aziza_2019@mail.ru
ORCID 0000-0001-6119-7212
Nishonova Marhabo Alisherbek qizi
Kokand University Andijan Branch teacher
Department of Physics and Mathematics
nishonovamarhabo001@gmail.com
ORCID 0009-0001-3003-6632
UDK 519.63:517.958

Abstract. This paper investigates numerical methods for solving Saint-Venant-type hyperbolic systems with variable coefficients. The problem is motivated by the need to analyze the stability and accuracy of finite difference schemes in the modeling of unsteady flows. The research methodology involves

the construction and comparative analysis of three classes of numerical schemes - namely, the Lax scheme, the Godunov scheme, and operator splitting methods. Particular attention is given to stability conditions, including the Courant–Friedrichs–Lewy (CFL) condition, as well as error assessment based on the $L_2 -$ norm. A series of computational experiments is conducted under various initial and boundary conditions, allowing for the identification of distinctive features in the behavior of each method. The main findings demonstrate that the schemes exhibit different stability and convergence properties, with the conditions $r \cdot s < 1$ and the CFL criterion playing a decisive role in ensuring the correctness of numerical solutions.

The conclusion highlights the effectiveness of the comparative approach and outlines directions for future research, including the optimization of discretization parameters and the extension of the analysis to more complex hydrodynamic models.

Keywords: finite difference schemes; numerical stability; Courant–Friedrichs–Lewy (CFL) condition; Saint-Venant equations; operator splitting; Lax scheme; Godunov scheme; L^2 norm; flux approximation; boundary conditions.

SAINT-VENANT TURIDAGI GIPERBOLIK SISTEMALARNI YECHISH UCHUN SONLI USULLAR: TAHLIL VA TAJRIBALAR

Annotatsiya. Mazkur maqolada o‘zgaruvchan koeffitsiyentlarga ega bo‘lgan Saint-Venant turidagi giperbolik sistemalarni yechish uchun qo‘llaniladigan sonli usullar tadqiq etiladi. Tadqiqot masalasi noturg‘un oqimlarni modellashtirishda chekli ayirmalar sxemalarining barqarorligi va aniqligini chuqur tahlil qilish zarurati bilan asoslanadi. Tadqiqot metodologiyasi uchta sinfga mansub sonli sxemalarni – ya’ni Laks sxemasi, Godunov sxemasi hamda operatorlarga ajratish usullarini qurish va ularni qiyosiy tahlil qilishdan iborat. Barqarorlik shartlariga, xususan, Kurant–Fridrixs–Lyui (CFL) shartiga alohida e’tibor qaratilgan bo‘lib, xatoliklar L_2-norma asosida baholanadi. Turli boshlang‘ich va chegaraviy shartlar ostida o‘tkazilgan hisoblash tajribalari har bir usulning xulq-atvoridagi o‘ziga xos xususiyatlarni aniqlash imkonini berdi. Olingan natijalar shuni ko‘rsatadiki, ko‘rib chiqilgan sxemalar turli darajadagi barqarorlik va yaqinlashuv xossalariga ega bo‘lib, $r \cdot s < 1$ sharti hamda CFL mezoni sonli yechimlarning to‘g‘riligini ta’minlashda muhim ahamiyat kasb etadi.

Xulosa qismida qiyosiy yondashuvning samaradorligi asoslab beriladi hamda istiqboldagi tadqiqot yo‘nalishlari, jumladan, diskretlash parametrlarini optimallashtirish va tahlilni yanada murakkab gidrodinamik modellar doirasida kengaytirish masalalari belgilab beriladi.

Kalit so‘zlar: chekli ayirmalar sxemalari; sonli barqarorlik; Kurant–Fridrixs–Lyui (CFL) sharti; Saint-Venant tenglamalari; operatorlarga ajratish usuli; Laks sxemasi; Godunov sxemasi; L^2-norma; oqim (flux) approksimatsiyasi; chegaraviy shartlar.

Introduction. Hyperbolic systems of equations, such as the Saint-Venant system, are widely used in modeling shallow water flows, hydraulic engineering processes, and related fields. The accurate numerical solution of such systems represents a challenging task, as it requires ensuring stability, monotonicity, and physical consistency of the obtained results. In particular, the choice of an appropriate finite difference scheme is crucial, as it must adequately capture wave dynamics in the presence of variable coefficients and complex boundary conditions.

The object of this study is the numerical solution of the Saint-Venant system over a finite interval subject to prescribed initial and boundary conditions. The central problem lies in the comparative assessment of different numerical approaches, which exhibit varying behavior in terms of stability, accuracy, and computational cost. In the context of increasing demands for precise hydrodynamic modeling, it becomes essential to determine which methods provide the most reliable results for specific classes of problems.

The research procedure includes the formal statement of the problem, the construction of computational grids, the derivation of Lax, Godunov, and splitting schemes, and the analysis of their stability conditions. In addition, a set of computational experiments is carried out to evaluate the performance of the methods through L_2 norm analysis and verification of the CFL condition. This comprehensive approach enables the identification of key characteristics of the considered schemes and supports well-founded conclusions regarding their applicability to the numerical solution of the Saint-Venant problem.

Literature review. The study of numerical methods for hyperbolic systems, including the Saint-Venant equations, is grounded in a broad spectrum of fundamental and applied research. The original formulation of the shallow water equations was introduced by Adhémar Barré de Saint-Venant in 1871, laying the foundation for modern theories of unsteady open-

channel flow [1].

The development of numerical methods for hyperbolic systems is closely associated with the pioneering work of S.K. Godunov, who in 1959 proposed a scheme based on the exact solution of the local Riemann problem, enabling accurate computation of shock waves and discontinuities [2]. A significant contribution to stability theory was made by P. Lax and R. Richtmyer, who established the equivalence of stability and convergence under the consistency condition [3]. These results have become a cornerstone for the analysis of modern numerical algorithms.

Considerable progress has also been achieved in flux-based approximation methods. Among these, the Rusanov flux stands out as a modification of the Lax–Friedrichs scheme, offering enhanced stability and computational simplicity [4]. Theoretical foundations and practical implementations of finite volume methods, particularly for shallow water equations, are comprehensively presented in the works of R. LeVeque and E. Toro [5], [6].

A substantial body of recent research focuses on well-balanced schemes that preserve steady-state solutions. Notably, the hydrostatic reconstruction method ensures accurate approximation of Saint-Venant systems with topographic source terms and maintains the “lake at rest” equilibrium [7].

Another important direction in the development of numerical methods is represented by high-order ENO and WENO schemes, originally proposed by Harten, Shu, and Osher, which enhance accuracy in smooth regions of the solution while effectively suppressing spurious oscillations near discontinuities [8], [9]. Such methods are widely employed in problems requiring high spatial resolution, although they are generally associated with increased computational cost.

Research methodology. For problems involving the decomposition of complex systems of equations, operator splitting methods play a significant role. A classical contribution to this field was made by G. Strang, who introduced second-order splitting schemes applicable to systems with source terms [10]. Contemporary studies demonstrate that splitting methods provide flexibility in combining discrete operators and contribute to improved computational efficiency.

Thus, an analysis of the scientific literature indicates that the Lax and Godunov schemes, along with operator splitting methods, remain fundamental tools for solving the Saint-Venant system. Current research is primarily focused on enhancing stability, accuracy, and the preservation of physical invariants, thereby confirming the relevance of comparative analyses of various finite difference schemes.

Results and discussions. 2.1. Problem Formulation. Let the Saint-Venant system of equations be given in the form

$$\frac{\partial Y}{\partial t} + A\frac{\partial Y}{\partial x} + DY = 0 \qquad (1.1)$$

for two unknown functions $Y = (V(x,t), H(x,t))^T$. The system with matrix $A = \|a_{ik}\| = \|a_{ik}(x,t)\|$, $D = \|d_{ik}\| = \|d_{ik}(x,t)\|$ is called **hyperbolic** if all roots of the characteristic equation $\det\|A - \lambda E\| = 0$ (E - identity matrix) are real and distinct.

As shown in [1], such a system can be reduced to a special canonical form:

$$\frac{\partial R}{\partial t} + A\frac{\partial R}{\partial x} + MR = 0 \qquad (1.2)$$

where $\Omega^{-1}A\Omega = \Lambda$ is a diagonal matrix.

Assume that the elements of the matrix Λ are ordered as follows:

$$\Lambda = \begin{pmatrix} \lambda_1 & 0 \\ 0 & -\lambda_2 \end{pmatrix}$$

We consider the solution of system (1.2) for $0 \le x \le l$, $t \ge 0$ with the following boundary conditions:

at $x = 0$: $R_1 = sR_2$ (1.3)

at $x = L$: $R_2 = rR_1$ (1.4)

The initial conditions for this problem are given by

$$R_i(x,0)=\varphi_i(x), \qquad 0\le x\le l, \ (i=1,N) \tag{1.5}$$

2.2. Lax difference scheme. **Consider the mixed problem (1.2) – (1.5).**

In the domain G, we construct a difference grid $G=\{(t_j,x_i):\ 0\le t_j\le T,\ 0\le x_i\le L\}$:

where $t_j=j\tau,\ j=0,\dots,N;\quad N\tau=T,\quad T=1,\qquad N=500,$ are the spatial and temporal step sizes, respectively.

The set of points marked with crosses in Fig. 1 is denoted by G_h, circles by Ω_h, squares by Γ_h^0, and triangles by Γ_h^l, respectively. The entire set of $(k\cdot\Delta,\ i\cdot h)$, $k=\overline{0,m},\ i=\overline{0,n}$ grid nodes is denoted by $\overline{G_h}$.

In the literature, $\overline{G_h}=G_h\cup\Gamma_h^0\cup\Gamma_h^l\cup\Omega_h$ the set G_h is referred to as the set of interior points, while Γ_h^0 and Γ_h^l - are called boundary point sets and Ω_h - is the set of initial points of the difference grid $\overline{G_h}$. We will also refer to Γ_h^0 as the left boundary and Γ_h^l as the right boundary of the grid.

Let U_i^k denote the approximate solution of the mixed problem (1.2)–(1.5) (Problem 1) at the point $k\cdot\tau, i\cdot h$ of the difference grid $\overline{\Omega_h}$. We use the standard notation for the step ratio τ/h

The Lax difference scheme for the mixed problem is formulated as follows:

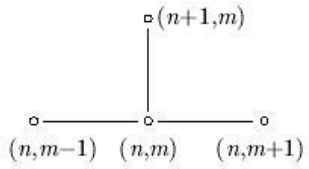
$$\begin{aligned}
&\frac{v_i^{j+1}-\frac{v_{i+1}^j+v_{i-1}^j}{2}}{\tau}+\Lambda\frac{v_{i+1}^j-v_{i-1}^j}{2h}+Mv_i^j=0\\
&v_i^{j+1}=\frac{v_{i+1}^j+v_{i-1}^j}{2}-\frac{\Lambda\tau}{h}\left(\frac{v_{i+1}^j-v_{i-1}^j}{2}\right)-Mv_i^j \qquad (2.1)\\
&v_i^{j+1}=\left(\frac{1-\sigma}{2}\right)v_{i+1}^j-\left(\frac{1+\sigma}{2}\right)v_{i-1}^j-Mv_i^j
\end{aligned}$$

where $\frac{1-\sigma}{2}=\alpha_{+1}^0$, $\frac{1+\sigma}{2}=\alpha_{-1}^0$.

For $|\sigma|\le 1$ the scheme is stable.

For $\alpha_\mu^\nu\ge 1$, the scheme is monotone (Friedrichs monotonicity condition, 1954).

The stencil of this difference scheme has the form:



We again consider system (1.2) on the interval $0\le x\le l,\ t\ge 0$ with boundary conditions:

at $x=0$: $$(v^I)_o^j=s(v^{II})_o^j \qquad (2.2)$$

at $x=l$: $$(v^{II})_l^j=r(v^I)_l^j \qquad (2.3)$$

The initial data are given by:

$$v_i^0=\varphi_i(x), \qquad (i=1,2) \qquad (2.4)$$

Numerical Experiment. In the domain $G=\{(t,x):0\le t\le 1,\ 0\le x\le 2000\}$, consider the system:

$$\begin{pmatrix}y_1\\y_2\end{pmatrix}_t+\begin{pmatrix}\lambda_1 & 0\\0 & -\lambda_2\end{pmatrix}\begin{pmatrix}y_1\\y_2\end{pmatrix}_x+\begin{pmatrix}0 & a(x)\\b(x) & 0\end{pmatrix}\begin{pmatrix}y_1\\y_2\end{pmatrix}=0 \qquad (1)$$

c

$$a(x)=\varphi(x)\delta_1(x), \qquad b(x)=\varphi^{-1}(x)\gamma_2(x) \qquad (2)$$

with boundary conditions:

$$y_1 = (t,0) = ry_2(t,0)$$
$$y_2 = (t,0) = sy_1(t,0) \qquad (3)$$

where $r = k_0 \frac{\varphi_1(0)}{\varphi_2(0)}$ $s = k_1 \frac{\varphi_1(L)}{\varphi_2(L)}$,

$$k_0 = \frac{\sqrt{gH*(0)} + b_0 H*(0)}{-\sqrt{gH*(0)} + b_0 H*(0)} \qquad k_0 = \frac{-\sqrt{gH*(L)} + b_1 H*(L)}{\sqrt{gH*(L)} + b_1 H*(L)}$$

and initial data:

$$y_1(0,x) = exp\left(\int_0^x \frac{\gamma_1(s)}{\lambda_1(s)} ds\right)\left(\sqrt{\frac{g}{H^*(x)}} h(x) + v(x)\right)$$
$$y_2(0,x) = exp\left(-\int_0^x \frac{\gamma_2(s)}{\lambda_2(s)} ds\right)\left(-\sqrt{\frac{g}{H^*(x)}} h(x) + v(x)\right) \qquad (4)$$
$$where\ h(x), v(x)\ are\ freely\ defined\ functions$$

For the numerical solution of this example, we apply the difference scheme (2.1)–(2.6). Let us compute the values of r and s:

1) Based on expressions (14) and (21) from [1], we select the parameters b_0 and b_1 as:

$$-\frac{g}{V*(0)} = -9.8\times10^4, \qquad -\frac{V*(0)}{H*(0)} = -1\times10^{-8}$$
$$-\frac{g}{V*(L)} = -487.562, \qquad -\frac{V*(0)}{H*(L)} = -4.04\times10^{-4}$$

From the obtained values, any value within the interval $\left(-9.8\times10^4, -1\times10^{-8}\right)$ can be chosen for b_0; we selected a specific value $b_0 = -0.001$. Similarly, for b_1, any real number outside a certain interval $\left(-487.562,\ -4.04\times10^{-4}\right)$ can be chosen; we selected a suitable value $b_1 = 0.001$.

2) Substituting the chosen values b_0 and b_1 into expression (4), we computed values of k_0 and k_1:

$$k_0 = \frac{\sqrt{9.8H^*(0)} + b_0 H^*(0)}{-\sqrt{9.8H^*(0)} + b_0 H^*(0)} = 0.94, \qquad k_1 = \frac{-\sqrt{9.8H^*(L)} + b_0 H^*(L)}{\sqrt{9.8H^*(L)} + b_0 H^*(L)} = 1.0045$$

3) During the computations, we encountered difficulties in evaluating definite integrals involving large functions. Therefore, we applied a numerical integration method. Using the rectangle method, the integral values were efficiently approximated.

Using the obtained results, we calculate the parameters r and s:

$$r = -0.938 \qquad s = -1.004$$

According to the stability condition, the product $r \cdot s$ must be less than 1:

$$|r \cdot s| < 1$$

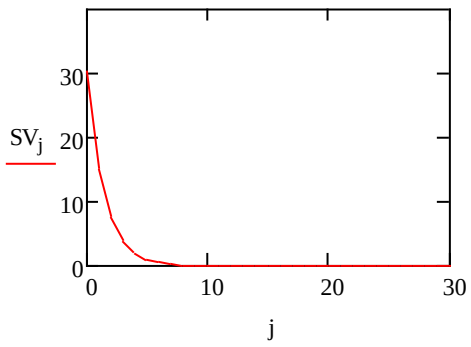
Verification shows that: $|r \cdot s| = 0.942$

Thus, the condition is satisfied.

Additionally, the CFL condition must also hold: $\frac{\tau}{h}\max|\lambda_i| \le 1, \quad i = 1,2$

$$\frac{\tau}{h}\max|\lambda_i| = 0.689 \qquad i = 1,2$$

In this case, the behavior of the L_2 norm is illustrated graphically as follows:



№	L^2-норма	Значение
1	V_0	30.323
2	V_{100}	$6.591\cdot10^{-5}$
3	V_{200}	$2.624\cdot10^{-7}$
4	V_{300}	$1.296\cdot10^{-9}$
5	V_{400}	$6.97\cdot10^{-12}$
6	V_{500}	$3.922\cdot10^{-14}$

2.3. Godunov difference scheme

Let us recall that we consider the mixed problem (1.2)–(1.5) in the case of variable coefficients.

In the domain G, we construct a difference grid: $G=\{(t_j,x_i):\ 0\le t_j\le T,\ 0\le x_i\le L\}$ where

$$t_j=j\tau,\quad j=0,\dots,N;\qquad N\tau=T,\qquad T=1,\qquad N=500,$$
$$x_i=ih;\quad i=0,\dots,M;\quad Mh=L;\qquad L=2000,\qquad M=2200,.$$

The Godunov difference scheme for the mixed problem (1.2)–(1.5) is formulated as follows:

$$(v^I)_i^{j+1}=(v^I)_i^j-\frac{\lambda_1\tau}{h}((v^I)_i^j-(v^I)_{i-1}^j)-a(x_i)(v^{II})_i^j \qquad (3.1)$$
$$(v^{II})_i^{j+1}=(v^{II})_i^j-\frac{\lambda_2\tau}{h}((v^{II})_{i+1}^j-(v^{II})_i^j)-b(x_i)(v^I)_i^j$$

We consider the solution of system (1.2) on the interval $0\le x\le l,\ t\ge 0$ with the following boundary conditions:

at $x=0$: $$(v^I)_0^j=s(v^{II})_0^j \qquad (3.2)$$

at $x=L$: $$(v^{II})_l^j=r(v^I)_l^j \qquad (3.3)$$

The initial data for this problem are specified as:

$$v_i^0=\varphi_i(x),\qquad (i=1,2) \qquad (3.4)$$

Numerical experiment

In the domain $G=\{(t,x):0\le t\le 1,\ 0\le x\le 2000\}$, consider the system (1)-(2), with boundary and initial conditions (3) - (4).

For the numerical solution of this example, we apply the difference scheme (2.1)–(2.6).

Let us compute the values of r and s:

1) Based on expressions (14) and (21) from [1], we select the parameters b_0 and b_1 as:

$$-\frac{g}{V^*(0)}=-9.8\times10^4,\qquad -\frac{V^*(0)}{H^*(0)}=-1\times10^{-8}$$
$$-\frac{g}{V^*(L)}=-4.667\times10^3,\qquad -\frac{V^*(L)}{H^*(L)}=-4.41\times10^{-6}$$

From the obtained values, any value within the interval $\left(-9.8\times10^4,-1\times10^{-8}\right)$ can be chosen for b_0; we selected a specific value $b_0=-0.001$. Similarly, for b_1, any real number outside a certain interval $(-4.667\times10^3,-4.41\times10^{-6})$ can be chosen; we selected a suitable value $b_1=0.001$.

2) Substituting the selected values b_0 and b_1 into expression (4), we compute k_0 and k_1:

$$k_0=\frac{\sqrt{9.8H^*(0)}+b_0H^*(0)}{-\sqrt{9.8H^*(0)}+b_0H^*(0)}=0.938,\qquad k_1=\frac{-\sqrt{9.8H^*(L)}+b_0H^*(L)}{\sqrt{9.8H^*(L)}+b_0H^*(L)}=-1.001$$

3) During the computations, difficulties arose in evaluating definite integrals involving

large functions. Therefore, a numerical integration method was employed. Using the rectangle method, the integral values were efficiently approximated.

Using the obtained results, we calculate the parameters r and s:

$$r = -0.938 \qquad s = -1.001$$

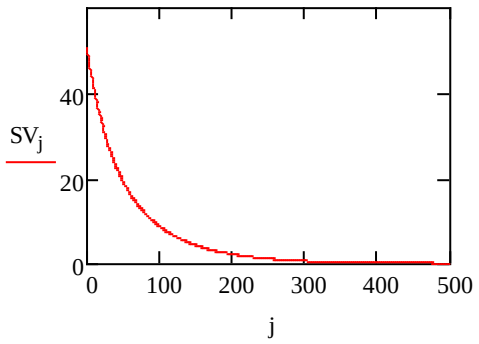
According to the stability requirement, the product $r \cdot s$ must satisfy: $|r \cdot s| < 1$

Verification shows that this condition holds.

Additionally, the Courant–Friedrichs–Lewy (CFL) condition $\frac{\tau}{h}\max|\lambda_i| \le 1, \ i = 1,2$ must also be satisfied:

$$\frac{\tau}{h}\max|\lambda_i| = 0.689 \qquad i = 1,2$$

In this case, the behavior of the L^2 – norm can be illustrated graphically as follows:



№	$\mathbb{L}^2$-норма	Значение
1	V_0	50.464
2	V_{100}	8.74
3	V_{200}	2.306
4	V_{300}	0.72
5	V_{400}	0.314
6	V_{500}	0.221

2.4. Splitting difference Scheme

Let us recall that we consider the mixed problem (1.2)–(1.5) in the case of variable coefficients.

In the domain G, we construct a difference grid: $G = \{(t_j, x_i): \ 0 \le t_j \le T, \ 0 \le x_i \le L\}$ where

$$t_j = j\tau, \quad j = 0,\dots,N; \qquad N\tau = T, \qquad T = 1, \qquad N = 500,$$

$$x_i = ih; \quad i = 0,\dots,M; \quad Mh = L; \qquad L = 2000, \qquad M = 2200,$$

The splitting difference scheme for the mixed problem (1.2)–(1.5) is formulated as follows:

$$\begin{cases} (z_1)_i^j = (v_1)_i^j - (\lambda_1)_i \dfrac{\Delta t}{\Delta x}\left[(v_1)_i^j - (v_1)_{i-1}^j\right], \ i = 1,\dots,M; \\ (z_2)_i^j = (v_2)_i^j - (\lambda_2)_i \dfrac{\Delta t}{\Delta x}\left[(v_2)_i^j - (v_2)_{i+1}^j\right], \ i = 0,\dots,M-1, \end{cases} \quad j = 0,\dots,N-1.$$

$$\begin{cases} (v_1)_i^{j+1} = (z_1)_i^j - \Delta t a_i (z_2)_i^j, \ i = 1,\dots,M; \\ (v_2)_i^{j+1} = (z_2)_i^j - \Delta t b_i (z_1)_i^j, \ i = 0,\dots,M-1, \end{cases} \quad j = 0,\dots,N-1. \qquad (4.1)$$

We consider the solution of system (1.2) on the interval $0 \le x \le l, \ t \ge 0$ with boundary conditions:

at $x = 0$:

$$(v^I)_0^j = s(v^{II})_0^j \qquad (4.2)$$

at $x = l$:

$$(v^{II})_l^j = r(v^I)_l^j \qquad (4.3)$$

The initial data are given by:

$$v_i^0 = \varphi_i(x), \qquad (i = 1,2) \qquad (4.4)$$

Numerical experiment. In the domain $G = \{(t,x): 0 \le t \le 1, \ 0 \le x \le 2000\}$, consider the system (1)-(2), with boundary and initial conditions (3) - (4).

For the numerical computation of this example, we apply the difference scheme (2.1)–

(2.6).

Let us compute the values of r and s:

1) Based on expressions (14) and (21) from [1], we select the parameters b_0 and b_1 as:

$$-\frac{g}{V^*(0)} = -9.8\times10^4, \qquad -\frac{V^*(0)}{H^*(0)} = -1\times10^{-8}$$

$$-\frac{g}{V^*(L)} = -4.667\times10^3, \qquad -\frac{V^*(L)}{H^*(L)} = -4.41\times10^{-6}$$

From the obtained values, any value within the interval $\left(-9.8\times10^4, -1\times10^{-8}\right)$ can be chosen for b_0; we selected a specific value $b_0 = -0.001$. Similarly, for b_1, any real number outside a certain interval $(-4.667\times10^3, -4.41\times10^{-6})$ can be chosen; we selected a suitable value $b_1 = 0.001$.

2) Substituting the chosen values b_0 and b_1 into expression (4), we computed values of k_0 and k_1:

$$k_0 = \frac{\sqrt{9.8H^*(0)} + b_0H^*(0)}{-\sqrt{9.8H^*(0)} + b_0H^*(0)} = 0.938, \qquad k_1 = \frac{-\sqrt{9.8H^*(L)} + b_0H^*(L)}{\sqrt{9.8H^*(L)} + b_0H^*(L)} = -1.001$$

3) As in the previous case, the evaluation of definite integrals involving large functions posed computational difficulties. Therefore, numerical integration was applied. Using the rectangle method, the integral values were obtained efficiently.

Using these results, we determine the parameters r and s:

$$r = -0.938 \qquad s = -1.001$$

The stability condition requires: $|r\cdot s| < 1$

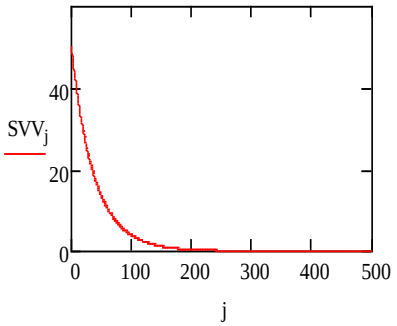
Let us now verify the fulfillment of this condition: $|r\cdot s| = 0.939$

As evidenced, the resulting value is strictly less than unity, thereby ensuring that the condition is satisfied.

The CFL condition $\frac{\tau}{h}\max|\lambda_i| \le 1, \quad i = 1,2$ must also hold:

$$\frac{\tau}{h}\max|\lambda_i| = 0.689 \qquad i = 1,2$$

The corresponding graphical representation of the L^2 norm is given below:



№	$\mathbb{L}^2$-норма	Значение
1	V_0	50.146
2	V_{100}	3.93
3	V_{200}	0.437
4	V_{300}	0.154
5	V_{400}	0.123
6	V_{500}	0.109

Conclusion. In the course of this study, three different approaches to the numerical solution of the Saint-Venant system of equations were examined and analyzed: the Lax difference scheme, the Godunov scheme, and the operator splitting scheme. For each method, a theoretical justification was provided, a finite difference approximation was constructed, and stability conditions were investigated, including the requirements $r\cdot s < 1$ and the Courant–Friedrichs–Lewy (CFL) condition. The analysis demonstrated that an appropriate choice of

discretization parameters plays a crucial role in ensuring both the stability and the physical consistency of the numerical solution.

The results of the computational experiments revealed notable differences in the behavior of the schemes. The Lax scheme offers simplicity of implementation and satisfactory stability under appropriate grid step restrictions. The Godunov scheme, based on the solution of the local Riemann problem, exhibits high accuracy in capturing discontinuities and wave propagation. The splitting scheme provides flexibility when dealing with equations of complex structure and allows for efficient treatment of source terms.

The comparative analysis indicates that the selection of a particular method depends on the required level of accuracy, computational cost, and the specific features of the problem under consideration. Based on the conducted experiments, it can be concluded that each of the considered schemes possesses its own advantages and domain of applicability.

Overall, the results of this study confirm the relevance of investigating finite difference schemes for the Saint-Venant equations and outline promising directions for future research, including the analysis of high-order methods, well-balanced approaches, and adaptive grid techniques.

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PARALLEL METALLIC STRUCTURES ON THE THREE-DIMENSIONAL SOL^3 MANIFOLD

Jasurbek Aslonov
National University of Uzbekistan
jasurbek05@gmail.com
ORCID 0000-0001-7519-5779
UDK 514.765

Abstract. Polynomial structures on differentiable manifolds have been actively studied in modern differential geometry. Among them, metallic structures represent an important class that generalizes the well-known golden structure. In this paper we investigate left-invariant metallic structures on the three-dimensional Sol manifold. We prove that any parallel left-invariant metallic structure on Sol^3 is trivial. Geometric properties of metallic structures, including integrability, parallelism, and curvature relations, have been investigated in various settings such as almost product manifolds, contact manifolds, and Riemannian manifolds. On the other hand, three-dimensional model geometries introduced by Thurston provide a natural framework for studying invariant geometric structures. Among these geometries, the Sol geometry is particularly interesting due to its non-isotropic structure and solvable Lie group structure.

Key words: Riemannian manifolds, polynomial structure, Lie group, Sol geometry, differentiable manifolds, metallic structures.

UCH O‘LCHAMLI SOL^3 KO‘PXILLIGIDAGI PARALLEL METALLIK STRUKTURALAR

Annotatsiya. Zamonaviy differensial geometriyada differensiallanuvchi ko‘pxilliklardagi polinomial strukturalar faol o‘rganilgan. Ular orasida metall strukturalar taniqli oltin kesimni umumlashtiruvchi muhim sinfni ifodalaydi. Ushbu maqolada uch o‘lchamli Sol ko‘pxilligidagi chap-invariant metall strukturalarni tadqiq etamiz. Sol³ ko‘pxilligidagi har qanday parallel chap-invariant metall struktura trivial ekanligini isbotladik. Metall strukturalarning geometrik xossalari, shu jumladan integrallanuvchilik, parallellik va egrilikka oid munosabatlar turli xil sharoitlarda tekshirilgan. Boshqa tomondan, Thurston tomonidan kiritilgan uch o‘lchovli geometriyalar o‘zgarmas geometrik strukturalarni o‘rganish uchun tabiiy asos yaratadi. Ushbu geometriyalar orasida Sol geometriyasi o‘zining izotrop bo‘lmagan tuzilishi va yechilishi mumkin bo‘lgan Lie gruppasi tuzilishi tufayli, ayniqsa, qiziqarli hisoblanadi.

Kalit so‘zlar: Riman ko‘pxilligi, polinomial struktura, Li gruppasi, Sol geometriyasi, differensiallanuvchi ko‘pxilliklar, metall strukturalar.

Introduction. Polynomial structures on differentiable manifolds play an important role in modern differential geometry. Such structures are defined by tensor fields satisfying polynomial equations and appear naturally in various geometric contexts. One of the most studied examples is the golden structure, introduced as a tensor field J satisfying $J^2 = J + I$. This concept was later generalized to the class of metallic structures, which satisfy the quadratic equation

$$J^2 = pJ + qI$$

where p and q are real constants. Metallic structures were studied by several authors and represent a natural generalization of polynomial structures on Riemannian manifolds [4, 6].

The three-dimensional manifold Sol^3 is one of the eight model geometries in Thurston’s classification [3]. Its geometry is characterized by anisotropic curvature behaviour and a nontrivial Levi-Civita connection.

The aim of this paper is to investigate metallic structures on the Riemannian manifold Sol^3. In particular, we study the existence of parallel metallic structures which are compatible with the Levi-Civita connection. Our main result shows that the geometry of Sol^3 imposes strong restrictions on such structures.

More precisely, we prove that every left-invariant parallel metallic structure on Sol^3 must be trivial.

This result reveals a rigidity phenomenon for polynomial structures on the Sol geometry and indicates that non-parallel metallic structures constitute the most interesting class of tensor fields on this manifold.

The paper is organized as follows. In Section 2 we recall basic definitions of metallic structures and describe the Lie algebra of the manifold Sol^3. In Section 3 we compute the Levi-Civita connection. In Section 4 we investigate metallic structures and prove our main rigidity theorem. Finally, we discuss geometric consequences and possible directions for further research.

Preliminaries. The Sol manifold (denoted by Sol^3) is a Lie group structure on $\mathbb{R}^3$ given by the operation

$$(x, y, z) \cdot (x', y', z') = \left(x + e^{-z}x',\ y + e^{z}y',\ z + z'\right).$$

Its matrix representation is as follows

$$\begin{pmatrix} e^{-z} & 0 & x \\ 0 & e^{z} & y \\ 0 & 0 & 1 \end{pmatrix}$$

On the Sol^3 manifold, the left-invariant metric is defined by the formula

$$g = e^{2z}dx^2 + e^{-2z}dy^2 + dz^2.$$

Definition 2.1. Let M be a smooth manifold. A $(1,1)$ tensor field $J : TM \to TM$ is

called a metallic structure if there exist real positive numbers p and q such that

$$J^2 = pJ + qI$$

Definition 2.2. Let (M, g) be a Riemannian manifold. A metallic structure J is called parallel if

$$\nabla J = 0,$$

where ∇ is the Levi-Civita connection on M.

Let $\{E_1, E_2, E_3\}$ be a left-invariant orthonormal basis on Sol^3.

Definition 2.3. The Lie group Sol^3 is the three-dimensional solvable Lie group whose Lie algebra is generated by $\{E_1, E_2, E_3\}$ with brackets

$$[E_1, E_2] = 0, \qquad [E_1, E_3] = E_1, \qquad [E_2, E_3] = -E_2. \tag{1}$$

Levi-civita connection. Using the Koszul formula

$$2g(\nabla_X Y, Z) = Xg(Y, Z) + Yg(Z, X) - Zg(X, Y) - g(X, [Y, Z]) - \\ - g(Y, [X, Z]) + g(Z, [X, Y]),$$

we obtain the following nonzero components of the Levi-Civita connection:

$$\nabla_{E_1} E_3 = E_1,$$
$$\nabla_{E_2} E_3 = -E_2,$$
$$\nabla_{E_3} E_1 = 0,$$
$$\nabla_{E_3} E_2 = 0.$$

All other components vanish.

Main results. Now let us define the metallic structures on Sol^3. Consider a left-invariant metallic structure defined by

$$J(E_i) = \sum_{j=1}^{3} a_i{}^j E_j.$$

Lemma 4.1. If a metallic structure J on Sol^3 is parallel, then $a_{12} = a_{21} = 0$.

Proof. The condition $\nabla J = 0$ means $\nabla_X (JY) = J(\nabla_X Y)$ for all vector fields X, Y. For $X = E_1$, $Y = E_3$ we compute:

$$\nabla_{E_1}(JE_3) = \nabla_{E_1}(a_{13}E_1 + a_{23}E_2 + a_{33}E_3) = \\ = a_{13}\nabla_{E_1}E_1 + a_{23}\nabla_{E_1}E_2 + a_{33}\nabla_{E_1}E_3 = \\ = a_{33}E_1.$$

On the other hand,

$$J(\nabla_{E_1} E_3) = J(E_1) = a_{11}E_1 + a_{21}E_2 + a_{31}E_3.$$

Equating these gives $a_{21} = 0$ and $a_{31} = 0$. Similarly for $X = E_2$, $Y = E_3$ we obtain $a_{12} = 0$ and $a_{32} = 0$. Thus

$$a_{12} = a_{21} = 0.$$

Theorem 4.1. Any left-invariant parallel metallic structure on the Sol^3 manifold is necessarily scalar.

Proof. By Lemma 4.1 we have $a_{12} = a_{21} = 0$, $a_{13} = a_{23} = 0$, and $a_{31} = a_{32} = 0$. Hence J is diagonal:

$$J = \begin{pmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{pmatrix}$$

The metallic condition $J^2 = pJ + qI$ implies

$$a_{ii}^2 = pa_{ii} + q \quad \text{for } i = 1, 2, 3.$$

Thus each a_{ii} is one of the two metallic eigenvalues:

$$\lambda_{\pm} = \frac{p \pm \sqrt{p^2 + 4q}}{2}.$$

The parallel condition also forces $a_{11} = a_{22} = a_{33}$. Indeed, from $\nabla_{E_1} J = 0$ with $Y = E_1$ we obtain $a_{11} = a_{33}$, and from $\nabla_{E_2} J = 0$ with $Y = E_2$ we obtain $a_{22} = a_{33}$. Hence $a_{11} = a_{22} = a_{33} = \lambda$. Therefore $J = \lambda I$ is a scalar operator, and the metallic structure is trivial.

Proposition 4.1. Let J be a metallic structure satisfying $J^2 = pJ + qI$. Then every eigenvalue λ of J satisfies the equation $\lambda^2 = p\lambda + q$.

Proof. Let v be an eigenvector of J corresponding to eigenvalue λ, i.e., $Jv = \lambda v$. Applying the metallic condition we obtain $J^2 v = pJv + qv$. But

$$J^2 v = \lambda^2 v \text{ and } pJv + qv = p\lambda v + qv = (p\lambda + q)v.$$

Hence $\lambda^2 v = (p\lambda + q)v$. Since $v \neq 0$, we obtain $\lambda^2 = p\lambda + q$.

To better understand geometric properties of metallic structures, we recall the Nijenhuis tensor.

Definition 4.1. Let J be a $(1,1)$ tensor field. The Nijenhuis tensor of J is defined by

$$N_J(X,Y) = [JX, JY] + J^2[X,Y] - J[JX,Y] - J[X,JY].$$

If a metallic structure J is parallel, then its Nijenhuis tensor vanishes:

$$N_J = 0.$$

Indeed if $\nabla J = 0$, then J commutes with covariant differentiation. Using the torsion-free property of the Levi-Civita connection, the expression for N_J reduces to zero.

Now we consider general left-invariant tensor fields of type $(1,1)$ on Sol^3. For diagonal operators

$$J = \mathrm{diag}(\lambda_1, \lambda_2, \lambda_3),$$

the metallic condition reduces to $\lambda_i^2 = p\lambda_i + q$ for $i = 1,2,3$. Thus each λ_i must be one of the two metallic eigenvalues. Therefore all diagonal metallic structures are determined by choosing values $\lambda_i \in \{\lambda_+, \lambda_-\}$. However, the parallel condition forces $\lambda_1 = \lambda_2 = \lambda_3$. This yields the main rigidity phenomenon proved in the previous section.

In particular, the anisotropic structure of the Sol Lie algebra forces the covariant derivatives $\nabla_{E_1} E_3 = E_1$ and $\nabla_{E_2} E_3 = -E_2$, which prevents nontrivial diagonal metallic structures from being parallel. Thus non-parallel metallic structures become the natural object of study on Sol^3.

To better understand geometric restrictions on metallic structures, we compute some components of the curvature tensor.

The Riemann curvature tensor is defined by

$$R(X,Y)Z = \nabla_X \nabla_Y Z - \nabla_Y \nabla_X Z - \nabla_{[X,Y]} Z.$$

Using the previously computed Levi-Civita connection we obtain the nonzero components:

$$R(E_1, E_3)E_1 = -E_1, \quad R(E_2, E_3)E_2 = -E_2.$$

Hence the sectional curvatures satisfy

$$K(E_1, E_3) = -1,$$
$$K(E_2, E_3) = -1,$$
$$K(E_1, E_2) = 0.$$

Thus the geometry of Sol^3 is anisotropic and contains both zero and negative sectional curvatures.

Theorem 4.2. Let J be a left-invariant $(1,1)$ tensor field on Sol^3 satisfying a polynomial equation

$$J^n + c_{n-1}J^{n-1} + \cdots + c_1 J + c_0 I = 0.$$

If J is parallel with respect to the Levi-Civita connection, then J must be a scalar operator.

Proof. Let J be parallel. Then for any X, Y we have $\nabla_X (JY) = J(\nabla_X Y)$. Using the brackets of the Lie algebra (1), one shows that the parallel condition forces J to be diagonal and all diagonal entries equal. Hence $J = \lambda I$. Substituting into the polynomial equation yields

$$\lambda^n + c_{n-1}\lambda^{n-1} + \cdots + c_1\lambda + c_0 = 0,$$

which is automatically satisfied for some λ. Thus the operator is scalar.

Example. Although parallel metallic structures on Sol^3 are trivial, non-parallel structures exist. Consider the tensor field

$$J = \lambda_1 E_1 \otimes dx + \lambda_2 E_2 \otimes dy + \lambda_3 E_3 \otimes dz,$$

where $\lambda_1, \lambda_2, \lambda_3 \in \{\lambda_+, \lambda_-\}$ satisfy the metallic condition. If $\lambda_1 \neq \lambda_2$, then $\nabla J \neq 0$ and the metallic structure is not parallel. Thus Sol^3 admits many non-parallel metallic structures.

Conclusion. The obtained result shows a strong rigidity of the Sol geometry with respect to parallel metallic structures. In particular, the manifold Sol^3 does not admit nontrivial left-invariant parallel metallic structures. A natural continuation of this work is the classification of all metallic structures on Sol^3, including non-parallel ones, and the study of their integrability conditions. Further investigations may also include the study of metallic structures on other three-dimensional Thurston geometries.

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UCH O‘LCHAMLI PANJARADA IKKI BOZONLI SISTEMAGA MOS SHREDINGER OPERATORI XOS QIYMATLARI UCHUN ASIMPTOTIKALAR

Mamirov Berdiyor Ulugbekovich
Sharof Rashidov nomidagi Samarqand
davlat universiteti Matematik analiz
kafedrasi dotsenti
berdiyor@mail.ru
ORCID 0009-0007-7513-8337
UDK 51

Annotatsiya. Ushbu ishda uch o‘lchamli $\mathbb{Z}^3$ panjarada harakatlanuvchi va qisqa masofada ta’sirlashuvchi ikkita bir xil zarrachali (bozonlar) sistemaga mos Shredinger operatori ma’lum bir tipdagi potensiallar uchun qaralgan bo‘lib, berilgan fazoni invariant qism fazolarga ajratish natijasida uch o‘lchamli masala bir o‘lchamli masalaga keltirilgan.

Maqolada uch o‘lchamli $\mathbb{Z}^3$ panjarada harakatlanuvchi va qisqa masofada ta’sirlashuvchi ikkita bir xil zarrachali sistemaga mos Shredinger operatori muhim spektridan chapda yotuvchi karrali xos qiymatlar invariant qism fazolar yordamida oddiy xos qiymatlarga ajratilgan va ularning kvaziimpuls kichik qo‘zg‘alishdagi holati aniqlangan. Uch o‘lchamli panjarada ikkita bir xil zarrachali sistemaga mos Shredinger operatori xos qiymatlari uchun asimptotikalar olinib, ularga mos bo‘lgan xos funksiyalar topilgan.

Kalit so‘zlar. Hamiltonian, bog‘langan holat, Shredinger operatori, to‘la kvaziimpuls, xos qiymat.

ASYMPTOTICS OF EIGENVALUES OF THE SCHRÖDINGER OPERATOR FOR A TWO-BOSON SYSTEM ON A THREE-DIMENSIONAL LATTICE

Abstract. In this work, the Schrödinger operator corresponding to a system of two identical particles (bosons) moving on a three-dimensional lattice $\mathbb{Z}^3$ and interacting at short range is considered. By decomposing the given space into invariant subspaces, the three-dimensional problem is reduced to a one-dimensional problem.

The article shows that multiple eigenvalues located to the left of the essential spectrum of the Schrödinger operator for a system of two identical particles on a three-dimensional lattice are decomposed into simple eigenvalues using invariant subspaces. In addition, the behavior of these eigenvalues under small perturbations of the quasi-momentum is investigated.

Keywords. Hamiltonian, bound state, Schrödinger operator, total quasimomentum, eigenvalue.

Kirish. Kichik parametr qiymatlarida ikki zarrali klaster operatorlarining bog‘langan holatlari paydo bo‘lishining tabiati ilk bor R. A. Minlos va Sh. Mamatov tomonidan [1] da o‘rganilgan, shundan so‘ng yanada umumiy holatda R. A. Minlos va A. I. Mogilner tomonidan [2] da o‘rganilgan. Ikki zarrachali sistemaga mos $\mathbb{Z}^d$ panjaradagi H Hamiltonianning bog‘langan holatlarini o‘rganish $H(\mathbf{k})$ $\mathbf{k}\in\mathbb{T}^d=(-\pi,\pi]^d$ Shredinger operatorlari oilasining xos qiymatlarini tekshirishga keltiriladi.

[3] ishda $H(\mathbf{k})$ operatorning har bir $z_n(\mathbf{k})$ xos qiymatlarini $k_j\in[0,\pi]$ kordinatasi bo‘yicha monotonligi o‘rganilgan. [4, 5] da ikki zarrachali $H(\mathbf{k}),\ \mathbf{k}\in\mathbb{T}^\nu$ operator kontakt $\hat{v}(n_1-n_2)=\mu\delta_{n_1n_2}$ potensial bilan qaralgan bo‘lib, bunda $H(\mathbf{k})$ operatorni $z(\mathbf{k})$ xos qiymati yagonaligi va oddiyligi ko‘rsatilgan. [6] maqolada ikki zarrachali $H(\mathbf{k}),\mathbf{k}\neq 0$ operator uzluksiz spektrdan chapda joylashgan musbat xos qiymatga ega ekanligi $H(0)$ uchun vertual sath mavjudligi shartida ko‘rsatilgan.

Mazkur maqolada yuqoridagi o‘rganilgan masalalardan (ularda asosan xos qiymatlarning mavjudligi isbotlangan) farqi ma’lum tipdagi potensiallar uchun xos qiymat va xos funksiyalar asimptotik va aniq ko‘rinishlari topilgan.

Tadqiqot metodolgiyasi. Ikki zarrachali Shredinger operatorlarni spektral nazariyasini o‘rganishning uslubiy asosi matematik analiz, matematik fizika, chiziqli bo‘lmagan funksional analiz usullarining kombinatsiyasidan iborat. Tadqiqotda operatorning xos qiymatlarini topish uchun algebraik shakl almashtirishlar va chiziqli differensiallash usullari qo‘llanilgan. Ishda ma’lum bir tipdagi potensial uchun Shredinger operatori invariant

qism fazolarda o‘rganiladi. Umumiy holda keyin birlashtiriladi.

Uch o‘lchamli $T^3 \equiv (-\pi,\pi]^3$ tor berilgan bo‘lib, bunda $T^3 \equiv (-\pi,\pi]^3 \subset \mathbb{R}^3$ to‘plam elementlarini qo‘shish va haqiqiy songa ko‘paytirish amallari har doim $\mathbb{R}^3$ da $(2\pi\mathbb{Z}^3)$ modul bo‘yicha hisoblanadi.

Uch o‘lchamli $\mathbb{Z}^3$ panjarafagi ikki bozonli sistemaga mos $\hat{H}$ hamiltonian chegarlangan o‘z-o‘ziga qo‘shma operator bo‘lib, $\ell_2^{sym}(\mathbb{Z}^3 \times \mathbb{Z}^3) := \{ f \in \ell_2(\mathbb{Z}^3 \times \mathbb{Z}^3) =: f(\mathbf{x},\mathbf{y}) = f(\mathbf{y},\mathbf{x}) \}$ Hilbert fazosida quyidagicha tasvirlanadi:

$$\hat{H} = \hat{H}_0 - \hat{V}_2,$$

yuqorida $\hat{H}_0$ erkin hamiltonian $\left(\ell_2(\mathbb{Z}^3) \otimes \ell_2(\mathbb{Z}^3)\right)^{sym}$ fazosida quyidagicha tasvirlanadi:

$$\hat{H}_0 = -\frac{1}{2m}\Delta \otimes I - \frac{1}{2m} I \otimes \Delta.$$

Bunda m bozon og‘irligi bo‘lib, uni bir birlik sifatida hisoblaymiz. $\Delta_1 = \Delta \otimes I$ va $\Delta_2 = I \otimes \Delta$ panjaraviy Laplas operatori bo‘lib, $\Delta -$ esa

$$(\Delta\hat{\psi})(\mathbf{x}) = \sum_{j=1}^{3} [\hat{\psi}(\mathbf{x}+\mathbf{e}_j) + \hat{\psi}(\mathbf{x}-\mathbf{e}_j) - 2\hat{\psi}(\mathbf{x})], \quad \mathbf{x} \in \mathbb{Z}^3, \quad \hat{\psi} \in \ell_2(\mathbb{Z}^3),$$

zarrachalarni bir tugundan boshqa tugunga o‘tishini ifodalovchi ayirma operatoridir. $\mathbf{e}_1 = (1,0,0),\ \mathbf{e}_2 = (0,1,0),\ \mathbf{e}_3 = (0,0,1) -$ lar $\mathbb{Z}^3$ dagi birlik operatorlar. H Hamiltonian $\ell_2^{as}(\mathbb{Z}^2 \times \mathbb{Z}^2)$ Hilbert fazosida erkin Hamiltonian va ikki zarrachani ta’sirlashish potensiali V_2 bilan ayirmasini ifodalaydi.

Ikki zarrachalarini tasirlashish $\hat{V}_2$ operatori quyidagicha bo‘ladi:

$$(\hat{V}_2\hat{\psi})(\mathbf{x},\mathbf{y}) = \hat{v}(\mathbf{x}-\mathbf{y})\hat{\psi}(\mathbf{x},\mathbf{y}), \quad \hat{\psi} \in \ell_2^{sym}(\mathbb{Z}^3 \times \mathbb{Z}^3).$$

$H(\mathbf{k})$ operator uchun invariant qism fazolar.

$H(\mathbf{k})$ operatori uchun v potensialini tashuvchisi $D = \{\mathbf{x} = (n,m,k) \in \mathbb{Z}^3 : n \in \mathbb{Z},\ |m| + |k| \le 1\}$ bo‘lgan

$$\hat{v}(n,m,k) = \begin{cases} \overline{v}(n), & agar \quad m = k = 0 \\ \overline{v}(|n|+1), & agar \quad |m| + |k| = 1 \\ 0, & agar \quad |m| + |k| \ge 2, \end{cases} \qquad (1)$$

ko‘rinishda qaraymiz. Bu yerda $\overline{v} : \mathbb{Z} \to \mathbb{R} -$ funksiya $\mathbb{Z}_+$ dagi musbat monoton kamayuvchi funksiya, ya’ni ($\overline{v}(0) > \overline{v}(1) > \overline{v}(2) > \ldots$) va $\overline{v} \in \ell_1(\mathbb{Z})$.

$H(\mathbf{k})$ operatorning xos funksiyalari $\hat{H}$ hamiltonianni bog‘langan holatlarini ifodalaydi, xos qiymatlari esa bog‘langan holatlar energiyasini ifodalaydi. Shu maqsadda $H(\mathbf{k}), \mathbf{k} \in T^3,\ (-\pi,\pi]^3$ operatorning xos funksiyalarini o‘rgsanamiz, bu operator

$L_2^e(T^3) := \{ f \in L_2(T^3) : f(-\mathbf{q}) = f(\mathbf{q}) \}$ fazoda [7-8]

$$(H(\mathbf{k})f)(\mathbf{q}) = \varepsilon_{\mathbf{k}}(\mathbf{q}) f(\mathbf{q}) - \frac{1}{(2\pi)^{\frac{3}{2}}} \int_{T^3} v(\mathbf{q}-\mathbf{s}) f(\mathbf{s}) d\mathbf{s}$$

formula bilan aniqlanadi. Bunda qo‘zg‘almas $H_0(\mathbf{k})$ operator

$$\varepsilon_{\mathbf{k}}(\mathbf{q}) = \varepsilon(\frac{\mathbf{k}}{2} + \mathbf{q}) + \varepsilon(\frac{\mathbf{k}}{2} - \mathbf{q}) = 2\sum_{j=1}^{3} \left[1 - \cos\frac{k_j}{2} \cos q_j \right] \qquad (2)$$

funksiyaga ko‘paytirish operatori. Fur'e almashtirishi natijasida $V -$ integral operatorini v yadrosi qo‘yidagicha bo‘ladi:

$$v(\mathbf{p}) := (F\widehat{v})(\mathbf{p})\frac{1}{(2\pi)^{3/2}}\sum \widehat{v}(\mathbf{n})e^{i(\mathbf{n},\mathbf{p})} = \frac{1}{(2\pi)^{3/2}}[\overline{\hat{v}}(0) + 2\overline{\hat{v}}(1)\cos p_2 + 2\overline{\hat{v}}(1)\cos p_3 +$$

$$+ 2\sum_{n=1}^{\infty}(\overline{\hat{v}}(n)\cos np_1 + 2\overline{\hat{v}}(n+1)\cos p_2\cos np_1 + 2\overline{\hat{v}}(n+1)\cos p_3\cos np_1)].$$

$\cos(p-q) = \cos p\cos q + \sin p\sin q$
formula va

$$\int_{T^3}\sin q\ f(\mathbf{q})d\mathbf{q} = 0,\ \ \forall f \in L_2^e(T^3)$$

dan foydalanib $\frac{1}{(2\pi)^{3/2}}v(\mathbf{p}-\mathbf{q})$ yadroli V operator quyidagi ko‘rinishda bo‘ladi:

$$(Vf)(\mathbf{p}) = \frac{1}{(2\pi)^3}\int_{T^3} v(\mathbf{p}-\mathbf{q})\,f(\mathbf{q})d\mathbf{q} =$$

$$\frac{1}{(2\pi)^3}\int_{T^3}[\ \overline{\hat{v}}(0) + 2\overline{\hat{v}}(1)\cos p_2\cos q_2 + 2\overline{\hat{v}}(1)\cos p_3\cos q_3 + 2\sum_{n=1}^{\infty}\overline{\hat{v}}(n)\cos np_1\cos nq_1 +$$

$$+4\sum_{n=1}^{\infty}\overline{\hat{v}}(n+1)[\cos np_1\cos nq_1\cos p_2\cos q_2 + \sin np_1\sin nq_1\sin p_2\sin q_2 +$$

$$+\cos np_1\cos nq_1\cos p_3\cos q_3 + \sin np_1\sin nq_1\sin p_3\sin q_3]\ ]f(\mathbf{q})d\mathbf{q}. \quad (3)$$

$L_2^+(\mathbb{T}) = \{f \in L_2(\mathbb{T}): f(p) = f(-p)\}$ va $L_2^-(\mathbb{T}) = \{f \in L_2(\mathbb{T}): f(-p) = -f(p)\}$ lar orqali mos ravishda $L_2(\mathbb{T})$ fazoning juft va toq qism fazolarini belgilaymiz, natijada quyidagi yoyilma o‘rinli:

$$L_2^e(\mathbb{T}^3) = L_2^{+++}(\mathbb{T}^3)\oplus L_2^{+--}(\mathbb{T}^3)\oplus L_2^{-+-}(\mathbb{T}^3)\oplus L_2^{--+}(\mathbb{T}^3), \quad (4)$$

bunda

$$L_2^{+++}(\mathbb{T}^3) = L_2^+(\mathbb{T})\otimes L_2^+(\mathbb{T})\otimes L_2^+(\mathbb{T}), \qquad L_2^{+--}(\mathbb{T}^2) = L_2^+(\mathbb{T})\otimes L_2^-(\mathbb{T})\otimes L_2^-(\mathbb{T}) \text{ va}$$
$$L_2^{-+-}(\mathbb{T}^2) = L_2^-(\mathbb{T})\otimes L_2^+(\mathbb{T})\otimes L_2^-(\mathbb{T}), \qquad L_2^{--+}(\mathbb{T}^3) = L_2^-(\mathbb{T})\otimes L_2^-(\mathbb{T})\otimes L_2^+(\mathbb{T}).$$

1-lemma. $L_2^{+++}(T^3)$, $L_2^{+--}(T^3)$, $L_2^{-+-}(T^3)$ *va* $L_2^{--+}(T^3)$ *qism fazolar* $H(\mathbf{k})$ *opratorga nisbatan invariant qism fazo tashkil qiladi.*

Isbot. Dastlab $L_2^{+--}(T^3)$ qism fazoni $H_0(\mathbf{k})$ ga keyin V ga nisbatan invariant qism fazo tashkil qilishini ko‘rsatamiz. (2) ga ko‘ra $\varepsilon_{\mathbf{k}}$ funksiya $L_2^{+++}(T^3)$ fazoga tegishli bo‘ladi. $f \in L_2^{+--}(T^3)$ ga ko‘ra $\varepsilon_{\mathbf{k}}\,f \in L_2^{+--}(T^3)$ bo‘ladi. Demak $L_2^{+--}(T^3)$ qism fazo $H_0(\mathbf{k})$ operatorga nisbatan invariant qism fazo tashkil qiladi.

$f \in L_2^{+--}(T^3)$ da (3) ga ko‘ra

$$(Vf)(p_1,p_2) = \frac{1}{2\pi}\int_{T^3} v(p_1-s_1,p_2-s_2,p_3-s_3)\,f(s_1,s_2,s_3)\,\mathrm{d}s_1\mathrm{d}s_2\mathrm{d}s_3$$

operator $L_2^{+--}(T^3)$ fazoga tegishli bo‘ladi. Bu esa $L_2^{+--}(T^3)$ fazo $H(\mathbf{k})$ operatorga nisbatan invariant qism fazo ekanligi kelib chiqadi. Qolgan fazolarni ham shu usulda invariant qism fazo bo‘lishini ko‘rsatish mumkin .

$H(\mathbf{k})$ operatorni $L_2^{+++}(T^3)$ invariant fazodagi qismini o‘rganamiz. $H(\mathbf{k})$ operatorni $L_2^{+++}(\mathbb{T}^3)$ invariant qism fazodagi qismini $H^{+++}(k_1,k_2,k_3)$ bilan belgilaymiz. $H^{+++}(k_1,k_2,k_3)$ operatorni $f \in L_2^{+++}(\mathbb{T}^3)$ elementga ta’siri

$$H^{+++}(\mathbf{k})\,f(\mathbf{p}) = \varepsilon_{\mathbf{k}}(\mathbf{p})\,f(\mathbf{p}) - (V^{+++})(\mathbf{p}),$$

bo‘ladi, bunda

$$(V^{+++}f)(\mathbf{p}) = \frac{1}{(2\pi)^3}\int_{T^3}[\ \overline{\hat{v}}(0) + 2\overline{\hat{v}}(1)\cos p_2\cos q_2 + 2\overline{\hat{v}}(1)\cos p_3\cos q_3 + 2\sum_{n=1}^{\infty}\overline{\hat{v}}(n)\cos np_1\cos nq_1$$

$$+4\sum_{n=1}^{\infty}\overline{\hat{v}}(n+1)[\cos np_1\cos nq_1\cos p_2\cos q_2 + \cos np_1\cos nq_1\cos p_3\cos q_3]]f(\mathbf{q})\mathrm{d}\mathbf{q},\ f \in L_2^{+++}(T^3).$$

Ma'lumki, $\{\phi_n^-(q)=\frac{1}{\sqrt{\pi}}\sin nq\}_{n\in\mathbb{N}}$ va $\{\phi_0^+(q)=\frac{1}{\sqrt{2\pi}},\phi_n^+(q)=\frac{1}{\sqrt{\pi}}\cos nq\}_{n\in\mathbb{N}}$ vektorlar mos ravishda $L_2^-(T)$ va $L_2^+(T)$ fazodagi ortonormal bazislar tashkil qiladi.

Ixtiyoriy $n\in\mathbb{N}$ uchun $L^-(n)$ va $L^+(n-1)$ lar bilan ϕ_n^- va ϕ_{n-1}^+ vektorlarga tortilgan qism fazolarni belgilaymiz.

$\varphi_0^+(q)=\frac{1}{\sqrt{2\pi}}$, $\{\varphi_n^+(q)=\frac{1}{\sqrt{\pi}}\cos nq\}_{n\in\mathbb{N}}$ vektorlar $L_2^+(T)$ ortonormal bazis tashkil qiladi. Ixtiyoriy $n\in\mathbb{N}$ uchun $L^+(n)$ bilan ϕ_n^+, $n\in\mathbb{Z}_+$ vektorga tortilgan qism fazoi belgilaymiz.

Ma'lumki, $L_2^+(T)$ fazo

$$L_2^+(T)=\sum_{n=0}^{\infty}\oplus L^+(n) \qquad (5)$$

to'g'ri yig'indiga ajraladi. (4) dagi yoyilma natijasida

$$L_2^+(T)\otimes L_2^+(T)\otimes L_2^+(T)=\sum_{m=0}^{\infty}\oplus\{\sum_{n=0}^{\infty}\{\oplus L_2^+(n)\otimes L_2^+(m)\otimes L_2^+(T)\}\}=\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\oplus\mathfrak{R}_{n,m}^{+3},$$

$$L_2^+(T)\otimes L_2^+(T)\otimes L_2^+(T)=\sum_{m=0}^{\infty}\oplus\{\sum_{n=0}^{\infty}\{\oplus L_2^+(n)\otimes L_2^+(T)\otimes L_2^+(m)\}\}=\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\oplus\mathfrak{R}_{n,m}^{+2}$$

ega bo'lamiz, bunda $\mathfrak{R}_{n,m}^{+3}=L_2^+(n)\otimes L_2^+(m)\otimes L_2^+(T)$ и $\mathfrak{R}_{n,m}^{+2}=L_2^+(n)\otimes L_2^+(T)\otimes L_2^+(m)$.

2-lemma. *Ixtiyoriy* $n\in\mathbb{N}$ *uchun* $\mathfrak{R}_{n,m}^{-2}$ ($\mathfrak{R}_{n,m}^{-3}$) *fazo* $H(\pi,k_2,\pi)$ ($H(\pi,\pi,k_3)$) *operatorga nisbatan invariant qism fazo tashkil qiladi.*

$H(\pi,k_2,\pi)$ va $H(\pi,\pi,k_3)$ operatorlar unitar ekvivalent ekanligidan bittasini o'rganish yetarli hisoblanadi.

Har bir $(n,m)\in\mathbb{N}\times\mathbb{N}$ uchun $\mathfrak{R}_{n,m}^{+3}$ fazoda $H^+(\pi,\pi,k_3)$ operatorni qismi

$$H^+(\pi,\pi,k_3)|_{(n,m)}=I_n\otimes I_m\otimes[4I+H_0(k_3)-V_{nm}^+] \qquad (6)$$

ko'rinishda bo'adi. Bunda I_n-operator $L^+(n)$ dagi birlik operator $L_2^+(T)$ fazodagi bir o'lchamli ikki zarrachali $H^{+nm}(k_3):=4I+H_0(k_3)-V_{nm}^+$ operator quyidagicha bo'ladi:

$$(H^{+nm}(k_3)f)(p)=(4+\varepsilon_{k_3}(p))f(p)-(V_{nm}^+f)(p),\quad f\in L_2^+(T).$$

Bu holda agar $m\geq 2$, bo'lsa $V_{nm}^+=V^+|_{\mathfrak{R}_{n,m}^{+3}}=0$, shuning uchun V_{nm}^+ operatorni $m=0,1$ holatlarini o'rganamiz, ya'ni

$$(V_{n0}^+f)(p)=\frac{1}{2\pi}\int_T[\overline{\hat{v}}(n)+2\overline{\hat{v}}(n+1)\cos p\cos s]f(s)\mathrm{d}s.$$

$$(V_{n1}^+f)(p)=\frac{1}{2\pi}\int_T\overline{\hat{v}}(n+1)f(s)\mathrm{d}s.$$

Tahlil va natijalar. (6) tenglikga ko'ra $H^+(\pi,\pi,k_3)|_{(n,m)}$ operatorni xos qiymatlarini o'rganish masalasi $H^{+nm}(k_3)$ operator xos qiymatini o'rganish masalasiga keladi, ya'ni ikki o'lchamli masala bir o'lchamli masalaga keltiriladi.

1-teorema. *Har bir* $k_3\in(-\pi,\pi)$ *uchun* $H^{+n1}(k_3)$ *operator yagona xos*

$$z_{n1}^+(k_3)=6-\sqrt{\overline{v}^2(n+1)+4\cos^2\frac{k_3}{2}}$$

qiymatga ega bo'lib, unga mos xos funksiyasi

$$f_{n1}^{+++}(p)=\frac{C\cos p_1\cos p_2}{6-2\cos\frac{k_3}{2}\cos p_3-z_{n1}^+(k_3)}\in\mathfrak{R}_{n,1}^{+3}$$

bo'ladi, bunda C o'zgarmas son.

Isbot. $H^{+n1}(k_3)$ operator o'z-o'ziga qo'shma bo'lganligi uchun uning xos qiymatlari haqiqiy son bo'ladi. Xos qiymat uchun $H^{(1)}(\pi,\pi,k_3)f(\mathbf{p}) = zf(\mathbf{p})$ tenglama quyidagi tenglama bilan teng kuchli

$$(6-2\cos\frac{k_1}{3}\cos q_3)f(\mathbf{p}) - \frac{2\overline{v}(n+1)}{(2\pi)^3}\int\limits_{T^3}\sin q_1 \sin s_1 f(\mathbf{s})\mathrm{d}\mathbf{s} = z f(\mathbf{p}). \quad (7)$$

$$C = \frac{1}{(2\pi)^3}\int\limits_{\mathbb{T}^3}\sin s_1 f(\mathbf{s})\mathrm{d}\mathbf{s} \quad (8)$$

almashtirishni olamiz. (7) ga ko'ra $f(\mathbf{p})$ xos qiymat quyidagicha bo'ladi:

$$f(\mathbf{p}) = \frac{2\overline{v}(1)C\sin p_1}{6-2\cos\frac{k_3}{2}\cos p_3 - z}. \quad (9)$$

(9) ni (8) ga qoyib

$$C\left(1-\frac{2\overline{v}(n+1)}{(2\pi)^3}\int\limits_{T^3}\frac{\sin^2 s_1\,\mathrm{d}\mathbf{s}}{6-2\cos\frac{k_3}{2}\cos s_3 - z}\right) = 0$$

tenglamaga ega bo'lamiz. Agar $C=0$ bo'lsa, u holda (9) ga ko'ra $f(\mathbf{p})\equiv 0$ bo'ladi. Bu esa $f-$ ni xos funksiya bo'lishiga zid, shuning uchun

$$\Delta(z) = 1-\frac{2\overline{v}(n+1)}{(2\pi)^3}\int\limits_{T^3}\frac{\sin^2 s_1\,\mathrm{d}\mathbf{s}}{6-2\cos\frac{k_3}{2}\cos s_3 - z} = 0. \quad (10)$$

Agar $z > 6+2\cos\frac{k_3}{2}$ bo'lsa, u holda то $\Delta(z)>1.$ Shu maqsadda biz $z < 6-2\cos\frac{k_3}{2}.$ deb olamiz. (10) tenglamani yechiish uchun quyidagi integrallarni hisoblashimiz kerak:

$$\frac{2\overline{v}(n+1)}{(2\pi)^3}\int\limits_{T^3}\frac{\sin^2 s_1\,\mathrm{d}\mathbf{s}}{6-2\cos\frac{k_3}{2}\cos s_3 - z} = \frac{\overline{v}(n+1)}{2\pi}\int\limits_{T}\frac{\mathrm{d}s_3}{6-2\cos\frac{k_3}{2}\cos s_3 - z}. \quad (11)$$

Tenglikning o'ng qismidagi integral

$$\frac{1}{2\pi}\int\limits_{T}\frac{\mathrm{d}s_3}{6-2\cos\frac{k_3}{2}\cos s_3 - z} = \frac{1}{\sqrt{(6-z)^2-4\cos^2\frac{k_3}{2}}} \quad (12)$$

ga teng bo'ladi. Buni (11) ga qo'yish natijasida quyidagi tenglamaga ega bo'lamiz:

$$\Delta(z) = 1-\frac{\overline{v}(n+1)}{\sqrt{(6-z)^2-4\cos^2\frac{k_3}{2}}} = 0.$$

Ushbu tenglama

$$z_1 = 6-\sqrt{\overline{v}^2(n+1)+4\cos^2\frac{k_3}{2}}, \qquad z_2 = 6+\sqrt{\overline{v}^2(n+1)+4\cos^2\frac{k_3}{2}}.$$

yechimlarga ega bo'ladi. $z_1 < m(\pi,\pi,k_3)$ ekanligidan (6) ga ega bo'lamiz.

Ma'lumki, $H^{+nm}(-k_3) = H^{+nm}(k_3),$ shuning uchun $k_3\in[0,\pi]$ olsak bo'ladi. Agar $k_3\in\pi-2\theta$ belgilash olsak, u holda $k_3\in[0,\pi]$ ga ko'ra $\theta\in[0,\frac{\pi}{2}]$ bo'ladi.

2-teorema. Har bir $n\in\mathbb{Z}_+$ *uchun shunday* $\beta_n>0$ *son mavjud bo'lib, ixtiyoriy* $\theta\in(0,\beta_n)$ *lar uchun* $H^{+n0}(\pi-2\theta)$ *ikkita har hil oddiy xos* $z_n^+(\pi-2\theta)$ *u* $z_{n+1}^+(\pi-2\theta)$ *qiymatlarga ega bo'lib, ular*

$$z_n^+(\pi-2\theta)=6-\bar{v}(n)-\frac{2}{\bar{v}(n)-\bar{v}(n+1)}\theta^2+O(\theta^4),\qquad \theta\to 0,$$

$$z_{n+1}^+(\pi-2\theta)=6-\bar{v}(n+1)-\frac{\bar{v}(n)-3\bar{v}(n+1)}{\bar{v}(n+1)(\bar{v}(n)-\bar{v}(n+1))}\theta^2+O(\theta^4),\qquad \theta\to 0$$

assimptotik ko'rinishda bo'ladi va ularga mos xos funksiyalar

$$f_n^+(p)=\frac{(\alpha_1(n)+\beta_1(n)\cos p_3)\cos np_1}{6-2\cos\theta\cos p_3-z_n^+(\pi-2\theta)}\in\mathfrak{R}_{n,0}^{+3},$$

$$f_{n+1}^+(p)=\frac{(\alpha_2(n)+\beta_2(n)\cos p_3)\cos np_1}{6-2\cos\theta\cos p_3-z_{n+1}^+(\pi-2\theta)}\in\mathfrak{R}_{n,0}^{+3},$$

bunda $\alpha_1(n),\alpha_2(n),\beta_1(n),\beta_2(n)$ - *lar o'zgarmas sonlar.*

Xulosa va takliflar. Mazkur ish uch o'lchamli panjaradagi qisqa yoki uzoq masofada kuchsiz ta'sirlashuvchi ikkita zarrachali sistemalarga mos diskret Shredinger operatorlarining xos qiymatlari qo'zg'alishlarini tadqiq etishga bag'ishlangan. Tadqiqot natijasida xos qiymatlar uchun asimptotik formulalar olingan hamda ularga mos xos funksiyalar aniqlangan. Ma'lumki, tabiatda zarrachalarning o'zaro ta'sirlashuvi natijasida energiya holatlari vujudga keladi. Ushbu energiyalarning ta'sirlashuv kuchiga bog'liqligini o'rganish fizik nuqtayi nazardan muhim ahamiyatga ega. Bunday masalalarni tadqiq etish matematik modellar yordamida Shredinger operatorlari va ularga mos tenglamalarni o'rganishga olib keladi. Ishda xos qiymatlar uchun olingan natijalar zarrachalarning o'zaro ta'siri natijasida hosil bo'ladigan energiya holatlarini ifodalaydi, bu esa nazariy va amaliy jihatdan dolzarb masala hisoblanadi. Kelgusida mazkur tadqiqot natijalarini uch o'lchamli panjaradagi qisqa yoki uzoq masofada kuchsiz ta'sirlashuvchi ko'p zarrachali sistemalar uchun ham umumlashtirish va yanada chuqurroq o'rganish mumkin.

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IKKI KARRA NOCHIZIQLI MANBA EGA NODIVERGENT KO‘RINISHDAGI PARABOLIK TENGLAMALAR ORQALI TAVSIFLANUVCHI ISSIQLIK TARQALISH MASALASINING YECHIM XOSSALARI

[1]Djabbarov O.R.,[2]Samadova M.N, [3]Karimov M.M. [4]Abdurasulova K.V.
[1]Qarshi davlat universiteti, Amaliy matematika kafedrasi mudiri, PhD, dotsent
oybekjabborov1987@mail.ru
[2]Qarshi davlat universiteti, stajyor tadqiqotchi
mahbubasamadova@mail.ru
[3]Qarshi davlat universiteti,o‘qituvchi
muzaffarkarimov88030@gmail.com
[4]Qarshi davlat universiteti, 1-kurs magistranti
abdurasulovakamola@mail.ru
ORCID 0000-0002-5644-1513
UDK 517.957

Annotatsiya. Mazkur maqolada ikki karra nochiziqli manbaga ega bo‘lgan, nodivergent ko‘rinishdagi parabolik issiqlik tarqalish tenglamasining umumlashgan yechimlari xossalari o‘rganilgan. Maqolada manba hadlari va o‘zgaruvchan zichlikka ega nochiziqli diffuziya tenglamasi qaralib, klassik yechim mavjud bo‘lmagan holatlar uchun integral ayniyat ma’nosida umumlashgan yechim tushunchasi qo‘llanilgan. O‘zgaruvchini almashtirish va avtomodel yechimlar usuli yordamida masala nochiziqli parabolik tenglamadan oddiy differensial tenglamaga keltirilgan. Sekin diffuziya holida yechimlarning global mavjudligi solishtirish prinsipi asosida isbotlangan hamda Fujita tipidagi kritik eksponent aniqlangan. Olingan natijalar issiqlik o‘tkazuvchanligi, kimyoviy va biologik jarayonlarni tavsiflovchi nochiziqli modellarni sonli yechish uchun muhim nazariy ahamiyatga ega.
Kalit so‘zlar: global yechim, nodivergent tenglama, diffuziya, asimptotik yechim.

SOLUTION PROPERTIES OF THE HEAT DISSIPATION PROBLEM DESCRIBED BY NON-DIVERGENT PARABOLIC EQUATIONS WITH A DOUBLY NONLINEAR SOURCE

Abstract. This article studies the properties of generalized solutions of the parabolic heat dissipation equation in non-divergent form with a doubly nonlinear source. The article considers the nonlinear diffusion equation with source terms and variable density, and uses the concept of a generalized solution in the sense of an integral identity for cases where a classical solution does not exist. Using the method of change of variables and automodel solutions, the problem is reduced from a nonlinear parabolic equation to an ordinary differential equation. The global existence of solutions in the case of slow diffusion is proven on the basis of the comparison principle, and the Fujita-type critical exponent is determined. The results obtained are of important theoretical importance for the numerical solution of nonlinear models describing heat transfer, chemical and biological processes.
Keywords: global solution, non-divergent equation, diffusion, asymptotic solution.

Kirish. Nochiziqli parabolik tenglamalar, xususan, ikki karra nochiziqli va divergent, nodivergent diffuziya tenglamalari so‘nggi yillarda intensiv o‘rganilayotgan dolzarb yo‘nalishlardan biridir. A.A. Samarskiy va hammualliflarining kitobida nochiziqli parabolik tenglamalar uchun (blow-up), global mavjudlik va asimptotik xatti-harakat masalalari tizimli ravishda yoritilgan bo‘lib, keyingi tadqiqotlar uchun nazariy asos bo‘lib xizmat qiladi [1-2].

M.Aripov va Sh. Sadullayeva monografiyasida nochiziqli diffuziya jarayonlarining kompyuter modellashtirish masalalari ko‘rib chiqilib, nazariy natijalarni sonli tajribalar bilan tasdiqlash imkoniyatlari ko‘rsatilgan. Aripov va Bobokandov tomonidan bajarilgan tadqiqotlarda esa o‘zgaruvchan zichlikka ega, ikki karra nochiziqli parabolik tenglamalar uchun Koshi masalasi, umumlashgan yechimlarning mavjudligi va xossalari batafsil tahlil qilingan. Ushbu ishlar nodivergent ko‘rinishdagi tenglamalar uchun umumlashgan yechim tushunchasini rivojlantirishga muhim hissa qo‘shgan [1-4].

Daniel Andreuchchi va A.Tedeyev [5] tomonidan Fujita tipidagi kritik eksponent masalasi divergent parabolik tenglamalar uchun o‘rganilib, yechimlarning global mavjudligi va blow-up hodisasi o‘rtasidagi chegaraviy shartlar aniqlangan. Jin va Yin [7] ishlarida esa ikki karra nochiziqli nodivergent ko‘rinishdagi parabolik tenglamalar yechimlarining asimptotik xatti-harakati tadqiq etilgan. Zhou va hammualliflar [8] gradient hadli, nodivergent diffuziya tenglamalari uchun chegaraviy masalalarni o‘rganib, yechimlarning baholari va sifat

xossalarini aniqlagan.

Mahalliy tadqiqotlarda [9-10] M.Aripov, M.Bobokandov va boshqalar nodivergent tipdagi diffuziya tenglamalari uchun Koshi masalasi, kuchli va kuchsiz yechimlar, shuningdek, manba hadli ikki karra nochiziqli tenglamalar chuqur o‘rganilgan. Ushbu adabiyotlar majmui shuni ko‘rsatadiki, nodivergent ko‘rinishdagi ikki karra nochiziqli parabolik tenglamalar uchun global yechimlar, ularning baholari va kritik eksponentlarini aniqlash masalasi hanuz dolzarbligini saqlab qolmoqda va mazkur maqoladagi tadqiqotlar ushbu yo‘nalishni mantiqan davom ettiradi.

Masalaning qo‘yilishi. $Q=\{(x,t):\ x\in R^N, t>0\}$ sohada manba hadi va o‘zgaruvchan zichlikni o‘z ichiga olgan, nodivergent ko‘rinishdagi nochiziqli parabolik diffuziya tenglamasini qaraymiz:

$$|x|^{\alpha_1}\frac{\partial u}{\partial t}=u^{\beta}\frac{\partial}{\partial x}\left(|x|^{\alpha_2}u^{m-1}\left|\frac{\partial u}{\partial x}\right|^{p-2}\frac{\partial u}{\partial x}\right)+|x|^{\alpha_1}u^{q} \tag{1}$$

boshlang‘ich shartlar bilan

$$u(x,t)\big|_{t=0}=u_0(x)\ge 0,\ x\in R, \tag{2}$$

Bu yerda $\beta<1, m\ge 1, p\ge \max\{2,\alpha_2-\alpha_1\}, q>1, \alpha_1<0, \alpha_2<0$ sonli parametrlar bo‘lib, $u_0(x)$ uzluksiz, manfiy bo‘lmagan, chegaralangan funksiyadir. Ma’lumki, (1) tenglama buziluvchi xarakterga ega bo‘lib, $u(x,t)=0$ yoki $|u_x|=0$ holatlarda klassik ma’noda yechim mavjud bo‘lmasligi mumkin. Shu sababli, (1)-(2) masala uchun yechim integral ayniyat ma’nosida aniqlanadigan umumlashgan yechim sifatida qaraladi. Bunda

$$0\le u,\quad |x|^{\alpha_2}u^{m-1}\left|\frac{\partial u}{\partial x}\right|^{p-2}\frac{\partial u}{\partial x}\in C(R\times(t,+\infty))$$

shart bajarilishi talab etiladi va yechim (1) tenglamani integral tenglik ko‘rinishida qanoatlantiradi. Qayd etish joizki, (1)–(2) masalada ishtirok etuvchi parametrlarning turli qiymatlarida ushbu model ko‘plab issiqlik almashinuvi, kimyoviy reaksiyalar hamda biologik jarayonlarni tavsiflashda qo‘llaniladi. [1-16].

Tadqiqot metodologiyasi. Dastlab, (1) tenglamada quyidagicha belshilash kiritamiz:

$$y=u^{1-\beta}. \tag{3}$$

U holda (1), (2) masala quyidagi ko‘rinishga keladi:

$$(1-\beta)L(y)=y^{\frac{\beta}{1-\beta}}\left[|x|^{\alpha_1}y_t-\frac{\partial}{\partial x}\left(|x|^{\alpha_2}y^{\frac{m}{1-\beta}-1}\left|\frac{\partial y^{\frac{1}{1-\beta}}}{\partial x}\right|^{p-2}\frac{\partial y}{\partial x}\right)+(1-\beta)|x|^{\alpha_1}y^{\frac{q-\beta}{1-\beta}}\right]=0 \tag{4}$$

$$y\big|_{t=0}=y_0(x)=[u_0(x)]^{1-\beta},\ x\in R. \tag{5}$$

Ma’lumki, $\beta(1-\beta)>0$ shart bajarilganda $y=0$ funksiya (4) tenglamaning trivial yechimi hisoblanadi. Ushbu ishda tenglamaning trivial bo‘lmagan yechimlarini aniqlash maqsad qilib olingan. Shu sababli chiziqli bo‘lmagan ajratish usulidan foydalanib, (4), (5) masalaning yechimini quyidagi avtomodel ko‘rinishda izlaymiz:

$$y(x,t)=t^{-n_1}g(\eta),\ \eta=\frac{|x|}{t^{n_2}}, \tag{6}$$

bu yerda $n_1=\dfrac{1-\beta}{q-1}$, $n_2=\dfrac{p+q-(\beta+m+2)}{(q-1)(p-\alpha_2+\alpha_1)}$.

(6) ifodani hisobga inobatga olib, (4) tenglama avtomodel o‘zgaruvchi orqali quyidagi oddiy differensial tenglamaga keltiriladi:

$$\left(\eta^{\alpha_2}g^{\frac{m+\beta-1}{1-\beta}}\left|\left(g^{\frac{1}{1-\beta}}\right)'\right|^{p-2}g'\right)'+n_2\eta^{1+\alpha_1}g'+n_1\eta^{\alpha_1}g+(1-\beta)\eta^{\alpha_1}g^{\frac{q-\beta}{1-\beta}}=0. \tag{7}$$

Hosil bo‘lgan (7) avtomodel tenglama uchun manfiy bo‘lmagan, trivial bo‘lmagan va

fizik mazmunga ega yechimlarni qidiramiz. Bunda yechim quyidagi boshlang‘ich shartlarni qanoatlantirishi talab etiladi:

$$g'(0) = g(d) = 0,\ d \in R_+. \tag{8}$$

Olingan natijalar. Agar

$$\frac{m+p-2}{1-\beta} - 1 > 0$$

shart bajarilsa, ushbu holat sekin diffuziya rejimi sifatida talqin qilinadi. Bu holda (1) tenglama uchun umumlashgan yechimlarning global mavjudligi solishtirish prinsipi asosida isbotlanadi. (4)–(5) masala (1)–(2) masalaga ekvivalent bo‘lganligi sababli, keyingi tahlil aynan (4)–(5) masala doirasida olib boriladi. Solishtirish prinsipi natijasida (4)–(5) masalaning yuqori baholovchi yechimi quyidagi avtomodel ko‘rinishda aniqlanadi:

$$y_+(x,t) = t^{-n_1}\overline{g}(\eta), \tag{9}$$

$$\overline{g}(\eta) = A\left(a - \eta^{\gamma_1}\right)_+^{\gamma_2}. \tag{10}$$

Bu yerda $\gamma_1 = \dfrac{p-\alpha_2+\alpha_1}{p-1}$, $\gamma_2 = \dfrac{(p-1)(1-\beta)}{m-p+\beta+1}$, $a \geq 0$,

$$A = \left[\left|n_2\left(\frac{1}{1-\beta}\right)^{2-p}\right|^{1/(p-1)} / (\gamma_1\gamma_2)\right]^{\gamma_2},\ \gamma_1 \neq 0, \gamma_2 \neq 0. \tag{11}$$

1-Teorema. Agar quyidagi shartlardan kamida bittasi bajarilsa

$$\alpha_1 < -1,\ \mu_1 > \mu_2,\ \text{yoki}\ \alpha_1 = -1,\ \mu_1 > 1,$$

hamda

$$y(x,t) \leq y_+(x,t),\ x \in R,$$

munosabat o‘rinli bo‘lsa, u halda Q sohada (4), (5) masalaning global umumlashgan yechimi mavjud bo‘ladi va u quyidagi bahoni qanoatlantiradi

$$y(x,t) \leq y_+(x,t) = t^{-n_1}\overline{g}(\eta). \tag{12}$$

Bu yerda

$$\mu_1 = \frac{q-\beta}{1-\beta},\ \mu_2 = \frac{m+p-2}{1-\beta} + \frac{p-\alpha_2+\alpha_1}{\alpha_1+1}$$

bo‘lib, μ_2 – Fujita tipidagi kritik eksponent hisoblanadi.

Isbot. Taqqoslash funksiyasi sifatida (10) tenglama bilan aniqlangan funksiyani tanlaymiz. Ushbu funksiyani (4) tenglamaga qo‘yib, quyidagi baholashni olamiz:

$$(1-\beta)Ly = -y_+^{\beta/(1-\beta)}[(\eta^{\alpha_2}\overline{g}^{\frac{m}{1-\beta}-1}\left|\left(\overline{g}^{1/(1-\beta)}\right)'\right|^{p-2}\overline{g}')' + n_2\eta^{1+\alpha_1}\overline{g}' + \tag{13}$$

$$+ n_1\eta^{\alpha_1}\overline{g} + (1-\beta)\eta^{\alpha_1}\overline{g}^{\mu_1}] \leq 0.$$

Bu yerda $y_+(x,t)$ funksiyaning manfiy bo‘lmaganligi hamda $\overline{g}(\eta)$ funksiyaning

$$(\eta^{\alpha_2}\overline{g}^{m/(1-\beta)}\left|(\overline{g}^{1/(1-\beta)})'\right|^{p-2}\overline{g}')' + n_2\eta^{1+\alpha_1}\overline{g}' + n_2(\alpha_1+1)\eta^{\alpha_1}\overline{g} = 0$$

tenglamani qanoatlantirishini hisobga olib, (13) tengsizlikni quyidagi ko‘rinishga keltiramiz:

$$\eta^{\alpha_1}\overline{g}\cdot\left[n_1 - n_2(\alpha_1+1) + (1-\beta)\overline{g}^{\mu_1-1}\right] \geq 0. \tag{14}$$

η^{α_1} va $\overline{g}$ funksiyalarning manfiy bo‘lmaganligi hamda $\beta < 1$ shart bajarilishini inobatga olsak, (14) tengsizlik bajarilishi uchun quyidagi shart yetarli bo‘ladi:

$$n_1 \geq n_2(\alpha_1+1).$$

Agar, $\alpha_1 + 1 = 0$ bo‘lsa, u holda

$$0 \leq n_1 = \frac{1}{\mu_1 - 1}$$

tengsizlik avtomatik ravishda bajariladi. Olingan tengsizliklar teorema shartlarida keltirilgan munosabatlar bilan mos keladi. Demak,

$$y(x,t) \le y_+(x,t)$$

bahosi o‘rinli bo‘ladi. Teorema isbotlandi.

Yechim asimptotikasi. Ushbu bo‘limda (7)-(8) masalalar uchun olingan yechimlarning asimptotik xossalariga oidteorema bayon qilinadi hamda uning isboti keltiriladi 2-teorema. Agar $\gamma_2 > 0$ va $\mu_1 \ge 1 - 1/\gamma_2$ shartlar bajarilsa, u holda (7)-(8) masalaning kompakt tashuvchiga ega bo‘lgan yechimlari $\eta \to a_-^{\frac{1}{\gamma_1}}$ da quyidagicha asimptotik ifodaga ega bo‘ladi:

$$g(\eta) = c_1 A\left(a - \eta^{\gamma_1}\right)_+^{\gamma_2}(1 + o(1)). \tag{15}$$

Bu yerda $c_1 -$ mos nochiziqli algebraik tenglamaning yechimini ifodalaydigan doimiy sondir.

Isbot. (7)-(8) masalaning kompakt tashuvchili yechimlarining asimptotikalarini tadqiq etish maqsadida, (7) avtomodel tenglamaning yechimini quyidagi ko‘rinishda qidiramiz:

$$g(\eta) = \overline{g}(\eta) w(\xi),\ \ \xi = -\ln\left(a - \eta^{\gamma_1}\right). \tag{16}$$

Bu yerda $\overline{g}(\eta) = A\left(a - \eta^{\gamma_1}\right)_+^{\gamma_2},\ a = const > 0, w(\xi) -$ izlanayotgan funksiya.

Ravshanki, $\eta \to a_-^{\frac{1}{\gamma_1}}$ da $\xi \to +\infty$ bo‘ladi.

(16) tenglikni (7) tenglamaga olib borib qo‘yamiz, natijada $w(\xi)$ ga nisbatan quyidagi tenglamaga ega bo‘lamiz:

$$\frac{d}{d\xi}(K_- w) + \left(\frac{\alpha_1 + 1}{\gamma_1} a_0(\xi) - \gamma_2\right) K_- w + a_1(\xi)\left(\frac{dw}{d\xi} - \gamma_2 w\right) + \tag{17}$$
$$+ a_2(\xi) w + a_3(\xi) w^{\mu_1} = 0$$

bu yerda

$$a_0(\xi) = \frac{e^{-\xi}}{a - e^{-\xi}},$$

$$a_1(\xi) = n_2 \gamma_1 b,\ b = \gamma_1^{-p}\left(\frac{1}{1-\beta}\right)^{2-p} A^{\frac{1-(m+p+\beta)}{1-\beta}},\ a_2(\xi) = n_1 b a_0(\xi),$$

$$a_3(\xi) = (1-\beta) b A^{q-1} \frac{e^{(\gamma_2(1-\mu_1)-1)\xi}}{a - e^{-\xi}},\ K_\pm w = w^{\frac{m+\beta(p-1)-1}{1-\beta}} \left|\frac{dw}{d\xi} \pm \gamma_2 w\right|^{p-2}\left(\frac{dw}{d\xi} \pm \gamma_2 w\right).$$

Faraz qilamiz, $\eta \in [\eta_0, \eta_1), 0 < \eta_0 < \eta_1, \eta_1 = a^{\frac{1}{\gamma_1}}$, bo‘lsin. U holda, $\xi(\eta)$ funksiya quyidagi xossalarga ega bo‘ladi:

$$\eta \in [\eta_0, \eta) \text{ da } \xi'(\eta) > 0,\ \xi_0 = \xi(\eta_0),\ \lim_{\eta \to \eta_1} \xi(\eta) = +\infty.$$

Quyidagicha belgilash kiritamiz

$$v(\xi) = K_-(w) = w^{\frac{m+\beta(p-1)-1}{1-\beta}} \left|\frac{dw}{d\xi} - \gamma_2 w\right|^{p-2}\left(\frac{dw}{d\eta} - \gamma_2 w\right). \tag{18}$$

Natijada (17) tenglama quyidagi ko‘rinishda ifodalanadi:

$$v'(\xi) = -\left(\frac{\alpha_1 + 1}{\gamma_1} a_0(\xi) - \gamma_2\right) v(\xi) - a_1(\xi)\left(\frac{dw}{d\xi} - \gamma_2 w\right) - a_2(\xi) w - a_3(\xi) w^{\mu_1}. \tag{19}$$

Quyidagi funksiyani qaraymiz

$$z(\xi) = -\left(\frac{(\alpha_1 + 1) a_0(\xi)}{\gamma_1} - \gamma_2\right)\lambda - a_1(\xi)\left(\frac{dw}{d\xi} - \gamma_2 w\right) - a_2(\xi) w - a_3(\xi) w^{\mu_1}. \tag{20}$$

Bu yerda $\lambda \in R.$

$\gamma_2 > 0$ tengsizlik bajarilsin, shuningdek $\xi \to \infty$ dagi

$$\lim_{\xi \to \infty} a_0(\xi) = \lim_{\xi \to \infty} a_2(\xi), \lim_{\xi \to \infty} a_1(\xi) = n_2 \gamma_1 b,$$

$$\overset{0}{a}_3 = \lim_{\xi \to \infty} a_3(\xi) = \begin{cases} \infty, & \gamma_2(1-\mu_1) > 1 \\ 0, & \gamma_2(1-\mu_1) < 1 \\ (\beta - 1) b A^{q-1} a^{(\alpha_1 - \alpha_2)/\gamma_1 - 1}, & \gamma_2(1-\mu_1) = 1 \end{cases}$$

limitlarni hisobga olsak, u holda λ parametrning har bir fiksirlangan qiymatida $z(\xi)$ funksiyalar uchun $[\xi,+\infty)\subset[\xi_0,+\infty)$ mos ravishda shunday intervallar mavjudki, bu intervallarda $z(\xi)$ o‘z ishorasini saqlab qoladi. Yani,

$$z(\xi)>0 \text{ yoki } z(\xi)<0. \tag{21}$$

Faraz qilaylik, $z(\xi)$ funksiyasi $\xi\to+\infty$ da chekli limitga ega emas bo‘lsin. Agar (21) tengsizliklarning birini ma’lum oraliqda bajarilsa, u holda quyidagi holatlar yuzaga kelishi mumkin.Xususan, $z(\xi)$ funksiyasi $\overline{z}=\lambda$ to‘g‘ri chiziq atrofida tebranuvchi funksiya bo‘lgani sababli, uning grafigi $[\xi,\infty)$ oraliqda ushbu tog‘ri chiziqni cheksiz ko‘p marta kesib o‘tadi. Biroq bunday holatning oshishi mumkin emas. Chunki $[\xi,\infty)$ oraliqda (21) tengsizliklardan faqat bittasi bajariladi. Natijada, (20) tenglikka muvofiq, $z(\xi)$ funksiyaning grafigi $\overline{z}=\lambda$ to‘g‘ri chiziqni $[\xi_i,\infty),(i=1,2)$ oraliqda faqat bitta nuqtada kesib o‘tishi mumkin. Shunday qilib, $z(\xi)$ funksiyasi uchun $\xi\to+\infty$ da limit mavjud bo‘lishi zarur. Endi $z(\xi)$ funksiyasi (20) tenglik orqali aniqlanganini hisobga olsak, $\xi\to+\infty$ da $z(\xi)$ ning limiti mavjud bo‘lishidan $w'(\xi)$ hosilasining ham limiti mavjudligi kelib chiqadi va ushbu limit nolga teng bo‘ladi.

Demak, $\xi\to+\infty$

$$v(\xi)=w^{\frac{m+\beta(p-1)-1}{1-\beta}}\left|\frac{dw}{d\xi}-\gamma_2 w\right|^{p-2}\left(\frac{dw}{d\eta}-\gamma_2 w\right)=-\gamma_2^{p-1}w_0^{\frac{m+p-2}{1-\beta}}+o(1),\ w_0=\lim_{\xi\to\infty}w(\xi), \tag{22}$$

limit mavjud. Bunga asosan (19) tenglikda $z(\xi)$ funksiyaning hosilasini $\xi\to+\infty$ dagi limiti mavjud va nolga teng. (17)-(22) tengliklardan quyidagi natijani olamiz

$$\gamma_2^p w_0^{\frac{m+p-2}{1-\beta}-1}-n_2 b\gamma_1\gamma_2+\overset{0}{a}_3 w_0^{\mu_1-1}=0. \tag{23}$$

Teorema isbotlandi.

Natija. Agar $\dfrac{m+p-2}{1-\beta}-1>0$ tengsizlik o‘rinli bo‘lsa, u holda (1)-(2) masalaning umumlashgan yechimi $|x|\to a^{\frac{1}{\gamma_1}}t^{n_2}$ da quyidagi asimptotikaga ega

$$u_A(x,t)=(c_1A)^{1-\beta}t^{-n_1(1-\beta)}\left(a-\left(|x|t^{-n_2}\right)^{\frac{p-\alpha_2+\alpha_1}{p-1}}\right)_+^{\frac{(p-1)(1-\beta)}{m+p-2}-1}(1+o(1)),$$

Bu yerda c_1- (23) algebraik tenglamaning yechimi.

$\dfrac{m+p-2}{1-\beta}-1<0$ bo‘lgan hol tez diffuziya holi deb nomlanadi. Faraz qilaylik (7) tenglama quyidagi shartlarni qanoatlantirsin

$$g'(0)=g(\infty)=0. \tag{24}$$

Tez diffuziya holi uchun $y_-(x,t)=t^{-n_1}h(\eta),h(\eta)=D\left(d+\eta^{\gamma_1}\right)^{\gamma_2}$ funksiyani qaraymiz, bu yerda $D,d>0$ va $n_1,\gamma_1\gamma_2$ lar yuqorida aniqlangan konstantalar.

3-teorema. Agar $\alpha_1>-1,\ \mu_1>\mu_2,\ \dfrac{D^{\frac{m+p-2}{1-\beta}-1}|\gamma_1\gamma_2|^p}{(1-\beta)^{p-2}}=n_2,\ \eta\ge\max\left\{\left(A_1^{1/|\gamma_2|}-d\right)^{1/\gamma_1},0\right\}$

Shuningdek boshlang‘ich shart

$$y(x,0)\ge y_-(x,0),\ x\in R,$$

o‘rinli bo‘lsa, u holda Q sohada (4)-(5) masalaning global yechimi mavjud bo‘ladi. Bundan tashqari, ushbu yechim uchun quyidagi baho bajariladi:

$$y(x,t)\ge y_-(x,t)=t^{-n_1}h(\eta).$$

Bu yerda $A_1 = \dfrac{(1-\beta)(\mu_1-1)(p-\alpha_2+\alpha_1)D^{\mu_1-1}}{(\alpha_1+1)(\mu_1-\mu_2)}$.

Maskur teorema isboti 1-teorema isbotiga o‘xshash usulda amalga oshiriladi.

4-teorema. Agar $\gamma_2 < 0$ bo‘lsa, u holda (7),(24) masalaning $\eta \to \infty$ da kamayuvchi yechimlari quyidagi asimptotikaga ega bo‘ladi:

$$g(\eta) = c_2 D\left(d + \eta^{\gamma_1}\right)^{\gamma_2}\left(1 + o(1)\right). \tag{26}$$

Bu yerda $c_2 -$ mos nochiziqli algebraik tenglamaning yechimini ifodalovchi doimiy sondir.

Isbot. (7), (24) masala yechimlarini asimptotikalarini o‘rganishimiz uchun (7) avtomodel tenglamaning $\eta \to \infty$ da kamayuvchi yechimini quyidagi ko‘rinishda izlaymiz:

$$g(\eta) = h(\eta)\cdot z(\xi),\ \ \xi = \ln\left(a + \eta^{\gamma_1}\right), \tag{27}$$

Bu yerda $h(\eta) = D\left(d + \eta^{\gamma_1}\right)^{\gamma_2}, d > 0, z(\xi) -$ qidirilayotgan funksiya.

(27) ni (7) tenglamaga qo‘yamiz, natijada $z(\eta)$ ga nisbatan quyidagi tenglamaga ega bo‘lamiz:

$$\frac{d}{d\xi}(K_+ z) + \left(\frac{(\alpha_1+1)}{\gamma_1} d_0(\xi) + \gamma_2\right) K_+ z + d_1(\xi)\left(\frac{dz}{d\xi} + \gamma_2 z\right) + \\ + d_2(\xi) z + d_3(\xi) z^{\mu_1} = 0 \tag{28}$$

bu yerda $d_0(\xi) = \dfrac{1}{1 - de^{-\xi}}$, $d_1(\xi) = n_2\gamma_1 d_4,\ d_4 = \gamma_1^{-p}\left(\dfrac{1}{1-\beta}\right)^{2-p} D^{1-\frac{m-(p-2)}{1-\beta}}$,

$d_2(\xi) = n_1 d_4 d_0(\xi)$, $d_3(\xi) = (1-\beta) d_4 D^{q-1} \dfrac{e^{\gamma_2(\mu_1-1)\xi}}{1-de^{-\xi}}$,

$K_+ z = z^{\frac{m+\beta(p-1)-1}{1-\beta}}\left|\dfrac{dz}{d\xi} + \gamma_2 z\right|^{p-2}\left(\dfrac{dz}{d\xi} + \gamma_2 z\right)$.

Shularga asoslangan holda, 4-teorema ham 2-teorema kabi isbotlanadi va yakunda quyidagi natijani olamiz:

$$\left(\gamma_2 + (\alpha_1+1)/\gamma_1\right)\gamma_2^{p-1} z_0^{\frac{m+p-2}{1-\beta}-1} + \overset{0}{d}_3\, z_0^{\mu_1-1} + \left(n_1 + n_2\gamma_1\gamma_2\right) d_4 = 0. \tag{29}$$

Bu yerda:

$$\overset{0}{d}_3 = \lim_{\xi\to\infty} d_3(\xi) = \begin{cases} \infty,\ \gamma_2(\mu_1-1) > 0 \\ 0,\ \ \gamma_2(\mu_1-1) < 0 \\ (1-\beta) d_4 D^{q-1},\ \gamma_2(\mu_1-1) = 0 \end{cases}$$

Natija. Agar $\dfrac{m+p-2}{1-\beta} - 1 < 0$ tengsizlik o‘rinli bo‘lsa, u holda (1)-(2) masalaning umumlashgan yechimi $\eta = |x|t^{-n_2} \to \infty$ da quyidagi asimptotikaga ega:

$$u_A(x,t) \approx (c_2 D)^{1-\beta} t^{-n_1(1-\beta)}\left(d + \left(|x|t^{-n_2}\right)^{\frac{p-\alpha_2+\alpha_1}{p-1}}\right)^{(p-1)(1-\beta)/(\frac{m+p-2}{1-\beta}-1)}\left(1 + o(1)\right)$$

Bu yerda $c_2 -$ (29) algebraik tenglamaning yechimi.

Kritik hol. $\dfrac{m+p-2}{1-\beta} - 1 = 0$ holni kritik hol deymiz va bu holda ham (4) tenglamaning umumlashgan yechimlarining global yechim bo‘lishini ko‘rsatamiz. Solishtirish prinsipiga asosan $y_k(x,t)$ yechimni quyidagicha ko‘rinishda qidiramiz

$$y_k(x,t) = t^{-n_1} K(\eta), \tag{30}$$

$$K(\eta) = C_0 \exp\left(-A_1\eta^{\gamma_1}\right), C_0 > 0, A_1 = \left|\frac{n_2}{(1-\beta)^{2-p}}\right|^{\frac{1}{p-1}} / \gamma_1 \tag{31}$$

5-Teorema. Agar $\dfrac{m+p-2}{1-\beta} - 1 = 0$, quyidagi shartlardan biri $\alpha_1 < -N, \mu_1 > \mu_2$ yoki

$\alpha_1 = -N, \mu_1 > 1$ va $y(x,0) \le y_k(x,0), \quad x \in R^N$, munosabatlar o‘rinli bo‘lsa, Q sohada (19), (20) ,masalaning global yechimi mavjud va uning uchun quyidagi baho o‘rinli

$$y(x,t) \le y_k(x,t) = t^{-n_1} K(\eta), \quad x \in R^N,$$

Teoremani isboti 1-teorema isboti kabi isbotlanadi.

Xulosa. Mazkur maqolada ikki karra nochiziqli manbaga ega bo‘lgan nodivergent ko‘rinishdagi parabolik issiqlik tarqalish tenglamasi uchun Koshi masalasi o‘rganildi. Klassik yechim mavjud bo‘lmagan holatlarda umumlashgan yechim tushunchasi kiritilib, masala integral ayniyat ma’nosida qaraldi. O‘zgaruvchini mos almashtirish va avtomodel yechimlar usuli yordamida masala soddalashtirilib, tenglamaning sifat xossalarini tahlil qilish imkoniyati yaratildi. Sekin diffuziya holida solishtirish prinsipi asosida yechimlarning global mavjudligi isbotlandi hamda Fujita tipidagi kritik eksponent aniqlanib, yechimlarning global saqlanishi o‘rtasidagi chegaraviy shartlar belgilandi. Olingan natijalar nodivergent tipdagi nochiziqli parabolik tenglamalar nazariyasini rivojlantiradi hamda issiqlik almashinuvi, kimyoviy va biologik jarayonlarni modellashtirishda qo‘llash uchun nazariy asos bo‘lib xizmat qiladi.

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AL_2O_3/Co/Al NANOGETEROSTRUKTURALARIDA YENGIL METALLAR ORQALI ORBITAL MOMENT HOSIL QILISH VA INTERFEYS OKSIDLANISHINING SPIN TRANSPORTIGA TA'SIRI: ADABIYOTLAR TAHLILI

Alberto Riminucci
Nanostrukturali materiallar instituti, CNR-ISMN, Bologna, Italiya
alberto.riminucci@cnr.it
ORCID 0000-0003-0976-1810
Ilhom Bekpulatov
Qarshi davlat universiteti, Ilmiy ishlar va innovatsiyalar bo'yicha prorektor
ilkhomjon31121985@gmail.com
ORCID 0000-0001-7955-3932
Quvondiq Dovranov
Qarshi davlat universiteti, Nazariy va eksperimental fizika kafedrasi v.b.dotsenti
q.dovranov@qarshidu.uz
ORCID 0000-0003-1476-6552
Jahongir Parmonov
Qarshi davlat universiteti, Qarshi, O'zbekiston
jahongir24011992@gmail.com
UDK 538.975, 621.793

Annotatsiya. Mazkur sharh maqola yengil metallar asosidagi orbital moment (OT) hosil qilish mexanizmlarini, Co yupqa plyonkalarida sirt oksidlanishining spin transportiga ta'sirini va Al_2O_3/Co/Al ko'p qatlamli nanogeterostrukturalarida interfeys muhandisligining orbitronik samaradorlikka ta'sirini tizimli ravishda ko'rib chiqadi. Spintronikadan orbitronikaga o'tishning nazariy asoslari, orbital Hall effekti (OHE) va orbital Rashba-Edel'shtein effekti (OREE) tahlil qilinib, Ti, Cr, Zr kabi yengil metallardagi katta orbital Hall o'tkazuvchanligi ($\sigma_{OHE} \sim 10^3$ $(\hbar/e)\Omega^{-1}sm^{-1}$) imkoniyatlari muhokama qilinadi. Zr/$[Co/Pt]_3$ tizimida erishilgan $\xi_{OT} \approx 0.78$ ferromagnit qatlamning spin-orbit korrelyatsiya funksiyasi ($\eta_{L\text{-}S}$) ahamiyatini ko'rsatadi. Kobalt yupqa plyonkalarining sirt oksidlanishi (CoO, Co_3O_4 fazalari), magnit va transport xossalariga ta'siri va oksidni kamaytirish strategiyalari ko'rib chiqiladi. Co/Al_2O_3 interfeysining magnit xossalari o'rganilgan bo'lib, Al_2O_3 to'siqli Co qatlamlari in-plane anizotropiyasini ko'rsatgan. SIMTRA Monte-Karlo simulyatsiyasi natijalari Al taglikiga Co atomlarining cho'kishini modellashtirdi. Al_2O_3(0001)/Co nanoplyonkasida dastlabki eksperimental natijalar - SEM, Raman spektroskopiyasi va HMS-5000 Hall o'lchovlari keltiriladi.

Kalit so'zlar: orbitronika, orbital Hall effekti, orbital moment, magnetron changlatish, sirt oksidlanishi, spin transport Monte-Karlo simulyatsiya.

ORBITAL TORQUE GENERATION VIA LIGHT METALS IN Al_2O_3/Co/Al NANOHETEROSTRUCTURES AND THE EFFECT OF INTERFACE OXIDATION ON SPIN TRANSPORT: A REVIEW

Abstract. This review article systematically examines the mechanisms of orbital torque (OT) generation based on light metals, the impact of surface oxidation on spin transport in Co thin films, and the influence of interface engineering on orbitronic efficiency in Al_2O_3/Co/Al multilayer heterostructures. The theoretical foundations of the transition from spintronics to orbitronics, as well as the orbital Hall effect (OHE) and the orbital Rashba-Edelstein effect (OREE), are analyzed, with a discussion on the potential of high orbital Hall conductivity ($\sigma_{OHE} \sim 10^3$ $(\hbar/e)\Omega^{-1}$ cm^{-1}) in light metals such as Ti, Cr, and Zr. The orbital torque efficiency of $\xi_{OT} \approx 0.78$ achieved in the Zr/$[Co/Pt]_3$ system highlights the significance of the spin-orbit correlation function (η_{L-S}) of the ferromagnetic layer. The surface oxidation of cobalt thin films (CoO and Co_3O_4 phases), its effect on magnetic and transport properties, and strategies for oxide reduction are reviewed. The magnetic properties of the Co/Al_2O_3 interface are investigated, demonstrating that Co layers with an Al_2O_3 barrier exhibit in-plane anisotropy. SIMTRA Monte Carlo simulation results modeled the deposition of Co atoms onto the Al substrate. Preliminary experimental results for the Al_2O_3(0001)/Co nanofilm, including SEM, Raman spectroscopy and HMS-5000 Hall measurements, are presented.

Keywords: orbitronics, orbital Hall effect, orbital torque, magnetron sputtering, surface oxidation, spin transport, Monte Carlo simulation.

Kirish. ***1.1. Spintronikada OT va SOT.*** So'nggi o'n yil ichida energiya tejamkor xotira va mantiqiy qurilmalarga bo'lgan talabning ortishi spin-orbit momentlari (SOT) asosidagi tizimlardan muqobil mexanizmlarni izlashga undadi. An'anaviy spintronikada og'ir metallar (Pt, Ta, W) kuchli spin-orbit bog'lanishi (SOC) orqali spin tokini hosil qiladi va

ferromagnit (FM) qatlamning magnit momentini boshqaradi [1, 2]. Biroq, bu metallar qimmat, katta energiya yo‘qotishlari va miqyoslanish muammolariga ega [3]. Orbitronika – elektronning orbital burchak momenti (OAM) xossalaridan foydalanadigan yangi soha - bu cheklovlarga muqobil yo‘l sifatida jadal rivojlanmoqda [4, 5]. Orbital Hall effekti (OHE) tashqi elektr maydoni ta’sirida ko‘ndalang orbital tok hosil qilishga imkon beradi, va bu hodisa hatto zaif SOCga ega yengil metallarda ham sodir bo‘ladi [6, 7]. Natijada Ti, Cr, Zr, Nb kabi arzon va CMOS-mos materiallar spin boshqaruv qurilmalari uchun strategik ahamiyat kasb etmoqda [8].

Shu bilan birga, orbitronik qurilmalar uchun qo‘llaniladigan ferromagnit qatlamlarning sirt oksidlanishi muhim muammo bo‘lib qolmoqda. Kobalt (Co) - yuqori Kyuri harorati T_c = 1388 K, katta to‘yinish magnitlanishi $M_s \approx 1440$ kA/m va kuchli spin-bog‘liq transport xossalari tufayli spintronikada keng ishlatiladigan material atmosferaga chiqarilganda tez CoO va Co_3O_4 fazalarini hosil qiladi [9,10]. Bu oksid fazalar magnit va transport xossalarini sezilarli buzadi va orbitaldan spinga konversiya samaradorligini ($\eta_{L\text{-}S}$) pasaytiradi [11]. Maunoury va boshqalar UHV ion beam sputtering bilan hosil qilingan Co/Al_2O_3/Co qo‘shilmasida Co qatlamining 40 Å dan past qalinlikda paramagnit xususiyat ko‘rsatishini ko‘rsatdi [14].

Yang va boshqalarning ishlari orbitronikada muhim bosqich bo‘ldi [8]. Zr (10 nm)/$[Co/Pt]_3$ namunasi $Al_2O_3(0001)$ taglikda magnetron changlatish usuli bilan hosil qilinib, ikkinchi garmonik Hall o‘lchovlari amalga oshirildi. $\xi_{OT,DL} \approx 0.78$ va $\xi_{OT,FL} \approx 0.39$ qiymatlari aniqlandi [8]. Bu OHM tizimlarida qayd etilgan eng yuqori ko‘rsatkichlardan biridir. To‘liq magnit kommutatsiyasi $J_s \approx 2.6\times10^6$ A/sm² da erishildi, bu W/$[Co/Pt]_3$ dan 2.5 marta kam. Ti da orbital Hall effekti bevosita kuzatilishi Choi va boshqalar (2023, Nature) tomonidan MOKE orqali namoyish etildi [12]. Orbital diffuziya uzunligi Ti da 74 nm, Cr da 7 nm ekanligi aniqlangan [4]. Lee va boshqalar (2021) Cr/CoTb tizimida $\xi_{OT} \approx -0.57$ qiymatiga erishdi [15, 22]. Hayashi va boshqalar orbital tokning spin tokidan o‘n martadan ortiq uzoqroq masofaga tarqalishini namoyish etdi [6, 24]. Porrati va boshqalar (2015) FEBID usulida $HFeCo_3(CO)_{12}$ heteronuklear precursordan CoFe qotishma nanostrukturalari sintez qildi [17]. TEM tahlili bcc CoFe fazasi va Co_2FeO_4 shpinel oksid nanozarrachalar (5 nm) birgaligini ko‘rsatdi. Bu ikki fazali sistema magnit histerezisda wasp-waist shakl va alohida sakrash bosqichlarini namoyon etdi [17]. Benini va boshqalar (Nat. Commun., 2025) ishida kuzatilgan vorteks va Rayleigh buzilishi hodisalariga o‘xshash.

Tadqiqot metodologiyasi.

2. Nazariy asoslar: spintronikadan orbitronikaga

2.1. Spin-orbit momentlari, Orbital Hall effekti va ularning cheklovlari

An’anaviy SOT tizimida og‘ir metall/ferromagnit (HM/FM) geterostrukturasi yaratiladi. HM qatlamida spin Hall effekti (SHE) orqali zaryad toki (J_C) spin tokiga (J_S) aylantiriladi [1,2]:

$$\xi_{SOT} = \theta_{SHE} = (2e/\hbar)\cdot\sigma_{SHE}/\sigma_{xx}$$

bu yerda σ_{SHE} - spin Hall o‘tkazuvchanligi, σ_{xx} - elektr o‘tkazuvchanligi. Og‘ir metallarda $\sigma_{SHE} \sim 10^2 \div 10^3$ $(\hbar/e)\Omega^{-1}sm^{-1}$, $\theta_{SHE} \sim 0.1 \div 0.4$ [2]. SOT tizimining asosiy cheklovi shundaki, ξ_{SOT} faqat HM qatlamining SOC xossasiga bog‘liq [4]. Orbital Hall effektida (OHE) esa tashqi elektr maydoni E ta’sirida yengil metallarda ko‘ndalang orbital tok (J_L) hosil bo‘ladi [6,7]:

$$\xi_{OT} = \eta_{L\text{-}S} \cdot \theta_{OHE} = (2e/\hbar)\cdot\eta_{L\text{-}S}\cdot\sigma_{OHE}/\sigma_{xx}$$

bu yerda $\eta_{L\text{-}S}$ - FM qatlamning orbitaldan spinga konversiya koeffitsiyenti, σ_{OHE} - orbital Hall o‘tkazuvchanligi. SOT dan farqli o‘laroq, ξ_{OT} ham OHM qatlamining θ_{OHE} ga, ham FM qatlamning $\eta_{L\text{-}S}$ ga bog‘liq, bu qurilmani ikkala qatlam orqali optimallashtirishga imkon beradi [8].

2.2. Yengil metall orbital tok manbalari va ηL-S: FM qatlamning roli

3d (Ti, Cr, Mn, Cu) va 4d (Zr, Nb, Mo) metallari katta σ_{OHE} qiymatlariga ega: $\sigma_{OHE} \sim 10^3$ $(\hbar/e)\Omega^{-1}sm^{-1}$ bo‘lib, bu og‘ir metallar σ_{SHE} dan kam emas yoki undan ham katta [5,6]. Ayniqsa Zr da $\sigma_{OHE} \approx 5300$ $(\hbar/e)\Omega^{-1}sm^{-1}$ - katta orbital tok manbayi sifatida ajralib turadi [8]. Orbital Rashba-Edel'shtein effekti (OREE) nosimetrik tizimlarda orbitaldan spinga konversiyaga hissa qo‘shadi [4]. Ti va Cr kabi metallarda orbital to‘planish MOKE orqali

bevosita kuzatilgan [4,12]. Yang va boshqalarning ishlari ko‘rsatdiki, bir xil OHM (Zr) bilan ikkita turli FM materiallar $[Co/Pt]_3$ va CoFeB/Gd/CoFeB birgalikdagi ξ_{OT} qiymatlari mos ravishda 0.78 va 0.04 [8] ga teng bo‘lib, keskin farq qiladi. Bu farq FM qatlamning $\eta_{L\text{-}S}$ qiymatidagi katta tafovutdan kelib chiqadi. $[Co/Pt]_3$ strukturasida Pt atomlarining d-orbital gibridizatsiyasi kuchli spin-orbit korrelyatsiya markazlarini hosil qiladi ($\eta_{L\text{-}S} \approx 1.161$), CoFeB da esa Fe dominantligi tufayli bu samaradorlik ancha past ($\eta_{L\text{-}S} \approx 0.171$) natijalarni berdi [8]. Jiangong Li va boshqalar (2007) ball milling bilan hosil qilingan Co/Al_2O_3 nanokompozit tozalamalarida Co donasi kichrayishi bilan to‘yinish magnitlanishi kamayib, koersitivlikning 380 Oe gacha ortishini ko‘rsatdi [16]. Superparamagnit kritik o‘lcham Co uchun 7 nm ekanligi tasdiqlandi [16]. Bu natijalar bizning $Al_2O_3/Co/Al$ tizimidagi Co qatlam qalinligi va morfologiyasi uchun muhim asos bo‘ladi.

Magnetron changlatish – sanoatda keng qo‘llaniladigan, katta maydonda bir xil qoplama beruvchi, yaxshi interfeys hosil qiluvchi usul [13]. Yang va boshqalar $Zr/[Co/Pt]_3$ namunalarini magnetron changlatish orqali hosil qilib, sirt o‘rtacha dag‘allik $R_a \approx 0.139$ nm ekanligini AFM bilan tasdiqladi [8]. Engelhart va boshqalar (2011) dual magnetron changlatish bilan 550°C da Al_2O_3 plyonka hosil qildi va tuzilma “pseudo γ-Al_2O_3” deb nomlandi [18]. (400) va (440) refleksiyalari kuchli, ammo (111), (220), (311) ko‘rinmaydi, Al va O sublattice'lari tartibsiz. Plyonkada ~5 at.% Ar mavjud bo‘lib, qattiqlik 2348 HV ga erishdi [18]. Musil va boshqalar (2010) reaktiv magnetron changlatish bilan hosil qilingan γ-Al_2O_3 plyonkalar 1000°C gacha termal barqaror ekanligini ko‘rsatdi [19]. Bu Al_2O_3 to‘siq qatlami sifatida 600°C annealingda ham tuzilmasini saqlab qoladi. DC rejimlari metall qatlamlar (Co, Ti, Cr, Al) uchun tez va samarali. Impulsli RF rejimi zaryadlanish to‘planishini oldini oladi, plyonkaning atom silliqligini oshiradi, interfeysdagi diffuziya va aralashishni kamaytiradi [13]. Thornton (1974) strukturaviy zona diagrammasi ko‘rsatdiki, bosim va taglik haroratining o‘zgarishi plyonka morfologiyasini keskin o‘zgartiradi [13].

Natijalar va muhokama.

3. Eksperimental dalillar: kobalt yupqa plyonkalarida sirt oksidlanishi

3.1. Tabiiy oksidlanish jarayoni va hosil bo‘ladigan fazalar

Kobalt (Co) ferromagnet bo‘lib, Kyuri harorati $T_c = 1388$ K, to‘yinish magnitlanishi $M_s \approx 1440$ kA/m, solishtirma qarshilik $\rho \approx 6\times10^{-6}$ Ω·sm [9]. Biroq, 20 nm dan past qalinlikdagi ultra yupqa Co plyonkalar atmosfera sharoitida 1–2 nm qalinlikdagi CoO va Co_3O_4 oksid qatlamini tez hosil qiladi [9–11]. Oksidlanish kinetikasi Cabrera-Mott mexanizmi bo‘yicha sodir bo‘ladi: dastlabki bir necha soat ichida oksidlanish tez, keyin diffuziya tomonidan cheklanadi.

CoO – antiferromagnitik izolyator (Neel harorati $T_N = 291$ K), Co_3O_4 esa p-tipli yarimo‘tkazgich sifatida xarakterlanadi [10]. Heikkinen va boshqalar (2021) in-situ XRD va TPR tahlillari asosida kobalt oksidlarining ikki bosqichli kamaytirish jarayonini tasdiqladi [9]:

$Co_3O_4 \rightarrow CoO$ (250–300 °C da) → Co (380–400 °C da, vakuumda)

Demak, to‘liq kimyoviy kamaytirish uchun 400 °C harorat kerak. 220–250 °C da faqat qisman passivatsiya sodir bo‘ladi, CoO qatlami saqlanib qoladi [9].

3.2. Oksid qatlamlarining transport va magnit xossalarga ta’siri

Bali va boshqalar (2025) kobalt oksid fazalarining elektr xossalari metallik Co dan keskin farq qilishini ko‘rsatdi [10]. CoO va Co_3O_4 ning mavjudligi magnitlanish rezistansini (MR) kamaytiradi, anomal Hall effektini (AHE) buzadi va orbital-to-spin konversiya koeffitsiyenti $\eta_{L\text{-}S}$ ni kamaytiradi [10,11]. Haniam va boshqalar (2014) qalinligi 20 nm dan past bo‘lgan Co plyonkalarida metall Co va CoO fazalarining birga mavjudligi ayniqsa kuchli ta’sir ko‘rsatishini ta’kidladi [11]. Jiangong Li va boshqalar (2007) Co/Al_2O_3 nanokompozit tizimida Co granulalar o‘lchamining kamayishi bilan to‘yinish magnitlanishining pasayishi $Co–Al_2O_3$ interfeys ta’siri va superparamagnit holat bilan bog‘liq ekanligini ko‘rsatdi [16]. Tanaka va boshqalar (2018) FeRh/Pt bilayerida ST-FMR o‘lchovlari orqali spin Hall samaradorligi $\xi_{SH} = 24 \pm 3\%$ ni aniqladi. Bu Pt uchun odatiy qiymatdan ancha yuqori [20]. Xuddi shu ST-FMR metodologiyasi Ti/Co/Al va Cr/Co/Al tizimlarimizda orbital Hall samaradorligini ξ_{OH} aniqlash uchun qo‘llaniladi.

3.3. Oksidlanishni kamaytirish strategiyalari

Adabiyotlar asosida sirt oksidlanishini kamaytirish uchun quyidagi usullar taklif etilgan [9–11,14]:

(1) Vakuumda termal tavlash (250–400 °C) - oksid faollashuvi kamayganda samarali, lekin to‘liq kamaytirish uchun yetarli emas [9];

(2) Ar^+ ionli o‘yish (0.5–1 keV) - sirt oksidini mexanik olib tashlash va darhol Al nanoplyonkasi bilan qoplash imkoni [11];

(3) In-situ Al qoplama qatlami – vakuumdan chiqarmasdan Al qoplash eng samarali strategiya. Al atmosfera kislorodi bilan o‘z-o‘zini chegaralovchi Al_2O_3 qatlamini hosil qilib, Co sirtini himoya qiladi [11,14].

Monuri va boshqalar (2004) $Co/Al_2O_3/Co$ qo‘shilmasida Al_2O_3 to‘siq qatlamining Co ni oksidlanishdan to‘liq himoya qilishini va Co/Al_2O_3 hamda Al_2O_3/Co interfeyslari magnitlanishga deyarli ta’sir qilmasligini ko‘rsatdi [14]. Al-qoplangan Co plyonkalar magnit-transport o‘lchovlarining takrorlanishini oshiradi va atrof-muhit degradatsiyasiga chidamliligini saqlab qoladi.

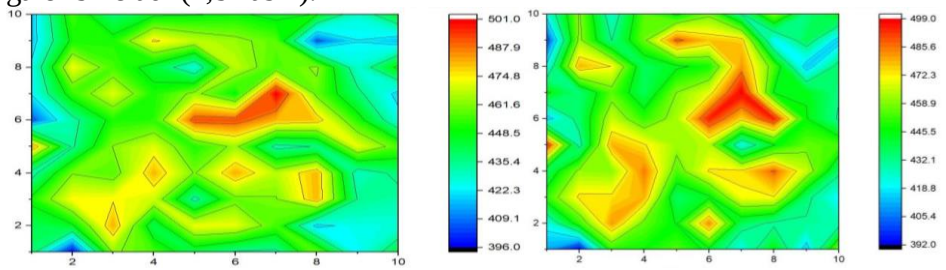
4. Simtra monte-karlo simulyatsiyasi

4.1. Simulyatsiya metodologiyasi

SIMTRA – gaz fazasi orqali purkalgan atomlarning tashilishini simulyatsiya qiluvchi ikkilik to‘qnashuv Monte-Karlo dasturi [21]. Nishon sifatida Cobalt (Co) elementi, argon (Ar) esa inert gaz sifatida ishlatildi. Simulyatsiya tizimi quyidagilarni o‘z ichiga oladi: tushayotgan bug‘ oqimini yupqa plyonka yuzasiga aniq tashish; o‘sayotgan plyonka yuzasiga yaqin sirtlararo diffuziya effektlari; o‘sayotgan plyonkada polikristalli strukturaning shakllanishi [21, 23]. Plyonka o‘sishi Volmer-Veber rejimiga amal qiladi. Yadroli orollar to‘qnashuvgacha o‘sadi, natijada uzluksiz polikristalli plyonka hosil bo‘ladi. Bu Thornton (1974) T zona xatti-harakatiga past haroratli II zona xususiyatlariga mos keladi [13]. Olinayotgan Co plyonkaning sirt morfologiyasining vakuum bosimi, taglik harorati, Co nishonning Al taglikga tushish burchagi va undan masofa kabi parametrlarga bog‘liqligi o‘rganildi. Simulyatsiya va eksperiment natijalarni taqqoslash taklif qilingan modelning haqiqiyligini isbotladi.

4.2. Taglik haroratining ta’siri

SIMTRA simulyatsiyasi natijalari Co atomlarining sirt bo‘ylab taqsimlanishiga taglik harorati sezilarli ta’sir ko‘rsatishini namoyon etdi. 5×10^{-3} Pa bosim va 90° burchak ostida o‘tkazilgan hisoblashlarda 400 K va 600 K haroratlarda olingan taqsimotlar o‘zaro solishtirildi. 400 K haroratda hosil bo‘lgan taqsimot ancha notekis bo‘lib, sirt bo‘ylab bir nechta lokal maksimumlar kuzatildi. Bu atomlarning sirt bo‘ylab harakatchanligi past ekanligi bilan izohlanadi, sirtga tushgan atomlar deyarli o‘z joyida qolib ketadi va qayta taqsimlanish jarayoni sust kechadi (1,a-rasm). 600 K haroratda esa taqsimot sezilarli darajada tekisroq bo‘lib, yuqori zichlikka ega hududlar kengroq maydonga yoyilganligi kuzatildi. Ushbu holat yuqori haroratda atomlarning sirt bo‘ylab diffuziyasi kuchayishi bilan tushuntiriladi [13]. Bundan tashqari, yuqori haroratda qayta uchib ketish (re-emission) va sochilish (scattering) jarayonlari ham kuchayishi mumkin, bu esa maksimal cho‘qqi qiymatlarining biroz pasayishiga olib keladi (1,b-rasm).

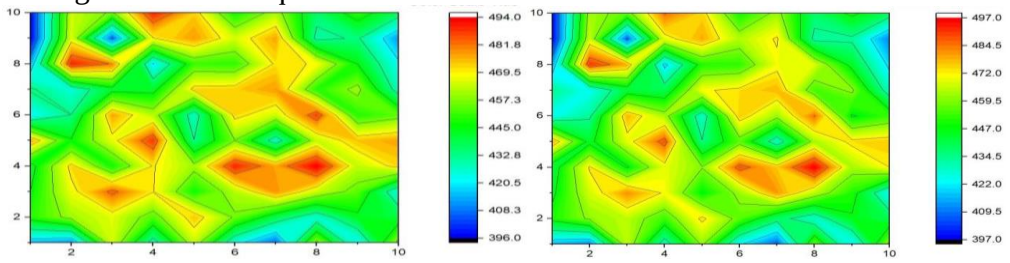


1-rasm: a) 400 K, bosim 5×10^{-3} Pa; b) 600 K, bosim 5×10^{-3} Pa - SIMTRA simulyatsiyasi

4.3. Gaz bosimining ta’siri

5×10^{-5} Pa past bosim sharoitida hosil bo‘lgan taqsimotlar nisbatan aniqroq va yo‘naltirilgan xarakterga ega. Bu gaz fazasida zarrachalar to‘qnashuvining kamayishi bilan izohlanadi. Purkalgan atomlar taglikga deyarli to‘g‘ri trayektoriya bo‘ylab yetib boradi, natijada sirt bo‘ylab taqsimot ko‘proq anisotrop bo‘ladi [13]. 400 K haroratda, past bosimda ham taqsimot notekis bo‘lib, lokal maksimumlar saqlanib qoladi (2,a-rasm). 600 K haroratda

esa taqsimot yanada tekisroq bo‘lib, yuqori zichlikka ega hududlar kengayganligi kuzatiladi (2,b-rasm). Past bosim sharoitida zarrachalarning erkin yo‘l uzunligi oshib, yo‘naltirilgan cho‘kishni ta’minlaydi, yuqori harorat esa sirt bo‘ylab diffuziya orqali plyonka bir jinsliligini yaxshilaydi. Shu sababli, yupqa plyonkalarning optimal xossalarini olish uchun bosim va haroratni birgalikda nazorat qilish muhim hisoblanadi.

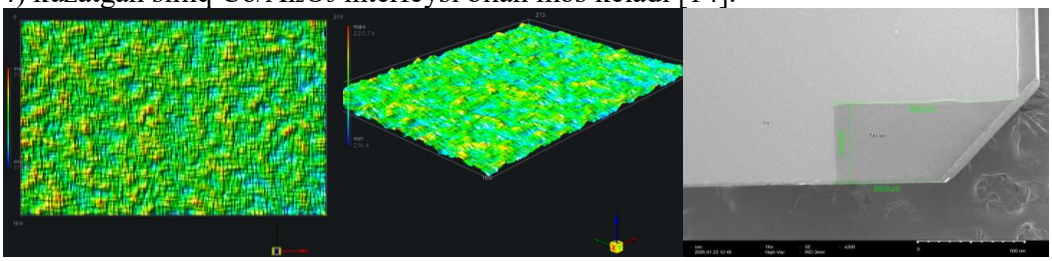


2-rasm: a) 400 K, bosim 5×10^{-5} Pa; b) 600 K, bosim 5×10^{-5} Pa - SIMTRA simulyatsiyasi

Natijalar shuni ko‘rsatadiki, Al taglikga Co nanoplyonkasi hosil qilishda optimal sharoit past bosim ($\leq 5\times10^{-5}$ Pa) va o‘rtacha-yuqori harorat (500–600 K) olib borilganda sifatli namunalar olish mumkinligini ko‘rsatadi. Bu natijalar Ti/Co/Al va Cr/Co/Al geterostrukturalarini magnetron changlatish usuli bilan hosil qilishda changlatish parametrlarini optimallashtirishga to‘g‘ridan to‘g‘ri qo‘llaniladi.

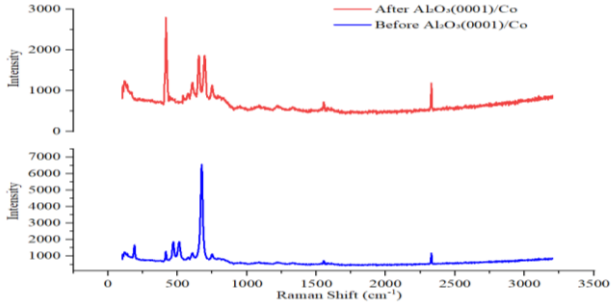
5. Al_2o_3(0001)/co nanoplyonkasidagi dastlabki eksperimental natijalar

Ion-nur changlatish (UHV IBS) usulida Al_2O_3(0001) taglikka 18 nm qalinlikdagi Co nanoplyonkasi hosil qilindi. Namuna sirt morfologiyasi skanerlovchi elektron mikroskop (SEM) yordamida o‘rganildi (3-rasm). SEM tasviri donador (granular) strukturani ko‘rsatib, Co plyonkasining uzluksizligini va taglik bilan yaxshi adgeziyasini tasdiqladi. Kesim tasviri Co qatlamining Al_2O_3(0001) bilan aniq ajralgan, silliq interfeys hosil qilishini ko‘rsatdi. Bu orbital-to-spin konversiya jarayonlari uchun muhim shart. Bu natijalar Maunoury va boshqalar (2004) kuzatgan silliq Co/Al_2O_3 interfeysi bilan mos keladi [14].



3-rasm. Al_2O_3(0001)/Co nanoplyonkasining 2D va 3D sirt morfologiyasi hamda SEM tasviri

Kobalt yupqa plyonkasining sirt oksidlanish darajasini aniqlash maqsadida in-situ ion-nurli tozalash jarayonidan oldin va keyin Raman spektroskopiyasi tahlili o‘tkazildi (4-rasm). Tozalashdan oldingi spektrda 675 cm^{-1} (A1g), 514 cm^{-1} (F2g) va 469 cm^{-1} (Eg) to‘lqin sonlarida namoyon bo‘lgan xarakterli modlar Co_3O_4 shpinel fazasining mavjudligini tasdiqlaydi. Shuningdek, 191 cm^{-1} to‘lqin sonida ham Co_3O_4 ga tegishli cho‘qqi kuzatiladi. 417 cm^{-1} dagi pik Al_2O_3 (sapfir) tagligiga xos bo‘lib, 18 nm qalinlikdagi plyonkaning lazer nuri uchun shaffof ekanligini bildiradi. In-situ tozalashdan so‘ng oksid fazasiga xos cho‘qqilarning keskin pasayishi tabiiy oksid qatlamining bartaraf etilganligini ko‘rsatadi. Bu natija Heikkinen va boshqalar (2021) ko‘rsatgan Co_3O_4 → CoO → Co qaytarish yo‘lini tasdiqlaydi [9].



4-rasm. Al_2O_3(0001)/Co nanoplyonkasining Raman spektri

Elektr va magnit-transport xossalari HMS-5000 Hall o‘lchash tizimi (Ecopia) yordamida van der Pauw konfiguratsiyasida xona haroratida (298 K) o‘rganildi. Plyonka qarshiligi R_s = 19–33 Ω/□, solishtirma qarshilik $\rho = (3.4–6.0)\times10^{-5}$ Ω·smga teng ekanligi aniqlandi. Bu qiymatlar 20 nm dan past Co plyonkalar uchun adabiyotda keltirilgan ma’lumotlarga to‘liq mos keladi [9,10]. Monuri va boshqalar (2004) ko‘rsatganidek, 40 Å (4 nm) dan past Co qatlamlari paramagnit xususiyat ko‘rsatadi [14]. Bizning 18 nm qalinlikdagi namuna esa to‘liq ferromagnit hududda joylashgan. Magnit-qapshilik (MR) qiymatlari 2.3–8.9 Ω oralig‘ida bo‘lib, spin-bog‘liq sochilishning mavjudligini ko‘rsatadi.

Dastlabki natijalar Al_2O_3(0001)/Co nanoplyonkasining sifatli va uzluksiz strukturasini tasdiqladi. Co_3O_4 ning Raman tahlilida aniqlanganligi sirt himoyasi in-situ Al qoplama zarurligini bevosita ko‘rsatadi. Elektr o‘tkazuvchanlik metallik ekanligini tasdiqlaydi va keyingi orbital torque o‘lchovlari uchun asos bo‘la oladi.

Orbitronikada erishilgan yutuqlarga qaramay, muhim muammolar ochiq qolmoqda:

– magnetron changlatish orqali hosil qilingan polikristallik plyonkalarda orbital tok samaradorligi yetarlicha o‘rganilmagan [4,8];

– interfeys oksidlanishining orbital transportga ta’siri tizimli ravishda tekshirilmagan;

– Al qoplama qatlamining orbital tok uzatilishiga ta’siri (tunnel to‘siq yoki o‘tkazuvchan interfeys sifatida) ko‘rsatilmagan;

– DC va impulsli RF changlatish rejimlari interfeys silliqligiga ta’sirining orbital samaradorlikka aloqasi tadqiq qilinmagan.

Bu bo‘shliqlar Ti/Co/Al va Cr/Co/Al nanogeterostrukturalarida tizimli tadqiqot o‘tkazishni zarur qiladi. Ushbu tadqiqotda: (1) birinchi marta magnetron changlatish bilan hosil qilingan polikristallik Ti/Co/Al va Cr/Co/Al tizimlarida orbital Hall samaradorligi ξ_{OH} tizimli o‘lchanadi; (2) in-situ Al qoplama strategiyasining orbital samaradorlikka miqdoriy ta’siri aniqlanadi; (3) DC va RF changlatish rejimlari o‘rtasidagi farqning orbital transportga ta’siri ochib beriladi; (4) Tanaka va boshqalar (2018) [20] ST-FMR metodologiyasi orbitalromnik o‘lchovlarga moslashtiriladi.

Xulosa va takliflar. Mazkur sharh maqolada orbitronikaning nazariy asoslari, yengil metallar asosidagi OT tizimlarida erishilgan eksperimental yutuqlar, Co yupqa plyonkalarida sirt oksidlanishining fizikaviy ta’siri, SIMTRA Monte-Karlo simulyatsiyasi natijalari va magnetron changlatish usulining orbitronik qurilmalar uchun mosligi tizimli ravishda ko‘rib chiqildi. Orbital moment samaradorligi $\xi_{OT} = \eta_{L\text{-}S}\cdot\theta_{OHE}$ formula bilan belgilanib, eng yuqori qiymat Zr/[Co/Pt]$_3$ uchun $\xi_{OT} \approx 0.78$ ga yetganligini ko‘rsatadi [8]. Ti, Cr, Zr kabi yengil metallar $\sigma_{OHE} \sim 10^3$ $(\hbar/e)\Omega^{-1}sm^{-1}$ qiymatiga ega bo‘lib, og‘ir metallarning σ_{SHE} bilan raqobatlasha oladi va CMOS bilan mos [5,6]. Co yupqa plyonkalarida CoO va Co_3O_4 fazalari magnit va transport xossalarini sezilarli buzadi, to‘liq oksid kamaytirish uchun 400 °C kerak [9], in-situ Al qoplama amaliy va samarali sirt himoya strategiyasi [11,14].

SIMTRA simulyatsiyasi ko‘rsatdiki, past bosim (5×10^{-5} Pa) va o‘rtacha harorat (500–600 K) Co plyonkasining Al taglikda eng bir jinsli taqsimotini beradi. Taglik haroratini oshirish atomlar diffuziyasini kuchaytirib, plyonka bir jinsliligini yaxshilaydi [13].

Al_2O_3(0001)/Co nanoplyonkasida dastlabki SEM, Raman va HMS-5000 natijalari sifatli metallik plyonka hosil bo‘lganini, biroq sirt Co_3O_4 mavjudligini ko‘rsatdi. Bu in-situ himoya zarurligini tasdiqlaydi. Magnetron changlatish usuli in-situ tozalash va qoplash imkoniyati bilan orbitronik nanogeterostrukturalar uchun eng mos texnologik platforma hisoblanadi. Ti/Co/Al va Cr/Co/Al tizimlarini tizimli o‘rganish orqali polikristallik OT tizimlarida orbital samaradorlikni oshirish yo‘llari aniqlanishi va sanoatga mos arzon orbitronik qurilmalar yaratilishi mumkin.

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MONOETANOLAMIN BILAN MODIFIKATSIYALANGAN POLIVINILXLORID ASOSIDAGI SORBENTNING SINTEZI, IQ-SPEKTROSKOPIK VA TERMIK TAHLILI

Bozorov Lutfulla Ubaydullaevich
Termiz davlat pedagogika instituti
texnika fanlari doktori, dotsent
lutfullob15@gmail.com
Rajabova Dilrabo Shavkat qizi
Termiz davlat pedagogika instituti doktoranti
Ruziyev Umid Ural o‘g‘li
Termiz davlat universiteti doktoranti
ORCID 0009-0002-3747-7198
UDK 541.49;546.185.56.57

Annotatsiya. Zamonaviy ilm-fan o‘ziga xos tarixiy davrda rivojlanib, faoliyat yuritmoqda. U insoniyatning hayotiy strategiyasini tanlash hamda samarali rivojlanishning yangi yo‘llarini izlash kabi muhim muammolarni hal etishda muhim o‘rin tutadi. Mamlakatimizda kimyo sanoatini jadal rivojlantirish maqsadida zamonaviy talablarga javob bera oladigan yangi turdagi sorbentlarni ishlab chiqarishga alohida e’tibor qaratilmoqda. Bu yo‘nalishda amalga oshirilgan dasturiy chora-tadbirlar asosida muayyan natijalarga, ayniqsa, yangicha yondashuvga asoslangan, metall ionlariga yuqori selektiv sorbentlar olishning ilmiy asoslarini yaratishga erishildi va ichki bozorni import o‘rnini bosuvchi mahalliy sorbentlar bilan ta’minlash sohasida keng ko‘lamli tadbirlar amalga oshirilmoqda. O‘zbekiston Respublikasini yanada rivojlantirish bo‘yicha Harakatlar strategiyasida “Ichki va tashqi bozorlarda milliy tovarlarning raqobatbardoshligini ta’minlaydigan mahsulot va texnologiyalarning tubdan yangi turlarini ishlab chiqarishni o‘zlashtirish”ga yo‘naltirilgan muhim vazifalar belgilab berilgan. Bu borada, jumladan, mahalliy xomashyolar asosida sorbsion materiallarni ishlab chiqarish uchun iqtisodiy jihatdan samarali va ekologik toza texnologiyalarni yaratish, yangi yuqori samarali sorbentlar sintez qilish va ulardan metall ionlarini konsentrlash hamda ajratib olish uchun foydalanish muhim ahamiyat kasb etadi.

Kalit so‘zlar: polivinilxlorid, monoetanolamin, sorbent, IQ-spektr, termik tahlil, sorbsiya, modifikatsiya.

SYNTHESIS, IR SPECTROSCOPIC AND THERMAL ANALYSIS OF A SORBENT BASED ON POLYVINYL CHLORIDE MODIFIED WITH MONOETHANOLAMINE

Abstract. Modern science develops and operates in a specific historical period, its participation is necessary in solving the problem of choosing a vital strategy for humanity, searching for new ways of effective development. In order to rapidly develop the chemical industry in our country, special attention is paid to the production of new types of sorbents that can meet modern requirements. On the basis of the program measures implemented in this direction, certain results have been achieved, in particular, the creation of a scientific basis for obtaining highly selective sorbents for metal ions based on a new approach, and large-scale activities are being carried out in the field of providing the domestic market with local sorbents that can replace imports. The Strategy of Actions for the Further Development of the Republic of Uzbekistan sets out important tasks aimed at “Mastering the production of fundamentally new types of products and technologies that ensure the competitiveness of national goods in the domestic and foreign markets”. In this regard, it is important to create cost-effective and environmentally friendly technologies for the production of sorption materials based on local raw materials, synthesize new highly efficient sorbents and use them to concentrate and separate metal ions.

Keywords: Polyvinyl chloride, modification, sorption, kinetics, 3d metal ions, thermal analysis

Kirish. Sanoat tarmoqlarining jadal rivojlanishi bilan birga ekologik muammolar ham kuchaymoqda. Xususan, og‘ir metall ionlari, bo‘yoqlar va boshqa toksik birikmalar bilan ifloslangan oqava suvlarni tozalash masalasi dolzarb muammolardan biridir. Bunday muammolarni hal etishda yuqori sorbsion qobiliyatga, selektivlikka ega, termik hamda kimyoviy jihatdan barqaror ion almashinuvchi materiallar muhim ahamiyat kasb etadi. Shu bois, ilmiy tadqiqotlarda ion almashinuvchi reagentlar, membrana texnologiyalari va kompleks hosil qiluvchi sorbentlarni sintez qilishga alohida e’tibor qaratilmoqda. Ayniqsa, ikkilamchi polimerlar asosida yangi turdagi sorbentlar olish orqali nafaqat texnologik samaradorlikka, balki ekologik xavfsizlikka ham erishish mumkin.

Adabiyotlar tahlili va metodologiyasi. Polimer materiallarni modifikatsiyalash asosida yangi funksional materiallar olish bugungi kunda kimyo va materialshunoslikning dolzarb

yo‘nalishlaridan biri hisoblanadi. Ayniqsa, polivinilxlorid asosidagi sorbentlar yuqori kimyoviy barqarorligi, mexanik mustahkamligi va turli ionlarni selektiv yutish qobiliyati sababli keng tadqiq qilinmoqda. Polivinilxlorid asosidagi ion almashinuvchi materiallar olish bo‘yicha bir qator ilmiy tadqiqotlar olib borilgan.

Yusupova N.M., Gafurova D.A. va Muxamediyev M.G. tomonidan polivinilxlorid asosida yangi anionitlar sintez qilinib, ularning fizik-kimyoviy xossalari o‘rganilgan. Tadqiqot natijalariga ko‘ra, polivinilxlorid asosida olingan ion almashinuvchi materiallar yuqori sorbsion xususiyatlarga ega bo‘lib, metall ionlarini ajratib olish jarayonlarida samarali qo‘llanishi mumkinligi aniqlangan [1].

3d-metall ionlarining sorbsiya jarayonlarini o‘rganishda poliamfolit tipidagi sorbentlarning termodinamik va kinetik xususiyatlari ham muhim ahamiyatga ega. Koplova V.D., Kargman V.B., Valdman A.I. va Valdman D.I. tomonidan olib borilgan tadqiqotlarda iminodiuksusli poliamfolitlar yordamida 3d-metall ionlarining sorbsiya jarayonlari o‘rganilgan. Tadqiqotlar sorbsiya jarayonining entalpiyasi va kinetik xususiyatlari sorbentning kimyoviy tuzilishiga bevosita bog‘liq ekanligini ko‘rsatgan [2].

Polivinilxloridni turli reaktiv moddalar bilan modifikatsiyalash orqali yangi sorbentlar olish bo‘yicha ham qator ilmiy ishlar amalga oshirilgan. Yusupova N.M., Gafurova D.A. va Muxamediyev M.G. tomonidan polivinilxlorid geksametilendiamin bilan kimyoviy modifikatsiyalanib yangi funksional materiallar sintez qilingan. Ushbu modifikatsiya jarayoni natijasida polimer tarkibiga azotli funksional guruhlar kiritilib, sorbentning metall ionlariga nisbatan selektivligi oshirilgan [3].

Polivinilxlorid asosidagi sorbentlarda metall ionlarining sorbsiya jarayonlarini o‘rganish ham muhim ilmiy yo‘nalish hisoblanadi. Yusupova N.M., Rustamov M.K., Gafurova D.A. va Berdiyev S.D. tomonidan polivinilxlorid asosidagi sorbentlarda molibden ionlarining yutilish jarayonining kinetik va termodinamik xususiyatlari tadqiq qilingan. Tadqiqot natijalariga ko‘ra, sorbsiya jarayonining tezligi va samaradorligi sorbentning kimyoviy tuzilishi hamda reaksion markazlarning tabiatiga bog‘liq ekanligi aniqlangan [4].

Polivinilxloridni modifikatsiyalash orqali yangi funksional materiallar olish texnologiyasi boshqa tadqiqotchilar tomonidan ham o‘rganilgan. Karimov M.M., Rustamov M.K., Muxamedov N.R., Kayumov M.B. va Mirzaaxmedov Sh.Ya. tomonidan polivinilxloridni modifikatsiyalashning turli usullari ishlab chiqilgan va ularning fizik-kimyoviy xossalari o‘rganilgan. Mualliflar tomonidan modifikatsiyalangan polimer materiallarning korroziyaga chidamliligi hamda sorbsion xususiyatlari sezilarli darajada yaxshilanishi aniqlangan [5].

Yusurova N.M., Gafurova D.A. va Mukhamediyev M.G. tomonidan polivinilxloridning ammiak bilan geterogen sharoitda o‘zaro ta’siri o‘rganilgan. Tadqiqot natijalari polimer zanjirida yangi funksional guruhlarning hosil bo‘lishi sorbentning kimyoviy faol markazlarini ko‘paytirishini ko‘rsatgan [6].

Shuningdek, Yusupova N.M., Rustamov M.K. va Gafurova D.A. tomonidan polivinilxlorid asosida ammiak bilan modifikatsiyalangan sorbentda xrom ionlarining sorbsiya kinetikasi o‘rganilgan. Tadqiqot natijalari sorbentning metall ionlarini yutish qobiliyati yuqori ekanligini va uning amaliy ahamiyatga ega ekanligini ko‘rsatgan [7].

Bekchanov D.J. tomonidan polivinilxlorid asosida azot va fosfor tutuvchi ionitlar sintez qilinib, ularning fizik-kimyoviy xossalari tadqiq qilingan. Tadqiqotlar natijasida olingan ionitlar yuqori ion almashinish sig‘imiga ega ekanligi aniqlangan [8-9].

Polimer sorbentlar sintezi va ularning kompleks hosil qiluvchi xususiyatlari bo‘yicha Restov A.V., Slerukhin R.A., Yatluk Y.G., Sharushin V.N. va Shurakhin O.N. tomonidan ham tadqiqotlar olib borilgan. Mualliflar SNH reaksiyasi yordamida xelat hosil qiluvchi polimer sorbentlar sintez qilgan va ularning metall ionlariga nisbatan yuqori selektivligi aniqlangan [10-11].

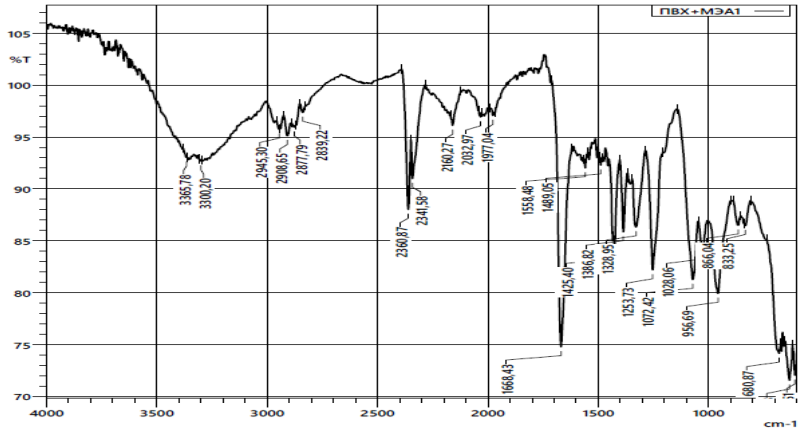
Shunday qilib, olib borilgan tadqiqotlar polivinilxlorid asosida modifikatsiyalangan polimer sorbentlar metall ionlarini ajratish va konsentrlash jarayonlarida yuqori samaradorlikka ega ekanligini ko‘rsatadi. Shu sababli polivinilxloridni turli amin birikmalari bilan modifikatsiyalash orqali yangi kompleks hosil qiluvchi sorbentlar sintez qilish dolzarb

ilmiy masala hisoblanadi.Modifikatsiyalash asosida olingan sorbentlar differensial-termik tahlil asosida sorbentlarning termik barqarorligi o‘rganildi. Olingan sorbentlar tarkibini IQ- va UB-spektroskopik metodlar yordamida, skanerlovchi elektron mikroskopiya (SEM), differensial termik tahlil, element tahlili kabi zamonaviy ekspermental usullarda o‘rganildi. Shuningdek, sintez qilingan birikmalar reaksion qobiliyatini kvant-kimyoviy tavsiflandi.

Polivinilxloridni dietilamin, monoetanolamin va difenilaminlar bilan modifikatsiyalab sorbentlar olindi hamda sorbentlarni sentiz qilib olishning eng maqbul sharoitlari tanlandi, olingan sorbentlarning tarkibi, tuzilishi va fizik-kimyoviy xossalari, sorbentlarning kimyoviy barqarorligi va dinamik sharoitlarda qayta ishlatish hamda qo’llash imkoniyatlari zamonaviy analiz usullari yordamida aniqlangan.

Yuqori mustahkamlik va afzal fizik-kimyoviy xususiyatlarga ega bo‘lgan yangi polimer materiallarni olish bo‘yicha ilmiy tadqiqotlarning rivojlanishi shuni ko‘rsatadiki, sintezning an’anaviy usullari asosan qo‘shbog‘ tutgan va xususiyatlari ma’lum darajadan ancha yuqori bo‘lgan polimerlar va sopolimerlarni sintez qilish ehtimoli sezilarli darajada oshgan . Hozirgi vaqtda polimer materiallarni olishning yana bir yo‘nalishi - polimerlarni modifikatsiyalash jadal rivojlanmoqda.

Natijalar. Sintez qilingan sorbentlarning koordinatsiya markazlari va koordinatsiyalanish yo‘llarini aniqlash maqsadida sintez qilingan birikmalarni IQ-spektroskopik usulda tahlili olib borildi. Tadqiqot davomida sintez qilingan kompleks hossaga ega bo‘lgan sorbbentlarning tuzilishini identifikasiya qilish uchun IQ-spektrlari olindi. Polivinilxlorid va monoetanolamin asosida olingan RD-1 kompleks hosil qiluvchi sorbentning IQ-spektri 1-rasmda keltirildi.



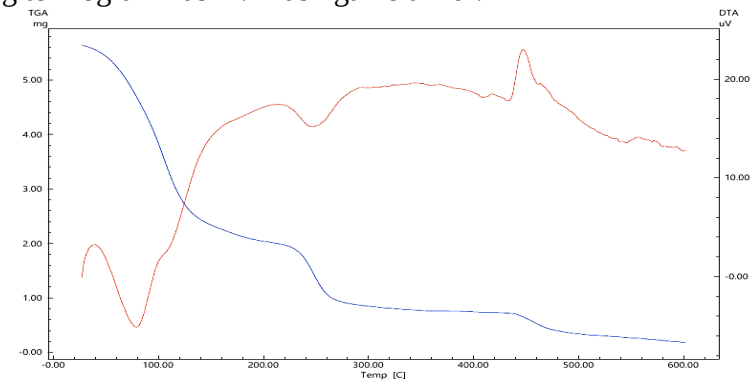
1-rasm. Polivinilxloridni monoetanolamin bilan modifikatsiyalab sintez qilingan sorbentning IQ-spektri

Olingan kompleks hosil qiluvchi sorbentning IQ-spektrida imino va gidroksil guruhining simmetrik valent tebranishi ν_s(NH)+ν_s(OH) 3365 sm^{-1} da, imino guruhining asimmetrik valent tebranishi ν_{as}(NH) 3300 sm^{-1} da, metilen guruhi (-CH_2) ning asimmetrik valent tebranishi ν_{as}(CH_2) 2945 sm^{-1} da, H bog‘li gidroksil guruhining asimmetrik valent tebranishi ν_{as}(OH) 2900 sm^{-1} da, metilen va sianid (CH_2)+(CN) guruhlarining simmetrik va asimmetrik valent tebranishlari ν_s(CH_2)+(CN) 1668 sm^{-1} va ν_{as}(CH_2)+(CN) 1568 sm^{-1} da C-OH bog‘ning simertik va asimmetrik valent tebranishlari ν_s(C-OH) 1250 sm^{-1}, N-CH_2 bog‘ining tebranishi δ_s(N-CH_2) 1425 sm^{-1} da, C-O bogining simmetrik valent tebranishlari ν_s(C-O) 1328 sm^{-1} da va ν_{as}(C-OH) 956 sm^{-1} sohalarda aniqlandi.

Olingan natijalardan ko‘rinib turibdiki, polivinilxlorid va monoetanolamin asosida olingan RD-1 sorbentning IQ spektr natijalarini polivinilxloridning IQ-spektri bilan solishtirilganda ham spektrlarda farq qiluvchi tebranish chastotalari mavjudligi yangi sorbent olinganligidan dalolat beradi.

Polivinilxlorid asosida sintez qilingan sorbentlarning differensial termik tahlili. Sorbentlarning differensial termik barqarorligini aniqlash maqsadida tajribada olingan namunalarni qizdirish jarayonida birikmalar tuzilishining destruksiyasi natijasida massa o‘zgarishi bilan kuzatiladigan turli ekzotermik va endotermik issiqlik effektlari differensial termik tahlil yordamida o‘rganildi. Bir vaqtning o‘zida namunaning massasi, olingan

sorbentlarning parchalanish massasi va termik barqarorligi temperatura ortib borishi bilan o‘zgarishi aniqlanadi. Shunday qilib, termik analiz natijasida sorbentlarning parchalanishini va suyuqlanishini, va ularning kompleks hosil qilishining oxirgi mahsulotlari o‘rganildi. Taqdim etilgan namunalarni termik barqarorligi TKTITIning laboratoriyasida Netzssh Simultaneous Analyzer STA 409 RG (Germaniya) qurilmasida, K-tipdagi (Low RG Silver) va alyuminiy xaltachalari yordamida amalga oshirildi. Barcha o‘lchovlar inert azotli atmosferada, azotning oqim tezligi 50 ml/min bo‘lgan atmosferada o‘tkazildi. Haroratni o‘lchash diapazoni 25-370 °C, isitish tezligi 5 K/min. Bir o‘lchov uchun namunaning miqdori 5-10 mg ni tashkil qildi. PME sorbentning termogrammasi 2.7-rasmga keltirildi.



2-rasm. PME sorbentning termogrammasi

2.7-rasmda keltirilgan PME sorbentning termogrammasida 126, 275, 362, 484 ^{0}C haroratlarda to‘rtta endotermik va 162, 246, 284, 332, 543 ^{0}C haroratlarda beshta ekzotermik effektlar kuzatildi. Bunga makromolekula tarkibidagi bog‘larning uzilishi va polimerni destruksiyaga uchrab boshlashi sabab bo‘lishi mumkin. 120^{0}C haroratgacha sorbent barqaror bo‘ladi va termik destruksiyaga uchramaydi, ammo haroratning bundan ko‘tarilishida sorbent massasi yo‘qotilishi keskin borishini ko‘rsatadi. 126 ^{0}C haroratdagi birinchi endoeffekt, sorbent tarkibidagi gigroskopik suvning chiqib ketishi bilan bog‘liq bo‘lib, bunda massa kamayishi 0,8 % ni tashkil qiladi. 282 ^{0}C haroratda ikkinchi endoeffekt kuzatilib, polimer tabiatiga ko‘ra sorbentning yumshab, parchalanishi bilan bog‘liq va shu haroratgacha massani keskin pasayishi 33,7 % gacha kuzatildi. 40-600 ^{0}C harorat oralig‘ida umumiy massa kamayishi 92,42 % ni tashkil qiladi.

1-jadval.

PME sorbent termogrammasining natijalari

Effektning harorat intervali, ^{0}C	Effekt cho‘qqisi, ^{0}C	Massa o‘zgarishi, %	Umumiy massa o‘zgarishi, %	Effekt tabiati
40-115	126	0,8	0,8	endotermik
136-180	162	13	14,5	ekzotermik
220-250	246	17,7	24,2	ekzotermik
250-285	275	14,5	44,7	endotermik
265-290	284	6,5	52,2	ekzotermik
305-345	332	12	60,2	ekzotermik
350-386	362	18,4	72,4	endotermik
460-510	484	24,1	81,3	endotermik
520-560	543	10,8	92,42	ekzotermik

Xulosa. 1. Yuqori samarali ion almashinuvchi va kompleks hosil qiluvchi yangi RD-1 markali sorbent sintez qilindi hamda sorbentni sintez qilishning maqbul sharoitlari taklif etildi.

2. Differentsial-termik tahlil natijalari asosida olingan sorbentlarning termik barqarorligi aniqlandi. Skanerlovchi elektron mikroskop – energiya dispersion analiz usuli tahlilida polivinilxloridni monoetanolamin bilan modifikatsiyalab olingan sorbentlarning mikrog’ovakli tuzilishi ko’rsatib berildi.

3. Sintez qilingan yuqori samarali ionalmashinuvchi va kompleks hosil qiluvchi yangi olingan sorbentlarning statik va dinamik sharoitlarda individual hamda aralash eritmalardan Cu (II), Cd (II), Zn (II), Ag (I) ionlariga nisbatan sorbtsion sig’imlari aniqlandi.

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MORPHOLOGICAL CHARACTERISTICS OF POTASSIUM NITRATE BASED ON LOCAL RAW MATERIALS

Normamatov Farxod Haydarali o‘g‘li
Karshi State Technical University, assistant professor
Komilova Marjona Sherzodovna
Amonov Islombek Odil o‘g‘li
Karshi State Technical University, masters
normamatov_1986@mail.ru
ORCID 0009-0002-4751-0246

UDC 661.832.43

Annotatsiya. Ushbu maqolada mahalliy xom ashyolardan kaliy nitrat ishlab chiqarish usullari tahlil qilingan va ilmiy jihatdan asoslab berilgan. Yechilayotgan muammoning dolzarbligi hamda konversion usulda kaliy nitratini olish jarayoniga texnologik parametrlarning ta’siri o‘rganilgan. Turli haroratlarda K+, Mg2+ // Cl-, NO3- – H2O to‘rt komponentli o‘zaro ta’sir etuvchi suv-to‘z tizimidagi fazaviy muvozanatlar haqidagi ma’lumotlardan foydalanilgan. Kaliy nitrat olishning optimal sharoitlari shuningdek magniy nitrati va kaliy xloridi konversiya jarayoniga parametrlari belgilangan. Shu bilan birga, sintez jarayoni natijasida hosil qilingan mahsulot zamonaviy fizik-kimyoviy tahlil usullari orqali batafsil o‘rganildi. Olingan namunaning tarkibi, tozalik darajasi hamda fazaviy holatini aniqlash maqsadida kompleks tahlil ishlari amalga oshirildi. Xususan, moddaning kristall tuzilishi, eruvchanligi, namlik miqdori va asosiy modda ulushi tekshirildi.

Tadqiqot jarayonida kaliy xloridi va magniy nitrati ishtirokida kechadigan almashinish (konversiya) reaksiyasining texnologik xususiyatlari atroflicha o‘rganildi. Jumladan, reaksiya muhitining harorati, reaksion massa konsentratsiyasi, moddalarning molyar nisbati, aralashtirish tezligi va jarayon davomiyligi kabi omillar mahsulot hosil bo‘lishiga qay darajada ta’sir ko‘rsatishi tahlil etildi. Tajribalar natijasida kaliy nitratining maksimal chiqish unumdorligini ta’minlaydigan optimal texnologik parametrlar aniqlandi.

Kalit so‘zlar: konversiya, kaliy xloridi, magniy nitrati, ko‘p komponentli suv–to‘z tizimi, kristallanish, harorat, filtratsiya.

Abstract. This article analyzes methods for producing potassium nitrate from local raw materials and provides their scientific justification. The relevance of the problem is substantiated, and the influence of technological parameters on the conversion process of potassium nitrate production has been studied. Data on phase equilibria in the four-component water–salt system K^+, Mg^{2+} // Cl^-, NO_3^- – H_2O at various temperatures were used. The optimal conditions for potassium nitrate production, as well as the parameters of the conversion process involving magnesium nitrate and potassium chloride, were determined.

In addition, the product obtained as a result of the synthesis process was comprehensively investigated using modern physicochemical analysis methods. A set of analyses was carried out to determine the composition, purity level, and phase state of the obtained sample. In particular, the crystal structure, solubility, moisture content, and the proportion of the main substance were examined.

During the research, the technological features of the exchange (conversion) reaction between potassium chloride and magnesium nitrate were studied in detail. Specifically, the effects of reaction temperature, concentration of the reaction mass, molar ratio of the reactants, mixing rate, and process

duration on product formation were analyzed. As a result of the experiments, the optimal technological parameters ensuring the maximum yield of potassium nitrate were identified.

Keywords: conversion, potassium chloride, magnesium nitrate, multicomponent water–salt system, crystallization, temperature, filtration.

Introduction. The chemical industry is considered a fundamental sector closely connected with all branches of the economy and holds an important position within the agrochemical complex. The industry's production must be based on advanced technologies and ensure the manufacture of high-quality products that meet international standards.

One of the main directions of economic development in the Republic of Uzbekistan is the utilization of natural resources, their integrated use, and the creation of competitive, import-substituting products based on local raw materials [1].

Developing a highly efficient technology for producing potassium nitrate from local raw materials in Uzbekistan is a pressing task, as it enables meeting domestic market demand and increasing the country's export potential [2].

Currently, there is a rapidly growing global demand in agriculture for environmentally safe and highly efficient mineral fertilizers. In particular, potassium fertilizers that do not contain chloride ions are of great importance for agricultural crops. This is because chloride can negatively affect many crop types, deteriorate the agrochemical properties of the soil, and impact the quality of the produce. For this reason, the production of complex NK and NPK mineral fertilizers using chloride-free potassium sources is one of the most promising directions in the modern agro-industrial market.

From this perspective, developing technologies for producing chloride-free potassium fertilizers, including complex NK and NPK fertilizers, based on local raw material sources is crucial for ensuring the sustainable development of the country's agriculture, increasing the volume of import-substituting products, and enhancing the competitiveness of the agro-industrial complex.

At present, Uzbekistan does not have large-scale producers of these fertilizers, which is associated with the lack of a raw material base for producing chloride-free potassium fertilizers.

Research methodology: In the technology for producing potassium nitrate via the conversion method, locally produced potassium chloride and magnesium nitrate, manufactured by chemical industry enterprises operating in the territory of the Republic of Uzbekistan, are used as raw materials. This method is economically feasible and allows for efficient utilization of the existing production infrastructure.

The process of obtaining potassium nitrate involves several consecutive technological stages. In the first stage, an ion-exchange reaction occurs between potassium chloride and magnesium nitrate, resulting in the formation of potassium nitrate in the solution. This process is carried out under specific temperature and concentration conditions to ensure complete reaction and maximize product yield.

In the next stage, the resulting reaction mass — the pulp — is separated using mechanical and physicochemical methods. During this stage, magnesium chloride, which forms as a by-product, is removed from the solution, playing an important role in ensuring the purity of potassium nitrate in subsequent processes.

Potassium nitrate is then obtained from the separated solution through a crystallization process. By controlling the size and morphology of the formed crystals, the product achieves high agronomic and chemical purity.

In the final stage, the separated potassium nitrate crystals undergo a drying process, reducing the moisture content to standard levels. The drying process enhances the product's storage stability and prepares it for further use or packaging.

Studying the crystallization rate within a specific temperature range and determining the K_2O yield depending on key technological parameters are important directions of the research. The obtained potassium nitrate and intermediate solutions were analyzed using commonly accepted methods [3].

The following physicochemical analysis methods were used in the research: scanning electron microscopy, infrared spectroscopy, thermoanalytical methods, and X-ray phase analysis. The thermal stability of the samples was determined using differential thermal analysis (DTA) and thermogravimetric analysis (TGA).

The morphology and microstructure of the samples were studied using a scanning electron microscope, SEM – EVO MA 10 (Carl Zeiss, Germany). The local elemental composition of the powders was determined using an energy-dispersive X-ray analyzer (EDX, Oxford Instruments).

During the measurements, an accelerating voltage of 10 kV was applied to the electron beam, and the working distance was 8.5 mm. The local elemental analysis was carried out at a scale of 100 μm using the Aztec Energy Advanced software package [4–6].

Results and discussions: Analysis of the research results showed that during the stepwise cooling of the solutions obtained after the conversion process, the formation of Potassium nitrate crystals was observed in the system, resulting in the formation of a suspension consisting of crystals and a liquid phase. This phenomenon directly affects the technological efficiency of the crystallization and subsequent filtration stages in the process of potassium nitrate separation.

In order to determine the effect of crystal content on the crystallization intensity and the main technological parameters of the filtration process during potassium nitrate production, experiments were carried out at different stoichiometric ratios. In particular, the $KCl/Mg(NO_3)_2$ ratios were selected as 1:0.8, 1:1, and 1:1.2. These ratios made it possible to more thoroughly analyze the completeness of the reaction, the composition of the solution, and the crystal formation process.

The conversion process was carried out in the temperature range of 80–90 °C, with reaction times set at 10 and 15 minutes. These parameters were evaluated as key factors influencing the reaction rate, the degree of ion exchange, and the subsequent crystallization ability of the solution. After completion of the reaction, the solutions were cooled under specified conditions, and the crystallization process was conducted at 10–20 °C [7–9].

The experimental results showed that a decrease in crystallization temperature led to an intensified formation of Potassium nitrate crystals, an increase in crystal yield, and changes in their morphological characteristics. It was also noted that the amount of formed crystals significantly affected the filtration rate, filtration resistance, and the purity of the separated product.

Thus, optimization of the cooling conditions of the conversion solutions, as well as the proper selection of raw material ratios and temperature–time parameters, was found to be crucial for improving the efficiency of the crystallization and filtration stages in the production of potassium nitrate.

Table 1

Effect of Technological Parameters on the Production of Potassium nitrate by the Conversion Method

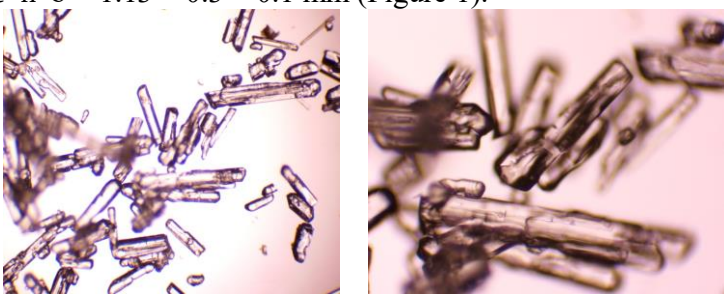
№	KCl/ Mg(NO₃)₂	Conversion temperature	Conversion time	Crystallization temperature	Crystallization time	Filtration rate V	Moisture content of the solid phase%	Liquid-to-Solid ratio L:S	K_2O yield, %
1	1;0,8	80	10	10	15	1051	3,5	5,3;1	35,55
2			10	20	10	837	3,9	5,79;1	41,91
3		90	15	10	15	667,7	5,6	7,78;1	30,31
4			15	20	10	732	5,23	7,94;1	30,26
5	1;1	80	10	10	15	1086,3	17,6	5,34;1	46,9
6			15	20	10	942,2	11,5	7,1;1	49,1
7		90	15	10	15	895	13,7	3,7;1	45,37
8			15	20	10	1031	9,6	5;1	44,98
9	1;1,2	80	10	10	15	817	12,3	4,4;1	49,59
10			10	20	10	1093	3,87	5;1	45,37
11		90	15	10	15	1866	3,54	5,2;1	50,06
12			15	20	10	791	9,4	5,6;1	50,70

According to the results of the conducted experiments, the liquid-to-solid phase ratio (L:S) varies within the range of 3,7–7,94 depending on the technological conditions of crystallization. At the same time, the filtration rate does not have a significant effect on the duration of the exchange decomposition reaction or on the K_2O yield.

As shown in Table 1, the moisture content of the product after filtration decreases from 17,6% to 9,6% and from 12,3% to 3,54%. The highest degree of solution clarification is observed at a temperature of 10 °C. When the temperature exceeds 20 °C, the potassium yield in the potassium chloride : magnesium nitrate ratio remains almost unchanged.

At a potassium chloride : magnesium nitrate ratio of 1:0.8, the potassium conversion degree decreases by more than 15.15% compared to the 1:1.2 ratio. The maximum potassium conversion degree is observed at a potassium chloride : magnesium nitrate ratio of 1:1.08 at 20 °C, ranging between 30.26–41.91%. At 10 °C, this value increases to 30.31–50.06%.

Under these parameters, the filtration rate of the suspension is relatively high, reaching 732–1051 kg/m²·h.As a result, the chlorine content in the dry, unwashed product decreases from 2–3% to 1.7–1.8%. This can be explained by the formation of large prismatic crystals with dimensions e–h–b = 1.13 × 0.3 × 0.1 mm (Figure 1).



4x **10x**

Figure 1. Micrographs of Potassium nitrate crystals (×4 and ×10) obtained from the samples prepared according to Table 1

Analysis of the provided microscopic images clearly reveals the morphological characteristics of Potassium nitrate crystals. Specifically, the crystals are predominantly elongated, prismatic, and needle-like in shape, reflecting the characteristic crystal structure of potassium nitrate. The orientation of the crystals in various directions, as well as the observation that many of them are interconnected or form small aggregates, indicates that crystal growth during the crystallization process occurred in both parallel and oblique directions [10–11].

The well-defined edges and relatively smooth surfaces of the crystals suggest that the crystallization process was carried out under stable temperature and concentration conditions. Such morphological features indicate that there was no excessive rapid cooling or abrupt supersaturation in the solution, resulting in uniform and regular crystal growth.

Microscopic analysis also confirmed that the crystal sizes were not uniform, indicating the presence of a polydisperse structure. Some crystals were large and relatively elongated, while others were shorter and smaller in size. Additionally, certain crystals exhibited internal zoning and growth lines, indicating that during the crystallization of potassium nitrate from the solution, the material precipitated in a stepwise manner and that the degree of solution saturation changed over time.

The image shows that foreign mechanical inclusions are rare and that the crystals are mostly transparent, indicating that the obtained Potassium nitrate has relatively high chemical purity. This suggests that it is suitable for further technological processing as well as for agrochemical applications.

Overall, the microscopic analysis results fully reveal the morphological characteristics typical of potassium nitrate crystals and demonstrate that the obtained product possesses high technological and agronomic efficiency.

The crystals were analyzed using an optical microscope. They are predominantly needle-like and elongated prismatic in shape, which is a morphological feature characteristic of KNO_3 crystals.

The results indicate that the studied technological parameters have a significant effect on the morphology and external characteristics of Potassium nitrate crystals. In particular, the formation of large prismatic crystals with dimensions of L × h × b = 0.125–1.627 × 0.1–0.5 × 0.1–0.3 mm demonstrates that the crystallization process proceeded in a stable manner and that growth had a clearly directional character. This confirms that the technological parameters were optimally selected. The width of the crystals is considerably smaller than their length, indicating anisotropic growth. This means that the growth rate of KNO_3 crystals is not uniform in different crystallographic directions.

The largest crystals exhibit a needle-like shape, which may be associated with the high degree of solution supersaturation. In the first microphotograph, the crystals show a wide size distribution. Precise measurements revealed that the crystal lengths ranged from 6.75 μm to 14.28 μm, with dominant values around 7.31 μm and 13.32 μm. Such a size distribution indicates that during the initial stage of crystallization, numerous nuclei were formed, followed by limited subsequent growth [12–13].

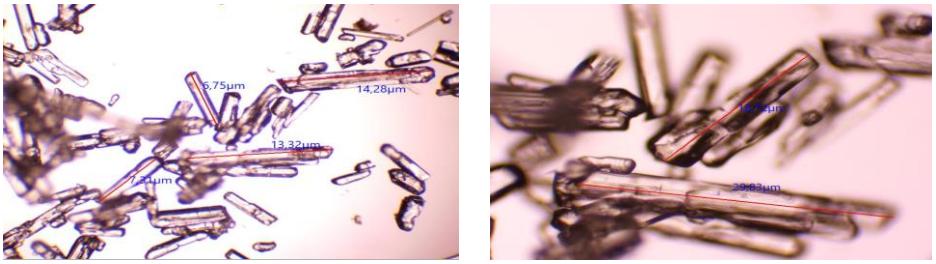


Figure 2. Effect of technological parameters on the particle size distribution of Potassium nitrate crystals after crystallization at a KCl:$NaNO_3$ ratio of 1:1 and a temperature of 10 °C.

In the second microphotograph, relatively large and well-formed crystals are observed, with lengths ranging from 18,72 μm to 29,83 μm. This indicates that in the later stages of crystallization, the number of nuclei decreased, allowing the existing crystals to grow freely. Additionally, some crystals are seen to have adhered to each other (agglomeration), which may suggest a higher degree of supersaturation in the solution.

The variation in crystal sizes and differences in morphology confirm that technological parameters—specifically, solution concentration, cooling rate, stirring intensity, and crystallization time—are directly related to crystal formation. By optimizing these factors, the size and shape of Potassium nitrate crystals can be purposefully controlled.

Overall, the microscopic analysis results indicate that the obtained potassium nitrate crystals are morphologically stable, have controllable sizes, and possess high quality. This further supports their effective use in agriculture as a chlorine-free potassium fertilizer.

Conclusion. Based on the results of the conducted experimental research, it can be concluded that the obtained potassium nitrate (KNO_3) fully meets the requirements for use in agriculture as an effective chlorine-free potassium fertilizer. During the research process, the chemical composition of the produced material was analyzed, and it was determined that the content of potassium nitrate constituted 98–99%. This indicator confirms the high purity of the obtained product and demonstrates that the technological process was properly organized.

In addition, it was noted that the amount of foreign ions and impurities in the product was below the permissible limits, which contributes to improving the agrochemical properties of potassium nitrate. In particular, the assimilation rate of the potassium ion (K^+) was found to be 97–98%, indicating that potassium can be easily and efficiently absorbed by plants.

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UGLEROD NANONAYCHALARI BILAN MUSTAHKAMLANGAN POLIOLEFIN NANOKOMPOZITLARNING TERMIK BARQARORLIGI VA TERMO-OKSIDLANISH DESTRUKSIYASI

Raxmonkulov Alikul Amirkulovich
Qarshi davlat texnika universiteti professori
raxmankulovalicul@gmail.com
ORCID 0000-0001-8075-6630
Xaydarov Tuymurod Zoyirovich
Qarshi davlat texnika universiteti dotsenti
tuymurodxaydarov228@gmail.com,
ORCID 0000-0003-2459-9815
UDK 66.091.3; 678.4.043

Annotatsiya. Ushbu tadqiqotda uglerod nanonaychalari bilan modifikatsiyalangan polipropilen va polietilen asosidagi polimer kompozitlarning termik barqarorligi kompleks differensial termik tahlil usullari yordamida baholandi. Uglerod nanonaychalari polimer matritsaga 0,01–1,0 mass.% miqdorda kiritildi.

Namunalarning termik xossalari differensial termik tahlil (DTA), termogravimetrik tahlil (TG) va differensial skanerlovchi kalorimetriya (DSC) usullari orqali o‘rganildi. Natijalar past haroratlarda kuzatilgan endoeffektlar polimer matritsaning erish jarayoniga mos kelishini va massa yo‘qotilishi bilan kechmasligini ko‘rsatdi. Yuqori haroratlarda termo-oksidlanish destruksiyasi sodir bo‘lib, nanonaychalar kiritilishi destruksiya boshlanish haroratining oshishiga olib kelishi aniqlandi. DSC tahlili nanomodifikatorlar polimerlarning kristallik darajasi va erish entalpiyasini oshirishini, natijada materiallarning issiqlikka chidamliligi yaxshilanishini tasdiqladi. Olingan natijalar uglerod nanonaychalari bilan modifikatsiyalangan polimer kompozitlarning termik barqarorligi sezilarli darajada ortishini hamda ularni yuqori ekspluatatsion talablarga ega muhandislik sohalarida qo‘llash istiqbolli ekanligini ko‘rsatadi.

Kalit so‘zlar: Uglerod nanonaychalari; polimer nanokompozitlar; polipropilen; polietilen; termik barqarorlik; differensial termik tahlil; termogravimetrik tahlil; DSC; termo-oksidlanish destruksiyasi.

THERMAL STABILITY AND THERMO-OXIDATIVE DEGRADATION OF POLYOLEFIN NANOCOMPOSITES REINFORCED WITH CARBON NANOTUBES

Abstract. In this study, the thermal stability of polypropylene- and polyethylene-based polymer composites modified with carbon nanotubes was evaluated using integrated differential thermal analysis techniques. Carbon nanotubes were incorporated into the polymer matrix in concentrations ranging from 0.01 to 1.0 wt.%. The thermal properties of the samples were investigated by differential thermal analysis (DTA), thermogravimetric analysis (TG), and differential scanning calorimetry (DSC).

The results showed that endothermic effects observed at low temperatures correspond to the melting process of the polymer matrix and occur without mass loss. At elevated temperatures, thermo-oxidative degradation of the polymer composites takes place, while the incorporation of carbon nanotubes leads to an increase in the degradation onset temperature. DSC analysis confirmed that nanomodifiers increase the degree of crystallinity and melting enthalpy of polymers, thereby improving the heat resistance of the materials.

The obtained results demonstrate a significant enhancement in the thermal stability of carbon-nanotube-modified polymer composites and indicate their strong potential for applications in engineering fields requiring high operational performance.

Keywords: carbon nanotubes; polymer nanocomposites; polypropylene; polyethylene; thermal stability; differential thermal analysis; thermogravimetric analysis; differential scanning calorimetry; thermo-oxidative degradation.

Kirish. Hozirgi kunda polimer materiallar sanoat, qurilish, transport, elektrotexnika hamda energetika sohalarida keng qo‘llanilishi bilan ajralib turadi. Shu nuqtayi nazardan, uglerod nanotubalarini (UNT) o‘stirishning qulay va iqtisodiy jihatdan samarali usullaridan biri sifatida asetilen gazidan foydalanishga asoslangan texnologiyalar muhim ahamiyat kasb etadi [1].

Ayniqsa, polipropilen va polietilen asosidagi polimerlar nisbatan past zichligi, texnologik qayta ishlash qulayligi hamda yuqori iqtisodiy samaradorligi tufayli muhim konstruksion materiallar qatoriga kiradi. Biroq ushbu polimerlarning ekspluatatsion xossalari, xususan, yuqori va past haroratlar ta’sirida barqarorligi cheklangan bo‘lib, bu ularning amaliy qo‘llanish sohasini sezilarli darajada toraytiradi [2,3]. Ma’lumki, polimer materiallarning ishlash harorat oralig‘i ularning mo‘rtlik harorati va erish harorati bilan chegaralanadi [4,5]. Shu sababli polimerlarning termik barqarorligini oshirish, issiqlik ta’sirida sodir bo‘ladigan termo-oksidlanish va destruksiya jarayonlarini sekinlashtirish zamonaviy polimer materialshunosligining dolzarb ilmiy-texnik muammolaridan biri hisoblanadi. Ushbu muammoni hal etishda polimer matritsaga yuqori samaradorlikka ega nanomodifikatorlarni kiritish istiqbolli yo‘nalish sifatida qaralmoqda.

So‘nggi yillarda uglerod asosidagi nanomodifikatorlar, xususan, uglerod nanonaychalari (UNT) va boshqa uglerodli nanoto‘ldiruvchilar yuqori mexanik mustahkamligi, katta solishtirma sirt maydoni hamda noyob fizik-kimyoviy xossalari tufayli polimer kompozitlarning strukturaviy va funksional xususiyatlarini yaxshilash imkonini beruvchi samarali qo‘shimchalar sifatida e’tirof etilmoqda [6]. Ularning juda kichik miqdorda kiritilishi ham polimer matritsaning kristallanish jarayonlari, issiqlik o‘tkazuvchanligi, termik barqarorligi va destruksiya mexanizmlariga sezilarli ta’sir ko‘rsatishi aniqlangan [7]. Shunga qaramay, uglerod nanomodifikatorlarining polimer matritsa bilan o‘zaro ta’sir mexanizmlari, ularning turli konsentratsiyalarda polimerning yuqori va past harorat sharoitidagi barqarorligiga ta’siri yetarli darajada tizimli o‘rganilmagan [8].

Ayniqsa, differensial termik tahlil (DTA), differensial termogravimetrik tahlil (DTG) va differensial skanerlovchi kalorimetriya (DSC) usullari asosida olingan eksperimental natijalarni kompleks tahlil qilish orqali polimer nanokompozitlarning termik xulq-atvorini chuqur baholash muhim ilmiy ahamiyatga ega [9].

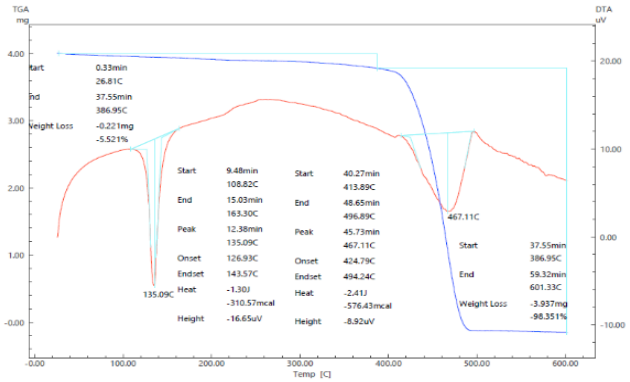
Tadqiqot doirasida nanomodifikator konsentratsiyasining polimerlarning erish harorati, destruksiya boshlanish nuqtalari, massa yo‘qotilishi va kristallik darajasiga ta’siri aniqlanib, olingan natijalar asosida issiqlikka chidamli polimer nanokompozitlar yaratishning ilmiy asoslari ishlab chiqiladi.

Tadqiqot metodologiyasi. Mazkur tadqiqotda uglerod nanomodifikatorlari bilan modifikatsiyalangan polipropilen va polietilen asosidagi polimer kompozitlarning yuqori va past harorat sharoitidagi termik barqarorligi kompleks differensial termik tahlil usullari yordamida o‘rganildi. Tadqiqot obyekti sifatida I-1561 va F-0120 markali polietilenlar hamda polipropilen asosidagi matritsalar tanlandi.

Nanomodifikator sifatida uglerod nanonaychalari (UNN) ishlatilib, ular polimer matritsaga 0,01; 0,05; 0,1 va 1,0 mass.% miqdorlarda kiritildi. Kompozit namunalar standart texnologik rejimda eritma va mexanik aralashtirish usuli yordamida tayyorlandi, bu esa nanomodifikatorlarning polimer matritsa bo‘ylab nisbatan bir tekis taqsimlanishini ta’minladi.

Polimer nanokompozitlarning termik xossalarini baholash uchun differensial termik tahlil (DTA)**,** differensial termogravimetrik tahlil (DTG)**,** differensial skanerlovchi kalorimetriya (DSC) usullaridan foydalanildi. Tajribalar inert atmosfera sharoitida, haroratni oshirish tezligi doimiy bo‘lgan holda amalga oshirildi. Ushbu usullar yordamida namunalar uchun erish haroratlari, destruksiya boshlanish nuqtalari, massa yo‘qotilishi hamda kristallik darajalari aniqlandi.

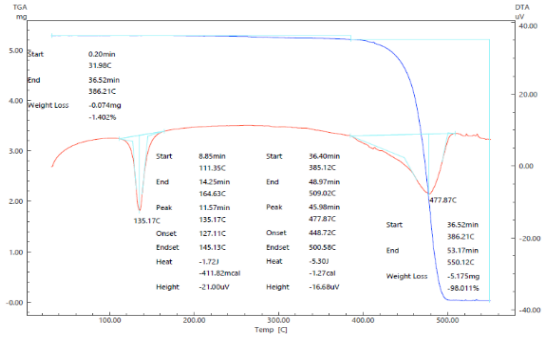
Natijalar va muhokama. Differensial termik va termogravimetrik tahlil natijalari uglerod nanonaychalari bilan modifikatsiyalangan polimer kompozitlarning DTA va DTG egri chiziqlari nanomodifikator miqdoriga sezilarli darajada bog‘liq ekanligini ko‘rsatdi. Tadqiqot natijalariga ko‘ra, barcha namunalar uchun past harorat sohasida kuzatilgan birinchi endoeffekt massa kamayishi bilan kechmadi, bu esa polimer matritsaning suyuqlanish jarayoniga mos kelishini ko‘rsatadi.



1-rasm. 0,1 mas.% uglerodli nanotrubkalar bilan modifikatsiyalangan I-1561 markali polietilenning differensial termik tahlili (DTA) va termogravimetrik (TG) egri chiziqlari.

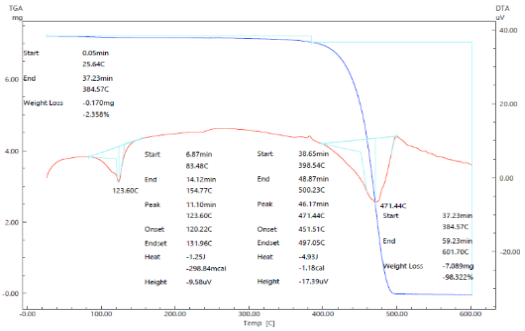
Rasmda polimer nanokompozit namunasining differensial termik (DTA) va termogravimetrik (TG) egri chiziqlari keltirilgan. Past haroratlar sohasida (~120–140 °C) DTA egri chizig‘ida kuzatilgan endoeffekt massa yo‘qotilishi bilan kechmaydi, bu esa polimer matritsaning erish jarayoniga mos keladi. Yuqori haroratlar oralig‘ida (~400–500 °C) DTA va TG egri chiziqlarining bir vaqtda o‘zgarishi polimerning termo-oksidlanish destruksiyasi bilan izohlanadi [6,10].

Destruksiya boshlanish haroratining yuqori qiymatlarga siljishi uglerod nanomodifikatorlarining polimer matritsada issiqlik ta’sirida strukturaviy barqarorlikni oshiruvchi to‘siq rolini bajarishini ko‘rsatadi. Umumiy massa yo‘qotilishining yuqori bo‘lishiga qaramay, parchalanish jarayonining kechikishi nanokompozitning issiqlikka chidamliligi yaxshilanganini tasdiqlaydi.



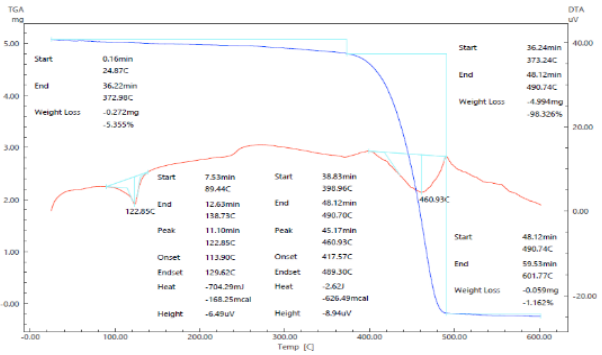
2-rasm. 1,0 mas.% uglerodli nanotrubkalar bilan modifikatsiyalangan I-1561 markali polietilenning differensial termik tahlili (DTA) va termogravimetrik (TG) egri chiziqlari.

DTA va TG egri chiziqlari past haroratlar sohasida (~120–140 °C) massa yo‘qotilmasdan kechuvchi erish jarayonini, yuqori haroratlarda esa (~450–500 °C) polimerning asosiy termo-oksidlanish destruksiyasini namoyon etadi. Destruksiya boshlanishining yuqori haroratlarga siljishi uglerod nanomodifikatorlarining polimer matritsani termik jihatdan samarali barqarorlashtirganini tasdiqlaydi [6,10].



3-rasm. 0,1 mas.% uglerodli nanotrubkalar bilan modifikatsiyalangan F-0120 markali polietilenning differensial termik tahlili (DTA) va termogravimetrik (TG) egri chiziqlari.

DTA va TG egri chiziqlari past haroratlar sohasida (~120–140 °C) massa yo‘qotilmasdan kechuvchi erish jarayonini, yuqori haroratlarda esa (~450–500 °C) polimerning termo-oksidlanish destruksiyasini namoyon etadi. Destruksiya boshlanish haroratining yuqoriroq qiymatlarga siljishi uglerod nanomodifikatorlarining polimer matritsani termik barqarorlashtiruvchi samarali ta’sirini tasdiqlaydi [6,10].



4-rasm. 0,05 mas.% uglerodli nanotrubkalar bilan modifikatsiyalangan F-0120 markali polietilenning differensial termik tahlili (DTA) va termogravimetrik (TG) egri chiziqlari.

DTA va TG egri chiziqlari past harorat oralig‘ida (~120–135 °C) massa yo‘qotilmasdan kechuvchi erish jarayonini ko‘rsatadi, yuqori haroratlarda esa (~460–500 °C) polimerning asosiy termo-oksidlanish destruksiyasi kuzatiladi. Destruksiya bosqichining yuqori haroratlarga siljishi uglerod nanomodifikatorlarining polimer matritsa termik barqarorligini oshirganini tasdiqlaydi [6,10].

Yuqori harorat sohasida kuzatilgan ikkinchi endoeffekt esa massa yo‘qotilishi bilan kechib, polimer nanokompozitlarning termo-oksidlanish destruksiyasi bilan izohlanadi. Uglerod nanonaychalari kiritilishi natijasida destruksiya jarayonining boshlanish harorati yuqoriroq sohalarga siljigan, bu esa nanomodifikatsiyalangan namunalar issiqlikka nisbatan yuqori barqarorlikka ega ekanligini ko‘rsatadi.

Xususan, 0,1 mass.% UNN kiritilgan namunalar uchun destruksiya harorati eng yuqori qiymatlarga ega bo‘lib, massa yo‘qotilishi jarayoni kechroq boshlanishi aniqlandi. Bu holat uglerod nanonaychalarining polimer matritsada issiqlik ta’sirida hosil bo‘ladigan mikroyoriqlar rivojlanishini cheklashi bilan izohlanadi.

Differensial skanerlovchi kalorimetriya (DSC) natijalari asosida polimer kompozitlarning erish harorati, erish entalpiyasi va kristallik darajalari aniqlandi. Olingan ma’lumotlar 1-jadvalda keltirilgan.

1-jadval

Differential scanning calorimetry (DSC) parameters of polypropylene composites modified with various contents of carbon nanomodifiers.

Namuna	**T_erish boshl., °C**	**T_erish cho‘qqisi, °C**	**ΔH_erish, J/g**	**T_krist., °C**	**Kristallik darajasi, %**
Asosiy PP	155,0	171,0	90,57	112,0	75,0
PP + 0,01 mass.% UNN	156,5	172,3	92,4	114,8	79,7
PP + 0,05 mass.% UNN	156,4	172,4	104,3	117,2	89,4
PP + 0,1 mass.% UNN	159,0	178,6	106,7	117,8	91,5
PP + 1,0 mass.% UNN	155,6	176,5	91,7	117,4	79,0

Jadvaldan ko‘rinib turibdiki, uglerod nanonaychalari miqdori oshishi bilan polimer kompozitlarning erish harorati va kristallik darajasi ortadi. Ayniqsa, 0,1 mass.% UNT kiritilgan namunalar uchun kristallik darajasi maksimal qiymatga ega bo‘lib, bu holat nanomodifikatorlarning kristallanish markazlari sifatida faol ishtirok etishini ko‘rsatadi.

Xulosa. Tadqiqot natijalari shuni ko‘rsatdiki, uglerod nanomodifikatorlari bilan modifikatsiyalangan polipropilen va polietilen asosidagi polimer kompozitlar yuqori va past harorat sharoitida sezilarli darajada yaxshilangan termik barqarorlikka ega. Nanomodifikatorlarning optimal miqdori 0,1 mass.% atrofida bo‘lib, aynan shu konsentratsiyada erish haroratlari, destruksiya boshlanish nuqtalari va kristallik darajalarining maksimal qiymatlari kuzatildi.

Olingan natijalar issiqlikka chidamli va yuqori ekspluatatsion xossalarga ega polimer nanokompozitlarni ishlab chiqish uchun ilmiy asos bo‘lib xizmat qiladi hamda ularni sanoat va muhandislik amaliyotida qo‘llash imkoniyatlarini kengaytiradi.

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SYNTHESIS, HIRSCHFELD SURFACE ANALYSIS, AND SPECTROSCOPIC PROPERTIES OF A CD (II) COORDINATION POLYMER WITH HYDROXYNAPHTHOATE

Saidov Dilmurod Khursan ugli
Doctoral student of Termez State University
saidovdilmurod514@gmail.com
Khayit Khudaynazarovich Turaev
Doctor of Chemical Sciences, Professor, Termez State University
Aziz Bakhtiyarovich Ibragimov
Doctor of Chemical Sciences, Professor of the Institute of General and Inorganic Chemistry of the Academy of Sciences of Uzbekistan
Lutfulla Ubaydullaevich Bozorov
Doctor of Technical Sciences, Associate Professor
Termez State Pedagogical Institute
Ruziev Umid Ural ugli
Doctoral student of Termez State University
Kuvonch Bakhtiyor ugli Kholturaev
Doctoral student of Termez State University
ORCID 0009-0007-4185-086
UDK 546.742:544.653

Abstract. This study reports the synthesis and comprehensive characterization of a novel Cd(II)-based coordination polymer (HNA-CP) derived from 4-hydroxy-1-naphthoic acid. Single-crystal X-ray diffraction analysis revealed the formation of a well-defined two-dimensional polymeric framework with extended structural connectivity and ordered arrangement. Hirshfeld surface analysis indicated that hydrogen bonding and π···π stacking interactions play a dominant role in stabilizing the crystal structure. Furthermore, spectroscopic investigations demonstrated notable optical properties and confirmed the material's structural integrity. The combined structural and physicochemical features suggest that HNA-CP possesses significant potential for applications in gas adsorption, heterogeneous catalysis, and optoelectronic devices, making it a promising candidate for future advanced material design and functional applications in modern chemistry.

Keywords: Cd(II) coordination polymer; X-ray diffraction (XRD), Hirshfeld surface analysis, FT-IR spectroscopy.

Annotatsiya. Ushbu tadqiqotda 4-gidroksi-1-naftoy kislota asosida yangi Cd(II) koordinatsion polimeri (HNA-CP) sintezi va kompleks tavsifi keltirilgan. Yakka kristalli rentgen difraksiyasi natijalari uning yaxshi tartiblangan, ikki o'lchamli 2D polimer tuzilishga ega ekanligini ko'rsatdi. Hirshfeld sirt tahlili kristall panjaraning barqarorlashuvida vodorod bog'lari hamda π···π o'zaro ta'sirlar muhim rol o'ynashini aniqladi. Bundan tashqari, spektroskopik tadqiqotlar materialning sezilarli optik xususiyatlarga ega ekanligini tasdiqladi. Olingan natijalar HNA-CP ning gaz adsorbsiyasi, geterogen kataliz hamda optoelektron qurilmalarda qo'llash uchun istiqbolli material ekanligini ko'rsatadi. Mazkur xususiyatlar ushbu birikmaning zamonaviy materiallar kimyosida yuqori funksional imkoniyatlarga ega bo'lgan istiqbolli material sifatida baholanishiga asos yaratadi hamda uni gaz adsorbsiyasi, katalitik jarayonlar va optoelektron tizimlarda samarali qo'llash uchun keng ilmiy-amaliy salohiyatga ega ekanligini ko'rsatadi.

Kalit so'zlar: Cd(II) koordinatsion polimeri; rentgen difraksiyasi (XRD), Hirshfeld sirt tahlili, FT-IR spektroskopiyasi.

Introduction. In recent years, research on coordination polymers (CPs) has developed rapidly and has become an important and promising area in modern science, particularly in fields such as catalysis, sensing technologies, and nanotechnology. The unique structure-property relationships of these materials not only attract significant fundamental scientific

interest but also provide broad opportunities for practical applications [1]. Coordination compounds are complex chemical systems composed of central metal ions and organic or inorganic ligands that form coordination bonds through donor atoms. During the polymerization process, these compounds can assemble into one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D) extended frameworks through coordination interactions [2-4]. As a result, coordination polymers with diverse topologies and architectures are formed, exhibiting distinctive physicochemical properties. The rapid development of interdisciplinary research has significantly expanded the possibilities for the rational design and synthesis of new coordination polymer structures, as well as for the detailed investigation of their structural and functional properties. Consequently, these materials have attracted considerable attention due to their potential applications in catalysis, gas adsorption, sensing systems, and other advanced technological fields [5].

The distinctions between metal-organic frameworks (MOFs) and coordination polymers (CPs) are primarily reflected in their structural features, stability, and functional properties. MOFs are characterized by high porosity and well-defined crystalline architectures; however, they are often relatively fragile in terms of mechanical stability [6,7], and certain types may undergo structural degradation under acidic or humid conditions. Such flexibility allows precise tuning of both structural architecture and functional properties, often rendering CPs more versatile than MOFs in practical applications [8]. Consequently, coordination polymers have attracted significant interest for various scientific and technological applications, including gas storage and separation, catalysis, luminescence, sensing, proton and electron conductivity, and energy conversion processes [9-10].

In this study, 1-hydroxy-2-naphthoic acid was selected as the ligand for the synthesis of coordination polymers. A novel Cd(II)-based coordination polymer was successfully synthesized, and its physicochemical properties were thoroughly investigated. Comprehensive characterization was carried out using powder and single-crystal X-ray diffraction (XRD) to elucidate the crystalline structure, scanning electron microscopy (SEM) to evaluate the surface morphology and microstructural features. These combined analytical techniques provided detailed insights into the structural, electronic, and morphological attributes of the newly synthesized coordination polymer, establishing a clear correlation between its framework architecture and functional properties.

Research methodology. The Cd(II)-based coordination polymer was synthesized using 1-hydroxy-2-naphthoic acid (HNA) under solvothermal conditions. Its structural features were analyzed by single-crystal and powder X-ray diffraction (XRD) and Hirshfeld surface analysis to elucidate crystallinity, phase composition, and intermolecular interactions. These techniques collectively provided a comprehensive characterization of the polymer's structural and physicochemical properties.

Experimental. To synthesize the coordination polymer, 0.376 g of 1-hydroxy-2-naphthoic acid (HNA, 0.1 M) was first dissolved in 15 mL of 96% ethanol, followed by the addition of 5 mL of dimethylformamide (DMF). The solution was stirred magnetically for 30 minutes, yielding a dark brown homogeneous mixture. Separately, 0.266 g of Cd(II) acetate (CA, 0.1 M) was dissolved in 10 ml of distilled water and added dropwise to the ligand solution under continuous stirring. The resulting mixture was filtered to remove any insoluble impurities, producing a brown filtrate. To promote gradual solvent evaporation and crystal growth, the filtrate was maintained at 50-60 °C in a thermostat for 10 days. Dark brown crystalline products were obtained at the end of the process, representing the HNA-based coordination polymer, denoted as HNA-CP. A schematic representation of the synthetic procedure is presented in.

Results and Discussions: Infrared Studies: Fourier-transform infrared (FT-IR) spectroscopy was employed to further investigate the structural features of the synthesized HNA-CP in the range of 400-4000 cm^{-1}. A broad band observed at 3335 cm^{-1} is attributed to the O-H stretching vibrations of the HNA ligand and residual moisture. The aromatic C-H stretching vibrations appear near 3058 cm^{-1}, while additional bands at 2929 cm^{-1} correspond to DMF and acetate residues in the polymer. Asymmetric and symmetric deformation vibrations

of the aromatic rings were detected at 1404 and 1281 cm^{-1} , respectively. The strong band at 1647 cm^{-1} is assigned to the carbonyl (C=O) stretching vibration. Furthermore, C=C stretching vibrations of the aromatic rings were observed in the 1573-1539 cm^{-1} region, and Cd-O stretching modes appeared between 672-542 cm^{-1} . Collectively, these spectral features confirm the proposed structural framework of HNA-CP [13].

Hirshfeld Surface Analysis. Hirshfeld surface analysis of the synthesized coordination polymer was carried out using its CIF file, with the asymmetric unit selected for detailed evaluation of intermolecular interactions and crystal packing. The Hirshfeld surface was constructed based on normalized contact distances (d_{norm}) and the di and de parameters, which quantify the distances from the surface to the nuclei inside and outside the molecular boundary, respectively. Quantitative analysis revealed a total surface volume of 597.87 $Å^3$ and a surface area of 518.56 $Å^2$, reflecting extensive intermolecular interactions within the crystal lattice. Normalized contact distances ranged from -0.6655 to 1.6852 a.u., with an average of 0.4692 a.u., while di and de values spanned 0.6976-2.9473 a.u. and 0.6959-2.7280 a.u., respectively, indicating heterogeneous but well-distributed atomic contacts across the surface. Crystal void analysis demonstrated the presence of intrinsic cavities between molecular fragments, occupying a volume of 836.28 $Å^3$ and a surface area of 2158.01 $Å^2$ per asymmetric unit. When combined with the Hirshfeld surface, the total volume and surface area reached 1434.15 $Å^3$ and 2676.57 $Å^2$, highlighting significant channels and free space within the structure that can facilitate gas adsorption, ion mobility, or inclusion of guest molecules, which are critical for functional applications of 2D coordination polymers. Two-dimensional fingerprint plots of the Hirshfeld surface provided detailed insights into the nature and prevalence of intermolecular interactions. The analysis revealed a dominance of H···H contacts (41.7%), underscoring the stabilizing role of hydrogen bonding. O···H/H···O and C···H/H···C interactions contributed 23.9% and 20.6%, respectively, highlighting the significance of polar and weak van der Waals interactions in the packing. Additionally, Cd···O/O···Cd (7.5%) and O···O (2.7%) interactions further stabilize the 3D arrangement, while minor interactions including Cd···H/H···Cd, O···C/C···O, C···C, C···N/N···C, and O···N/N···O, collectively contribute to the intricate network of forces maintaining the crystal integrity. Overall, the Hirshfeld surface analysis illustrates a complex interplay of hydrogen bonding, van der Waals forces, and dipole-dipole interactions that govern the packing and stability of the coordination polymer. The combination of large surface area, intrinsic voids, and diverse intermolecular interactions underscores the potential of this material for applications in gas storage, molecular recognition, and ion transport, providing a comprehensive understanding of its structural and functional properties (Figs. 1).

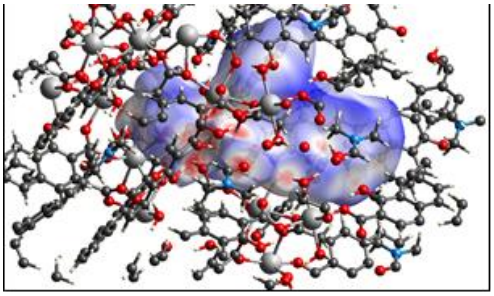

Fig. 3. Hirschfeld surface of d_{norm} HNA-CP, interactions inside and outside the surface.

Single-Crystal X-ray Structure Analysis: Single-crystal X-ray diffraction (SCXRD) was employed to elucidate the structural framework of the synthesized HNA-CP.

The crystallographic analysis confirms that the coordination polymer is constructed through the coordination of Cd(II) ions with 1-hydroxy-2-naphthoic acid (HNA), acetic acid (AA), and solvent molecules of dimethylformamide (DMF). Within the coordination sphere of the Cd(II) centers, HNA and AA ligands exhibit fluxional behavior, whereas two DMF molecules occupy positions in the outer coordination sphere, contributing to the overall structural stabilization. The crystallographic parameters and refinement statistics are presented

for a comprehensive understanding of the polymer's framework (Fig 2).

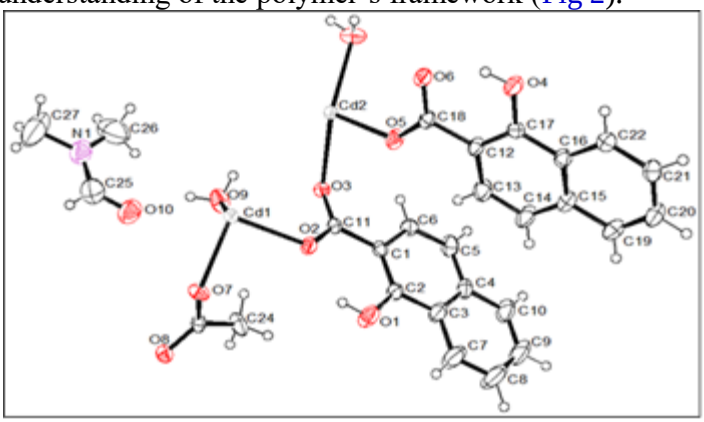

Fig. 2 ORTEP of the asymmetric unit of HNA-CP., showing the atom-numbering scheme with displacement ellipsoids drawn at the 35% probability level.

Conclusion. A novel Cd(II)-based coordination polymer (HNA-CP) was successfully synthesized and comprehensively characterized. Single-crystal X-ray diffraction revealed a well-defined two-dimensional framework, with HNA and acetic acid ligands coordinating the Cd(II) centers and DMF molecules stabilizing the peripheral coordination environment. Hirshfeld surface analysis provided quantitative insights into intermolecular interactions, highlighting dominant H···H, O···H/H···O, and C···H/H···C contacts, alongside Cd···O and other van der Waals and dipole interactions, which collectively stabilize the crystal packing. The observed intrinsic voids and channels suggest potential for gas adsorption, ion transport, and guest molecule incorporation. Collectively, these results establish HNA-CP as a robust and porous 2D coordination polymer with diverse intermolecular interactions, indicating its promise for functional material applications.

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SYNTHESIS AND PHYSICOCHEMICAL CHARACTERIZATION OF A NOVEL CO-NA-EDTA COORDINATION POLYMER

Ruziyev Umid Ural ugli
Doctoral Student, Termez State University
ruziyevumid86@gmail.com
Khayit Khudaynazarovich Turaev
Doctor of Chemical Sciences, Professor
Termez State University
hhturaev@rambler.ru
Aziz Bakhtiyarovich Ibragimov
Doctor of Chemical Sciences, Professor
Institute of General and Inorganic Chemistry,
Academy of Sciences of the Republic of Uzbekistan
Lutfulla Ubaydullaevich Bozorov
Doctor of Technical Sciences, Associate Professor
Termez State Pedagogical Institute
Dilmurod Khursan ugli Saidov
Doctoral Student, Termez State University
Kuvonch Bakhtiyor ugli Kholturaev
Doctoral Student, Termez State University
ORCID 0009-0004-7809-004X
UDK 546.742:544.653

Annotatsiya. Ushbu ishda EDTA ligandi asosida kobalt va natriy ionlari ishtirokida yangi koordinatsion polimer $[CoNa_2(EDTA)(H_2O)_3]_n$ sintez qilindi. Kompleks eritmada sintez qilinib, sekin bug'lanish usuli yordamida kristall shaklda olindi. Olingan birikmaning tuzilishi va funksional guruhlarining koordinatsiyada ishtiroki FT-IR spektroskopiya yordamida o'rganildi. Spektr natijalari EDTA ligandining karboksilat va amin donor atomlari orqali metall markaz bilan koordinatsiyalanganini ko'rsatdi. TGA-DTA termik tahlili kompleksning ko'p bosqichli parchalanishini aniqladi: dastlab 100-180 °C da suv molekulalari ajralishi, undan keyin esa 200-600 °C oralig'ida ligand parchalanishi kuzatildi. Natijalar sintez qilingan birikmaning koordinatsion tuzilishga ega ekanini va 200 °C gacha termik barqarorligini ko'rsatadi.

Kalit so'zlar. Koordinatsion polimer; EDTA ligandi; Kobalt kompleksi; FT-IR spektroskopiya; Termik tahlil (TGA-DTA); Metall-organik birikmalar; Koordinatsion kimyo.

Abstract. In this work, a new coordination polymer $[CoNa_2(EDTA)(H_2O)_3]_n$, based on the EDTA ligand and cobalt and sodium ions, was synthesized using a solution method followed by slow solvent evaporation. The structural features and participation of functional groups in coordination were examined with FT-IR spectroscopy, which confirmed that the EDTA ligand coordinates to the metal center through carboxylate oxygen and nitrogen donor atoms. Thermal analysis (TGA-DTA) showed a multistep decomposition process. The initial weight loss in the 100-180 °C range corresponds to the removal of water molecules, while the subsequent mass loss between 200-600 °C is related to the decomposition of the EDTA ligand. The results confirm the formation of a coordination polymer structure that remains thermally stable up to approximately 200 °C.

Keywords. Coordination polymer; EDTA ligand; Cobalt complex; FT-IR spectroscopy; Thermal analysis (TGA-DTA); Metal-organic compounds; Coordination chemistry.

Introduction. Coordination polymers (CPs) and metal-organic frameworks (MOFs) represent an important and rapidly developing area of modern inorganic chemistry and materials science. In these systems, metal ions or clusters are linked by multidentate organic ligands to form extended one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D) coordination structures. Such materials often exhibit unique physicochemical properties, including structural diversity, good thermal and chemical stability, and potential applications

in adsorption, catalysis, sensing technologies, and electrochemical systems [1-4].

Multidentate ligands play a crucial role in the formation of coordination polymers because they can bind to metal centers through several donor atoms simultaneously, enabling the construction of complex coordination networks. One of the most widely studied ligands is ethylenediaminetetraacetic acid (EDTA), which forms highly stable chelate complexes with metal ions through two nitrogen atoms and four carboxylate oxygen atoms. In addition to acting as a chelating ligand, EDTA can also function as a bridging ligand, allowing the formation of polynuclear complexes and extended coordination structures [5-6].

Complexes formed between EDTA and 3d transition metals, particularly cobalt, have attracted significant interest due to the variable oxidation states, flexible coordination environments, and diverse magnetic and redox properties of cobalt ions. These features make cobalt-based complexes promising materials for applications in catalysis, electrochemical systems, and sensing technologies [7-9].

In addition, alkali metal ions such as sodium can influence the structural organization of EDTA-based systems. Interactions between sodium ions, carboxylate groups, and hydrated water molecules may transform discrete complexes into extended coordination networks, leading to the formation of coordination polymer structures [10-11].

In this work, a new coordination polymer based on cobalt, sodium, and EDTA was synthesized and characterized. The physicochemical properties of the obtained complex were investigated using IR spectroscopy and thermal analysis in order to better understand the coordination behavior of EDTA in the Co-Na system.

Synthesis of the Co-Na-EDTA coordination complex

Ethylenediaminetetraacetic acid (EDTA, 0.377 g, 1.29 mmol) was dissolved in 20 mL of distilled water with continuous stirring until a clear solution was achieved. The pH was adjusted to approximately 7.0 by adding dropwise 0.05 M NaOH, and the solution was then stirred magnetically at 25 ± 1 °C for 1 hour.

Cobalt(II) acetate dihydrate ($Co(CH3COO)_2 \cdot 2H2O$, 0.32 g, 1.29 mmol) was dissolved in 20 mL of a 1:1 mixture of distilled water and methanol. This metal solution was added dropwise to the EDTA solution under constant stirring. A homogeneous pink solution was formed, which was then treated in an ultrasonic bath for 15 minutes to ensure complete mixing and homogenization.

The reaction mixture was transferred to a thermostat set at 35-40 °C and left undisturbed to allow slow solvent evaporation. After approximately 7 days, red crystalline products formed. The crystals were collected via filtration, washed multiple times with cold distilled water and ethanol, and dried in air at room temperature. The yield of the product was about 80%.

FT-IR analysis

The FT-IR spectrum of the synthesized Co-Na-EDTA-H_2O coordination polymer provides important details about the coordination environment and the involvement of functional groups in the complex formation (Fig.1).

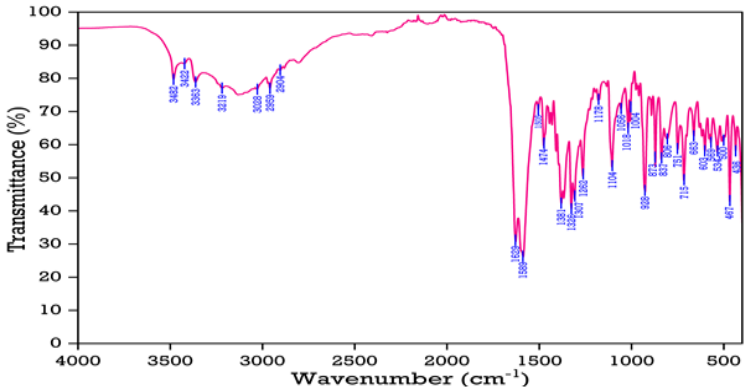

Fig.1. Infrared Spectrum of $[CoNa_2(EDTA)(H_2O)_3]_n$ complex.

A broad absorption band observed in the 3300-3550 cm^{-1} region (3482, 3422, and 3363 cm-1) can be attributed to the O-H stretching vibrations of water molecules. The broad nature of this band indicates hydrogen-bonding interactions, suggesting the presence of water molecules either as coordinated water or as lattice water within the crystal structure. The absorption bands in the 2900-3100 cm^{-1} range (3028, 2959, and 2904 cm^{-1}) correspond to the C-H stretching vibrations of the EDTA ligand. These bands confirm that the organic framework of the EDTA ligand remains intact in the coordination polymer. Two strong bands at 1629 cm^{-1} and 1589 cm-1 are assigned to the asymmetric stretching vibrations of the carboxylate groups ($\nu\_as(COO^{-})$), indicating that the carboxyl groups are mainly in the deprotonated carboxylate form and participate in coordination with the metal centers. This suggests that the oxygen atoms of the carboxylate groups play a significant role in binding the metal ions within the polymeric framework.

In the low-frequency region below 600 cm^{-1}, several bands can be attributed to metal-ligand vibrations. The bands near 500, 467, and 436 cm^{-1} are characteristic of M-O and M-N stretching modes, confirming the coordination of cobalt ions with both oxygen atoms of the carboxylate groups and nitrogen atoms of the EDTA ligand. These spectral features support the formation of a Co-Na-EDTA coordination polymer that includes coordinated or lattice water molecules.

Thermal analysis (TGA-DTA)

The thermal behavior of the coordination polymer $[CoNa_2(EDTA)(H_2O)_3]_n$ was examined using simultaneous TGA and DTA analysis. The thermogram shows a multistep thermal decomposition process, indicating the gradual removal of coordinated molecules followed by the breakdown of the organic ligand framework. Fig.2) .

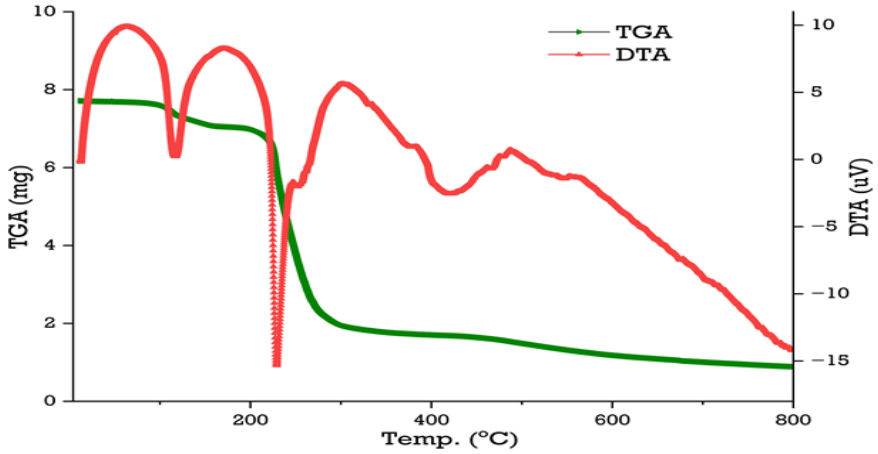

Fig. 2. TG-DTA curves of $[CoNa_2(EDTA)(H_2O)_3]_n$ complex.

The first weight loss occurs between 100-180 °C and involves the removal of three water molecules linked to the complex. Based on the molecular makeup of the complex, the estimated mass loss for these three H_2O molecules is around 12-13%, aligning with the initial drop seen in the TGA curve. The weak endothermic DTA peak supports that this stage relates to dehydration.

A significant weight loss occurs in the 200-300 °C range, accompanied by a strong exothermic peak near 230-250 °C in the DTA curve. This stage can be attributed to the thermal decomposition of the EDTA ligand, including the breakdown of coordinated carboxylate groups and the partial destruction of the organic backbone. Further gradual mass loss happens between 300 and 600 °C, correlating with the complete degradation of the remaining organic fragments of the EDTA ligand. The broad DTA signals observed in this

region suggest complex decomposition processes involving fragmentation and oxidation of the organic components.

Above 600 °C, the mass becomes relatively stable, indicating the formation of a thermally stable inorganic residue. This residue most likely comprises metal oxides such as CoO/Co_3O_4 along with sodium oxide species formed after the full decomposition of the coordination polymer. Overall, the TGA-DTA results show that the $[CoNa_2(EDTA)(H_2O)_3]_n$ coordination polymer is thermally stable up to about 200 °C, after which dehydration and ligand decomposition begin. The multistep decomposition behavior observed further supports the presence of coordinated water molecules and an EDTA-based coordination framework in the synthesized complex.

Conclusion. A new coordination polymer $[CoNa_2(EDTA)(H_2O)_3]_n$ was successfully synthesized using EDTA as a multidentate ligand, with cobalt and sodium ions as the metal centers. The FT-IR analysis confirmed that the ligand coordinates through carboxylate oxygen and nitrogen donor atoms, forming a stable coordination framework. Thermal analysis showed that the complex undergoes a multistep decomposition process, starting with dehydration followed by decomposition of the organic ligand. The compound remains thermally stable up to about 200 °C, after which structural decomposition occurs. The results confirm the formation of a cobalt-sodium EDTA-based coordination polymer and provide insight into its structural features and thermal stability.

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SYNTHESIS, CRYSTAL STRUCTURE AND HIRSHFELD SURFACE ANALYSIS OF A TWO-DIMENSIONAL ZINC(II) COORDINATION POLYMER BASED ON NICOTINIC ACID

Kuvonch Bakhtiyor ugli Kholturaev
Doctoral Student, Termez State University
quvonch.xolturaev@gmail.com
Khayit Khudaynazarovich Turaev
Doctor of Chemical Sciences, Professor
Termez State University
hhturaev@rambler.ru
Aziz Bakhtiyarovich Ibragimov
Doctor of Chemical Sciences, Professor
Institute of General and Inorganic Chemistry,
Academy of Sciences of the Republic of Uzbekistan
Lutfulla Ubaydullaevich Bozorov
Doctor of Technical Sciences, Associate Professor
Termez State Pedagogical Institute
Dilmurod Khursan ugli Saidov
Doctoral Student, Termez State University
Umid Ural ugli Ruziyev
Doctoral Student, Termez State University
ORCID 0009-0001-2032-9060
UDK 546.742:544.653

Annotatsiya. Nikotin kislotasi asosida rux(II) koordinatsion polimeri solvotermal sharoitda sintez qilindi. Monokristalli rentgen difraksiyasi tahlili natijasida Zn(II) ionlari va nikotin kislotasi ligandlari asosida hosil bo‘lgan ikki o‘lchamli koordinatsion polimer tuzilishi aniqlangan. Zn(II) markazi kislorod va azot donor atomlari orqali hosil bo‘lgan buzilgan tetraedrik koordinatsion geometriyaga ega. Poliedrik parametrlar hisoblash natijalari metall markazi atrofidagi koordinatsion muhitning buzilganligini tasdiqladi. Bundan tashqari, kristall strukturasidagi molekulalararo o‘zaro ta’sirlarni aniqlash maqsadida Hirshfeld sirt tahlili va ikki o‘lchamli barmoq izit diagrammalari qo‘llanildi. Tahlil natijalari O···H/H···O tipidagi o‘zaro ta’sirlar kristall qadoqlanishida ustunlik qilishini ko‘rsatdi hamda vodorod bog‘lanishlari supramolekulyar arxitekturaning barqarorlashuvida muhim rol o‘ynashini tasdiqladi.

Kalit so‘zlar. Koordinatsion polimer; Rux(II); Nikotin kislotasi; Kristall tuzilishi; Hirshfeld sirt tahlili; Supramolekulyar o‘zaro ta’sirlar.

Abstract. A zinc(II) coordination polymer based on nicotinic acid was synthesized under solvothermal conditions. Single-crystal X-ray diffraction analysis revealed the formation of a two-dimensional coordination polymer constructed from Zn(II) ions and nicotinate ligands. The Zn(II) center adopts a distorted tetrahedral coordination geometry formed by oxygen and nitrogen donor atoms. Polyhedral parameter calculations confirmed the distortion of the coordination environment around the metal center. In addition, Hirshfeld surface analysis and two-dimensional fingerprint plots were employed to investigate intermolecular interactions within the crystal structure. The analysis revealed that O···H/H···O interactions dominate the crystal packing, indicating the important role of hydrogen bonding in stabilizing the supramolecular architecture.

Keywords. Coordination polymer; Zinc(II); Nicotinic acid; Crystal structure; Hirshfeld surface analysis; Supramolecular interactions

Introduction. Coordination polymers constructed from transition metal ions and multifunctional organic ligands have attracted considerable attention in recent years due to their structural diversity and potential applications in various fields such as catalysis, adsorption, sensing, and functional materials. These compounds are formed through the self-assembly of metal ions with organic linkers capable of coordinating through different donor atoms, resulting in extended architectures with one-, two-, or three-dimensional frameworks. The structural diversity of coordination polymers is largely governed by the coordination geometry of the metal centers and the binding modes of the organic ligands. Consequently, the rational design of coordination polymers remains an important topic in modern coordination chemistry and crystal engineering [1-4].

Among the wide range of organic ligands employed in the construction of

coordination polymers, pyridine-carboxylate derivatives are particularly attractive because they contain both nitrogen and oxygen donor atoms within the same molecule. The pyridine nitrogen atom and the carboxylate oxygen atoms can simultaneously coordinate to metal centers, allowing the ligand to adopt various coordination modes including monodentate, chelating, and bridging configurations. Owing to these versatile coordination properties, pyridine-carboxylate ligands have been widely used in the synthesis of coordination polymers with transition metal ions such as Zn(II), Cd(II), Mn(II), Ni(II), and Co(II). These systems often generate coordination architectures ranging from discrete complexes to extended one-dimensional chains, two-dimensional layers, and three-dimensional frameworks depending on the ligand geometry and the reaction conditions [5-7].

The topology of coordination polymers formed from pyridine-carboxylate ligands is strongly influenced by both the structural characteristics of the ligand and the coordination preferences of the metal ions. In many reported systems, bent or asymmetrical pyridine-carboxylate ligands promote the formation of two-dimensional coordination networks when coordinated with transition metal ions such as Zn(II) and Cd(II). The carboxylate groups frequently act as bridging linkers connecting adjacent metal centers, while the pyridine nitrogen atoms provide additional coordination stabilization. As a result, various structural motifs such as grid-like layers, ladder-type frameworks, and corrugated sheets can be generated. Moreover, supramolecular interactions such as hydrogen bonding and π-π stacking interactions between aromatic rings often play an important role in stabilizing the crystal packing and promoting the formation of extended architectures [8-10].

In this study, a zinc(II) coordination compound based on isonicotinic acid was synthesized under solvothermal conditions. Single-crystal X-ray diffraction analysis revealed the formation of a two-dimensional coordination polymer constructed from Zn(II) ions and isonicotinate ligands. The coordination environment around the Zn(II) center and the structural features of the polymeric framework were analyzed in detail. In addition, polyhedral parameter analysis was used to evaluate the distortion of the coordination geometry, while Hirshfeld surface analysis and two-dimensional fingerprint plots were employed to investigate the intermolecular interactions and supramolecular packing within the crystal structure. These analyses provide insight into the structural characteristics and intermolecular interactions responsible for stabilizing the coordination polymer.

Experimental. The synthesized coordination polymer $[Zn_2(NK)_2NO_3]_n$ was structurally characterized by single-crystal X-ray diffraction analysis in order to determine its crystal structure and coordination environment. The obtained crystallographic data were used to describe the structural features of the compound and to analyze the coordination geometry around the Zn(II) center. In addition, polyhedral parameter calculations were performed to evaluate the distortion of the coordination environment and to provide a quantitative description of the metal coordination geometry. Furthermore, Hirshfeld surface analysis and two-dimensional fingerprint plots, generated using Crystal Explorer 17, were employed to investigate intermolecular interactions and the supramolecular packing within the crystal lattice.

Results and discussion. The crystal structure of the coordination polymer **[**$[Zn_2(NK)_2NO_3]_n$ was determined by single-crystal X-ray diffraction analysis, and the crystallographic parameters are summarized in Table 1. The compound crystallizes in the monoclinic crystal system with the C2/c space group (No. 15). Structural analysis shows that Zn(II) centers are linked by NK ligands through bridging coordination modes, forming an extended coordination polymer network. This connectivity propagates throughout the crystal lattice and is further stabilized by weak intermolecular interactions such as hydrogen bonding and van der Waals forces.

Table 1. Crystal data for $[Zn_2(NK)_2NO_3]_n$

Crystal Data	
Formula	$C_{12}\ H_8\ N_3\ O_7\ Zn_2$
Formula Weight	371.58

Crystal System	monoclinic
Space group	C2/c (No. 15)
a, b, c [Å]	13.0218(11) 7.7954(6) 13.4149(8)
α, β, γ [°]	90 97.301(7) 90
V [Å^3]	1350.71(18)
Z	4
D(calc) [g/cm^3]	1.827
Mu (CuKα) [mm^{-1}]	2.968
F(000)	748
Crystal Size [mm]	0.15 x 0.20 x 0.25

Polyhedral parameter analysis (Table 2) was performed to evaluate the coordination geometry around the Zn(II) center. The calculated polyhedral volume (3.988 Å^3), distortion index (0.04767), quadratic elongation (1.0768), and bond angle variance (260.79 deg^2) indicate a noticeable deviation from an ideal tetrahedral geometry. The effective coordination number (3.43) further supports the presence of a slightly distorted coordination environment. These parameters confirm that the Zn(II) center adopts a distorted tetrahedral coordination geometry, which contributes to the formation of a stable extended coordination polymer framework in the crystal structure.

Table 2. Polyhedral parameters for [Zn$_2$(NK)$_2$NO$_3$]$_n$

Bond	**Distance (Å)**
Zn(1)-O(2)	1.902(4)
Zn(1)-O(3)	2.219(6)
Zn(1)-O(1)	2.007(4)
Zn(1)-N(1)	2.081(4)
Average bond length Å	2.0521
Polyhedral volume Å^3	3.9882
Distortion index (bond length)	0.04767
Quadratic elongation	1.0768
Bond angle variance deg^2	260.7930
Effective coordination number	**3.4327**

Hirshfeld Surface Analysis. To obtain deeper insight into the intermolecular interactions governing the crystal packing of the coordination polymer [Zn$_2$(NK)$_2$NO$_3$]$_n$, a Hirshfeld surface analysis was performed using the Crystal Explorer program. The Hirshfeld surface mapped over d_{norm}, d_e, d_i, and curvedness provides a detailed visualization of the close intermolecular contacts present within the crystal lattice (Fig. 1). This method allows the identification and qualitative analysis of the interactions responsible for stabilizing the supramolecular architecture of the structure.

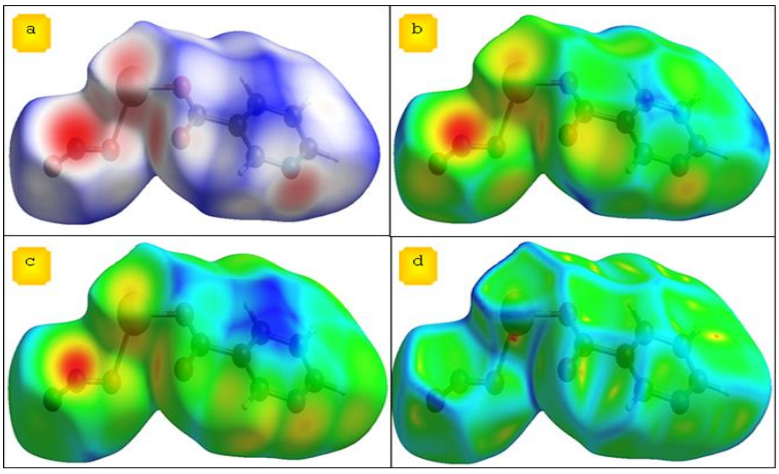

Fig. 1 Hirshfeld surface maps of [Zn$_2$(NK)$_2$NO$_3$]$_n$: (a) d_{norm} map, (b) d_e map, (c) d_i map and (d) curvedness map.

The d_{norm} surface clearly reveals several prominent red spots, which correspond to intermolecular contacts shorter than the sum of the van der Waals radii. These regions are mainly associated with interactions involving oxygen and hydrogen atoms, indicating that hydrogen bonding interactions play an important role in the stabilization of the crystal structure. The white areas represent contacts close to the van der Waals distances, while the blue regions correspond to longer contacts with weaker intermolecular interactions. The d_e and d_i surfaces provide complementary information about the distances from the Hirshfeld surface to the nearest external and internal atoms, respectively, allowing the identification of atoms participating in close intermolecular contacts. Meanwhile, the curvedness surface illustrates the curvature of the Hirshfeld surface, where relatively flat regions correspond to areas of significant intermolecular packing between neighboring molecular units. These flat regions are typically associated with planar interactions and indicate efficient packing within the crystal lattice.

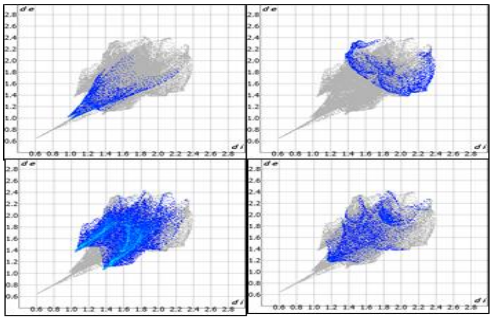

Fig. 2. Fingerprint plots of $[Zn_2(NK)_2NO_3]_n$.

Further quantitative analysis was obtained from the two-dimensional fingerprint plots (Fig. 2). The results show that O···H/H···O interactions make the largest contribution (41.5%) to the Hirshfeld surface, confirming that hydrogen bonding between ligand hydrogen atoms and oxygen atoms from nitrate or carboxylate groups dominates the crystal packing. Other contributions include H···H contacts (9.3%), C···H/H···C (6.9%), and N···H/H···N (6.7%), which represent weak van der Waals and hydrogen bonding interactions. Additional contacts such as Zn···O/O···Zn (6.3%) and Zn···N/N···Zn (5.3%) indicate secondary interactions involving the metal center. Minor contributions from C···C, C···O/O···C, O···O, and other contacts further support the stabilization of the three-dimensional supramolecular framework.

Conclusion. Zinc(II)-based coordination polymer was successfully synthesized using nicotinic acid under solvothermal conditions. Single-crystal X-ray diffraction analysis revealed the formation of a two-dimensional coordination polymer with a distorted tetrahedral coordination environment around the Zn(II) center. Polyhedral parameter analysis confirmed the deviation from an ideal tetrahedral geometry. Hirshfeld surface and fingerprint plot analyses showed that O···H/H···O interactions dominate the intermolecular contacts, indicating that hydrogen bonding plays a key role in stabilizing the supramolecular structure. These results provide insight into the structural features and intermolecular interactions governing the stability of the coordination polymer.

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QATLAM SUVI TARKIBIDAGI BARIY IONLARIDAN BARIY SULFAT TUZI HOSIL BO‘LISH REAKSIYASI TAHLILI

Sultonova Fotima Normurodovna
fotimasultonova@gmail.com
Ataqulova Dilbar Dusmurodovna
Iqtisodiyot va pedagogika universiteti, (PhD) dotsent.,
dilbarataqulova362@gmail.com
Qurbanov Mingniqul Jumagulovich
Qarshi davlat universiteti t.f.d. dots.
qurbanovmeyliqul@gmail.com
ORCID 0000-0001-7867-4185
UDK.050 (045)

Annotatsiya. Neft konlarini o‘zlashtirishning boshlang‘ich va yakuniy bosqichlarida bariy sulfat tuzining quduq tubiga cho‘kish muammosi quduq va erosti uskunalarini ishlatish davomida uning doimiy hamrohi hisoblanadi. Ushbu maqolada quduqda bariy sulfat tuzining cho‘kish sharoitlarini o‘rganishda laboratoriya tajribalariga asoslangan natijalar keltirib o‘tilgan. Quduq tubi eritmasida tuz hosil bo‘lganligini aniqlashning asosiy mezonlaridan biri eritma tarkibidagi qattiq zarrachalarda bariy sulfat tuzining mavjudligi qayd etilgan. Shu o‘rinda eritmaning sho‘rligi, bariy ioni va sulfat ionlari konsentratsiyasi kabi yakuniy tarkibi bo‘lgan qattiq zarrachalardagi bariy sulfat konsentratsiyasini aniqlash orqali eritma tarkibidagi bariy ionlarining aralashma tarkibidagi konsentratsiyasini hisoblash mumkinligi yoritilgan. Shunga ko‘ra qatlam suvini tahlil qilish natijalari asosida bariy sulfat hosil bo‘lish reaksiyasining tugash vaqtini hisoblash mumkin.

Kalit so‘zlar: tuz cho‘kindilari, bariy sulfat, cho‘kish, suv aralashtirish, kristallarni o‘sishi, aralashtirish konsentratsiyasi, sulfat ionlari, bariy ionlari.

ANALYSIS OF THE REACTION OF BARIUM SULPHATE SALT FORMATION FROM BARIUM IONS IN AQUATIC WATER

Abstract. The problem of salt deposits is a constant companion to the operation of downhole and underground equipment, both at the initial and final stages of oil field development. The paper presents the results of laboratory experiments to study the conditions of barium sulfate deposition in downhole equipment. One of the main criteria for determining the formation of salt in the wellbore solution is the presence of barium sulfate salt in the solid particles in the solution. It is explained that by determining the concentration of barium sulfate in the solid particles with the final composition such as the salinity of the solution, the concentration of barium ions and sulfate ions, the concentration of barium ions in the solution can be calculated. Accordingly, based on the results of the analysis of the formation water, the completion time of the barium sulfate formation reaction can be calculated.

Keywords: scaling, barium sulfate, precipitation, water mixing, seed crystals, mixing concentration; sulfate ions; barium ions.

Kirish. Mamlakat neft sanoati oldida turgan eng muhim vazifalardan biri o‘ta qiyin geologik, fizik va texnologik sharoitlarda neft qazib olish jarayonlarini takomillashtirishdir. Bu mamlakatdagi yuqori mahsuldor ko‘pgina neft konlarini o‘zlashtirishning kech bosqichiga o‘tayotgani va ularning umumiy hajmida o‘zlashtirilishi qiyin bo‘lgan zaxiralar ulushi ortib borayotgani bilan bog‘liq.

Ko‘pgina tadqiqotchilar yangi turdagi metalorganik birikmalarni sintezlashda ko‘p tarmoqli xelatlovchi fosfonat guruhlari orqali bog‘lanishlar hosil qiluvchi organik ligandlarning istiqbollari ustida ilmiy izlanishlar olib borishmoqda. Fosfat kislota molekulasidagi kislorod atomlarining bariy kationlari kabi ionlar bilan mustahkam kimyoviy bog‘lar hosil qilishi ko‘pgina birikmalarni sintezlashda muhum o‘rin tutadi [1-3]. Yangi metallorganik birikmalarni sintezlashda fosfat kislota kabi bog‘lovchilardan foydalanish, ushbu birikmalarning tez reaksiyaga kirishishi bilan izohlanadi. Bu esa ushbu hosil bo‘lgan birikmalarning tuzilishini aniqlash va tahlil qilish uchun zarur bo‘lgan yirik monokristallarning o‘sishi ustidan nazoratni saqlab qolishni sezilarli darajada qiyinlashtiradi [4-7].

Ayrim mualliflarning[8] fikricha, kon sharoitida ishlatilayotgan eritmalar ish jarayoni paytida suyuqlik suv osti elektr motori va nasosning o‘zidan o‘tayotganda qizib ketishi mumkin ekanligini va suyuqlikning isib ketishi bariy sulfatning eruvchanligini oshirishi mumkin ekanligini qayd etishgan.

Shuningdek, ushbu texnologik jarayonlarda qattiq faza hosil bo‘lish mexanizmining ba’zi nazariy jihatlarini tahlil qilish mumkinligi va ushbu jarayonlar tahlili bir necha bosqichlardan iborat murakkab jarayon ekanligi ilmiy tadqiqotchlar tomonidan o‘rganilgan [9, 10].

Tadqiqot metodologiyasi. Bariy sulfat tuzi hosil bo‘lish jarayonini tavsiflash va bashorat qilishda odatda faqat kimyoviy (ion konsentratsiyasi va eritmaning ion kuchi) va termodinamik (bosim va harorat) tavsifnomalari qo‘llaniladi.

Quyidagi 1-jadvalda Buxoro-Xiva neft-gaz mintaqasida joylashgan neft-gaz kondensatli Shakarbuloq koni suvining tarkibiy tahlili keltirilgan.

1-Jadval

Shakarbuloq koni suvining tarkibiy tahlili

Ko‘rsatkichlar	Quduq № 4		Quduq № 9		Quduq № 22	
Ionlar	mg/l	mmol/l	mg/l	mmol/l	mg/l	mmol/l
Xloridlar (Cl)	87455,0	2457,3	88357,50	2492,45	88357,5	2492,45
Sulfatlar (SO_4^{-2})	458,82	9,55	1989,60	41,42	682,58	14,21
Gidrokarbonatlar (HCO_3^-)	433,10	7,10	411,75	6,75	564,25	9,25
Kalsiy (Ca^{+2})	8316,60	415,00	7915,80	395,00	8216,40	410,00
Magniy (Mg^{+2})	911,25	75,00	1215,00	100,00	1032,75	85,00
Natriy+kaliy (Na^++K^+)	47654,9	1993,93	48890,52	2045,63	48299,8	2020,92
Umumiy qattiqlik, mmol/l	490,00		495,00		49500	
Umumiy minerallashuv, mg/l	145239,72		148780,2		147153,36	
Vodorod ko‘rsatkich, pH	9,0		8,74		9,27	
Muallaq zarrachalar miqdori, mg/l	2413,00		8007,00		1869,00	
Zichlik, г/см^3	1,0835		1,0815		1,0835	
Sulin bo‘yicha tasnifi	Kalsiy xlorli tip		Kalsiy xlorli tip		Kalsiy xlorli tip	
Namuna tashqi ko‘rinishi	Mayda qattiq muallaq zarrachalar saqlovchi jigarrang tusli va neft plyonkasi cho‘kmasini hosil qiluvchi loyqa eritma		Mayda qattiq muallaq zarrachalar saqlovchi qoramtir jigarrang tusli va neft plyonkasi cho‘kmasini hosil qiluvchi loyqa eritma		Mayda qattiq muallaq zarrachalar saqlovchi jigarrang tusli va neft plyonkasi cho‘kmasini hosil qiluvchi loyqa eritma	

Shu o‘rinda bariy sulfat tuzi hosil bo‘lishini oldindan aytib o‘tish uchun SI bo‘yicha quyidagi tenglamani keltirish mumkin:

$$SI = \log [Ba^{2+}] \cdot [SO4^{2-}] - 4{,}063\ \mu\ 0{,}5 + 2{,}787\ \mu - 3{,}33\cdot10^{-3}\ T\mu^{0,5} - 7{,}561\cdot10^{-3}\ T + +10^{-3}T + 3{,}775\cdot10^{-5}T^2 - 7{,}709\cdot10^{-3}P + 10$$

bu yerda: P – bosim, Mpa. T – harorat, ^oC. μ - eritmaning ion kuchi $[Ba^{2+}] \cdot [SO4^{2-}]$ SI>0 molyar konsentratsiyalarda tuzlarning cho‘kishi, SI<0 da cho‘kma hosil bo‘lmaydi.

Ko‘rinib turibdiki, bunday bashorat tenglamasi bir qavatli quduq uchun harorat va bosim sharoitida sezilarli o‘zgarishlar bilan bariy sulfat hosil bo‘lish holatini tavsiflaydi. Bundan tashqari, tenglama quduq boshidan olingan sirt namunalarining natijalari uchun tahlil

qilinsa yaxshi natijalarni bermaydi. Chunki u quduqning yuqori qismida joylashgan va qattiq muallaq zarrachalar shaklida mavjud bo‘lgan bariy sulfatni hisobga olmaydi. Yuqorida keltirilgan tenglamani tahlil qilib, biz past bosimli (20-30 MPa) va qatlam harorati past (25-27 °C) bo‘lgan quduqni ishlatganda, termodinamik parametrlarning hissasi ahamiyatsiz darajada bo‘lib, u 3% dan ko‘p emas va bosim hissasi odatda minimal darajada, ya’ni 1% dan kam. Bu qiymat kimyoviy parametrlarni (ion kuchi va molyar konsentratsiyasini) aniq darajada aniqlangan aniqlikdan pastroq. Shuni ta’kidlash kerakki, ESN ni ishlatish paytida suyuqlik suvosti elektr motori va nasosning o‘zidan o‘tayotganda qizib ketadi. Isitish bariy sulfatning eruvchanligini oshirganligi sababli, ESN ning ishchi tizimlarida cho‘kma xavfini kamaytirish kerak. Amalda esa bu kuzatilmaydi. Agar bariy sulfatning cho‘kishi eritmadgi qattiq zarrachalarning ESN ishchi tizimi mikrotengsizligi bois jipslashuvi natijasida sodir bo‘ladi deb faraz qilsak, va keyinchalik ushbu zarrachalarning o‘ta to‘yingan eritmadan o‘sishi (termodinamik parametrlarning o‘zgarishi tufayli) sodir bo‘ladi. Demak, ESN ning chugun g‘ildiraklarini plastikli ESN g‘ildiraklari bilan o‘zgartirilsa, bariy sulfat tuzlari bilan murakkablashgan quduqlarda ta’mirlashlara davri ortishini kuzatish mumkin. Afsuski, amalda bunday holat kuzatilmaydi yoki quvur uskunalarini ta’mirlash davrining ortib borishi ahamiyatsiz bo‘lib qoladi. Yuqoridagilardan kelib chiqan holda, shunday xulosaga kelish mumkinki, quduqni burg‘ulash ishlarida bariy sulfat tuzi cho‘kishining asosiy sababi sifatida shuni ko‘rsatish mumkinki, ya’ni ko‘p zonali quduqlarning suvlari, qotib qolgan o‘zaro oqimli bir zonali quduqlar yoki ishlab chiqarish korpusidagi uzilishlar bilan ishlash natijasida har xil turdagi suvlarning (sulfat va barit) aralashishi hisobidan hosil bo‘ladi.

Natijalar muhokamasi. Ushbu texnologik jarayonlarda qattiq faza hosil bo‘lish mexanizmining ba’zi nazariy jihatlarini tahlil qilish mumkin. Ushbu jarayonlar tahlili bir necha bosqichlardan iborat murakkab jarayonlarni o‘z ichiga oladi.

Quduq tubi va geologik qazish ishlari davomida ishlatiladigan eritmalarda hosil bo‘luvchi kristallanish jarayonlarini quyidagicha izohlash mumkin:

– birinchidan, Cho`kma hosil qiluvchi ionlarning suvsizlanishi. Eritmadagi ionlar gidratlangan holda bo‘ladi, shuning uchun kristall hosil bo‘lishidan oldin ular gidratlangan suvini yo‘qotishi kerak;

– ikkinchidan, birlamchi kristallanish markazlarining hosil bo‘lishi – bu kristallar murtagining hosil bo‘lishidir. Qarama-qarshi qutbli ikkita ion molekulaga birlashganda, hali kristalli shakl hosil qilmaydi. Birlamchi bariy sulfat kristalining hosil bo‘lishi bir qator oraliq bosqichlar orqali amalga oshadi: birinchi bosqichda $Ba^{2+} + SO4^{2-} \leftrightarrow Ba^{2+} \cdot SO4^{2-}$ ionlarining bir biriga tortilishi hisobidan ushbu ionlar jufti hosil bo‘ladi; ikkinchi bosqichda esa, $Ba^{2+} \cdot SO4^{2-} \leftrightarrow BaSO_4$ yoki $Ba^{2+} \cdot SO4^{2-} \leftrightarrow [Ba(SO4)_2^{2-}]$ yoki qachonki bariy kationining miqdori mo‘l bo‘lganda $2Ba^{2+}$ kationlariga ikkita silfat ionining birikishidan hosil bo‘lgan bariy kationini tutuvchi $[Ba_2SO_4]^{2+}$ komplekslarining hosil bo‘lishi, shuningdek eritmada sulfat ionlari miqdori mo‘l bo‘lganda, $[Ba(SO_4)_2]^{2-}$ kompleks ionlarini saqlovchi oraliq moddalarning hosil bo‘lishi sodir bo‘ladi. Bu jarayon esa eritmada doimiy ravishda induksion tarzda davom etadi;

– uchinchidan, birlamchi kristallanish markazlarining o‘sishi, ularda ionlar sonining ko‘payishiga olib keladi, natijada eritmadagi kattaroq agregat tuzilishiga ega bo‘lgan kristallalanish markazlariga ionlarning birikishini ta’minlaydi. Buning natijasida eritma tarkibidagi bariy sulfat tuzining yirik kristallari hosil bo‘lishiga sababchi bo‘ladi. Ammo ushbu holatda ayni shu yirik kristallanish jarayonida hosil bo‘lgan birikma hali eritmadan cho‘kma sifatida ajralib chiqishga qodir bo‘lmaydi. Bu jarayonni eritma va eritmadagi ionlar ishtirokidagi hosil bo‘luvchi erimaydigan birikma hosil bo‘lishining kolloid bosqichi deb hisoblash mumkin;

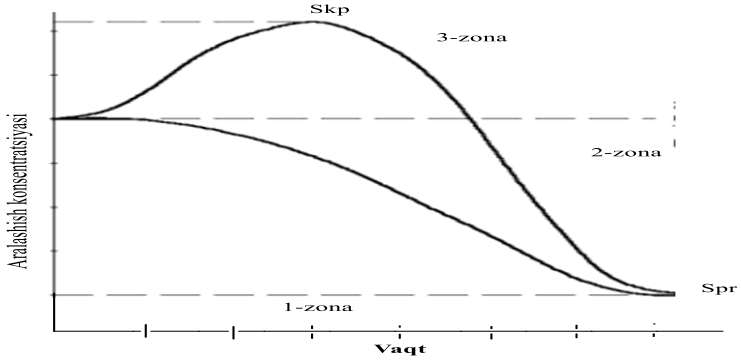
– to‘rtinchidan, eritmadagi kristallar yoki kristallar agregatlarining ma’lum vaqt oralig‘ida hosil bo‘lishi, ularning eritma muhitida qola olmasligi va qattiq fazani hosil qilib (cho‘kma) ajralib chiqishini ta’minlaydi. Cho‘kmaning ajralib chiqishi tabiatini ikkita jarayonlar tezligining nisbatlariga bog‘lash mumkin. Birinchi jarayonda eritmadagi bariy sulfat tuzini hosil qiluvchi dastlabki bariy sulfat hosil bo‘lishini boshlab beruvchi kristallar murtagining paydo bo‘lish tezligi - υ1va ushbu kristall murtagining vaqtga bog‘liq holda

o‘sish tezligi -υ2 bilan izohlanadi.

Tadqiqotdagi υ1 va υ2 qiymatlari (Q-P)/P formulasi bo‘yicha aniqlangan nisbiy o‘ta to‘yinganlik darajasi bilan aniqlanadi, bu erda Q - istalgan vaqtda o‘ta to‘yingan eritmadagi erigan moddaning konsentratsiyasi va P – ma’lum bir haroratda qattiq faza va eritma o‘rtasidagi muvozanatga erishilganda ushbu moddaning eruvchanligi. Shunday qilib, (Ccm), bariy sulfatning boshlang‘ich konsentratsiyasi, bu odatda ma’lum mineralizatsiya va haroratda Cpr dan (cheklangan eruvchanlikdan) past yoki undan yuqori bo‘lishi mumkin. Shubhasiz, birinchi holda, kristall yadrolarning shakllanishi va mavjud bo‘lganlarning o‘sishi mumkin emas.

Jumladan, Ccm>Cpr (Ccm-aralashtirish konsentratsiyasi, Cpr-cheklovchi eruvchanlik) bo‘lgan holatda aralash konsentratsiya diapazoni 1-rasmda ko‘rsatilganidek, uchta zonaga bo‘linishi mumkin:

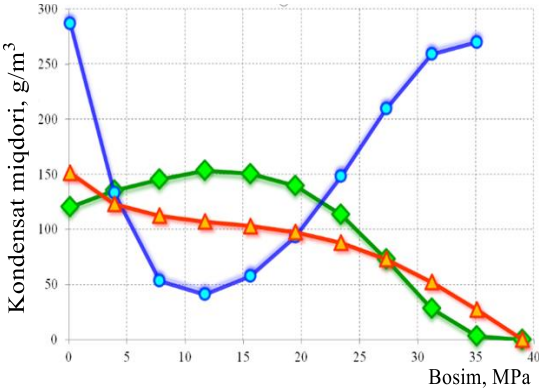
– ushbu rasmdagi zonalarni tavsifiga ko‘ra, birinchi zona eritmaning to‘yinish zonasi bo‘lib, bu sohada kristallar hosil bo‘lishi kuzatilmaydi. Bunday konsentratsiyada doimiy termodinamik (birinchi navbatda harorat) va fizik-kimyoviy (sho‘rlanish va qarama-qarshi ionlar nisbati — sulfat ionlari va bariy ionlari) sharoitida hech qanday kristallar hosil bo‘lmaydi va mavjud kristallar o‘smaydi.



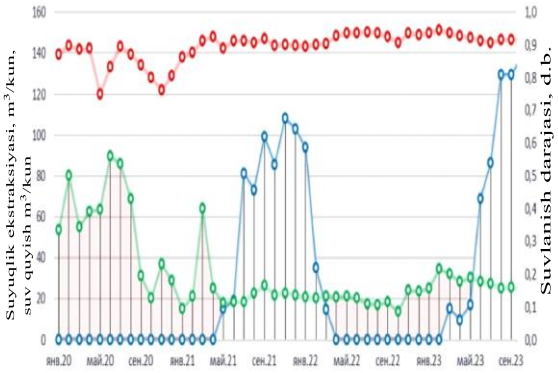
1-Rasm. Aralash konsentratsiyasining vaqtga bog‘liqligi

– ikkinchi zona esa Skp dan kichik biroq Spr dan katta bo‘lgan holat metastabil soha bo‘lib, qattiq muallaq zarrachalar hosil bo‘lmaydi, biroq ushbu sohada kristallar o‘sishi mumkin.

– uchinchi zona (Skp) kretik konsentratsiya zonasi bo‘lib, undan yuqori konsentratsiyada hamisha kristallanish markazi hosil bo‘lishi kuzatiladi ya’ni ushbu holatda qattiq muallaq zarrachalar hosil bo‘ladi. Quyidagi 2-rasmda Shakarbuloq koni №4-qudug‘i kondensat miqdorining quduq bosimiga bog‘liqlik diagrammasi keltirilgan.



2-Rasm. № 4- Quduq qatlam aralashmasining defferentsial kondensatsiya egri chiziqlari - qatlam yo‘qotishlari, -potensial tarkib, -kondensat qazib olish



3-Rasm. № 4- Quduq qatlamining suvlanish darajasi
-suv quyish, m^3/kun, -suyuqlik ekstratsiyasi, m^3/kun, -suvlanish darajasi, %.

Ushbu quduqning suyuqliklarini ekstraksiyalashning suvlanish darajasiga bog‘liqlik gistogrammasi keltirilgan. Unga ko‘ra quduqdan kondensatni qazib olishga nisbatan suvlanish darajasi yuqori ekanligini ko‘rish mumkin.

Xulosa. Demak, asosiy xulosa sifatida shuni aytish mumkinki, eritmada tuz hosil

bo‘lganligini aniqlashning asosiy mezonlaridan biri, eritma tarkibidagi qattiq zarrachalarda bariy sulfat mavjudligidir. Shuning uchun, hosil bo‘lgan eritmaning yakuniy tarkibi (sho‘rligi, bariy ioni va sulfat ionlari konsentratsiyasi) va qattiq zarrachalardagi bariy sulfat konsentratsiyasini aniqlab, biz eritma tarkibidagi bariy ionlarining aralashma tarkibidagi konsentratsiyasini hisoblashimiz mumkin. Ushbu munosabatlarga asoslanib, qatlam suvini tahlil qilish natijalari asosida bariy sulfat hosil bo‘lish reaksiyasining tugash vaqtini hisoblash mumkin.

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DON TARKIBIDAGI MAKRO VA MIKROELEMENT MIQDORINI RENTGEN-FLUORESSENT USULIDA ANIQLASH

Xamrayev Nurbek Ulug‘bekovich
Xorazm Ma’mun akademiyasi, Tabiiy fanlar bo‘limi katta ilmiy xodimi, b.f.f.d.
nurbek.hamraev@gmail.com
ORCID 0000-0002-9349-3048
Polvonov Boburbek Ilxomovich
Xorazm Ma’mun akademiyasi tayanch doktoranti
boburpolvonov15@gmail.com
UDK 633.111.1; 543.423.8

Annotatsiya. Ushbu maqolada Xorazm viloyati tuproq-iqlim sharoitida bir xil agrotexnik usullar asosida yetishtirilgan 6 ta kuzgi yumshoq bug‘doy navlari (Chillaki, Bezostaya-1, Krasnodar-99, Fortuna, Kroshka va Pamyat) don tarkibidagi makro (Mg, P, S, K, Ca) va mikroelementlar (Si, Mn, Fe, Ni, Cu, Zn) miqdori o‘rganildi. Elementlar tarkibi to‘lqin uzunlik-dispersiyali rentgen-fluoressent spektrometri yordamida aniqlanib, natijalar quruq modda asosida baholandi. Tadqiqot davomida navlar o‘rtasida makro va mikroelementlar miqdori sezilarli darajada farq qilishi aniqlandi. Ayrim navlar muayyan elementlar bo‘yicha yuqori ko‘rsatkichlarni namoyon etgan bo‘lsa, boshqalari nisbatan past qiymatlarni qayd etdi. Olingan natijalar bug‘doy navlarining oziqaviy tarkibini baholash hamda seleksiya jarayonida istiqbolli shakllarni tanlashda muhim ilmiy-amaliy ahamiyatga ega ekanligini ko‘rsatadi.

Kalit so‘zlar: Kuzgi yumshoq bug‘doy, don tarkibi, rentgen-fluoressent tahlil, makro va mikroelement miqdori.

DETERMINATION OF MACRO-AND MICRO-ELEMENTS IN GRAINS USING X-RAY FLUOROSIS METHOD

Abstract. This article examines the content of macroelements (Mg, P, S, K, Ca) and microelements (Si, Mn, Fe, Ni, Cu, Zn) in the grains of six winter wheat varieties (Chillaki, Bezostaya-1, Krasnodar-99,

Fortuna, Kroshka, and Pamyat) grown under the soil and climatic conditions of the Khorezm region using uniform agronomic practices. The elemental composition was determined by wavelength-dispersive X-ray fluorescence spectrometry, and the results were evaluated on a dry matter basis. The study revealed significant differences in the content of macro- and microelements among the varieties. Some varieties demonstrated higher levels of certain elements, while others showed comparatively lower values. The obtained results indicate that these findings are of important scientific and practical significance for assessing the nutritional composition of wheat varieties and for selecting promising genotypes in breeding programs.

Keywords: Bread wheat, grain composition, X-ray fluorescence analysis, macro and microelements content.

Kirish. Donli ekinlar inson ratsionida muhim o‘rin tutuvchi asosiy oziq moddalarning muhim manbayi hisoblanadi. Ular tarkibida oqsillar, uglevodlar, vitaminlar hamda ayniqsa kaliy (K), fosfor (P), magniy (Mg), temir (Fe), rux (Zn) va mis (Cu) kabi mineral elementlar mavjud [13, 9].

Uglerod, vodorod va kislorod atmosferadan va suvdan olinadi, qolgan zaruriy makro va mikroelementlar esa asosan tuproq orqali ta’minlanadi. Tuproqdagi ularning konsentratsiyasi va o‘simlikning o‘sish jarayonidagi miqdoriy talabiga asoslanib, zarur ozuqalar makroelementlar (N, P, K, Ca, Mg va S) va mikroelementlar sifatida tasniflanadi [14, 11].

Makro va mikroelementlarning holatini, shuningdek, ularning tuproq xossalari bilan o‘zaro ta’sirini baholash donli ekinlarni samarali yetishtirish va barqaror ishlab chiqarishni ta’minlash uchun muhim ahamiyatga ega [10]. Makro va mikroelementlarning ikkalasining ham o‘simlik oziqlanishiga qo‘shgan hissasi muhim bo‘lib, hosilni optimallashtirish va sifatini yaxshilashda asosiy rol o‘ynaydi [15]. O‘simliklarning oziq moddalarni qabul qilishi mikro- va makroelementlar orqali amalga oshadi, ular o‘simliklarning o‘sishi va rivojlanishi uchun javobgardir. Mikroelementlar oz miqdorda kerak bo‘lsa, makroelementlar katta miqdorda talab qilinadi. Kasalliklarga chidamlilik va hosildorlik mikroelementlar tomonidan ta’minlanadi [4]. O‘simliklarda asosiy oziq moddalarni qabul qilish va metabolizm jarayonlari, shuningdek, hujayra devori rivojlanishi, fotosintez, nafas olish faoliyati, xlorofill hosil bo‘lishi, fermentlar faolligi, gormonlar sintezi, azot fiksatsiyasi va reduksiya jarayonlari kabi turli jarayonlar amalga oshadi. Mikroelementlar bog‘dorchilik mahsulotlarining sifatini, hosildorligini va yig‘imdan keyingi saqlash muddatini oshiradi [12]. Mikroelementlar asosan o‘simlik metabolik jarayonlarida katalizator vazifasini bajaradi. Ularning yetishmasligi boshqa ozuqalarni so‘rilishi va samarali ishlatilishini cheklashi mumkin, ularning ko‘p miqdorda yetishmasligi esa sezilarli fiziologik buzilishlarga olib keladi [1, 5]. Tuproqlarda mikroelementlarning mavjudligi intensiv qishloq xo‘jaligi amaliyotlari natijasida tobora kamayib bormoqda [3].

Makro- va mikroelementlarning yetishmasligi turli tuproq va o‘simlik tahlillari orqali aniqlanadi. Yuqori hosildorlik tufayli turli mikro- va makroelementlarning yetishmasligi ortib bormoqda, bu esa meva ekinlari uchun oziq moddalarni qabul qilish talabining oshishiga olib keladi. Ushbu elementlar o‘simliklarning o‘sishi va rivojlanishini yaxshilash uchun ishlatiladi. Makroelementlar tuproqqa qo‘llanganda, u tuproq unumdorligini oshiradi, ildiz tugunlarida azot fiksatsiya qiluvchi bakteriyalarni faollashtiradi, o‘simlik o‘sishini kuchaytiradi, vegetatsiya va meva rivojlanishini yaxshilaydi. Mikroelementlar o‘simlik barglariga qo‘llanganda, turli muhim oziq moddalar so‘riladi va bu barglardagi oziq moddalar harakatliligini oshiradi. Ushbu elementlar o‘simliklarda barqarorlikni saqlash va hosilni ta’minlash uchun muhimdir [6].

Past sifatli urug‘, tuproq sho‘rlanishi, suv bosishi, noto‘g‘ri o‘g‘itlash amaliyoti, sug‘orish suvining cheklanganligi, yuqori ishlab chiqarish xarajatlari, fermerlarning past darajadagi malakasi hamda mikroelementlar va organik o‘g‘itlarning yetarlicha qo‘llanilmasligi bug‘doy hosildorligining past bo‘lishiga asosiy sabablar sifatida tan olingan [8]. Mineral o‘g‘itlar qo‘llanilganda bug‘doy donlaridagi mis (Cu), temir (Fe), marganes (Mn) va rux (Zn) konsentratsiyalari oshadi. Shuningdek, makro va mikroelementlarni qo‘llash usullari ham ekin hosiliga sezilarli ta’sir ko‘rsatadi [7].

Tadqiqot metodologiyasi. Tadqiqot obyekti sifatida Xorazm viloyati tuproq va iqlim

sharoitida bir xil agrotexnik usullar qo‘llanib yetishtirilgan Chillaki, Bezostaya-1, Krasnodar-99, Fortuna, Kroshka hamda Pamyat kuzgi yumshoq bug‘doy navlari tanlab olindi.

Bug‘doy namunasidagi makro va mikroelementlar miqdori Rigaku ZSX Primus III NEXT (*Yaponiya, Rigaku Corporation*) to‘lqin uzunlik-dispersiyali rentgen-fluoressent spektrometri yordamida aniqlandi. Tahlillar vakuum rejimida olib borildi, bu esa yengil elementlarning aniqlanish sezgirligini oshirdi. Barcha qiymatlar quruq modda bo‘yicha mg/kg birlikda ifodalangan. Bug‘doy donining kul miqdori 1,8 % (quruq modda bo‘yicha), namlik miqdori esa 13 % ni tashkil etdi. Qizdirilganda massa yo‘qotilishi (LOI) 98,6 % deb baholandi.

Natijalar va muhokama. Tajribalarda bug‘doy navlari doni tarkibidagi makroelementlar Mg, P, S, K va Ca miqdorlari aniqlandi va tahlil qilindi. Ushbu makroelementlarning navlar doni tarkibidagi miqdori 1-jadvalda keltirilgan.

1-jadval

Navlarning don tarkibidagi makroelementlar miqdori, mg/kg

T/r	Nav nomi	Mg	P	S	K	Ca
1	Chillaki	6552,0	3060,0	815,4	5058,0	554,4
2	Bezostaya-1	595,8	1854,0	1962,0	8694,0	2070,0
3	Krasnodar-99	284,4	991,8	568,8	6264,0	871,2
4	Fortuna	5364,0	2574,0	921,6	5994,0	806,4
5	Kroshka	5832,0	2988,0	1029,6	5256,0	687,6
6	Pamyat	588,6	1926,0	1774,8	8730,0	2142,0

O‘rganilgan kuzgi yumshoq bug‘doy navlari doni tarkibida makroelementlardan magniy (Mg) elementi miqdori tahlil qilinganda 284,4-6552,0 mg/kg oralig‘ida bo‘lib, eng kam miqdorda Krasnodar-99 navida va eng ko‘p miqdorda Chillaki va Kroshka navlarida aniqlandi.

Fosfor va magniy o‘rtasida sinergik o‘zaro ta’sirlar kuzatiladi, chunki magniy kinaza fermentlarining faollashtiruvchisi sifatida xizmat qiladi hamda fosfat guruhlarining ko‘chirilishi bilan bog‘liq bo‘lgan reaksiyalarning aksariyatini ta’minlaydi [2]. Bug‘doy navlarining doni tarkibidagi makroelementlardan fosfor (P) miqdori o‘rganilganda eng kam ko‘rsatkich Krasnodar-99 navida (991,8 mg/kg) va eng ko‘p miqdorda P saqlagan nav Chillaki (3060,0 mg/kg) navi ekanligi aniqlandi.

Bug‘doy navlari doni tarkibidagi makroelementlar ichida oltingugurt (S) miqdori o‘rganilganda navlar orasida sezilarli farqlar kuzatildi. Eng yuqori ko‘rsatkich Bezostaya-1 navida aniqlanib, u 1962,0 mg/kg ni tashkil etdi. Aksincha, oltingugurtning eng past miqdori Krasnodar-99 navida qayd etilib, 568,8 mg/kg ga teng bo‘ldi.

O‘tkazilgan tahlillar bug‘doy donida kaliy (K) elementi miqdori navlarga qarab turlicha ekanligini ko‘rsatdi. Mazkur element bo‘yicha eng yuqori qiymat Pamyat navida kuzatilib, u 8730,0 mg/kg ni tashkil qildi. Eng past ko‘rsatkich esa Chillaki navida aniqlanib, 5058,0 mg/kg ga teng bo‘ldi.

Don tarkibidagi yana bir muhim makroelement — kalsiy (Ca) miqdori ham navlar kesimida baholandi. Natijalarga ko‘ra, Pamyat navi 2142,0 mg/kg ko‘rsatkich bilan kalsiyga eng boy nav sifatida qayd etildi. Shu bilan birga, ushbu elementning eng kam miqdori Kroshka navida aniqlanib, uning qiymati 687,6 mg/kg ni tashkil etdi.

Bug‘doy navlarining don tarkibidagi mikroelementlardan Si, Mn, Fe, Ni, Cu va Zn miqdori o‘rganildi. Ushbu mikroelementlarning navlar doni tarkibidagi miqdori 2-jadvalda keltirilgan.

Tadqiqotda o‘rganilgan bug‘doy navlari doni tarkibidagi Si mikroelementi qiyosiy o‘rganilganda 262,8-1333,8 mg/kg oralig‘ida aniqlandi. Eng ko‘p miqdorda Fortuna (1333,8 mg/kg), Kroshka (1294,2 mg/kg) navlarida kuzatilgan bo‘lsa, eng kam miqdordagi Si elementini Krasnodar-99 (262,8 mg/kg) navi doni tarkibida ekanligi aniqlandi (2-jadval).

2-jadval

Don tarkibidagi mikroelementlar miqdori, mg/kg

T/r	Nav nomi	Si	Mn	Fe	Ni	Cu	Zn
1	Chillaki	1134,0	10,08	27,00	4,10	5,31	12,24

2	Bezostaya-1	628,2	155,70	378,00	62,28	55,80	157,50
3	Krasnodar-99	262,8	71,46	157,68	26,10	20,70	37,08
4	Fortuna	1333,8	15,71	34,20	5,96	6,71	17,73
5	Kroshka	1294,2	14,98	32,04	4,12	5,40	48,51
6	Pamyat	597,6	163,80	320,40	48,60	62,28	133,56

Bug‘doy navlari doni tarkibidagi mikroelementlardan biri bo‘lgan marganes (Mn) miqdori ham alohida tahlil qilindi. O‘tkazilgan qiyosiy tadqiqot natijalari ushbu elementning navlar donida turli darajada to‘planishini ko‘rsatdi. Aniqlangan ma’lumotlarga ko‘ra, marganes miqdori o‘rganilgan bug‘doy navlari doni tarkibida 10,08 mg/kg dan 163,80 mg/kg gacha bo‘lgan diapazonda o‘zgarib turishi qayd etildi. Tahlil natijalari shuni ko‘rsatdiki, marganesning eng yuqori ko‘rsatkichi Pamyat navida aniqlanib, uning miqdori 163,80 mg/kg ni tashkil etdi. Bu holat mazkur nav donida ushbu mikroelementning nisbatan ko‘proq to‘planishini ko‘rsatadi. Aksincha, marganesning eng past miqdori Chillaki va Kroshka navlari doni tarkibida qayd etildi. Xususan, Kroshka navida ushbu element 14,98 mg/kg**,** Chillaki navida esa 10,08 mg/kg miqdorda ekanligi aniqlandi.

Bug‘doy doni tarkibidagi Fe elementi miqdori qiyosiy o‘rganilganda 27,00-378,00 mg/kg oralig‘ida aniqlandi. Tadqiqotda Fe elementini eng ko‘p miqdorda Bezostaya-1 (378,00 mg/kg) navida, eng kam miqdorda Kroshka (32,04 mg/kg) va Chillaki (27,00 mg/kg) navlarida aniqlandi.

O‘rganilgan bug‘doy navlari doni tarkibidagi nikel (Ni) mikroelementi miqdori ham taqqoslab baholandi. Tadqiqot natijalariga ko‘ra, ushbu elementning miqdori navlar kesimida 4,10–62,28 mg/kg diapazonda o‘zgarishi aniqlandi. Eng yuqori ko‘rsatkich Bezostaya-1 navida kuzatilib, 62,28 mg/kg ni tashkil etdi. Aksincha, nikelning eng past miqdori Chillaki (4,10 mg/kg) hamda Kroshka (4,12 mg/kg) navlari doni tarkibida qayd etildi.

Navlarining don tarkibida Cu miqdori tahlil qilinganda 5,31-62,28 mg/kg oralig‘ida aniqlandi. Don tarkibidagi mikroelementlardan mis eng ko‘p miqdorda Pamyat (62,28 mg/kg) navida kuzatildi. Eng kam miqdor Kroshka (5,40 mg/kg) va Chillaki (5,31 mg/kg) navlarida ekanligi aniqlandi.

Navlarning don tarkibidagi Zn mikroelementi qiyosiy o‘rganilganda 12,24-157,50 mg/kg oralig‘ida aniqlandi. Eng ko‘p miqdorda Bezostaya-1 (157,50 mg/kg) navida va eng kam miqdorda Chillaki (12,24 mg/kg) navida kuzatildi.

Xulosa va takliflar. Don tarkibidagi makroelementlar miqdori navlar kesimida tahlil qilinganda Chillaki navida Mg, P va K, Fortuna navida Mg va K, Bezostaya-1 navida K va Ca, Kroshka navida Mg va P, Pamyat navida S, K va Ca elementlar miqdori yuqori ekanligi aniqlandi. Krasnodar-99 navida esa K ning miqdori boshqa elementlarga nisbatan anchagina yuqori ekanligi tahlillar natijasida aniqlandi.

Mikroelementlar miqdori tahliliga ko‘ra Chillaki, Fortuna va Kroshka navlarida Si miqdori boshqa mikroelementlarga nisbatan ko‘p miqdorda bo‘lishi aniqlandi. Bezostaya-1 va Krasnodar-99 navlari esa Fe moddasiga boy ekanligi ma’lum bo‘ldi. Pamyat va Bezostaya-1 navlarida Zn mikroelementi miqdori boshqa navlarga qaraganda ko‘p miqdorda uchradi. Olingan natijalar bug‘doy navlari o‘rtasida makro va mikroelementlar tarkibi sezilarli darajada farq qilishi mumkinligini ko‘rsatadi hamda navlarning oziqaviy qiymatini baholashda bunday ko‘rsatkichlar muhim ahamiyatga ega ekanligini tasdiqlaydi.

Tadqiqot jarayonida o‘rganilgan bug‘doy navlari seleksiya ishlarida ota-ona shakllari sifatida xizmat qildi. Ushbu navlar asosida duragaylash ishlari olib borilib, hozirgi kunga kelib ularning ishtirokida F_5 avlodiga mansub duragay kombinatsiyalari olindi. Kelgusidagi ilmiy izlanishlarimizda mazkur duragay kombinatsiyalar doni tarkibidagi makro va mikroelementlar miqdorini aniqlash, ularning navlararo farqlarini baholash hamda oziqaviy va biologik ahamiyatini tahlil qilish rejalashtirildi. Shuningdek, olingan natijalar asosida istiqbolli duragaylarni tanlab olish va ularning seleksiya jarayonidagi samaradorligini aniqlash maqsad qilindi.

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6-AMINOXINAZOLIN-3(H)-4-ONNI AYRIM AROMATIK ATSETILEN SPIRTLARI ISHTIROKIDA ALKINILLASH REAKSIYALARI

[1]Ziyadullayev M.E., [2]Nurmanov S.E., [1]Suyunov S.A. [3]Bo‘rixonov B.X

[1]Chirchiq davlat pedagogika universiteti, Chirchiq, O‘zbekiston

[2]M.Ulug‘bek nomidagi O‘zbekiston Milliy universiteti, Toshkent, O‘zbekiston

[3]Qarshi davlat universiteti. Qarshi, O‘zbekiston

[1]ziyadullayev.91@mail.ru

ORCID 0000-0001-7476-7202

UDK 544.43.478.547.241.260.272.316.312

Annotatsiya. Ushbu tadqiqotda xinazolinon hosilalarining biologik faolligini oshirish maqsadida $Zn(OTf)_2$ katalizatori ishtirokida 6-aminoxinazolin-4(3H)-onning aromatik atsetilen spirtlari bilan xemoselektiv N-alkinillanish reaksiyalari o‘rganildi. Jarayon S_N1 mexanizmi orqali borishi va propargil kationining hujumi faqat 6-holatdagi -NH_2 guruhga yo‘naltirilganligi, yuqori regioselektivlikka ega ekanligi nazariy va amaliy jihatdan asoslandi. Reaksiya davomida ajralib chiquvchi suvni Dean-Stark qurilmasi yordamida azeotrop haydab chiqarish metodi qo‘llanildi, bu esa muvozanatni mahsulot hosil bo‘lishi tomon siljitib, unumni sezilarli darajada (82,1% gacha) oshirishga imkon berdi. Tadqiqot davomida harorat, vaqt, katalizator miqdori va erituvchi tabiatining (toluol, dixloretan) jarayon unumiga ta’siri tizimli tahlil qilinib, maqbul sharoitlar aniqlandi. Sintez qilingan yangi molekulyar gibrid birikmalarning individual tozaligi va tuzilishi IQ hamda ^1H, ^{13}C YaMR spektroskopiya usullari yordamida tasdiqlandi. Olingan natijalar farmatsevtik ahamiyatga ega yangi dori vositalari sintezi uchun muhim poydevor bo‘lib xizmat qiladi.

Kalit so‘zlar: 6-aminoxinazolin-4(3H)-on, katalizator, aromatik atsetilen spirtlari, *N*-alkinillanish, reaksiya davomiyligi, mahsulot unumi.

ALKYNYLATION REACTIONS OF 6-AMINOQUINAZOLIN-4(3H)-ONE WITH CERTAIN AROMATIC ACETYLENE ALCOHOLS

Abstract. In this study, the chemoselective N-alkynylation reactions of 6-aminoquinazolin-4(3H)-one with various aromatic acetylene alcohols were investigated in the presence of a $Zn(OTf)_2$ catalyst to enhance the biological activity of quinazolinone derivatives. It was theoretically and experimentally

established that the process proceeds via an S_N1 mechanism, characterized by high regioselectivity where the propargyl cation attack is exclusively directed at the 6-position -NH_2 group. To shift the equilibrium toward product formation, an azeotropic distillation method using a Dean-Stark apparatus was employed to continuously remove the water byproduct, which significantly increased the yield (up to 82.1%). The effects of temperature, reaction time, catalyst loading, and the nature of the solvent (toluene, dichloroethane) on the process efficiency were systematically analyzed to determine the optimal conditions. The individual purity and chemical structures of the synthesized novel molecular hybrid compounds were fully confirmed using IR and ^{1}H, ^{13}C NMR spectroscopy techniques. The results obtained serve as a significant foundation for the synthesis of new pharmaceutical agents with potential medicinal applications.

Keywords: 6-aminoquinazolin-4(3H)-one, catalyst, aromatic acetylenic alcohols, *N*-alkynylation, reaction duration, product yield.

Kirish. Geterohalqali birikmalar sinfiga kiruvchi (3H)-xinazolin-4-on hosilalari tibbiyot, farmasevtika va qishloq xo‘jaligida o‘zining antibakterial, antigelmint, yallig‘lanishga qarshi va ayniqsa, o‘simtalarga qarshi keng ko‘lamli biologik faolligi bilan alohida o‘rin tutadi [1-2]. Shu bilan birga, tarkibida uch bog‘, gidroksil guruhi hamda turli alifatik yoki aromatik o‘rinbosarlar saqlagan atsetilen spirtlari ham toksikologik jihatdan xavfsizligi va keng kimyoviy imkoniyatlari sababli organik sintezda istiqbolli ob’ektlar hisoblanadi [3-4]. Kimyoviy va farmakologik jihatdan qimmatli hisoblangan ushbu ikki xil fragmentni yagona molekulyar tuzilishda gibridlash, yuqori samaradorlikka ega yangi avlod geterohalqali birikmalarni sintez qilishda muhim ahamiyatga ega bo‘lgan dolzarb yo‘nalish hisoblanadi [5, 7]. So‘nggi tadqiqotlarda molekulasida atsetilen fragmentlarini saqlagan geterohalqali birikmalarni modifikatsiya qilishda yangi katalitik sistemalar muhim o‘rin tutmoqda. Xususan, Xitoy Fanlar Akademiyasining bir guruh olimlari tomonidan siklik etiniletilen karbonatlarning mis katalizatori ta’sirida qayta guruhlanishi natijasida oraliq mahsulot, allenal intermediatlari hosil bo‘lishi isbotlangan. Bunda siklik karbonat tarkibidagi terminal alkin protonining deprotonlanishi sodir bo‘lib, molekula ichki qayta guruhlanishga uchraydi. So‘ngra karbonat halqasining ochilishi va reaksion faol allenal intermediatlari ajralib chiqishi kuzatiladi. Ushbu bosqich semipinokol tipidagi siljish orqali emas, balki asos yordamida deprotonlanish orqali amalga oshishi DFT hisoblash usullari yordamida isbotlangan, reaksiya mexanizmlari taklif qilingan. Natijada murakkab tuzilishga ega allil va propargil allenollari, siklopropiliden hosilalari yuqori unumlarda sintez qilingan [8, 10].

Murakkab stereokimyoviy tuzilishga ega tizimlar sintezida propargil substratlarining asimmetrik [3+2] sikllanish reaksiyalari ham muhim ahamiyatga ega. Shao va uning ilmiy jamoasi tomonidan $[Cu(CH_3CN)_4]PF_6$ va xiral L-1 ligandi ishtirokida uchlamchi propargil karbonatlarining C,O-bisnukleofillar bilan yumshoq sharoitda (Et_2O, K_2CO_3) boradigan reaksiyasi ishlab chiqilgan. Mazkur jarayonda mis-alleniliden intermediatining hosil bo‘lishi reaksion markazni xiral muhitda fazoviy aniq yo‘naltirishi natijasida, to‘rtlamchi uglerod markazlarini shakllantirishdagi fazoviy to‘siqlarni yengib o‘tishi isbotlangan [11].

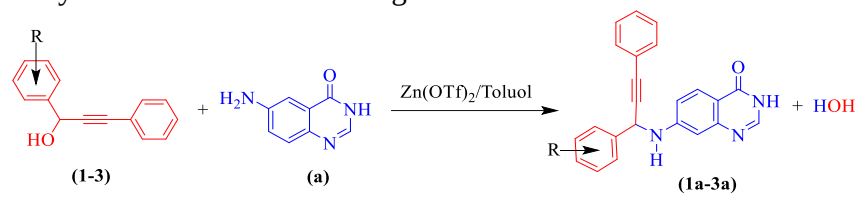
Yaponiyalik kimyogarlar K. Sakata va Y. Nishibayashi tomonidan e’lon qilingan tadqiqot ishida, turli metall komplekslari ishtirokida bir qator aminlar, iminlarning stereoselektiv reaksiyalarni qiyoslab, yangi asimmetrik transformatsiyalarni ratsional loyihalash uchun kvant-kimyoviy parametrlarning ahamiyati hamda propargil spirtlari ishtirokidagi xemoselektiv jarayonlarning mexanizmi va yangi katalitik sistemalarni tanlashda ilmiy asoslangan muhim natijalar keltirilgan [12].

Yuqoridagi adabiyotlar tahlilidan kelib chiqib, ushbu tadqiqotda $Zn(OTf)_2$ ishtirokida 6-aminoxinazolin-4(3H)-onni aromatik atsetilen spirtlari bilan xemoselektiv *N*-alkinillash reaksiyalarini amalga oshirish va jarayonning maqbul sharoitlarini aniqlash maqsad qilindi.

Tadqiqot metodologiyasi. 100 ml li dumaloq tubli kolbaga 177 mg (1,1 mmol) 6-aminoxinazolin-4(3H)-on, 1.0 mmol tegishli atsetilen spirti (1) va 36 mg (0,1 mmol) $Zn(OTf)_2$ solindi. Aralashmaga 20 ml toluol qo‘shildi. Kolba suv ajratib oluvchi Dean-Stark va qaytar sovutgich bilan jihozlandi. Reaksion aralashma moy hammomda 110 ^oC haroratda magnit aralashtirgich yordamida 8-12 soat davomida aralashtirildi. Reaksiya tugagach (YuQX nazorati, geksan:etilasetat 2:1), toluol past bosim ostida haydaldi. Qoldiq 30 ml etilatsetatda eritilib, to‘yingan $NaHCO_3$ va suv bilan yuvildi. Organik qatlam Na_2SO_4 yordamida quritildi. Texnik mahsulot silikagel to‘ldirilgan kolonkada (geksan:etilatsetat, 6:1) tozalandi va yakuniy

bosqichda etil spirtida qayta kristallash orqali kukun holatdagi, kimyoviy toza mahsulot ajratib olindi.

Natijalar va muhokama. Tadqiqotning ushbu bosqichida 6-aminoxinazolin-4(3H)-on va 1-(4-butoksifenil)-3-fenilprop-2-in-1-ol o‘rtasidagi tanlangan katalizatorlar ishtirokida xemoselektiv *N*-alkinillash reaksiyasining maqbul sharoitlarini aniqlash maqsad qilindi. Reaksiya umumiy sxemasi 1-rasmda keltirilgan.



R= (1; 4-OBu, 2; 2,4-OMe, 5-Br, 3; 4-S-Et)

1-rasm. $Zn(OTf)_2$ katalizatori ishtirokida 6-aminoxinazolin-4(3H)-onning aromatik atsetilen spirtlari bilan xemoselektiv *N*-alkinillanish reaksiyasi sxemasi

Reaksiya mexanizmi Lyuis kislotasi (Zn^{2+}) tomonidan propargil spirtidagi gidroksil guruhining aktivlanishi bilan boshlanadi. $Zn(OTf)_2$ spirt guruhining kislorod atomi bilan kompleks hosil qilib, uni oson chiqib ketuvchi guruhga aylantiradi. Natijada suv molekulasi ajralib chiqib, SN_1 tipi bo‘yicha barqarorlashgan propargil kationi hosil bo‘ladi. So‘ngra, 6-aminoxinazolin-4(3H)-onning nukleofil amino-guruhi ushbu kationga hujum qiladi. Ushbu tadqiqot ishining eng muhim jihatlaridan biri, bu yuqori regioselektivlikdir. 6-aminoxinazolin-4(3H)-on yadrosida bir nechta nukleofil markaz (masalan, 3-holatdagi -NH) mavjudligiga qaramay, reaksiya faqat 6-holatdagi $-NH_2$ guruhda sodir bo‘ladi. Bu holat $-NH_2$ guruhining yuqori nukleofilligi va propargil kationining ushbu markazga kinetik jihatdan hujum qilishi qulayligi bilan izohlanadi. Dean-Stark qurilmasi esa suvni sistemadan uzluksiz chiqarib yuborish orqali Le-Shatelye tamoyiliga muvofiq muvozanatni mahsulot tomonga siljitadi va katalizator barqarorligini ta’minlaydi. Shuni ta’kidlash kerakki, taklif etilgan $Zn(OTf)_2$ va Dean-Stark kombinatsiyasi texnologik soddaligi, arzonligi va ayniqsa oltingugurt saqlovchi murakkab substratlarda ham xemoselektivlikni saqlab qolishi bilan ajralib turadi. Tadqiqotlar davomida reaksiya unumiga katalizator tabiatining ta’siri, uning miqdori, erituvchi turi va suvni azeotrop haydash usullarining samaradorligi o‘rganildi. Olingan natijalar 1-jadvalda keltirilgan.

1-jadval

Reaksiya sharoitlarini optimallashtirish

№	Katalizator (mol%)	Erituvchi	Vaqt	Unum
1	$Zn(OTf)_2$ (10)	Dixloretan	24	55,4
2	$Fe(Cl)_3$ (10)	Toluol	12	62,1
3	$Cu(OTf)_2$ (10)	Toluol	15	58,3
4	$Zn(OTf)_2$ (5)	Toluol	18	65,7
5	$Zn(OTf)_2$ (10)	Toluol	10	82,1

Dastlabki tajribalarda turli metall tuzlarining (Fe, Cu, Zn) katalitik faolligi qiyoslandi. $FeCl_3$ va $Cu(OTf)_2$ katalizatorlari ishtirokida olib borilgan 2, 3-tajribalarda mahsulot unumi mos ravishda 62,1 % va 58,3 % dan oshmadi. Buning asosiy sababi sifatida Lyuis kislotalarining kislorod atomiga bo‘lgan yuqori yaqinligini ko‘rsatish mumkin. Bu esa hosil bo‘lgan atsetilen spirtining qisman parchalanishiga va qo‘shimcha jarayonlarning sodir bo‘lishiga olib keladi. Katalizator sifatida $Zn(OTf)_2$ ishtirokida olib borilgan reaksiyalar yuqori xemoselektivlik va mahsulot unumi 82,1% ni tashkil etdi (5-tajriba).

Erituvchi tabiatining unumga ta’siri dixloretan va toluol misolida baholandi. Dixloretan muhitida reaksiya 24 soat davom etgan bo‘lsa-da, unum 55,4 % dan oshmasligi kuzatildi. Bu holat past haroratda propargil kationi hosil bo‘lish tezligi sustligi hamda sistemadan suvni haydash imkoniyati yo‘qligi bilan izohlanadi. Toluol erituvchisi va Dean-Stark qurilmasi yordamida suvni doimiy azeotrop haydab turish esa reaksiyani 10 soat ichida yakunlash imkonini berdi. Katalizator miqdori 10 mol % dan 5 mol % gacha kamaytirilganda (4-tajriba), reaksiya vaqti keskin uzayishi (18 soat) va unumning 65,7 % gacha pasayishi aniqlandi. Bu 10 mol % miqdor substratlarni to‘liq aktivlash va reaksiya davomida hosil

bo‘ladigan suv molekulalari tomonidan yuzaga keladigan katalizator deaktivatsiyasini muvozanatlash uchun maqbul miqdor ekanligini tasdiqlaydi.

Ishlab chiqilgan optimal sharoitlarda turli o‘rinbosarli aromatik atsetilen spirtlarining reaksion qobiliyati o‘rganildi (2-jadval).

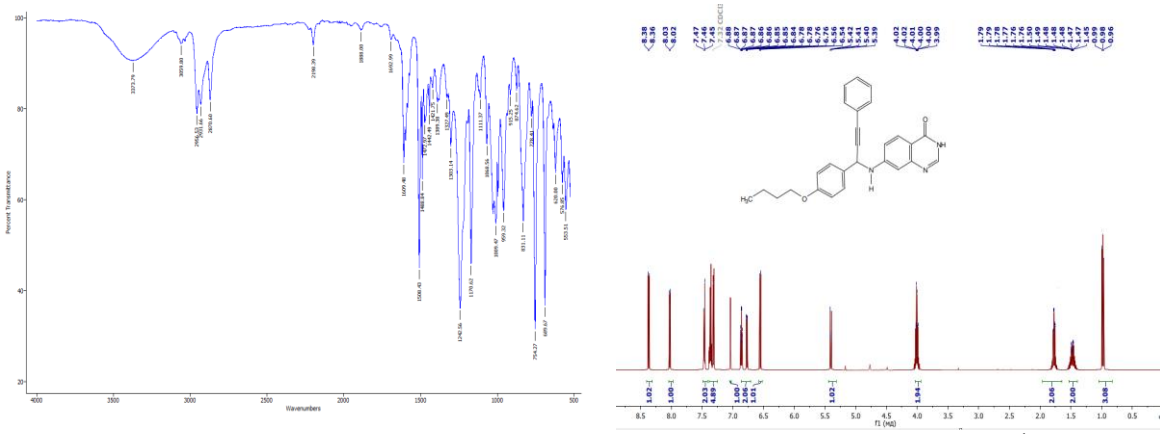
2-jadval

6-aminoxinazolin-4(3H)-onning aromatik atsetilen spirtlari bilan reaksiya natijalari

Mahsulot	Aromatik atsetilen spirtidagi o‘rinbosar (R)	Vaqt	Unum
1a	4-butoksifenil (4-OBu)	10	82,1
2a	5-brom-2,4-dimetoksifenil (5-Br, 2,4-OMe)	12	75,3
3a	4-etiltiofenil (4-SEt)	14	68,7

Jadvalda keltirilgan ma’lumotlardan ko‘rinib turibdiki, halqaning *para*-holatidagi -OC_4H_9 guruhi kuchli elektron beruvchi (+M) effekti hisobiga oraliq propargil kationini barqarorlashtiradi va reaksiyaning yuqori unum bilan (82,1 %) tugashini ta’minlaydi. 2a mahsulot sintezida aromatik halqada bir vaqtning o‘zida ikkita kuchli donor metoksi-guruh va bitta elektron-akseptor brom atomi mavjud bo‘lib, donor guruhlarning ustunlik qilishi hisobiga mahsulot 75,3% unum bilan olindi. Brom atomining saqlanishi ushbu molekulani kelajakda kross-birikish reaksiyalari uchun qulay markazga aylantiradi. 3a-birikma sintezida, substrat tarkibidagi oltingugurt atomi (+M) effektga ega bo‘lsada, u “yumshoq” Lyuis asosi sifatida katalizator faolligini biroz susaytirishi natijasida unumning 68,7% gacha pasayishi kuzatildi.

Maqsadli mahsulotlarning unumi 68,7% dan 82,1% gacha bo‘lishi aniqlandi. Tadqiqotlar natijasida olingan uchta (1a-3a) yangi molekulyar gibrid birikmalarning individual tuzilishi va tozaligi IQ va ^1H, ^{13}C YaMR spektral ma’lumotlari asosida to‘liq isbotlandi.



2-rasm. 6-((1-(4-butoksifenil)-3-fenilpropin-2-il)amino)xinazolin-4(3H)-onning (1a) IQ, ^1H YaMR spektri

Sintez qilingan 6-((1-(4-butoksifenil)-3-fenilpropin-2-il)amino)xinazolin-4(3H)-on birikmasining IQ spektri tahlil qilinganda, molekula tarkibidagi barcha xarakterli funksional guruhlarning tebranish chastotalari (ν, cm^{-1}) kutilgan sohalarda namoyon bo‘ldi. Spektrning yuqori chastotali sohasida 3373.7 cm^{-1} da kuzatilgan keng cho‘qqi xinazolinon yadrosidagi amid va yangi hosil bo‘lgan ikkilamchi amin (N-H) guruhlarining valent tebranishlariga to‘g‘ri keladi. Dastlabki propargil spirti tarkibidagi gidroksil guruhiga xos bo‘lgan keng va kuchli yutilish polosasining yo‘qolishi, reaksiya natijasida C-N bog‘i hosil bo‘lganligini isbotlaydi. Reaksiyaning muvaffaqiyatli borganligini tasdiqlovchi eng muhim isbotlardan biri bu 2198.4 cm^{-1} sohada namoyon bo‘lgan o‘rta intensivlikdagi cho‘qqidir. Ushbu signal propargil fragmentidagi atsetilen (C≡C) bog‘inining valent tebranishlariga mos keladi va gibrid molekulada alkin zanjiri saqlanib qolganligini ko‘rsatadi. Bundan tashqari, spektrda 1692.9 cm^{-1} chastotada xinazolinon yadrosiga xos bo‘lgan kuchli C=O guruhi signallari hamda 1242.5 cm^{-1} sohasida butoksi guruhining aromatik efir bog‘iga (Ar-O-C) xos valent tebranishlari qayd etildi. Aromatik halqalardagi C=C bog‘larining tebranishlari 1609.4 va 1506.4 cm^{-1} sohalarda, alifatik C-H bog‘lari esa 2956-2870 cm^{-1} oralig‘ida o‘z aksini topgan. IQ spektr ma’lumotlari YaMR natijalari bilan to‘liq mos kelib, maqsadli gibrid molekula

tuzilishini yanada ishonchli tasdiqlaydi.

Keltirilgan 6-((1-(4-butoksifenil)-3-fenilpropin-2-il)amino)xinazolin-4(3H)-onning ^{1}H YaMR spektridan ko‘rish mumkinki, molekula tarkibidagi barcha vodorod atomlari o‘ziga xos kimyoviy siljishlar bilan namoyon bo‘lgan. Spektrning aromatik sohasida (δ 8.38 va 8.03 m.u.) xinazolinon yadrosining H-2 va H-5 protonlariga tegishli singlet va dublet signallari kuzatiladi. Reaksiyaning xemoselektivligini isbotlovchi eng muhim dalil bu δ 5.40 m.u. sohada propargil markazidagi CH protonining dublet ko‘rinishidagi signalidir (J=6.4 Hz). Ushbu signalning integrali (1.02 H) va uning amino-guruhdagi (-NH-) proton bilan o‘zaro spin-spin ta’sirlashuvi (δ 6.55 m.u.) reaksiya aynan 6-holatdagi -NH_2 guruh bo‘yicha amalga oshganligini tasdiqlaydi. Butoksifenil fragmentidagi aromatik protonlar δ 6.87 m.u. sohadagi xarakterli dublet ko‘rinishidagi signallar hosil qilgan bo‘lsa, alifatik zanjirdagi butoksi guruhining signallari δ 4.01 m.u. (-OCH_2-), 1.77-1.48 m.u. (-CH_2-) va 0.98 m.u. (-CH_3) sohalarida kutilgan integrallar nisbatida (2:4:3) namoyon bo‘ldi. Spektrda qo‘shimcha mahsulotlar yoki boshlang‘ich moddalarga tegishli signallarning mavjud emasligi, sintez qilingan gibrid molekulaning tozalik darajasi yuqori ekanligidan dalolat beradi.

Shu bilan birgalikda 2a va 3a birikmalarning ham tuzilishi va tozaligi IQ va ^{1}H YaMR spektrlari yordamida tasdiqlandi. Olingan natijalar quyidagicha:

6-((1-(5-brom-2,4-dimetoksifenil)-3-fenilprop-2-in-1-il)amino)xinazolin-4(3H)-on (2a). Mahsulot unumi 75,3%. $T_{suyuq.}$ 244-246 °C. IQ spektri (KBr, cm^{-1}): 3370 (N-H), 3062 (C-H, ar.), 2202 (C≡C), 1690 (C=O), 1612, 1510 (C=C, ar.). ^{1}H YaMR (400 MHz, $CDCl_3$) δ: 8.38 (s, 1H, H-2), 8.04 (d, J=8.8 Hz, 1H, H-5), 7.52-7.48 (m, 4H, Ar-H), 7.42-7.30 (m, 6H, Ar-H), 7.10 (dd, J=8.8, 2.4 Hz, 1H, H-7), 6.80 (d, J=2.4 Hz, 1H, H-8), 6.58 (s, 1H, NH), 5.45 (d, J=6.4 Hz, 1H, CH-propargil).

6-((1-(4-(etiltio)fenil)-3-fenilprop-2-in-1-il)amino)xinazolin-4(3H)-on (3a). mahsulot unumi 68,7%; $T_{suyuq.}$ 261-262 °C. IQ spektri (KBr, cm^{-1}): 3375 (N-H), 3058 (C-H, ar.), 2965, 2928 (C-H, alifatik), 2195 (C≡C), 1694 (C=O), 1608, 1502 (C=C, ar.), 685 (C-S-C). ^{1}H YaMR (400 MHz, $CDCl_3$) δ: 8.37 (s, 1H, H-2), 8.03 (d, J=8.8 Hz, 1H, H-5), 7.48-7.44 (m, 2H, Ar-H), 7.39-7.31 (m, 5H, Ar-H), 7.23 (d, J=8.2 Hz, 2H, Ar-H), 7.08 (dd, J=8.8, 2.4 Hz, 1H, H-7), 6.78 (d, J=2.4 Hz, 1H, H-8), 6.60 (s, 1H, NH), 5.42 (d, J=6.4 Hz, 1H, CH-propargil), 2.94 (k, J=7.2 Hz, 2H, SCH_2), 1.32 (t, J=7.2 Hz, 3H, CH_3).

Xulosa. Olib borilgan tadqiqotlar natijasida ilk bor $Zn(OTf)_2$ katalizatori ishtirokida 6-aminoxinazolin-4(3H)-onni turli o‘rinbosarli aromatik atsetilen spirtlari bilan xemoselektiv *N*-alkinillashning yangi va qulay usuli ishlab chiqildi. Mahsulot unumiga katalizator miqdori, erituvchi tabiati va haroratning ta’siri tizimli o‘rganildi va optimal sharoitlar topildi. Reaksiya natijasida propargil kationining hujumi faqat 6-holatdagi -NH_2 guruhga nisbatan sodir bo‘lishi va boshqa nukleofil markazlarga ta’sir qilmasligi aniqlandi. Bu jarayon SN_1 mexanizmi orqali borishi nazariy jihatdan asoslandi. Sintez qilingan birikmalarning individual tuzilishi va tozaligi zamonaviy fizik-kimyoviy tadqiqot (IQ, ^{1}H YaMR) usullari yordamida tasdiqlandi.

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TECHNOLOGY FOR THE PRODUCTION OF THICKENERS BASED ON POLYMER COMPOSITIONS DERIVED FROM POLYSACCHARIDES AND MODIFIERS

Shabarova Umida Normuminovna
Karshi State Technical University Associate Professor, PhD
Department of Chemical Engineering and Biotechnology
Amonov Muxtar Raxmatovich
Buxoro State University Professor, Dsc
Abdurasulova Sugdiyona Inoyatovna
Karshi State Technical University, master
umidakimtex.gmail.com
ORCID 0009-0002-1629-9898
UDK 677.023.73.011

Аннотация. Химически модифицированные полисахариды, благодаря наличию активных гидроксильных групп, находят всё более широкое применение в текстильной промышленности. Простые и сложные эфиры крахмала, а также его производные, содержащие аминогруппы, обладают эффективными загущающими свойствами и широко используются в технологических процессах текстильного производства. Метиловые эфиры крахмала и эфиры карбоновых кислот, в частности натриевая соль карбоксиметилкрахмала, характеризуются способностью легко набухать и растворяться в холодной воде.

Путём этерификации крахмала можно значительно повысить его растворимость и улучшить физико-химические свойства. Частичное замещение гидроксильных групп эфирными группами позволяет преобразовать нерастворимые в воде крахмал и целлюлозу в водорастворимые соединения с высокой вязкостью. Благодаря этим свойствам модифицированный крахмал широко применяется в качестве эффективного загустителя и стабилизатора в текстильной промышленности.

Ключевые слова: крахмал, загуститель, предел текучести, степень тиксотропного восстановления, хлопчатобумажная ткань, акриловая эмульсия, поливинилацетат.

Abstract. Chemically modified polysaccharides are increasingly used in the textile industry due to the presence of active hydroxyl groups in their structure. Simple and complex starch ethers, as well as their derivatives containing amino groups, exhibit effective thickening properties and are widely used in textile processing technologies. Methyl ethers of starch and esters of carboxylic acids, particularly sodium carboxymethyl starch, are characterized by their ability to easily swell and dissolve in cold water.

Through the etherification of starch, its solubility can be significantly increased and its physicochemical properties improved. Partial substitution of hydroxyl groups with ether groups makes it possible to convert water-insoluble starch and cellulose into water-soluble compounds with high viscosity. Due to these properties, modified starch is widely used as an effective thickening and stabilizing agent in the

textile industry.

Keywords: Starch, thickener, yield stress, thixotropic recovery degree, cotton fabric, acrylic emulsion, polyvinyl acetate.

Introduction. Natural and synthetic polymers, in particular starch and its derivatives, are used in the textile industry not only for yarn sizing but also as thickeners for printing on blended fabrics. Therefore, the problem of developing or selecting optimal thickener compositions remains highly relevant in scientific research. One of the main reasons for this is the specific requirements that rheological modifiers must satisfy. These requirements include the ability to provide effective thickening at low polymer concentrations, storage stability, resistance to mechanical stress, good washability, brightness, water retention capacity, non-foaming behavior, and other important properties. For this reason, the rheological characteristics of polymer thickener solutions are of great importance. Based on these considerations, this section attempts to classify thickeners used in textile printing. Among them, polyacrylate-based thickeners occupy a special place. However, before using them as thickening components, it is necessary to study the chemical transformations that occur between polyacrylates and other polymers, oligomers, or ingredients.

Main part. It is well known that esters, nitriles, and amides of polyacrylic and polymethacrylic acids, as well as their copolymers, readily undergo polymer-analogous transformations when exposed to acidic and alkaline reagents in significant amounts [1]. Esters of polyacrylic acid and lower aliphatic alcohols undergo saponification in alkaline media. In some cases, degradation (destruction) reactions may also occur.

In addition to synthetic polymers, natural polymers are also widely used as thickeners. In particular, sodium alginate, obtained by alkaline treatment of marine algae and characterized by water solubility and swelling in alkaline media, is commonly used as a thickening agent in textile printing.

Ready-to-use printing pastes for the production of printed fabrics are highly viscous structured systems, in which the thickener is the main component. The thickener prevents undesirable reactions in the dye composition and ensures the sharpness of pattern contours on the printed fabric by resisting the capillary forces of the substrate [2].

In most cases, thickeners are true or colloidal solutions of water-soluble polymer substances. The component that forms the internal spatial structure or skeleton of the thickener is referred to as the thickening agent. The macromolecules of thickening substances interact with each other to form an internal spatial network structure .

At present, polymer thickeners used in industry can be divided into two main groups:

Single-phase aqueous polymer solutions, consisting of macromolecular substances such as plant-derived products, particularly starch (wheat, rice, corn, potato), their derivatives (simple and complex starch ethers), their degradation products (dextrins), alginates, and various synthetic thickeners;

Colloidal two-phase systems with a distinct interface, in which the thickening agents are low-molecular-weight substances (solid, liquid, or gaseous). In such systems, a stable internal structure is formed by at least three components: the dispersed phase, the dispersion medium (external phase), and a dispersing agent or emulsifier, as well as a stabilizer (for example, oil-in-water and water-in-oil emulsions, and foam-based compositions).

The selection of thickening components is one of the most important issues in the textile industry. In production, dyes are several times more expensive than thickeners, and their consumption (on a dry matter basis) is comparable to or slightly higher than that of thickeners. Therefore, the correct selection of a thickener contributes to dye savings, improves color fastness, and ensures high-quality printing results.

Most natural thickeners used in the textile industry are polysaccharides. More than 90% of natural thickeners used by volume consist of various types of starch and products obtained through its modification [3].

In this case, not only cellulose and starch, but also other polysaccharides of various origins can be used as starting materials .

Such polysaccharides include thickening agents based on cellulose ethers.

Only cellulose ethers are used as thickening agents among cellulose derivatives. The most widely used among them are methyl cellulose, ethyl cellulose, benzyl cellulose, carboxymethyl cellulose, hydroxyethyl cellulose, cyanoethyl cellulose, and others. Cellulose ethers are derivatives of cellulose in which the hydrogen atoms of the hydroxyl groups are replaced by alkyl groups.

The chemical formulas and the degree of substitution of the most important cellulose ethers produced on an industrial scale are presented in Table 1.1

Table 1.1

Cellulose ethers

Cellulose ether	Degree of substitution	Chemical formula
Methyl cellulose	140–200	$[C_6H_7O_2(OH)_{3-x}(OCH_3)_x]_n$
Ethyl cellulose	220–260	$[C_6H_7O_2(OH)_{3-x}(OC_2H_5)_x]_n$
Benzyl cellulose	190–240	$[C_6H_7O_2(OH)_{3-x}(OCH_2C_6H_5)_x]_n$
Carboxymethyl cellulose	40–120	$[C_6H_7O_2(OH)_{3-x}(OCH_2COONa)_x]_n$
Hydroxyethyl cellulose	a) 30–40 b) 150–250	$[C_6H_7O_2(OH)_{3-x}(OCH_2CH_2OH)_x]_n$
Cyanoethyl cellulose	a) 25–100 b) 220–290	$[C_6H_7O_2(OH)_{3-x}(OCH_2CH_2CN)_x]_n$

As can be seen from the table, the degree of alkyl substitution in industrially produced cellulose ethers varies over a wide range.

Among the many synthesized and studied cellulose ethers, nearly 15 types are used in practice. One of the most important among them is the sodium salt of carboxymethyl cellulose (Na-CMC). It is the highest-volume cellulose ether produced on an industrial scale [4].

Carboxymethyl cellulose was first obtained in 1918, and industrial production began in Germany in the early 1920s. Since then, significant improvements have been achieved in production technology, product quality, and manufacturing efficiency. Today, various grades of CMC are widely used in many industrial sectors and fully meet industrial demand .

At present, the global production volume of carboxymethyl cellulose (CMC) of various grades amounts to approximately 350 thousand tons per year, which represents about 47–50% of the total production of cellulose ethers. This large production volume is associated with the widespread use of CMC. According to literature data, the number of application fields of CMC exceeds 200 [5].

The rheological properties of thickening agents are significantly influenced by water-soluble dyes that exhibit affinity toward cellulose.

For printing with dyes containing acidic metal-complex compounds, thickening agents based on mixed cellulose ethers containing hydroxyalkyl and carboxyalkyl groups are mainly recommended . These types of thickeners exhibit good solubility and, unlike hydroxyethyl cellulose, do not cause coagulation of acidic metal-complex dyes in prepared printing compositions. The content of the thickener in the prepared dye composition usually does not exceed 5%.

Research methodology. Scanning Electron Microscopy (SEM) is an advanced analytical technique widely used for high-resolution imaging and microstructural characterization of materials. By scanning a focused electron beam across a specimen surface and detecting emitted signals, SEM provides detailed information about surface morphology, topography, and elemental composition. Due to its versatility and nanometer-scale resolution, SEM plays a critical role in materials science, metallurgy, nanotechnology, mineral processing, and industrial quality control.

Scanning Electron Microscopy is a surface-imaging method that uses a focused beam of high-energy electrons instead of visible light. Compared to optical microscopy, SEM offers significantly higher resolution (typically 1–10 nm in modern systems) and a large depth of field, enabling three-dimensional-like surface visualization[5-8;].

SEM has become an essential tool in scientific research and industrial analysis for studying microstructures, fracture surfaces, particle morphology, coatings, and phase distributions.

Images of carboxymethyl cellulose gels crosslinked with Al^{3+} ions are shown in the upper figure, while the xerogels formed during drying are presented in the lower figure.

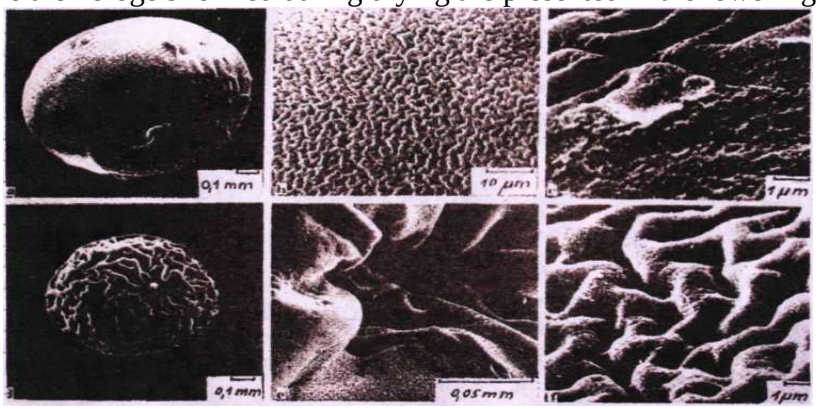
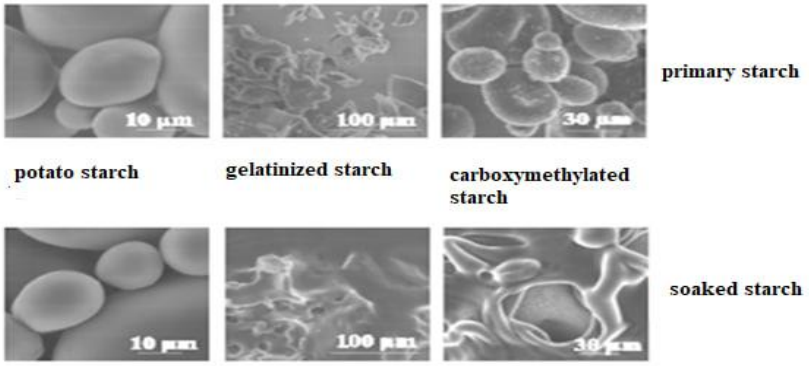


Figure 1.1. Carboxymethyl cellulose gels

Carboxymethyl cellulose is one of the products manufactured annually in large volumes by the chemical industry. One of the main disadvantages of this production is that cellulose is obtained from wood, which is a raw material requiring decades to form. In addition, the production of cold water-soluble CMC requires significant amounts of chemical reagents, such as monochloroacetic acid and caustic soda.

In contrast, starch has a lower degree of polymerization (DP), and when chemically modified, it does not require additional costs associated with oxidative degradation in alkaline media, or with the mechanical degradation and amorphization necessary for obtaining similar products from cellulose. Changes in the morphology of starch under various processing conditions are shown in the microphotographs presented in picture 1.2



Picture 1.2. Morphology of different types of starch

Viscous solutions prepared from modified starch exhibit high uniformity due to the homogeneous distribution of ether groups along the relatively short macromolecular chains. The presented examples demonstrate the feasibility of using starch, modified by chemical methods, for the preparation of various thickening agents and formulations, as well as its advantages over cellulose.

Results and Discussions. Carboxymethylated starch is recommended in cases where a thickener with a low dry matter content in solution is required. Thickening agents based on sodium carboxymethyl starch (Na-CMS) can be obtained when the initial organic substance content exceeds 6%. The viscosity of Na-CMS gels increases with increasing concentration; however, a sufficiently precise relationship between these parameters has not yet been fully established[9-11;].

Na-CMS solutions are resistant to the effects of bacteria and mold, as well as to acids, alkalis, and electrolytes present in the printing composition. They provide high dye penetration into the fabric, improve dye uniformity, are easily washed out during rinsing, and

can also be used in combination with other thickening agents.

Conclusion. The analysis of published scientific literature indicates that the study of thickening agents used in printing blended fabrics remains highly relevant both in the Republic and internationally. Despite significant research devoted to the development and application of high-performance thickeners, many of the proposed formulations still exhibit certain technological, physicochemical, or ecological limitations. Therefore, further improvement of thickening compositions and their functional properties continues to be an important scientific and practical task.

Although substantial progress has been achieved in the synthesis and characterization of thickeners, unresolved issues related to stability, compatibility with dyes, rheological behavior, environmental safety, and process efficiency necessitate continued investigation. The development of advanced thickening systems capable of ensuring uniform print quality, improved fixation, and reduced resource consumption remains a priority in textile printing technology.

Furthermore, the search for innovative and non-conventional approaches to thickener production, particularly those based on resource-saving and environmentally friendly technologies, is of increasing importance. The implementation of sustainable technological processes not only enhances the quality of printed fabrics but also improves labor productivity and reduces environmental impact. In this regard, continued research aimed at developing efficient, eco-friendly, and economically viable thickening agents is scientifically justified and industrially significant.

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THEORETICAL ANALYSIS OF THE TECHNOLOGY FOR PRODUCING A FILLER FOR POLYVINYL CHLORIDE BASED ON NATURAL BASALT AT THE PRESENT TIME

Jumaeva Anora Adham Kizi
Karshi State Technical University
Associate Professor, PhD
Department of Chemical Engineering and Biotechnology
a.jumayeva@kstu.uz
ORCID 0009-0001-5835-1714
Amonov Muxtar Raxmatovich
Buxoro State University Professor, Dsc
Khidirova Yulduz Khujanazarovna
Professor
Berdieva Mukhlisa Bahriddin kizi
Master
Karshi State Technical University
Department of Chemical Engineering and Biotechnology
UDC 678.743.22: 542.06

Abstract. Currently, polymer technology is rapidly developing worldwide, and the advancement of every field related to chemistry is of great importance. In particular, the introduction of innovations in polymer composite material technology plays a significant role. First of all, replacing or combining polymer composite materials with new fillers can open wide technological opportunities. The development of waste-free technologies requires that each component involved in the synthesis of complex substances should preferably be environmentally friendly, which creates favorable conditions for the production of eco-friendly materials.

The use of natural fillers not only promotes waste-free manufacturing technologies but also improves economic efficiency through rational utilization of natural mineral resources. Considering that many polymer products can remain undecomposed in landfills for hundreds of years and cause serious environmental problems, the incorporation of recycled natural fillers into polymers is highly important. One of such natural sources with significant reserves is basalt mineral.

Keywords: basalt, composite, filler, recycling, polyvinyl chloride composite material, modification.

Аннотация. В настоящее время технологии полимеров в мире стремительно развиваются, и развитие каждой области, связанной с химией, имеет большое значение. Значительную часть этого направления занимают технологии полимеров, и внедрение новых решений в данной области является особенно актуальным. Прежде всего, замена или комбинирование состава полимерных композиционных материалов новыми наполнителями может открыть широкие возможности.

Стремясь создать безотходный мир, важно учесть, чтобы каждая частица, участвующая в синтезе сложных веществ, имела природное происхождение, что создаёт большие возможности для производства экологически чистой продукции. Использование таких природных наполнителей способствует не только развитию безотходных технологий производства, но и повышению положительных экономических показателей за счёт рационального использования природных ресурсов.

В условиях, когда полимеры, способные сохраняться на полигонах отходов без разложения в течение сотен лет, представляют серьёзную экологическую проблему, использование переработанных наполнителей на основе природного сырья в составе полимеров приобретает особую актуальность.

Одним из таких природных источников является базальт, обладающий значительными запасами.

Ключевые слова: базальт, композит, наполнитель, переработка, поливинилхлоридный композиционный материал, модификация.

Introduction. Polyvinyl chloride (PVC) is one of the most widely used plastics in modern society. Its main applications include pipes, electrical cables, window profiles, siding, and other products. In recent years, PVC composites reinforced with wood fibers have become increasingly popular due to their acceptable mechanical properties, resistance to moisture and fungi, long service life, wood-like appearance, and recyclability. However, certain disadvantages of this material, including relatively low impact resistance and insufficient

thermal stability, limit its range of applications. This indicates the need for further scientific research on this important material [1].

The use of natural wood particles as fillers may also contribute to environmental concerns associated with the depletion of natural resources. Another commonly used filler for PVC is calcium carbonate (chalk). However, the compositional characteristics of calcium carbonate deposits found in the Central Asian region do not provide the required reinforcing and filling properties. Therefore, calcium carbonate, particularly Belgorod chalk from the Russian Federation, is mainly imported as a filler. This results in additional challenges related to transportation, customs procedures, and storage.

For this reason, there is a need for a filler material that has abundant reserves, low environmental impact, and low cost. Basalt mineral is proposed as a potential filler, and the development and improvement of its processing technology require a solid scientific foundation.

Main part. The processing of minerals used as fillers can vary depending on the intended application. The first and most fundamental processing method is the mechanical method, which prepares the mineral in a suitable condition for subsequent processing stages. Depending on the field of application, the required particle sizes may differ.

Mineral processing operations generally consist of a sequence of stages designed to separate ores into valuable mineral-rich products (concentrates) and waste streams. The distribution of mineral processing stages within the mining value chain is shown in Figure 2. Run-of-mine ore initially undergoes crushing, grinding, and classification processes, which reduce the particle size to an adequate level and ensure the liberation of minerals. These processes prepare the particles for subsequent separation stages, such as mineral flotation or gravity separation methods. It should be noted that the crushing stage is not required when processing tailings; however, this stage may be necessary for previously unprocessed mining waste[2;3].

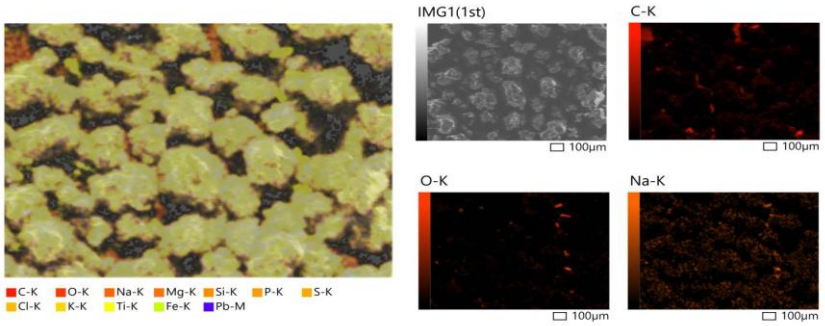
Basalt processing presents somewhat different challenges compared to the processing of conventional ores. At the same time, the general nature and sequence of the process remain unchanged. The main differences lie in the types of technologies used in each individual stage and the methods of their implementation.

Basalt is an extrusive igneous or volcanic rock that has a low silica content, dark in colour, and is very rich in iron and magnesium. Basalt rock is mainly composed of pyroxene, olivine, and plagioclase and is the most common rock on the earth's surface. The texture of basalt rocks is coarsely porous as those holes are left by gas bubbles. The specimens of these rocks are mostly fine-grained, glassy and compact. A large part of the ocean floors is made from basalt rocks. When erupted by volcanoes in ocean basins, it can lead to the formation of volcanic Islands. Basalt rocks have also built up huge plateaus on the surface of the land. Maria, the dark plains on the Moon and also volcanoes of Mars and Venus are known to be possibly made up of basalt. A basalt dark in colour can be called the dark basalt. We find its applications in textile industries, fire protection. From these places, we get a clear idea that understanding basalt use is really important for us. In this article, we will understand what basalt is, the use of basalt, basalt type, and more about this in detail.

Basalt is an igneous rock that is formed from the quick cooling of lava rich in magnesium and iron when exposed at or very near the surface of a terrestrial planet or the moon.(Image will be Uploaded soon)Point to NoteWe must note that more than 90% of all volcanic rock on Earth is basalt, and the eruption/bursting of basalt lava is seen by geologists at around twenty volcanoes every year. Basalt is also a crucial volcanic rock type on other planetary bodies in the Solar System. For example, the lunar maria are plains of flood basaltic lava flow and basalt is a common rock existing on the surface of Mars[4].

Research Methodology. Formation Basalt rocks are usually formed when the volcanic basaltic Lava rapidly cools from the deep interior of the earth's crust equivalent to plutonic gabbro-norite magma and gets exposed to the Earth surface. Gas cavities are absent in the basalt lows and these floors are generally quite thick and extensive. Basalt is now being added to the polymer composite materials component based on the results of new scientific

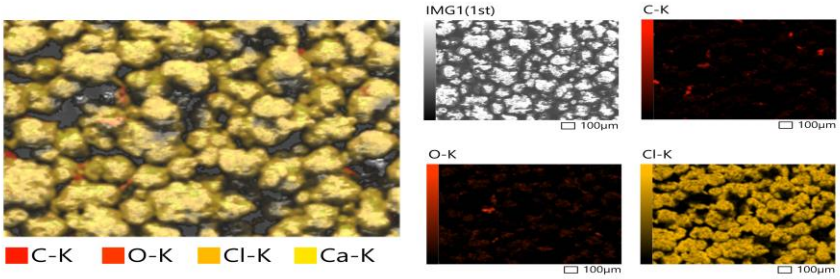
research. Based on this, we can obtain materials for many types of technical purposes, added as a filler for polyvinyl chloride. To obtain a composite material from polymers, only the filler is not enough, that is, it is necessary to add thermostabilizers, plasticizers, colors to the composition of the polymer. These compounds do not interact chemically, but small particles form a common physical bond with each other. A scanning electron microscope image showing the constituents and dimensions of a basalt-doped polymer composite is presented in picture № 1. Scanning Electron Microscope (SEM) is a type of high-precision microscope widely used in modern scientific research. Unlike conventional optical microscopes, SEM uses a beam of high-energy electrons instead of light. This method allows the surface structure of materials to be studied with accuracy down to the nanometer level. Using SEM, the types of elements present in basalt were identified, and it was observed that iron compounds, which negatively affect the physical and mechanical properties of polyvinyl chloride, are present in the basalt composition[5].



Picture №1 scanning electron microscope image of no modified **basalt**

The main visible elements in the image are S, Si, O, Fe, Mg, K, Pb, Cl. 4 of the photos are colored and one is colorless. In images magnified up to 200 and 500 times, we can extract each element from the image according to its color. [5]

The SEM image of basalt presented above represents the sample before mechanical treatment and separation, and the presence of iron compounds can be clearly observed. In the subsequent image presented, it can be distinctly seen that the ore has been purified from metal oxides (picture-2)



Technological section.

In the following sections, each stage of mineral processing presented in Figure 1 is discussed in detail. The fundamental principles underlying the operation of these processes are explained in each section. In addition, supplementary information is provided on the latest technological innovations that enable the adaptation of these processes for the reprocessing of mining waste [6].

The above scheme presents a three-stage technology for preparing natural basalt for further processing. Considering that basalt contains FeO + Fe_2O_3 (iron oxides) in the range of

8–12%, it can be observed that at the first stage up to 2–3% of metal oxides are removed from the composition of the primarily crushed basalt (1). In this process, basalt and iron oxides are separated into two fractions and directed for further processing.

Ore grinding is carried out in a ball mill (2). The basalt is ground to a particle size of up to 2 μm, as this is considered the standard filler size for polyvinyl chloride (PVC). A ball mill is regarded as the most suitable equipment for mechanical grinding, since other types of mechanical comminution may not provide the required particle size distribution for filler applications.

At the final stage, basalt is modified using gossypol oil, which is considered a waste oil (3). The modification process is preferably carried out at 80 °C, taking into account the frictional heating that may generate temperatures in the range of 30–35 °C during processing.

Magnetic separation is one of the key technological stages in the processing and purification of basalt intended for use as a mineral filler. This process is based on the difference in magnetic susceptibility between iron-bearing minerals and the non-magnetic silicate matrix of basalt. Iron-containing phases, such as iron oxides and iron-bearing silicates, can be selectively extracted under the influence of an external magnetic field, thereby improving the chemical purity and functional performance of the final material[7;8].

Mechanical grinding is a critical stage in the technological preparation of basalt for its use as a functional mineral filler. In this study, a ball mill was used for the comminution of basalt due to its high efficiency, operational reliability, and ability to produce ultrafine particles with controlled size distribution. Ball mills are widely used in mineral processing and materials engineering because they provide effective size reduction through impact and attrition mechanisms generated by the movement of grinding media.

The grinding process was carried out in a laboratory-scale ball mill equipped with hardened steel grinding balls. During operation, the rotation of the mill causes the grinding media to rise and fall, generating impact forces that fracture the basalt particles. In addition, friction and shear forces between the balls and the material contribute to further particle size reduction. This combined mechanism ensures efficient comminution and uniform particle refinement.

The basalt was ground to a particle size of up to 2 μm, which is considered suitable for use as a reinforcing filler in polymer composites, particularly in polyvinyl chloride (PVC) matrices. The ultrafine particle size increases the specific surface area of the material, improving its dispersion, interfacial interaction, and compatibility with the polymer matrix. Compared to other grinding methods, the ball mill provides superior control over particle size and ensures consistent production of fine powders required for advanced material applications.

Furthermore, the ball milling process promotes structural activation of the basalt surface, which can enhance its reactivity and improve the effectiveness of subsequent modification processes. The use of a ball mill therefore represents an optimal and reliable method for the preparation of finely dispersed basalt powders for industrial and scientific applications.

At the final stage of the technological process, a mechanical mixer was employed to ensure uniform modification of the basalt powder. The mixing process facilitates the treatment of basalt particles with waste oils, promoting the formation of a hygroscopic surface layer and improving the physicochemical compatibility of the material. The interaction between the finely dispersed basalt particles and the modifying oil leads to enhanced surface activation and improved dispersion characteristics[9].

The application of controlled mixing ensures homogeneous distribution of the modifying agent over the particle surface, which is essential for achieving consistent material properties. As a result, the basalt undergoes complete surface modification and becomes fully prepared for use as a functional filler material.

Conclusion. The combined application of electromagnetic separation, ball milling, and mechanical mixing represents an effective and technologically integrated approach for the comprehensive preparation of basalt intended for use as a functional filler in composite materials. Each stage of the process plays a critical role in improving the physicochemical and

structural properties of the basalt, ensuring its suitability for advanced material applications.

At the initial stage, electromagnetic separation enables the efficient removal of iron-containing phases, including iron oxides and other ferromagnetic impurities, from the basalt matrix. This purification step significantly reduces the FeO and Fe_2O_3 content, improving the chemical uniformity, color stability, and overall quality of the material. The reduction of metallic impurities is particularly important for applications in polymer composites, where the presence of iron compounds may negatively affect processing stability and final product performance[10;11].

Subsequently, the purified basalt undergoes mechanical grinding in a ball mill, resulting in a controlled reduction of particle size to the micrometer scale. This micronization process increases the specific surface area of the particles and enhances their surface activity, which is essential for improving interfacial interaction between the mineral filler and the polymer matrix. The ball milling process also ensures uniform particle size distribution, which contributes to improved dispersion and mechanical performance of the composite material.

At the final stage, mechanical mixing is employed to achieve surface modification of the basalt particles using waste oil as a modifying agent. This process promotes the formation of a functional surface layer, improves the hygroscopic and surface interaction properties, and enhances the compatibility of basalt with polymer systems. The modification process ensures uniform coating and stabilization of the particles, thereby improving their functional performance as a filler material.

Therefore, the integrated use of electromagnetic separation, ball milling, and mechanical mixing enables effective purification, micronization, and surface modification of basalt. As a result, the processed basalt becomes fully prepared for use as a high-performance mineral filler in composite systems, particularly in polymer-based materials such as polyvinyl chloride. This технологический approach not only improves the functional characteristics of basalt but also contributes to the efficient utilization of natural mineral resources and industrial waste materials, supporting sustainable and cost-effective material development.

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KREMNIY FTALOSIANIN PIGMENTINING SINTEZI VA UNING RENTGEN FAZAVIY TAHLILI

D.X. Shukurov
Denov tadbirkorlik va pedagogika instituti, dotsent
X.X.Turayev
Termiz davlat universiteti, professor
Sh.T.Boysariyev
Denov tadbirkorlik va pedagogika instituti, o‘qituvchi
I.E.Toshtemirov
Denov tadbirkorlik va pedagogika instituti, talaba
dkhursanovich@mail.ru
ORCID 0000-0001-9228-5645
UDK 667.287.5.

Annotatsiya. Hozirgi vaqtda energiya bilan bog‘liq bo‘lgan muammolarini hal qilishda eng samarali bo‘lgan yechimlardan biri – bu quyosh energiyasidan foydalanishdir. Organik yarimo‘tkazgich materiallar asosida arzon va istiqbolli quyosh elementlarini yaratish muhim ahamiyatga ega. Ushbu tadqiqotda tandem asosidagi quyosh elementlari uchun bo‘yoq sensibilizator sifatida ishlatiladigan yarimo‘tkazgich kompleks bo‘yoq pigmenti sintez qilindi hamda uning rentgen-vazaviy xossalari o‘rganildi. Ftal angidrid, uglerod (IV) xlorid, karbamid va katalizator ishtirokida [$C_{32}H_{16}SiN_8$] tarkibli kompleks birikma olindi. Sintez qilingan tarkibida kremniy saqlagan ftalosianin pigmenti (XRD-6100 SHIMADZU X-RAY Defractometer) markali rentgen-fazaviy analiz priborida tahlillar amalga oshirildi. Olingan bo‘yoq moddaning qatlamlar va atomlar qatorlari orasidagi o‘rtacha masofani o‘lchash, bitta kristall yoki molekulaning yo‘nalishini aniqlash, noma’lum materialning kristalli yoki amorf tuzilishi hamda kichik kristalli hududlarning o‘lchamini, shakli va ichki tuzilishi aniqlash uchun rentgen fazoviy tahlillar amalga oshirildi.

Kalit so‘zlar: organik pigment, kremniy, ftalosianin, kristall, amorf, tandem quyosh elementlari, rentgen-fazaviy analiz.

SYNTHESIS OF SILICON PHTHALOSIAN PIGMENT AND ITS X-RAY ANALYSIS

Abstract. One of the most effective solutions to energy-related problems today is the use of solar energy. It is important to create inexpensive and promising solar cells based on organic semiconductor materials. In this study, a semiconductor complex dye pigment used as a dye sensitizer for tandem-based solar cells was synthesized and its X-ray diffraction properties were studied. A complex compound containing [$C_{32}H_{16}SiN_8$] was obtained in the presence of phthalic anhydride, carbon (IV) chloride, urea and a catalyst. The synthesized phthalocyanine pigment containing silicon was analyzed using an X-ray diffraction spectrometer (XRD-6100 SHIMADZU X-RAY Defractometer). X-ray diffraction analyses were performed to measure the average distance between layers and atomic rows of the resulting dye, determine the orientation of a single crystal or molecule, determine the crystalline or amorphous structure of an unknown material, and determine the size, shape and internal structure of small crystalline regions.

Keywords: organic pigment, silicon, phthalocyanine, crystalline, amorphous, tandem solar elements, X-ray phase analysis.

Kirish. Markaziy atom sifatidagi metall va metalsiz ftalosianinlar qolaversa, ligandlar sifatidagi qatnashadigan ftalangidrid bilan bog‘ hosil qilib geterosiklik birikmalar saqlagan metall ftalosianinlar sintezi va tadqiqoti ko‘plab yangi turdagi yarimo‘tkazgich va fotoanod materiallar ishlab chiqarish kabi ilmiy tadqiqot yo‘nalishlarini ochilishida juda katta ahamiyatga ega bo‘lib bormoda. Ftalosianinlar kuchli kislotalar va ishqorlar bilan o‘zaro ta’sir qilmaydi, shuningdek, spektrlarning infraqizil va ko‘rinadigan qismida ahamiyatli optik yutilishga ega [1]. Hozirgi kunda J.B. Fayziyev, H.S. Beknazarov, A.T Djalilov, X.X. Turayev kabi olimlar ftalosianin hosilalariga asoslangan murakkab molekulyar komplekslar sintezi va tadqiqoti, shuningdek, metall tutgan ftalosianin molekulasi tarkibidagi ligandlar bilan bog‘lanadigan funksional guruhlarni kiritish orqali makrosikllar sonining ko‘paytirish natijasida ftalosianin komplekslarining modifikatsiyasi bo‘yicha juda ko‘plab ilmiy tadqiqotlar olib bormoqdalar [2]. Biroq metall hamda metalsiz ftalosianinlarning yarimo‘tkazuvchanlik va optik xususiyatlari qanday o‘zgarishi bo‘yicha, qolaversa, murakkab organik yarimo‘tkazgichlarda sodir bo‘ladigan optik, fotodinamik va elektrofizik jarayonlarni tavsiflash kabi yo‘nalishlarda ilmiy tadqiqotlar olib borish muhim ahamiyat kasb etadi [3].

Shuningdek, ftalosianin komplekslariga asoslangan organik yarimo‘tkazgichli materiallarning amaliy qo‘llanilishi bo‘yicha yetarlicha tadqiqotlar olib borilmaganligi bu boradagi tadqiqot ishlarining dolzarbligini yanada oshiradi. Ftalosianin komplekslariga asoslangan materiallarning harorat va kimyoviy ta’sirlarga chidamliligi ularni gaz sensorlari [4-5] va yorug‘lik chiqaradigan qurilmalarda [6] ishlatishga imkon beradi. Kremniy ftalosianin ko‘pincha amaliy ishlanmalarda qo‘llaniladi, chunki u ko‘proq o‘rganilgan va p-tipidagi yarimo‘tkazuvchanlik xususiyatni namoyon qiladi [7].

Ftalosianin komplekslari odatda p-tipli yarimo‘tkazgichlar hisoblangani uchun ularning gazlarga sezgirligi yuqori. Darhaqiqat, gaz molekulasi aniqlash jarayonida tekis elektron tashish vazifasini bajaradi va keyinchalik kamaytirilgan kompleks hosil qiladi. Qolgan musbat zaryad ikkita ftalosianin makrosikllari orqali delokalizatsiya qilinadi, bu esa qarshilikning keskin pasayishiga olib keladi, bu esa o‘z navbatida organik yarimo‘tkazgichni zaryadlash uchun zarur bo‘lgan vaqtni qisqartiradi. Ba’zi tadqiqotlar shuni ko‘rsatadiki, ftalosianin komplekslari samarali fotosensibilizator sifatida ham ishlatilishi mumkin [8] va turli tuzilmalarga ega ftalosianin komplekslariga asoslangan ko‘p komponentli yarimo‘tkazgichli tuzilmani yaratish orqali spektrning yaqin-IR mintaqasida fototok signalini sezilarli darajada oshirish mumkin [9-10].

Ftalosianinlarning bu xususiyati keyingi avlod tandem asosidagi quyosh batareyalarini yaratish, shuningdek, ftalosianin asosidagi gaz sensorlarining sezgirligini oshirish uchun ishlatilmoqda [11]. Ftalosianin komplekslarining yaqin-IR diapazonida elektromagnit nurlanishni faol ravishda yutish qobiliyati organik va noorganik yarimo‘tkazgichlarning xususiyatlarini birlashtirgan murakkab yarimo‘tkazgichli tuzilmalarni yaratish uchun ishlatilmoqda [12]. Organik yarimo‘tkazgich materiallar asosida arzon va istiqbolli quyosh elementlarini yaratish muhim ahamiyatga ega. Tandem asosidagi quyosh elementlari uchun yorug‘likka sezgir bo‘yoq molekulalari sifatida fotonlarni yutadigan va erkin elektronlar hosil qiladigan materiallar ekanligini takidlashimiz lozim [13]. Tandem quyosh elementlari ikki yoki undan ortiq fotoaktiv qatlamlardan tashkil topadi; bu qatlamlarning har biri quyosh spektrining muayyan sohasidagi nurlarni yutishga mo‘ljallangan. Bunday ko‘p qatlamli arxitektura yorug‘lik energiyasining samarali yutilishi va natijada elektr energiyasiga aylantirilish jarayonini sezilarli darajada yaxshilaydi. Natijada, bitta qatlamli an’anaviy fotoelementlarga nisbatan yuqoriroq samaradorlikka erishish mumkin [14].

Adabiyotlarda tandem quyosh elementlarining bir qator muhim jihatlari, jumladan, ularning termal va kimyoviy barqarorligi, optik moslashuvchanligi, turli spektral sharoitlarga moslashuv darajasi hamda sanoat darajasida ishlab chiqarishdagi texnologik muammolari keng muhokama qilinmoqda [15]. Ayniqsa, perovskit asosidagi tandem qurilmalar ultrabinafsha nurlar va atrof-muhit namligiga sezgir bo‘lgani sababli, ularning uzoq muddatli barqarorligi dolzarb ilmiy masalalardan biri bo‘lib qolmoqda. Shu bois, so‘nggi izlanishlar perovskit asosidagi tandemlarda barqarorlikni oshirishga qaratilgan jumladan, himoya qoplamalari, interfeys muvofiqligini ta’minlovchi materiallar va issiqlikka chidamli qatlamlar yaratish ustida olib borilmoqda [16]. Tandem quyosh elementlari o‘zining yuqori energiya samaradorligi, keng spektral qamrovi va konstruktsion moslashuvchanligi bilan kelajakda quyosh energiyasidan foydalanishni yangi bosqichga olib chiqishi mumkin [17]. Tandem quyosh fotoelementlari uchun samaradorligi yuqori bo‘lgan bo‘yoq moddalarni aniqlash yo‘lida istiqbolli tadqiqotlardan biri sifatida ftalosianin birikmalari alohida e’tiborni tortmoqda [18]. Ayniqsa, markaziy qismida metalmas ion tutuvchi ftalosianinlar so‘nggi yillarda ilmiy izlanishlarda katta qiziqish uyg‘otmoqda [19]. Ftalosianin molekulalari yuqori termal va kimyoviy barqarorlikka ega bo‘lishi, rivojlangan π-elektron tizimi hamda turli metalmas atomlar bilan barqaror koordinatsion komplekslar hosil qila olish qobiliyati bilan ajralib turadi. Jumladan, mis (Si^{4+}) atomi bilan hosil qilingan ftalosianin komplekslari yorug‘likka sezgir modda sifatida tandem asosidagi quyosh batareyalarida qo‘llanilishi bilan alohida ahamiyat kasb etadi [20]. Mazkur komplekslarning fizik-kimyoviy xossalarini chuqur o‘rganish, xususan, ularning ligand elektron tuzilmasini tahlil qilish, reaktivligini baholash, strukturaviy parametrlarini aniqlash va rentgen-fazaviy tahlillarini olib borish ushbu tadqiqot ishining dolzarb ilmiy maqsadlari hisoblanadi.

Tadqiqot metodologiyasi.

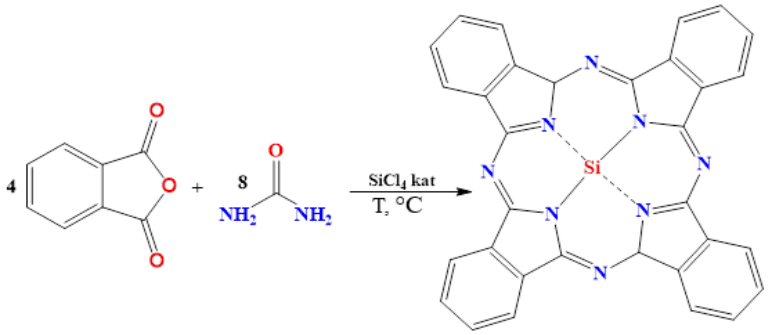
Tadqiqotning maqsadi. Ushbu tadqiqotning maqsadi tarkibida kremniy $Si4^{+}$ atomini saqlagan ftalosianin kompleks birikmasini sintez qilish. Shuningdek, sintez qilingan tarkibida kremniy saqlagan ftalosianin pigmentining rentgen fazaviy tahlilini o‘rganishdan iborat.

Tadqiqot usullari va vositalari. Tadqiqotda rentgen-fazaviy hisoblashlar zamonaviy (XRD-6100 SHIMADZU X-RAY Defractometer) markali rentgen fazaviy analiz priborida olib borildi. Shuningdek, kremniy ftalosianin pigmentining rentgen fazaviy analiz natijalaridagi difraksion spektrida $2\theta \approx 7–25°$ oralig‘ida bir qator aniq va intensiv piklar kuzatiladi. Bu holat olingan kremniy pigmentining fazoviy jihatdan toza, tartibli kristall tuzilishga ega ekanligini aniqlandi.

Tajribaviy qism.

Tarkibida kremniy saqlagan ftalosianin bo‘yoq moddasining sintezi

Kremniy IV-xlorid, karbamid va ftal angidrid hamda katalizator asosida tarkibida kremniy saqlovchi ftalosianin bo‘yoq moddasini sintez qilish uchun 6,8 gr (0,04 mol) kremniy IV-xlorid, 23,68 gr (0,16 mol) ftal angidrid, 19,2 gr (0,32 mol) karbamid va umumiy massaga nisbatan 0.01% miqdorda katalizator sifatida natriy borgidrid qo‘shib yaxshilab aralashtirildi. Oldindan yoqib tayyorlab qo‘yilgan qizdirish pechidagi harorat 290°C ga yetganda stakandagi reaksion aralashmani pechga 2,5 soat davomida qo‘yildi. Jarayonning oxirida, qo‘shimcha tozalash, eritish va neytrallash jarayonidan so‘ng ko‘k, och yashil kristallar paydo bo‘lib stakan tagiga cho‘ka boshlaydi. Olingan cho‘kmani ammiak eritmasi bilan neytrallab so‘ngra Byuxner voronkasida filtrlab, bir necha marotaba distillangan suv bilan yuvib olinadi. Yuvib olingan mahsulotni quritish pechida 50 °C haroratda 12 soat qo‘yib quritiladi. Quyida kremniy ftalosianin yarimo‘tkazgich pigmentining hosil bo‘lish reaksiyasining tahminiy reaksiya formulasi tasvirlangan 1-rasm**.**

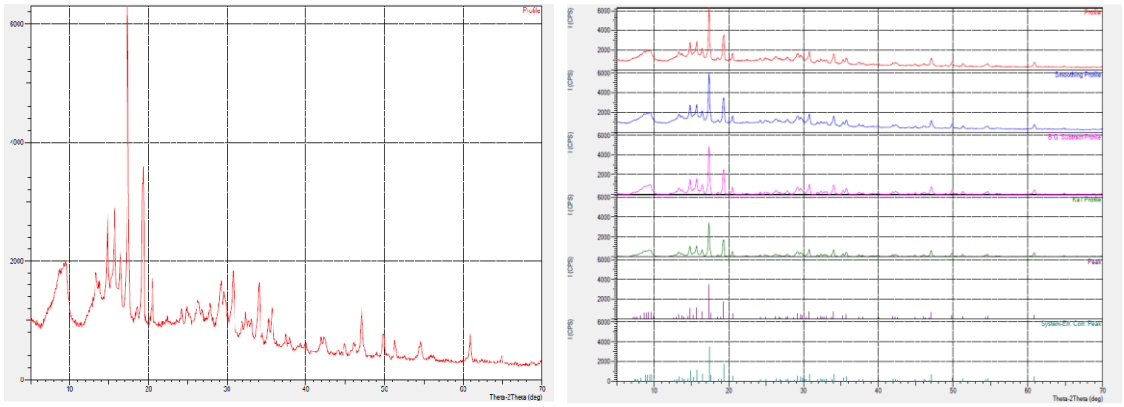


1-rasm. Kremniy ftalosianin yarimo‘tkazgich pigmentining hosil bo‘lish reaksiya tenglamasi.

Sintez qilingan yangi, tarkibida kremniy saqlagan ftalosianin bo‘yoq modda ekanligi adabiyotlardagi ma’lumotlarga solishtirib va fizik-kimyoviy analizlarni amalga oshirib aniqlandi. Sintez qilingan yangi fotokonduktiv bo‘yoq modda turli xossalari bilan ajralib turadi. Masalan, termik jihatdan barqarorligi, quyosh nuriga sezgirligi, hamda eritmada turg‘un ekanligi uning qo‘llanilish sohalarini kengaytiradi. Hozirgi kunda tarkibida kremniy saqlovchi ftalosianin bo‘yoq moddasining sintezi uni muqobil energiya manbalaridan biri bo‘lgan tandem asosida quyosh elementlariga qo‘llash bo‘yicha ilmiy tadqiqotlar ishlari olib borilmoqda.

Tadqiqot natijalar va ularning muhokamasi.

Si-ftalosianin pigmentining rentgen fazaviy analiz tahlili. Sintez qilingan tarkibida kremniy saqlagan ftalosianin pigmenti (XRD-6100 SHIMADZU X-RAY Defractometer) markali rentgen fazaviy analiz priborida tahlillar amalga oshirildi. Kremniy saqlagan ftalosianin pigmentining kristalli tuzilishi 2-rasmda ko‘rsatilganidek, 5–70° 2θ diapazonida rentgen difraksiyasi tahlili orqali o‘rganildi. Olingan bo‘yoq moddasining qatlamlar va atomlar qatorlari orasidagi o‘rtacha masofani o‘lchash, bitta kristall yoki molekulaning yo‘nalishini aniqlash, noma’lum materialning kristalli yoki amorf tuzilishi hamda kichik kristalli hududlarning o‘lchamini, shakli va ichki tuzilishini o‘lchash, shuningdek, moddaning sifat va miqdor tarkibini analiz qilib tahlillarini olishga imkon berdi.



2-rasm. Kremniy ftalosianin pigmentining rentgen difraksion spektrlari.

Yuqoridagi 2-rasmda kremniy saqlagan ftalosianin pigmentining rentgen difraksion spektrlari keltirilgan bo‘lib, ular ketma-ket dastlabki profil (Profile), silliqlangan profil (Smoothing Profile), fon chiqarib tashlangan profil (B.G. Subtract Profile), Kα1 ajratilgan profil (Ka1 Profile), aniqlangan pikslar (Peak) hamda tizimli xatoliklar tuzatilgan pikslar (System-Err. Corr. Peak) ko‘rinishida taqdim etilgan. Difraksion spektrda 2θ≈7–25° oralig‘ida bir qator aniq va intensiv piklar kuzatiladi. Bu holat namunaning kristall tuzilishga ega ekanligini va uning amorf holatda emasligini ko‘rsatadi. Piklarning tor va baland bo‘lishi kristallitlarning nisbatan yaxshi tartiblanganligini bildiradi. Shu bilan birga, 2θ > 30° sohada piklar intensivligining pasayishi va fonning deyarli tekis bo‘lishi pigment tarkibida organik ftalosianin matritsasi ustun ekanligi bilan izohlanadi.

Ftalosianin fazasining identifikatsiyasi: Kuzatilgan asosiy difraksion maksimumlar ftalosianinlarga xos bo‘lgan monoklin yoki triklin kristall panjarasi mavjudligini ko‘rsatadi. Ayniqsa, past burchaklarda (2θ≈7–10°) kuzatiladigan intensiv reflekslar ftalosianin molekulalarining π–π stacking orqali qatlamli joylashuviga mos keladi. Bu xususiyat pigmentning β-ftalosianin fazasiga yaqin kristall modifikatsiyada ekanligini taxmin qilish imkonini beradi. β-faza odatda yuqori termik barqarorlik va yaxshi rang mustahkamligiga ega bo‘lib, pigmentlar uchun muhim hisoblanadi.

Kremniy atomlarining ta’siri: Kremniy atomlarining ftalosianin makrosiklida mavjudligi kristall panjarada lokal deformatsiyalar hosil qilishi mumkin. Bu holat ayrim piklarning: joylashuvida kichik siljishlar, intensivligining nisbatan o‘zgarishi, ayrim past intensivlikdagi qo‘shimcha reflekslarning paydo bo‘lishi bilan namoyon bo‘ladi. Mazkur holatlar kremniy atomlarining markaziy koordinatsion tugunda joylashib, metall-ftalosianin analoglariga o‘xshash struktura hosil qilayotganini ko‘rsatadi.

Fonni chiqarib tashlash va Kα1 ajratish natijalari: Fon chiqarib tashlangan va Kα1 ajratilgan profillar difraksion piklarni aniqroq ajratib ko‘rsatadi. Natijada, pigment tarkibida begona kristall fazalar (masalan, SiO_2 yoki boshqa oksidlar) mavjud emasligi aniqlanadi. Bu esa sintez jarayonining yuqori tozaligini tasdiqlaydi. Kristallit o‘lchami va strukturaviy tartib: Piklarning nisbatan torligi Sherrer tenglamasiga asosan baholaganda, pigmentning kristallit o‘lchami nano-mikrokristall diapazonda ekanligini ko‘rsatadi. Bu holat pigmentning: yaxshi disperslanish xususiyati, yuqori rang intensivligi, optik barqarorligi bilan bevosita bog‘liqdir. Shuningdek, rentgen-fazaviy tahlil natijalariga ko‘ra, kremniy saqlagan ftalosianin pigmenti yaxshi kristallangan, fazaviy jihatdan toza va tartibli tuzilishga ega ekanligi aniqlandi. Kremniy atomlarining mavjudligi kristall panjaraga sezilarli buzilish keltirilmagan, aksincha, pigmentning strukturaviy barqarorligini oshirgan. Olingan natijalar ushbu pigmentning bo‘yoq, polimer yarimo‘tkazgich kompozitlar va tandem asosidagi quyosh elementlari uchun istiqbolli material ekanligini ko‘rsatadi.

1-jadval. Kremniy ftalosianin pigmentining difraktogramma ma’lumotlari

№	2theta-skanerlash burchagi [°2θ]	Piklari [cts]	FWHM integral kengligi [°2θ]	d-tekisliklararo masofa [Å]	I-piklar zichligi
1	7.3791	207	0.5458	11.9704	4

2	8.2667	246	0.3784	10.6870	5
3	9.6524	289	0.3520	9.7023	6
4	12.6824	494	0.5858	8.8386	6
5	15.3240	830	0.3680	6.9737	3
6	16.4913	873	0.3600	5.9767	6
7	18.6088	946	0.2790	4.7643	13
8	20.5409	989	0.2532	4.3203	9
9	24.9514	310	0.2705	3.6678	5
10	27.6769	177	0.3007	3.5652	7
11	29.2088	285	0.1804	3.3844	31
12	32.3409	679	0.1070	3.3241	10
13	35.4952	275	0.1754	3.2999	32
14	42.5823	337	0.1382	3.2182	11
15	46.6769	514	0.2757	3.1957	16
16	47.5481	832	0.1777	2.9678	5
17	49.2089	246	0.1678	2.7534	4
18	51.3227	199	0.3492	2.3985	7
19	54.6763	159	0.5123	1.9284	3
20	60.8658	155	0.1148	1.6773	5

2- jadval. Kremniy ftalosianin pigmentining Williamson-Hull tenglamasiga muvofiq zarrachalar hajmini hisoblash

№	**2theta-skanerlash burchagi [°2θ]**	**FWHM integral kengligi [°2θ]**	***d (nm)- kristallarning o‘rtacha o‘lchami***	***d (nm) o‘rtacha***
1	7.3791	0.5458	4.027	**7,929**
2	8.2667	0.3784	3.128	
3	9.6524	0.3520	3.3976	
4	12.6824	0.5858	7.4293	
5	15.3240	0.3680	5.639	
6	16.4913	0.3600	5.936	
7	18.6088	0.2790	5.1918	
8	20.5409	0.2532	5.2009	
9	24.9514	0.2705	6.749	
10	27.6769	0.3007	8.3030	
11	29.2088	0.1804	5.2575	
12	32.3409	0.1070	3.4604	
13	35.4952	0.1754	6.225	
14	42.5823	0.1382	5.884	
15	46.6769	0.2757	12.86	
16	47.5481	0.1777	8.449	
17	49.2089	0.1678	8.217	
18	51.3227	0.3492	17.92	
19	54.6763	0.5123	28.01	
20	60.8658	0.1148	6.987	

Ftalosianin asosidagi bo‘yoq pigmentlar tandem quyosh elementlari uchun istiqbolli bo‘yoq moddalardan biri hisoblanadi. Ularning yuqori kimyoviy barqarorligi, keng spektrdagi yorug‘likni so‘rish xususiyati va strukturaviy moslashuvchanligi tandem asosidagi quyosh elementlarning samaradorligini oshirishga xizmat qiladi. Ushbu rentgen fazaviy tahlil natijalari bu turdagi materiallardan maksimal darajada foydalanish imkoniyatini oshiradi. Kremniy ftalosianin pigmentining Williamson-Hull tenglamasiga muvofiq *d* o‘rtacha 7,929 hajmi (nm) ga teng ekanligi hisoblab topildi, zarrachalarning o‘lchami nano zarracha ekanligi isbotlandi. Olingan natijalar asosida ushbu pigmentlarning agregatsiya va sirtga bog‘lanishdagi muammolari hal qilinadi.

Xulosa va takliflar. Ftal angidrid, uglerod (IV) xlorid, karbamid va katalizator ishtirokida [$C_{32}H_{16}SiN_8$] tarkibli kompleks birikma sintez qilindi va uning rentgen fazaviy hamda yarimo‘tkazuvchanlik xossalari fizik-kimyoviy usullar yordamida o‘rganildi. Olingan kremniy ftalosianin pigmentini turli fizik kimyoviy xossalari adabiyotlardagi ma’lumotlar bilan solishtirib tahlil qilindi hamda sintez jarayonining optimal sharoitlari aniqlandi.

Shuningdek, kremniy ftalosianin pigmentining rentgen-fazaviy analiz natijalaridagi difraksion spektrida 2θ≈7–25° oralig‘ida bir qator aniq va intensiv piklar kuzatiladi. Bu holat olingan kremniy pigmentining fazaviy jihatdan toza, tartibli kristall tuzilishga ega ekanligini aniqlandi. Kremniy ftalosianin pigmentining bitta molekulasi Williamson-Hull tenglamasiga muvofiq *d* o‘rtacha 7,929 hajmi (nm) ga teng ekanligi hisoblab topildi va zarrachalarning o‘lchami nanozarracha ekanligi isbotlandi.

Ushbu XRD spektri o‘rganilgan moddaning yuqori kristallik darajasiga ega ekanligini, murakkab panjarali simmetriyaga ega bo‘lgan polikristall molekula ekanligini hamda tahlil qilingan cho‘qqilar orqali namunaning atomlararo masofalarini va kristall panjara turini to‘liq hisoblab chiqish mumkin. Olingan natijalar ftalosianin asosidagi metall komplekslarining elektron strukturasini chuqur tushunishga imkon berdi hamda bunday birikmalarning optoelektronika, kataliz, sensor hamda quyosh elementlari uchun sezgir bo‘yoq pigment materiallar sifatida qo‘llanilish salohiyatini tasdiqlaydi. Shuningdek, mazkur nazariy yondashuv kelgusidagi eksperimental tadqiqotlar uchun ishonchli ilmiy asos bo‘lib xizmat qiladi.

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ARGILLIT MINERALI BILAN TO‘LDIRILGAN IKKILAMCHI POLIETILEN VA POLIPROPILEN ASOSIDAGI GEOMEMBRANALARNING FIZIK-MEXANIK XUSUSIYATLARI

Davronova Munisa Nurali qizi
Toshkent davlat tibbiyot universiteti Termiz filiali, assistant
davronovamunisa33@gmail.com
ORCID 0009-0004-8098-9310
Eshqurbonov Furqat Bozorovich
Termiz davlat muhandislik va agrotexnologiyalar universiteti, professor
furqat-8484@mail.ru
ORCID 0000-0002-3182-9407
Ashurova Asal Abduolim qizi
Termiz davlat muhandislik va agrotexnologiyalar universiteti, talaba
asaashuroval@gmail.com
ORCID 0009-0001-6603-3556
Abdullayeva Rayxona Ilhom qizi
Termiz davlat muhandislik va agrotexnologiyalar universiteti, talaba
rayhona8306@gmail.com
ORCID 0009-0006-2562-3687
UDK. 541,64.678.05.01

Annotatsiya. Ushbu tadqiqotda mahalliy Sherobod konidan olingan argillit mineralining qayta ishlangan yuqori zichlikdagi polietilen, qayta ishlangan past zichlikdagi polietilen va qayta ishlangan polipropilen asosidagi geomembranalarning fizik-mexanik xususiyatlariga ta’siri qiyosiy tahlil qilingan. Tajriba natijalari nanodispers argillit minerali barcha turdagi polimer matritsalarda mustahkamlovchi markaz vazifasini bajarishini, biroq uning samaradorligi polimer zanjirlarining tuzilishiga qarab farqlanishini ko‘rsatdi. Xususan, cho‘zilishdagi eng yuqori mustahkamlik (32,8 MPa) qayta ishlangan polipropilen matritsasida kuzatilgan bo‘lsa, eng yuqori elastiklik va teshilishga chidamlilik qayta ishlangan yuqori zichlikdagi polietilen namunalarida qayd etildi va ularning uzilishdagi cho‘zilishi 700% dan oshdi. Rentgen-fluoressent tahlil argillit tarkibidagi alyumosilikat qatlamlari interpolimer to‘siq samarasini yuzaga keltirishini tasdiqladi. Ushbu tadqiqot natijalari gidrotexnika va irrigatsiya inshootlarining ekspluatatsiya sharoitlaridan kelib chiqib, optimal gibrid kompozitsiyani tanlash imkonini beradi.

Kalit so‘zlar: Ikkilamchi polimerlar, qayta ishlangan yuqori zichlikdagi polietilen, qayta ishlangan past zichlikdagi polietilen, qayta ishlangan polipropilen, Sherobod argilliti, nanokompozit geomembrana, fizik-mexanik xossalar, teshilishga qarshilik, qiyosiy tahlil, modifikatsiyalash.

PHYSICAL AND MECHANICAL PROPERTIES OF SECONDARY POLYETHYLENE AND POLYPROPYLENE-BASED GEOMEMBRANES FILLED WITH ARGILLITE MINERAL

Abstract. This study presents a comparative analysis of the effect of argillite mineral, sourced from the local Sherabad deposit, on the physicomechanical properties of geomembranes based on recycled high-density polyethylene, recycled low-density polyethylene, and recycled polypropylene. The experimental results indicated that the nanodispersed argillite mineral acts as a reinforcing center in all types of polymer matrices, but its effectiveness varies depending on the structure of the polymer chains. Specifically, the highest tensile strength (32.8 MPa) was observed in the recycled polypropylene matrix, while the highest elasticity and puncture resistance were recorded in the recycled high-density polyethylene samples, with their elongation at break exceeding 700%. X-ray fluorescence analysis confirmed that the aluminosilicate layers within the argillite create an interpolymer barrier effect. The findings of this study enable the selection of an optimal hybrid composition based on the operational conditions of hydrotechnical and irrigation structures.

Keywords: Secondary polymers, recycled high-density polyethylene, recycled low-density polyethylene, recycled polypropylene, Sherabad argillite, nanocomposite geomembrane, physicomechanical properties, puncture resistance, comparative analysis, modification.

Kirish. Global miqyosda polimer chiqindilarining ortib borishi va ularning atrof-muhitga salbiy ta’siri bugungi kunda barqaror rivojlanish yo‘lidagi eng dolzarb ekologik muammolardan biri hisoblanadi. Polimer mahsulotlarining asosiy qismini tashkil etuvchi polietilen va polipropilen chiqindilari yuqori kimyoviy barqarorlikka ega bo‘lgani sababli tabiiy muhitda uzoq vaqt davomida parchalanmaydi. Shu bois, ikkilamchi polimer resurslarini, xususan, past zichlikdagi polietilen, yuqori zichlikdagi polietilen va polipropilen chiqindilarini qayta ishlash hamda ular asosida yuqori sifatli texnik mahsulotlar, jumladan, geomembranalar kabi gidroizolyatsion materiallar ishlab chiqarish muhim ilmiy va amaliy ahamiyatga ega [1, 2]. Biroq ikkilamchi polimerlarning xossalari birlamchi xomashyolarnikiga qaraganda ancha past bo‘ladi. Bunga asosiy sabab, foydalanish va qayta ishlash jarayonida polimer zanjirlarining termooksidlanish va mexanik destruksiyaga uchrashidir. Masalan, ikkilamchi yuqori zichlikdagi polietilen zanjirlaridagi tarmoqlarning ko‘pligi tufayli yuqori elastiklikka ega bo‘lsa-da, uning mexanik mustahkamligi past; ikkilamchi past zichlikdagi polietilen esa chiziqli tuzilishi tufayli qattiq, lekin mo‘rt sinishga moyil [3]. Ikkilamchi polipropilen yuqori termal barqarorlikka ega, ammo past haroratlarda zarbaga chidamliligini yo‘qotadi [5]. Ushbu polimerlarning har biriga xos kamchiliklarni bartaraf etish va ularning xossalarini halqaro standartlar darajasiga yetkazish uchun samarali modifikatsiyalash usullarini qo‘llash talab etiladi.

Nanokompozit materiallar sohasidagi so‘nggi yutuqlar shuni ko‘rsatadiki, mahalliy mineral to‘ldirgichlar, xususan, qatlamli alyumosilikatlar (argillitlar) polimerlarning xossalarini yaxshilash uchun eng istiqbolli vositalardan biridir [4]. Sherobod koni argilliti o‘zining noyob kimyoviy tarkibi - silikat (SiO_2) va alyuminiy oksidi (Al_2O_3) qatlamlari bilan ajralib turadi. Bu qatlamlar nanodispers holatgacha maydalanganda polimer matritsasida yuqori solishtirma sirtni hosil qiladi [6].

Argillitning modifikatsiyalovchi roli uning polimer zanjirlari bilan interkalyatsiyalanishiga (qatlamlararo kirib borishiga) asoslanadi. Argillit qatlamlari ikkilamchi past zichlikdagi polietilen va polipropilen matritsalarida kristallanish markazlarini hosil qiluvchi agent vazifasini bajarib, polimerning mikrokristallik darajasini oshiradi va buning natijasida materialning mustahkamligi hamda issiqlikka chidamliligi sezilarli darajada ortadi [8, 9]. Ikkilamchi past zichlikdagi polietilen matritsasida esa argillit qatlamlari “egiluvchan to‘siqlar” hosil qilib, polimerning elastikligini saqlagan holda uning teshilish va yirtilishga chidamliligini oshiradi [10]. Bu sinergetik samara geomembranalarning agressiv tuproqli muhitlarda, sho‘rxok yerlarda va harorat keskin o‘zgarib turadigan sharoitlarda uzoq muddat xizmat qilishini ta’minlaydi [7].

Ushbu tadqiqotning ilmiy zarurati shundan iboratki, hozirgi kunga qadar aynan shu mahalliy argillit mineralining qayta ishlangan ikkilamchi yuqori zichlikdagi polietilen, past zichlikdagi polietilen va polipropilen xossalariga qiyosiy ta’siri hamda bu jarayondagi “tuzilish-xossa” bog‘liqliklari tizimli va qiyosiy jihatdan o‘rganilmagan. Mazkur maqolada

uch xil mikrostrukturaga ega argillit va polimer matritsalarining o‘zaro ta’siri qiyosiy baholanadi.

Tadqiqotning maqsadi - Sherobod koni argillit mineralining nanodispers zarrachalaridan foydalanib, qayta ishlangan yuqori zichlikdagi polietilen, past zichlikdagi polietilen va polipropilen asosidagi geomembranalarning fizik-mexanik xossalarini optimallashtirish, ularning teshilishga va agressiv muhitlarga chidamliligini oshirish, shuningdek, O‘zbekiston gidromelioratsiya tizimi uchun mahalliy xomashyodan tejamkor izolyatsiya materiallarini yaratish metodikasini ishlab chiqishdan iborat.

Obyekt va tadqiqot usullari. Tadqiqot obyektlari sifatida Surxondaryo viloyatidan yig‘ib olingan ikkilamchi polimer chiqindilari: qayta ishlangan yuqori zichlikdagi polietilen, qayta ishlangan past zichlikdagi polietilen va qayta ishlangan polipropilen granulalari tanlab olindi. Barcha polimerlar qo‘shimchalardan tozalash uchun dastlab 5% li ishqor eritmasida yuvilib, so‘ngra 80°C haroratda 5 soat davomida quritildi. Modifikator sifatida Sherobod konining mahalliy argillit mineralidan foydalanildi. Argillit zarrachalarini nanodispers holatga keltirish uchun mineral sharli tegirmonda 48 soat davomida mexanik faollashtirildi [11].

Nanokompozit geomembranalar sintezi ikki shnekli ekstruder (L/D=40) yordamida amalga oshirildi. Har bir polimer turi uchun alohida namunalar to‘plami tayyorlandi. Bu jarayonda polimer granulalari va nanodispers argillit kukunlari 5% massaviy nisbatda dozalandi. Ekstruderning harorat rejimlari polimerlarning erish haroratiga asosan quyidagi diapazonlarda nazorat qilindi: qayta ishlangan past zichlikdagi polietilen uchun 170–200°C, qayta ishlangan yuqori zichlikdagi polietilen uchun 190–220°C va qayta ishlangan polipropilen uchun 210–240°C [12].

Olingan namunalarning fizik-mexanik xossalari ASTM D6693 (cho‘zilishdagi mustahkamlik), ASTM D4833 (teshilishga qarshilik) va ISO 1133 (OER) halqaro standartlariga muvofiq universal sinov mashinalari va viskozimetrlar yordamida tahlil qilindi [13]. Materialning iqlimiy barqarorligini aniqlash uchun namunalar 30 ta muzlatish-eritish siklidan o‘tkazildi.

Natijalar va ularning muhokamasi. Qayta ishlangan yuqori zichlikdagi polietilen (YuZP), past zichlikdagi polietilen (PZP) va polipropilen (PP) asosida sintez qilingan nanokompozit geomembranalarning fizik-kimyoviy xossalari, ularning tarkibidagi argillit minerali miqdori va polimer matritsasining tabiatiga bog‘liqligi qiyosiy o‘rganildi. Olingan natijalar 1-jadvalda keltirilgan.

1-jadval

Sof polimerlar va argillit asosidagi nanokompozitlarning fizik-mexanik xossalari (2.0 mm qalinlik uchun)

Material turi	Tarkibi (Polimer + To‘ldirgich)	Mustahkamlik chegarasi, MPa	Uzilishdagi nisbiy uzayish, %	Teshilishga qarshilik, N
PZP	Toza PZP	22.0	600	650
r- PZP + A	Ikkilamchi HDPE + 5% Argillit	**25.4**	**550**	**780**
YuZP	Toza YuZP	14.0	500	380
r- YuZP + A	Ikkilamchi YuZP + 5% Argillit	**18.2**	**710**	**725**
PP	Toza polipropilen	30.0	400	750
r-PP + A	Ikkilamchi PP + 5% Argillit	**32.8**	**385**	**840**

Jadvaldagi ma’lumotlar tahlili shuni ko‘rsatadiki, ikkilamchi polimerlarning barcha turlariga 5% konsentratsiyadagi nanodispers argillitni kiritish ularning mustahkamlik xususiyatlarini birlamchi (yangi) polimerlar darajasiga yetkazishga, hatto undan oshirishga ham imkon beradi.

Xususan, Qayta ishlangan yuqori zichlikdagi polietilen + Argillit kompozitsiyasida mustahkamlik ko‘rsatkichi yangi yuqori zichlikdagi polietilenga nisbatan 30% ga oshib, 18,2 MPaga yetdi. Shunisi diqqatga sazovorki, ushbu namuna uchun nisbiy uzayish maksimal qiymatga - 710% ga yetgan. Bu hodisa argillitning qatlamli alyumosilikat tuzilishi bilan izohlanadi: u polimer zanjirlari orasida “sirpanuvchi qatlamlar” vazifasini bajaradi va

molekulalararo bog‘larni elastik mustahkamlaydi.

Qayta ishlangan past zichlikdagi polietilen va polipropilen asosidagi nanokompozitlarda mustahkamlikning mos ravishda 25,4 MPa va 32,8 MPaga yetgani kuzatildi. Bu natijalar argillit zarrachalari chiziqli va kristallanishga moyil polimer matritsalarda qo‘shimcha kristallanish markazlari bo‘lib xizmat qilishini tasdiqlaydi. Polipropilen matritsasidagi ustun mustahkamlik argillit zarrachalari bilan polipropilenning izotaktik zanjirlari o‘rtasidagi yuqori darajadagi adgezion bog‘lanish natijasidir.

Teshilishga chidamlilik xususiyatlari bo‘yicha eng yuqori natijalarni qayta ishlangan polipropilen + Argillit (840 N) va qayta ishlangan past zichlikdagi polietilen + Argillit (780 N) namunalari namoyon etdi. Bu toshli va shag‘alli tuproq sharoitida geomembranalarning mexanik butunligini saqlash uchun g‘oyat muhimdir. qayta ishlangan yuqori zichlikdagi polietilen asosidagi kompozitda teshilishga chidamlilikning (725 N) yangi polimerga (380 N) nisbatan qariyb ikki baravar ortgani Sherobod argillitining nanodispers zarrachalari polimer matritsasi ichida murakkab “to‘siq” strukturani hosil qilishidan dalolat beradi.

Tadqiqotning keyingi bosqichida mahalliy argillit mineralining turli ikkilamchi polimer matritsalar bilan o‘zaro ta’sirlashuv darajasi hamda uning ushbu matritsalarning fizik-mexanik xossalariga samaradorligi qiyosiy baholandi.

2-jadval

Turli ikkilamchi polimer matritsalarining argillit bilan modifikatsiyalanish darajasi (2.0 mm namuna)

Polimer turi (Ikkilamchi)	**To‘ldirgich miqdori (Argillit, %)**	**Mustahkamlik (σ), MPa**	**Nisbiy uzayish (ϵ), %**	**Teshilishga chidamlilik, N**
Qayta ishlangan- PZP (Nazorat)	0	18.0	500	450
Qayta ishlangan- PZP + A	5	**25.4** (+41%)	**550** (+10%)	**780** (+73%)
Qayta ishlangan - YuZP (Nazorat)	0	10.0	600	320
Qayta ishlangan - YuZP + A	5	**18.2** (+82%)	**710** (+18%)	**725** (+126%)
Qayta ishlangan -PP (Nazorat)	0	25.0	300	600
Qayta ishlangan -PP + A	5	**32.8** (+31%)	**385** (+28%)	**840** (+40%)

2-jadvaldagi ma’lumotlar argillit mineralining qo‘shilishi barcha qayta ishlangan polimerlarning xossalarini sezilarli darajada yaxshilaganini ko‘rsatadi; biroq modifikatsiyalash samaradorligi matritsa tabiatiga qarab farq qilgan.

Argillit minerali qayta ishlangan past zichlikdagi polietilenda eng yuqori modifikatsiya koeffitsiyentini namoyon etdi. Nazorat namunasiga nisbatan mustahkamlik 82%, teshilishga chidamlilik esa 126% ortdi. Bu hodisa qayta ishlangan past zichlikdagi polietilen zanjirlarining yuqori darajada tarmoqlangan tuzilishi hamda mineralning nanodispers zarrachalari ushbu tarmoqlangan zanjirlar orasidagi bo‘shliqlarni to‘ldirib, molekulalararo adgeziyani keskin kuchaytirishi bilan izohlanadi. Mineral zarrachalar polimerda “to‘siq” effektini hosil qilib, materialning dinamik yuklamalarga chidamliligini oshiradi.

Qayta ishlangan yuqori zichlikdagi polietilen namunalarida teshilishga chidamlilikning 73 %ga (450 N dan 780 N gacha) oshishi argillitning chiziqli polimer zanjirlari bilan yuqori darajada interkalyatsiyalashganidan dalolat beradi. Qayta ishlangan past zichlikdagi polietilenning yuqori kristallik darajasi argillit zarrachalari ta’sirida yanada tartiblashib, materialning qattiqligi va elastikligi o‘rtasida muvozanat yuzaga keldi (cho‘zilish 500 foizdan 550 foizgacha oshdi).

Qayta ishlangan polipropilen asosidagi kompozit eng yuqori mustahkamlik ko‘rsatkichiga (32,8 MPa) ega bo‘ldi. Polipropilenning izotaktik tuzilishi argillit zarrachalari bilan yuqori darajada mos keladi va mineral zarrachalari qo‘shimcha kristallanish markazlari vazifasini bajardi. Bu holat materialning mo‘rtlashishiga olib kelmasdan, uning yuk ko‘tarish qobiliyatini 31 %ga oshirdi.

Gidrotexnika inshootlarida geomembranalarning uzoq muddatli ishonchliligini

ta’minlash uchun ularning nafaqat mexanik mustahkamligi, balki agressiv kimyoviy muhitlarga va haroratning keskin o‘zgarishlariga chidamliligi ham hal qiluvchi ahamiyatga ega.

3-jadval

Modifikatsiyalangan geomembranalarning agressiv muhitga va iqlimga chidamliligi

Ko‘rsatkich nomi	**Qayta ishlangan - YuZP + A**	**Qayta ishlangan - PZP + A**	**Qayta ishlangan - PP + A**	**Izoh**
Suv shimuvchanlik, %	0.004	0.003	**0.002**	Nanoto‘ldirgich g‘ovaklarni samarali yopadi
Issiqlikka chidamlilik (Vika), °C	+92	+126	**+152**	PP eng yuqori termik barqarorlikka ega
Sovuqqa chidamlilik, °C	**-55**	-45	-15	LDPE past haroratlar uchun eng maqbul
Kimyoviy barqarorlik (tuzli muhitda)	Yuqori	Juda yuqori	Mukammal	Sho‘rlangan tuproq sharoitiga chidamlilik
Muzlatishdan keyingi mustahkamlik, %	**96**	94	92	30 sikldan so‘ng saqlangan mustahkamlik

3-jadvaldagi ma’lumotlar shuni ko‘rsatadiki, nanodispers argillit minerali barcha turdagi polimer matritsalarning germetikligini va termal barqarorligini sezilarli darajada yaxshilaydi.

Barcha namunalarda suv singdirish ko‘rsatkichining o‘ta pastligi (0,002–0,004%) argillitning qatlamli silikat tuzilishi polimer matritsa ichida suv o‘tkazmaydigan “labirint” samarasini yaratishidan dalolat beradi. Bu esa geomembrana orqali suv va unda erigan tuz ionlari diffuziyasini deyarli to‘xtatib, Surxondaryo kabi sho‘rxok tuproqli hududlar uchun alohida ahamiyat kasb etadi.

Issiqlikka chidamlilik bo‘yicha eng yuqori natijani (+152 °C) qayta ishlangan - PP + Argillit namunasi ko‘rsatdi. Bunga sabab mineral zarrachalarning polipropilen zanjirlari harakatini cheklab, materialning issiqlik ta’sirida deformatsiyalanishini sekinlashtirishidir. Sovuqqa chidamlilik borasida esa Qayta ishlangan - YuZP + Argillit (-55 °C) namunasi yaqqol ustunlik qiladi. Bu natija YuZP asosidagi geomembranalar qishning eng qahraton sharoitlarida ham o‘z egiluvchanligini saqlab qolishini isbotlaydi.

Materiallar mustahkamligining 30 ta muzlatish-eritish siklidan keyin ham 92-96% darajasida saqlanib qolgani ularning tarkibiy yaxlitligi yuqori ekanini ko‘rsatadi. Argillit zarrachalari polimerdagi mikroyoriqlarning kattalashishiga to‘sqinlik qiladi va materialdagi ichki zo‘riqishlarni muvozanatlashtiradi.

Xulosa. Tadqiqotlar natijasida mahalliy Sherobod koni argillit mineralining nanodispers zarrachalari ikkilamchi YuZP, PZP va PP polimer matritsalari uchun yuqori samarali hamda universal modifikator ekanligi ilmiy jihatdan asoslandi. Qiyosiy tahlil shuni ko‘rsatdiki, polimer matritsasiga 5% li modifikatorning kiritilishi ikkilamchi xomashyoning nafaqat fizik-mexanik xususiyatlarini tiklabgina qolmay, balki ularni birlamchi (yangi) polimerlar darajasiga, ba’zi ko‘rsatkichlar bo‘yicha esa undan ham yuqoriga ko‘taradi. Mineralning modifikatsiyalovchi samaradorligi qayta ishlangan PZP matritsasida eng yaqqol namoyon bo‘ldi: bunda teshilishga chidamlilikning 126% ga va mustahkamlikning 82% ga ortishi yuqori elastiklik (710%) bilan birgalikda materialning a’lo darajadagi dinamik bardoshliligini ta’minladi. Shu bilan birga, qayta ishlangan PP va YuZP asosidagi nanokompozitlarda argillit zarrachalari kristallanish markazlari vazifasini o‘tab, cho‘zilishga bo‘lgan mustahkamlikni 32,8 MPa gacha oshirdi va yuqori bosim ostida ishlaydigan gidrotexnik inshootlarda qo‘llash uchun zamin yaratdi.

Agressiv muhit va iqlim omillariga chidamlilik bo‘yicha o‘tkazilgan sinovlar argillit zarrachalarining polimer matritsasi ichida o‘tkazmaydigan “to‘siq” samarasini hosil qilishini tasdiqladi. Bu suv singdirishning minimal qiymatiga (0,002%) erishishga va materialning sho‘rlangan tuproq sharoitlariga chidamliligi keskin oshishiga olib keldi. 30 ta muzlatish-eritish siklidan so‘ng mustahkamligining 92-96 foizini saqlab qolishi mahalliy nanoto‘ldirgichning material uzoq muddat xizmat qilishini ta’minlashdagi hal qiluvchi rolini isbotlaydi. Umuman olganda, tanlangan gibrid kompozitsiyalar O‘zbekiston gidromelioratsiya

tizimi uchun foydalanish talablariga (masalan, elastiklik yoki maksimal mustahkamlikka) ko‘ra tabaqalashtirilgan, import o‘rnini bosuvchi, iqtisodiy tejamkor va yuqori sifatli geomembrana materiallari bo‘lib xizmat qiladi.

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BRASSICA L, SOLANUM LYCOPERSICUM, PISUM SATIVUM L, BETA URUG‘LARI TARKIBIDA KUP MIQDORDA BO`LGAN KVERSITIN FLOVONNOIDI BILAN GK VA GKMAT NI KOMPLEKS BIRIKMASINI OLISH

Xujakulov Axtam Pardaboyevich
Andijon davlat universiteti b.f.n., mustaqil izlanuvchi
xujakulovaxtam@gmail.com
Asqarov Ibrohim Rahmonovich
Andijon davlat universiteti professori
Islomov Akmal Xushvaqovich
O‘zR FA akademik O.S.Sodiqov nomidagi
Bioorganik kimyo instituti
Kompleks birikmalar laboratoriyasi etakchi ilmiy xodimi, k.f.d.
islomovakmal1972@gmail.com
ORCID 0009-0001-1484-0639

UDK 547.972:546.47/.48:543.42

Annotatsiya. Hozirgi kunda tibbiyot amaliyotida qo‘llaniladigan dori vositalarining ko‘pgina qismini tabiiy manbalardan olish yo‘lga qo‘yilgan. Tabiiy manbalardan olinadigan dorivor vositalar olinish samaradorligi, organizm tomonidan oson o‘zlashtirilishi, salbiy ta’sirlari kamligi, biologik mosligi hamda o‘ziga xos ta’sirlari tufayli sun’iy yaratilgan dorivor vositalardan tubdan farq qiladi. Ayniqsa antioksidant, antibakterial va zamburug‘larga hamda nafas yo‘llarining yallig‘lanish kasalliklariga qarshi ta’sirga ega kimyoviy birikmalarga farmatsevtika sanoatida talab yuqoriligi sababdan biologik faol moddalarga boy o‘simlik turlarini aniqlash, ulardan biologik faol moddalar ajratib olish va farmatsevtika sanoatiga tavsiya etish biologiya va kimyo sohasida muhim ahamiyat kasb etadi.

Ushbu maqolada Brassica L, Solanum lycopersicum, Pisum sativum L, Beta urug‘lari tarkibida kup miqdorda bo`lgan Kversitin flovonnoidi suvda yomon eriydi, ushbu kamchilikni bartaraf etish va biologik kirishuvchanligini oshirish maqsadida Glitsirrizin kislota (GK) va Glitsirrizin kislota monoammoniyli tuzi (GKMAT) bilan kompleks birikmasi sintezi amalga oshirilishi va fizik-kimyoviy xossalari hamda spektrlari haqida so‘z yuritiladi.

Kalit so‘zlar: Brassica L, Solanum lycopersicum, Pisum sativum L, Beta, IQ spektri, kversitin flovonnoidi, Glitsirrizin kislota (GK), Glitsirrizin kislota monoammoniyli tuzi (GKMAT)

Abstract. At present, a significant proportion of medicinal products used in medical practice are obtained from natural sources. Natural medicinal compounds differ fundamentally from synthetic drugs due to their high extraction efficiency, better bioavailability, low toxicity, biological compatibility, and unique pharmacological properties. In particular, the growing demand in the pharmaceutical industry for antioxidant, antibacterial, antifungal, and anti-inflammatory agents for the treatment of respiratory diseases highlights the importance of identifying plant species rich in biologically active compounds, isolating these compounds, and recommending them for pharmaceutical applications. This has become an important area of research in biology and chemistry.

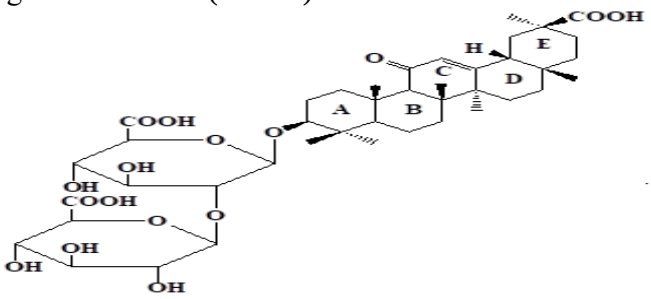
This article discusses the synthesis of inclusion complexes of quercetin, a flavonoid present in high concentrations in the seeds of Brassica L., Solanum lycopersicum, Pisum sativum L., and Beta, with glycyrrhizic acid (GA) and the monoammonium salt of glycyrrhizic acid (MASGA). Since quercetin exhibits poor water solubility, the formation of these complexes was carried out to overcome this limitation and enhance its bioavailability. The study also presents the physicochemical properties and infrared (IR) spectral characteristics of the synthesized complexes.

Keywords: *Brassica* L., *Solanum lycopersicum, Pisum sativum* L., *Beta,* IR spectrum, quercetin flavonoid, glycyrrhizic acid (GA), monoammonium salt of glycyrrhizic acid (MASGA).

Kirish. Dunyoda dorivor o‘simliklarni yetishtirish, dastlabki xomashyo bazalarini yaratish va ularning kimyoviy tarkibini o‘rganish, biologik faol birikmalarni ajratib olish hamda o‘simliklar asosida yangi turdagi import o‘rnini bosuvchi arzon va sifatli biologik faol qo‘shimchalar va dori vositalarini yaratish dolzarb muammolardan biri hisoblanadi. Kversitin flovonnoidi suvda yomon eriydi, uning suvda eruvchan birikmasini olish ucun GKMAT bilan kompleks birikmasi sintezi amalga oshiramiz buning uchun *Glycyrrhiza glabra* (shirinmiya) o‘simligi ildizidan adabiyotlardagi m`alum usul asosida GKMAT ajratib olamiz. GKMAT tuzini unumi qayta kristallashdan keyin TGK ga nisbatan 28-30% tashkil qiladi, GK ning miqdori o‘rtacha 22-23% ni tashkil etdi. GKMAT ning tozalik darajasi YuSSX usuli (80-81%) yordamida aniqlandi. Supramolekulyar kompleks birikmalarni olish uchun asosan tozalik darajasi 80-81% bo‘lgan GK, GKMAT dan foydalanildi.

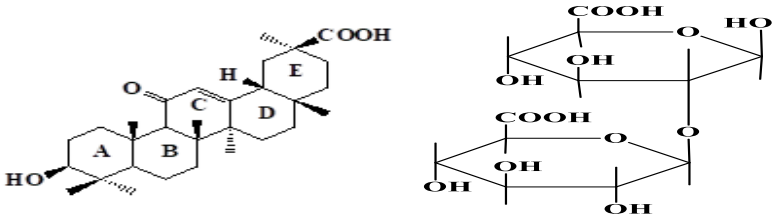
Nazariy qism. GK va uning hosilalari asosida dori vositalari yaratilishida uning solyubilizatsiya qilish xossasi asosiy omillardan biri bo‘lib xizmat qiladi. Ko‘pgina suvda yaxshi erimaydigan yoki umuman erimaydigan dori moddalar (aspirin, indometatsin va boshqalar), GK va uning tuzlari bilan molekulyar komplekslar hosil qilib, suvda eruvchan holatga o‘tishi ko‘rsatilgan. [1].

GK va uning hosilalarining tuzilishi to‘g‘risida ko‘p tadqiqotlar ma’lum [2-3]. Ushbu manbalardagi keltirilgan ma’lumotlarga ko‘ra, GK tuzilishi 3β-gidroksi-11-okso-12-en-18β-N, 20β-olean-30 kislotaning 3-O-(2'-O-β-D-glyukurono-piranozil)-β-D-glyukuron-opiranozidiga mos keluvchi struktura to‘g‘ri hisoblanadi (1-rasm)



1-rasm. Glitsirrizin kislotasining kimyoviy tuzilishi

Glitsirrizin kislotasi (GK) ikki qismdan iborat: gidrofob (aglikon triterpen) glitsirret kislotasi (a) va gidrofil (2 molekula qand, glyukuron kislota).si(b) dan tashkil topgan. 2-rasm.



a **b**

2-rasm. (a) Gidrofob (aglikon triterpen) glitsirret kislotasi va (b) Gidrofil (2 molekula qand, glyukuron kislota si).

Aglikon tuzilishi jihatidan, ayrim tomonidan glyukokortikoid gormonlariga o‘xshashligi mavjud. Shu xususiyatiga ko‘ra GK va uning tuzlari tuz almashinishini muvofiqlashtirish (Addison kasalligida) va yallig‘lanishga qarshi ta’sir etish xususiyatlariga ega. Bundan tashqari GK kortikosteroid gormonlar sinergisti hisoblanadi [4].

Supramolekulyar kimyo fanining nisbatan yosh yo‘nalishidan biri supramolekulyar kimyo, hisoblanib, o‘tgan asrning 60-70 yillarida makrotsiklik birikmalar, xususan, makrotsiklik metall ligandlari kimyosi bilan birga jadal rivojlana boshlagan. To‘liq bo‘lmasa-da, oddiy va murakkab supramolekulyar kimyoviy sistemalar haqidagi konsepsiya va tasavvurlar, zamonaviy kimyo fani shakllanish davridan ma’lum bo‘lgan [5-8].

Supramolekulyar kimyo rivojida Ch.Pedersen tomonidan kraun efirlar kashf etilishi muhim ahamiyatga ega bo‘ldi. U neft moylari oksidlanishidan saqlovchi ingibitorlar sintez qilib, qo‘shimcha mahsulot sifatida dibenzo-18-kraun-6 oldi. Keyinchalik Ch.Pedersen tarkibida 4 dan 20 gacha kislorod atomlari tutgan va o‘lchami 12 dan 60 a’zoligacha bo‘lgan 60 ga yaqin makrotsiklik poliefirlar sintez qildi. U kraun efirlari ishqoriy va ishqoriy-yer metallari kationlari bilan mustahkam komplekslar hosil qilishini va ularni kristall holda ajratib olish mumkinligini ko‘rsatdi [5-8].

Jan-Mari Len supramolekulyar kimyoni “molekulyar ansambllar va molekulalararo bog‘lar kimyosi” yoki “molekula tashqarisidagi kimyo” hamda “kovalent bog‘larsiz kimyo” deya ta’riflagan.

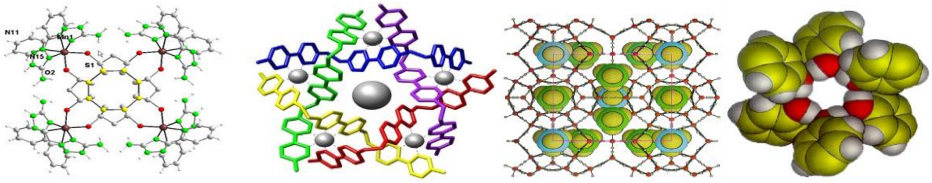
Jan-Mari Len supramolekulyar kimyoni ikki keng sohaga bo‘ladi: supermolekulalar kimyosi - bir necha komponentlarning (retseptor va uning substratlari) molekulalararo assotsiatsiyasi natijasida vujudga keladigan molekulalararo bir-birini “tanish” prinsipi asosida quriladigan hamda yaqqol chegaraga ega bo‘lgan oligomolekulyar zarrachalar;

Molekulyar ansambllar kimyosi – bir necha (aniq soni ma’lum bo‘lmagan) komponentlarning spontan assotsiatsiyasi natijasida hosil bo‘ladigan va aniqroq belgilangan mikroskopik tuzilmaga ega spetsifik fazaga o‘tuvchi hamda ularning xarakteristikalari tabiatiga bog‘liq (masalan klatratlar, membranalar, vezikulalar, mitsellalar) polimolekulyar sistemalardir [5-8].

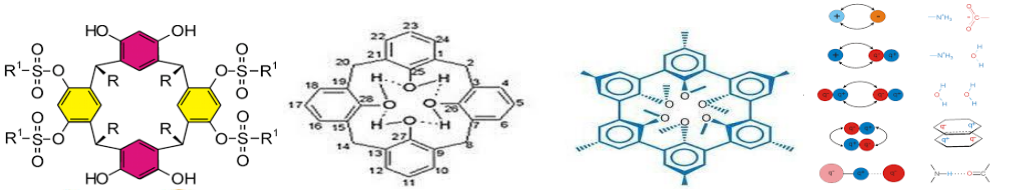
Donald Kram supramolekulyar kompleksda “mehmon-mezbon” molekulalari orasidagi munosabatga quyidagicha ta’rif bergan: komplekslar kovalent bog‘lar tabiatidan farq qilib, ikki va undan ortiq molekula yoki ionlardan tashkil topib, elektrostatik kuchlar hisobiga bog‘langan antiqa strukturali sistemadan tashkil topgan [8].

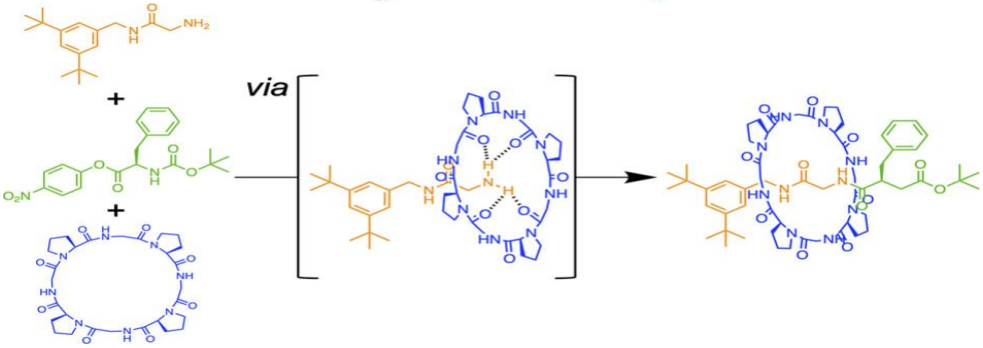
Ko‘plab bog‘lanish markazlari hisobiga strukturada kamida bitta mezbon va bitta mehmon ishtirokida yuzaga keladi. Mehmon va mezbon o‘rtasidagi ta’sir kuchlarini hisobga olib, mezbon birikmalarni sinflashda, agar mezbon-mehmon agregat elektrostatik kuchlar (ion-dipol, dipol-dipol va vodorod bog‘lar) evaziga bog‘langan bo‘lsa “kompleks” atamasi qo‘llaniladi. Kuchsiz, yo‘naltirilmagan (gidrofob, Van-der-vals va kristall panjara ta’sirlari va boshqa) kuchlar evaziga bog‘langan strukturalarga “kavitat” yoki “klatrat” atamasini qo‘llash qabul qilingan.

“Mehmon-mezbon” tipidagi kompleks hosil bo‘lishida “mezbon” molekulasi “mehmon” molekulasi bilan bog‘lanib supramolekulani hosil qiladi. Odatda mezbon vazifasini markazida kattagina bo‘shliq tutgan yirik molekula yoki agregat bajaradi. Mehmon o‘rnida esa biror anorganik kation, anion yoki gormon va fermentlar kabi murakkabroq molekula bo‘lishi mumkin (3-rasm).



yoki





yoki

3-rasm. Mehmon - mezbon tipidagi supramolekulyar komplekslarning turli xil ko‘rinishlari.

Supramolekulyar kimyoning birinchi o‘rganilgan ob’ektlari klatratlar hisoblanadi. Klatratlar - bu mehmon deb ataladigan molekulalarni mezbon deb nomlanuvchi boshqa molekulalar karkasiga kiritishdan hosil bo‘lgan birikmalardir. Ko‘pincha mehmon va mezbon molekulalar orasida Van-der-vals o‘zaro ta’sir kuchlaridan boshqa ta’sirlashishlar bo‘lmaydi. Klatratlarning termodinamik barqarorligi mezbon molekulasi karkasida mehmon molekulasini qulay joylashish geometriyasi bilan ta’minlanadi.

Glitsirizin kislotasining molekula tarkibida qutbli va qutbsiz guruh tutgan xamda mitsella hosil qilishga moyil modda xisoblanadi. Mitsellalar – ko‘plab molekulalardan iborat assotsiatlardir. Ular bir necha xil xarakterli shakllarga ega bo‘lishi mumkin: sfera, mono-, bi- va ko‘p qavatli. Mitsellaning qaysi shaklda bo‘lishi alohida molekulaning geometrik parametrlariga va molekulada elektr zaryadlangan uchastkalarning joylashuviga bog‘liq Adabiyotda keng yoritilgan ma’lumotlarga asosan mitsellaning sfera ko‘rinishi shaklida esa molekulalar suvdan o‘zining qutbli tomonlari bilan ajralgan bo‘ladi. Sferik mitsellani hosil qiluvchi molekulalar soni 50 tadan 1000 ta va 10000 tagacha xam etishi mumkin. Bu birinchi navbatda molekulaning tashqariga yo‘nalgan bosh sohasi (zaryadlangan qismi) bilan sfera ichkarisiga yo‘nalgan gidrofob qismi o‘lchamlari nisbatiga bog‘liq. Agar bu o‘lchamlamlar bir-biriga yaqin bo‘lsa, sfera juda katta va beqaror bo‘ladi. Bu xolda qatlamli konstruksiyalar hosil bo‘lish ehtimoli mavjud.

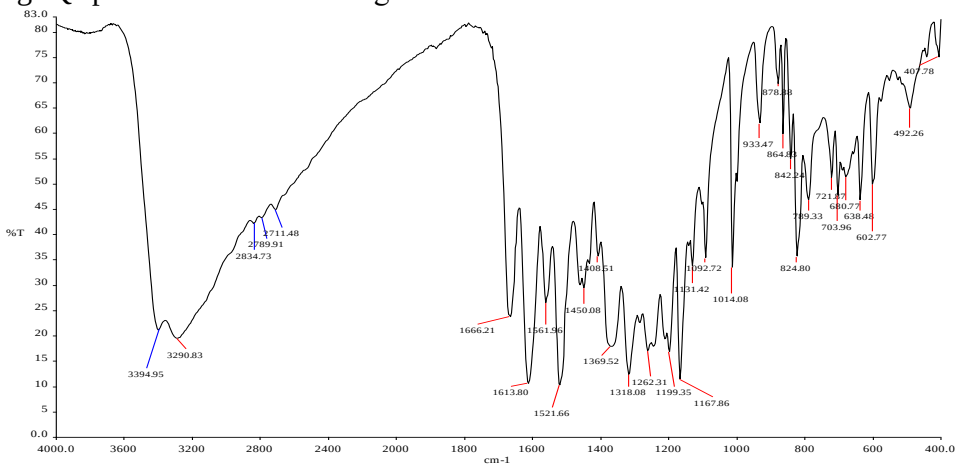
Natijalarni muhokamasi. *Brassica L, Solanum lycopersicum, Pisum sativum L, Beta* urug‘lari tarkibida kup miqdorda bo`lgan Kversitin flovonnoidi suvda yomon eriydi, ushbu kamchilikni bartaraf etish va biologik kirishuvchanligini oshirish maqsadida GK va GKMAT bilan kompleks birikmasi sintezi amalga oshirildi. *Brassica L, Solanum lycopersicum, Pisum sativum L, Beta* urug‘i tarkibidagi Kversitin miqdori YuSSX qurilmasida aniqlangandagi xromotografiyasi 1-jadvalda keltirilgan.

1-jadval

***Solanum lycopersicum, Pisum sativum L, Beta, Brassica L,* urug‘larini tarkibida Kversitin miqdorda borligi** , mg.

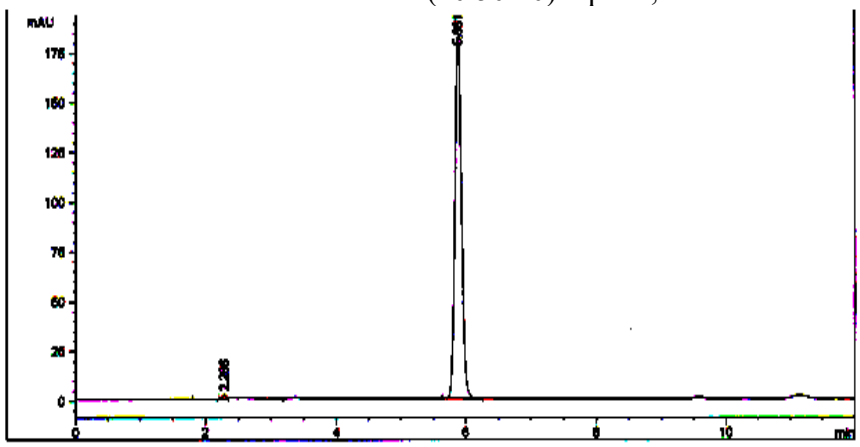
№	flovonoid	*anum lycopersicum, Pisum sativum L, Beta, Brassica L,* urug‘lari			
		Pomidor	Yashil no'xot	Lavlagi	Karam
5	Kversitin	11,22	22,51	17,21	18,95

Jadvaldagi ma'lumotlar shuni ko'rsatadiki, *Solanum lycopersicum* urug`i tarkibida kversitin 11,22 mg miqdorda va *Pisum sativum L*, da kversitin 22,51 mgni, *Beta*da kversitin 17,21 mgda hamda *Brassica L*, urug`i tarkibida kversitin 18,95 mg miqdorda bo`lishi hamda kimyoviy va fizik xossalari, spektrlari aniqlandi. Kvertsetinning IQ spektridagi 3395-3290 sm^{-1} sohalardagi tebranish chastotalari molekuladagi gidroksil gruppalarning valent tebranishlariga tegishlidir. 2835-2810 sm^{-1} sohadagi tebranish chastotalari rutin molekulasidagi metil, metilen gruppalarga tegishlidir. 1666-1614 sm^{-1} sohadagi intensiv tebranish chastotalari karbonil gruhlariga xos tebranishlar. Kvertsetin molekulasidagi aromatik halqaning tebranish chastotalari 900-700 sm^{-1} sohalarda kuzatilgan, molekuladagi C-O-C bog'ining defarmatsion tebranish chastotalari esa 1100-1000 sm^{-1} sohalarda namoyon bo'lgan. Kvertsetinning IQ spektri 4-rasmda keltirilgan.



4-rasm. Kversetin IQ spektri

Kvertsetinni ham YSSX da tekshirilganda, uning tozalik darajasi 91 % ni tashkil etgan. (5-rasm) Sistema: atsetonitril:metanol:bufer (40:50:10) oqim 1,2 ml/min



5-rasm. Kvertsetinning tozaligi xromatogrammasi

Kversetinning fizik-kimyoviy kattaliklari 2-jadvalda keltirilgan.

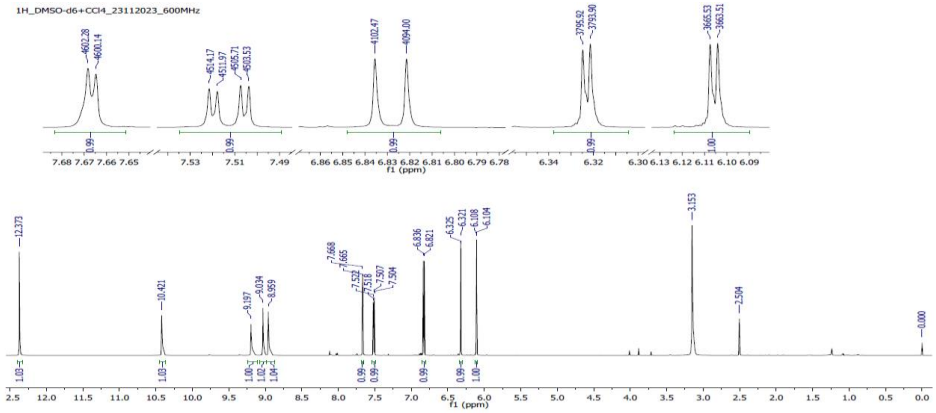
2-jadval

Kversetinning fizik-kimyoviy kattaliklari

№	Modda-lar	Brutto formu-lasi va M.og'.	T.suyuq. C^0	R_f^* (tizim)	IK spektri sm^{-1}
1	Kversetin	$C_{15}H_{10}O_7$ 302,236	316	0,55 (I)	1666(-O); 2835,(CH_3); 3395,(OH);

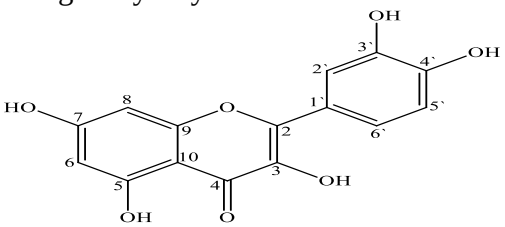
I.etilatsetat:etanol, 25:1 sistemada

Kversetinning ^1H YaMR spektrida uch turdagi protonlarning signallarining ko'rish mumkin: jumladan, aromatik halqa protonlari va gidroksil gurux protonlari va erituvchi proton signallaridir. Flavonolning asosiy tuzilishi benzopironning C-3-holatida gidroksil guruhi joylashgan bo'lib, uni 3-gidroksiflavonga aylantiradi. 6-rasmda keltirilgan.



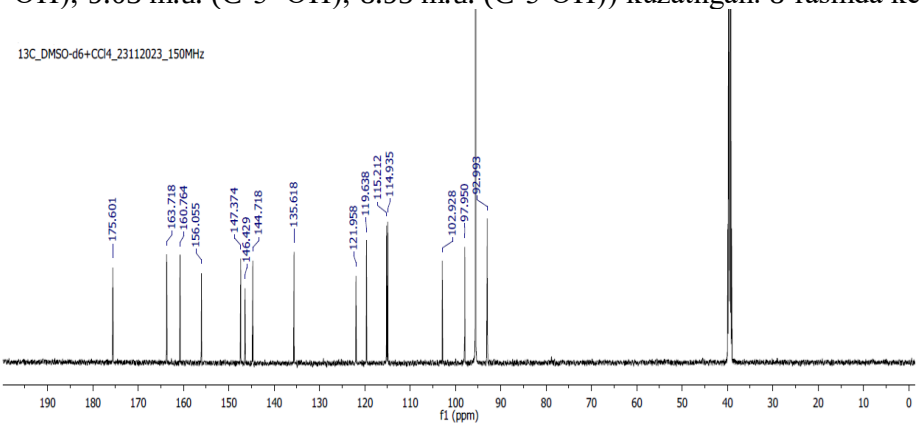
6-rasm. Kversetinning ^{1}H YaMR spektri

Kversetinning kimyoviy formulasi 7-rasmda keltirilgan.



7-rasm. Kversetin,($C_{15}H_{10}O_7$) ^{1}H YaMR spektri (600 MGs, Py-d_6, δ, m.u., J/Gs): 6.11 d (J=2.0 H-6), 6.32, d (J=2.0, H-8), 7.67 d (J=2.2, H-2′), 6.83 d (J=8.5, H-5′), 7.51 dd (J=8.5, 2.2, H-6′), 12.37 s (C-5 OH), 10.42 s (C-7 OH), 9.19 s (C-4′ OH), 9.03 s (C-3′ OH), 8.95 s (C-3 OH).

Benzopirondagi ikkita aromatik proton, C-6 va C-8 da, mos ravishda 6,11 m.u. va 6,32 m.u. da dublet ko‘rinishda namoyon bo‘ladi. C-2' (7.67 m.u) va C 5' (6.83 m.u) protonlari mos ravishda dublet shaklda, C-6' protonlari esa 7.51 m.u.da (J=8.5, 2.2) dublet-dublet shaklda namoyon bo‘ladi. Bundan tashqari molekuladagi OH guruxlarda joylashgan proton signalari signallari singlet shaklda kuzsiz maydonda (12.37 m.u. (C-5 OH), 10.42 m.u. (C-7 OH), 9.19 m.u. (C-4′ OH), 9.03 m.u. (C-3′ OH), 8.95 m.u. (C-3 OH)) kuzatilgan. 8-rasmda keltirilgan.



8-rasm. Kversetinning ^{13}C YaMR spektri

Kversetinning ^{13}C YaMR spektri (150 MGs, Py-d_5, δ, m.u.): 146.43 (C-2) 135.62 (C-3), 175.60 (C-4), 160.76 (C-5), 97.95 (C-6), 163.72 (C-7), 92.99 (C-8), 156.06 (C-9), 102.93 (C-10), 121.96 (C-1'), 114.94 (C-2'), 144.72(C-3'), [94;33-44-b.].

Kversitin flovonnoidi suvda yomon eriydi, uning suvda eruvchan birikmasini olish ucun GKMAT bilan kompleks birikmasi sintezi amalga oshiramiz buning uchun *Glycyrrhiza glabra* (shirinmiya) o‘simligi ildizidan adabiyotlardagi m`alum usul asosida GKMAT ajratib olamiz. GKMAT tuzini unumi qayta kristallashdan keyin TGK ga nisbatan 28-30% tashkil qiladi, GK ning miqdori o‘rtacha 22-23% ni tashkil etdi. GKMAT ning tozalik darajasi YuSSX usuli (80-81%) yordamida aniqlandi. Supramolekulyar kompleks birikmalarni olish uchun asosan tozalik darajasi 80-81% bo‘lgan GK, GKMAT dan foydalanildi. Ularning fizik-kimyoviy xususiyatlari 3-jadvalda keltirilgan.

3-jadval

GK va GKMAT tuzini ayrim fizik-kimyoviy kattaliklari

Moddalar	$T._{suyuq}$ C^0	$R_f^{*\,(tizim)}$	$[\alpha]_D$ 0,5% EtOH (50%)	IQ (ν, sm^{-1})	UB nm
GK (m.og‘.840) Oq kukun	210-213	0,07 (I)	+48	1045,(COC); 1654, (CO) 2873,(CH_3); 2938, (OH) 3407, (OH)	251
GKMAT $3H_2O$ (m.og‘ 894) Och sariq kukun	225-227	0,32 (II)	+40	1042,(COC); 1655, (CO) 2948, (OH); 3239, (OH)	253

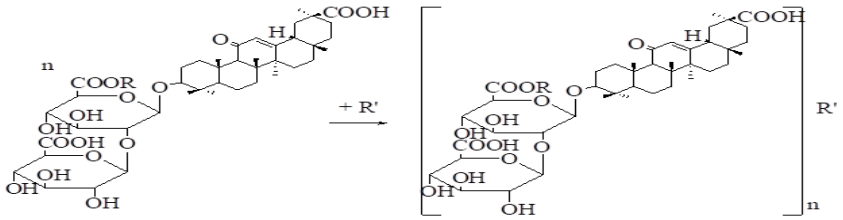
***I**.Etilatsetat- atseton 5:1, **II**.Butanol-sirka k-ta-suv 3:1:1,

Organik birikmalar orasidagi molekulalararo ta’sirlar va ushbu ta’sirlanishlar jarayonida qaysi funksional guruhlar ishtirok etayotganliklari haqidagi qimmatli ma’lumotlar, dastlabki moddalar va oxirgi mahsulotlar IQ-spektrlarini taqqoslash asosida olinishi mumkin. Shundan kelib chiqqan holda, atsetil almashgan lagoxilin hosilalarining GK va GKMAT bilan supramolekulyar kompleks hosil qilishini baholash jarayoni IQ-spektroskopiya usuli va boshqa fizik-kimyoviy tahlillar asosida olib borildi.

Kversitin flovonnoidi bilan GK va GKMAT tuzini supramolekulyar komplekslarini olish uchun GK va GKMAT ning 50% etonolda eritib, aralashtirib turgan holda mos ravishda kversitin flovonnoidi qo‘shiladi, reaksion aralashma 10-12 soat davomida xona haroratida aralashtiriladi. etonol haydab olinib, suvli qism liofil usulda quritilib olindi. Olingan supramolekulyar kompleks birikmalar oq va och sariq rangli, amorf kukun. GKMAT kompleks birikmalari 0,1% li suvli eritmalari gel hosil qilish xususiyatiga ega. Birinchi marotaba kversitin flovonnoidining GK va GKMAT tuzi bilan supramolekulyar komplekslari olindi. Ularning umumiy olinishi 1- sxemada keltirilgan.

1-sxema.

Kversitin flovonnoidi GK va GKMAT bilan supramolekulyar komplekslarini olishni umumiy sxemasi



Bu erda: R=H bo`lganda(GK); R=$NH_4$ , bo`lganda (GKMAT) bo`ladi. n=2; (1:2) n=4; (1:4). R^1= Kversetin

Kversitin flovonnoid bilan GK va GKMAT ni 1:2, 1:4 molekulyar nisbatlardagi supramolekulyar kompleks birikmalari och sariq amorf kukun bo‘lib, suvda yaxshi eriydi. Qutblangan yorug‘lik nuri tekisligini burish burchagi $[\alpha]_D$ aniqlandi. Ular optik faol birikmalar bo‘lib, qutblangan nur tekisligini o‘nga buruvchi moddalardir. Olingan supramolekulyar kompleks birikmalar ayrim fizik-kimyoviy va spektral parametrlari bilan tavsiflandi, ular 4-jadvalda keltirilgan.

4-jadval

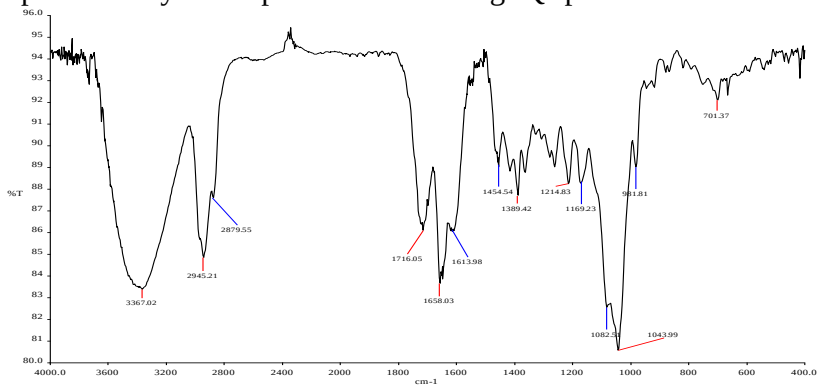
Kversitin flovonnoidi bilan GK va GKMAT tuzini supramolekulyar komplekslarining ayrim fizik-kimyoviy ko‘rsatkichlari

№	Moddalar mol.og‘	$T._{suyuq}.C^0$ parch.	R_f^*	$[\alpha]_D$ 0,5% EtOH(50%)	IK , sm^{-1}	Unum %
1	GK:KVRS: 2:1 (2076)	199-201	0,14 (I)	+61	1043,,(COC);1726 (CO) 2936,(CH_3);3407 (OH)	90,2
2	GK: KVRS: 4:1 (3756)	203-205	0,13 (II)	+53	1043,(COC);1632 (CO) 2946, (CH_3);3406 (OH)	80,0
3	GKMAT: KVRS: 2:1 (2189)	181-184	0,61 (III),	+21	1042, (COC);1659 (CO) 2941, (CH_3);3405 (OH)	90,9

4	GKMAT: KVRS: 4:1 (3972)	186-188	0,57 (III)	+17	1042, (COC);1632 (CO) 2945, (CH_3);3422 (OH)	89,2

I. Etilatsetat, **II.** Etilatsetat-atseton 5:1, **III.** Xloroform-etanol 5:1,

Kversitin flovonnoidi bilan olingan GKMAT ni 1:2, 1:4, molekulyar nisbatlardagi supramolekulyar kompleks birikmalarining IQ spektrida 1740-1725 sm^{-1} oralig‘idagi sohada GK va Kversitin flovonnoidining karbonil guruhi valent tebranishlari va 3400-3250 sm^{-1} oralig‘idagi sohada vodorod bog‘lari hosil qilishda qatnashgan gidroksil guruhlarining valent tebranishlari keng elka ko‘rinishida namoyon bo‘lishi va metil guruhlarining deformatsion tebranishlari 2935-2925 sm^{-1} oralig‘idagi sohada namoyon bo‘lishi kuzatildi. KVRT:GKMKT ni 1:2 nisbatdagi supramolekulyar kompleks birikmasining IQ spektri 9-rasmda keltirilgan.

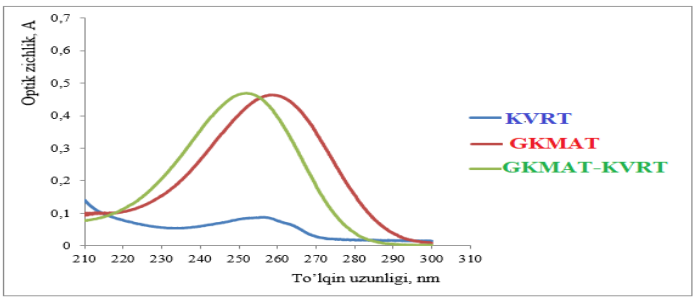


9-rasm. KVRT bilan GKMKT 1:2 nisbatdagi supramolekulyar kompleksining IQ spektri

Olingan barcha supramolekulyar kompleks birikmalar tuzilishini o‘rganishda organik molekulalarning elektromagnit nur bilan o‘zaro ta’sirlashuviga asoslangan fizikaviy usullar, xususan, ularning IQ- (molekuladagi atomlarning tebranish spektri, $\lambda=10^{-4}$-10^{-2} sm) spektri va UB- (tashqi pog‘onadagi elektronlarning energetik holati o‘zgarishiga asoslangan elektron spektri, $\lambda=10^{-6}$-10^{-4} sm) spektrlari keng qo‘llanildi. Ushbu usullar yordamida dastlabki moddalar va supramolekulyar komplekslarni spektridagi farqlar asosida yangi ta’sirlashuv hamda bog‘lar haqida xulosa chiqarish mumkin. Supramolekulyar komplekslarning tuzilishini tahlil qilishda ularning UB va IQ-spektri ma’lumotlaridan foydalanildi.

Kompleks moddalarning, jumladan, supramolekulyar birikmalarning tuzilishini o‘rganishda organik molekulalarning elektromagnit nur bilan o‘zaro ta’sirlashuviga asoslangan fizikaviy usullar, xususan, ularning UB- (tashqi pog‘onadagi elektronlarning energetik holati o‘zgarishiga asoslangan elektron spektri, $\lambda=10^{-6}$-10^{-4} sm) keng qo‘llaniladi.

UB-spektrda GKMAT ning C halqasidagi qo‘shbog‘ bilan kon’girlangan C=O ning π elektronlariga tegishli π-π^* o‘tishga mos keladigan intensiv yutilish maksimum qiymati suv:etanol (1:1) tizimda yaqin UB- sohada 250-253 nm to‘lqin uzunligida kuzatildi. Quyidagi 10-rasmda keltirilgan.



10-rasm. GKMAT bilan KVRT ni supramolekulyar kompleks (KVRT-GKMAT) (2:1) nisbatdagi birikmasini UB-spektri. Sm=510^{-5}mol/l,50% etanol erituvchi

Dastlabki moddalar (GKMAT, KVRT) spektrlari bilan kompleks birikmalari **(**GKMAT:KVRT 2:1) spektrlari va molekulyar massalarini taqqoslanganda yuzaga kelgan qator o‘zgarishlarni kuzatish mumkin va bu “gidrofob-gidrofob” ta’sirlashish va vodorod bog‘lari hisobiga vujudga kelishini taxmin qilib qarasak supramolekulyar kompleks birikma

hosil bo‘lganidan dalolat beradi. Dastlabki moddalarni IQ-spektrlarini supramolekulyar komplekslar spektrlari bilan taqqoslaganda yuzaga kelgan qator 15-20 sm^{-1} oralig‘idagi (siljishini)o‘zgarishlarni kuzatish mumkin va bu “mehmon-mezbon” ko‘rinishdagi supramolekulyar kompleks birikma hosil bo‘lganidan dalolat beradi.

Xulosa. 1. Kversitin flovonnoid bilan GK va GKMAT ni 1:2, 1:4 molekulyar nisbatlardagi supramolekulyar kompleks birikmalari olindi va ular och sariq amorf kukun bo‘lib, suvda yaxshi eriydi.

2. Dastlabki moddalar (GKMAT, KVRT) spektrlari bilan kompleks birikmalari **(**GKMAT:KVRT 2:1) spektrlari taqqoslanganda yuzaga kelgan qator o‘zgarishlarni kuzatish mumkin va bu “gidrofob-gidrofob” ta’sirlashish va vodorod bog‘lari hisobiga vujudga kelishini taxmin qilib qarasak supramolekulyar kompleks birikma hosil bo‘lganidan dalolat beradi.

3. Dastlabki moddalarni IQ-spektrlarini supramolekulyar komplekslar spektrlari bilan taqqoslaganda yuzaga kelgan qator 15-20 sm^{-1} oralig‘idagi (siljishini)o‘zgarishlarni kuzatish mumkin va bu “mehmon-mezbon” ko‘rinishdagi supramolekulyar kompleks birikma hosil bo‘lganidan dalolat beradi.

4. GKMAT bilan KVRT ni supramolekulyar komplekslarini UB-spektrda GKMAT ning C halqasidagi qo‘shbog‘ bilan kon’girlangan C=O ning π elektronlariga tegishli π-π^* o‘tishga mos keladigan intensiv yutilish maksimum qiymati suv:etanol (1:1) tizimda yaqin UB- sohada 250-253 nm to‘lqin uzunligida kuzatilishi aniqlandi.

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QASHQADARYO VILOYATI AHOLISI ORASIDA 2025-YIL DAVOMIDA O‘TKAZILGAN 25-OH VITAMIN D TAHLILLARI NATIJALARINING EPIDEMIOLOGIK TAHLILI

Ernazarov Erkin Fayzullayevich
Qarshi davlat universiteti Klinik anatomiya kafedrasi
stajyor o‘qituvchisi, vrach laborant
erik301989@gmail.com
ORCID 0009-0009-9134-7141
UDK 612.015.6:316.42(575.43)

Annotatsiya. Vitamin D organizmda suyak mineralizatsiyasi, immun tizimi faoliyati va metabolik jarayonlarning muhim regulyatoridir. Dunyo bo‘yicha vitamin D yetishmovchiligi keng tarqalgan bo‘lib, global meta-tahlillarda 25(OH)D < 20 ng/ml bo‘lganlar ulushi 47,9% ni tashkil etadi. O‘zbekiston hududida, jumladan, Qashqadaryo viloyatida vitamin D darajalari bo‘yicha epidemiologik ma’lumotlar cheklangan.

Qashqadaryo viloyati aholisi orasida 2025-yil davomida olingan 25-OH D tahlil natijalarini tahlil qilish va ularni global epidemiologik ko‘rsatkichlar bilan taqqoslash.

2025il 1-yanvardan 30-noyabrgacha o‘tkazilgan 1497 ta serum 25-OH D natijalari retrospektiv tarzda o‘rganildi. Natijalar quyidagi mezonlar asosida tasniflandi: <12 ng/ml (defitsit), 13–20 ng/ml (normadan past), 20–30 ng/ml (nisbiy normal), 30–100 ng/ml (normal), >100 ng/ml (yuqori). Statistik tahlil deskriptiv usulda amalga oshirildi.

Tekshiruvchilar orasida 25-OH D < 20 ng/ml bo‘lganlar ulushi **45,75%**ni tashkil etdi. Shundan 14,02% to‘liq defitsit (<12 ng/ml), 31,73% normadan past daraja (13–20 ng/ml) bo‘ldi. 20–30 ng/ml oralig‘ida 30,59%, 30–100 ng/ml oralig‘ida 22,37% normal darajalar qayd etildi. 1,26% holatlarda >100 ng/ml bo‘lgan yuqori ko‘rsatkichlar aniqlandi. Natijalar global meta-tahlil ko‘rsatkichlariga (47,9% <20 ng/ml) yaqin.

Qashqadaryo viloyati aholisi orasida vitamin D yetishmovchiligi keng tarqalgan bo‘lib, epidemiologik vaziyat global ko‘rsatkichlarga mos keladi. Hududda vitamin D defitsitining oldini olish, xavf guruhlarida skriningni kengaytirish va qo‘shimcha preparatlar qabulini tartibga solish zarur.

Kalit so‘zlar: Vitamin D, 25-OH D, defitsit, epidemiologiya, Qashqadaryo, O‘zbekiston, global taqqoslash, yetishmovchilik, toksiklik, laborator tahlil.

ANALYSIS OF THE RESULTS OF TESTS CONDUCTED AMONG THE POPULATION OF THE QASHQADARYO REGION IN 2025

Abstract. Vitamin D is an important regulator of bone mineralization, immune system function, and metabolic processes in the human body. Vitamin D deficiency is widespread worldwide; according to global meta-analyses, the proportion of individuals with 25(OH)D < 20 ng/ml is 47.9%. In Uzbekistan, including the Qashqadaryo region, epidemiological data on vitamin D levels are limited.

The aim of this study was to analyze 25-OH D test results obtained during 2025 among the population of the Qashqadaryo region and compare them with global epidemiological indicators.

A retrospective analysis was conducted on 1,497 serum 25-OH D test results performed between January 1 and November 30, 2025. The results were classified according to the following criteria: <12 ng/ml (deficiency), 13–20 ng/ml (below normal), 20–30 ng/ml (relatively normal), 30–100 ng/ml (normal), >100 ng/ml (high). Statistical analysis was performed using descriptive methods.

Among the examined individuals, the proportion with 25-OH D < 20 ng/ml was 45.75%. Of these, 14.02% had severe deficiency (<12 ng/ml) and 31.73% had below-normal levels (13–20 ng/ml). Levels of 20–30 ng/ml were observed in 30.59%, while 22.37% had normal levels (30–100 ng/ml). High levels (>100 ng/ml) were identified in 1.26% of cases. The results were close to those reported in global meta-analyses (47.9% <20 ng/ml).

Vitamin D deficiency is widespread among the population of the Qashqadaryo region, and the epidemiological situation corresponds to global indicators. It is necessary to strengthen preventive measures against vitamin D deficiency in the region, expand screening among risk groups, and regulate the use of vitamin D supplements.

Keywords: Vitamin D, 25-OH D, deficiency, epidemiology, Qashqadaryo, Uzbekistan, global comparison, insufficiency, toxicity, laboratory analysis.

Kirish. Vitamin D — metabolik jihatdan muhim yog‘da eriydigan vitamin bo‘lib, 25-hidroksivitamin D (25-OH D) plasma konsentratsiyasi uning holatini baholashda asosiy bioindikator hisoblanadi. 25-OH D ning yetarli darajasi, diagnostik chegaralari va optimal daraja bo‘yicha qator konsensuslar mavjud: IOM/US NAS 2011-yilda ruxsat etilgan minimal darajani 20 ng/ml (50 nmol/L) deb belgilagan va tavsiya etilgan RDA 600–800 IU/kun ni ko‘rsatgan. Endokrinologiya jamiyati esa amaliy qo‘llanmada klinik baholash va davolash

tamoyillarini batafsil bayon qilgan.[8];[10];[11]

Vitamin D organizmda kalsiy-fosfor almashinuvini, suyak mineralizatsiyasini, mushaklar faoliyatini va immunitetni boshqarishda muhim rol o‘ynaydigan vitamin-gormon hisoblanadi. Vitamin D yetishmovchiligi bolalarda raxit kasalligini, kattalarda esa osteomalatsiya holatini keltirib chiqarish bilan birgalikda, immunitet pasayishiga ham sabab bo‘ladi. Lekin bu vitamin D preparatlarini palapartish qo‘llash uchun ko‘rsatma bo‘lmasligi kerak. Har bir insonga davolovchi maqsadda yoki profilaktik maqsadda vitamin D buyurishdan avval qon tarkibida vitamin D miqdorini tekshirish kerakligi jahon sog‘liqni saqlash protokollarida ta’kidlab o‘tilgan.

Vitamin D qabul qilish me’yoridan oshirib yuborish ko‘plab og‘ir oqibatlarga olib kelishi mumkin. Ayniqsa 1 yoshgacha bo‘lgan bolalarda vitamin D palapartish qo‘llanishi erta buyrak yetishmovchiligi, liqildoqlarning erta bitib qolishi, suyaklanish kuchayishi natijasida o‘sish zonalari qotib qolishi ko‘plab ilmiy tajribalarda aniqlangan.[2];[4];[7]

Vitamin D yetishmovchiligi dunyo bo‘yicha keng tarqalgan bo‘lib, 2000–2022-yillar oralig‘ida o‘tkazilgan 7,9 million kishini qamrab olgan meta-tahlil natijalariga ko‘ra, global miqyosda 25(OH)D < 12 ng/ml bo‘lganlar ulushi 15,7%, < 20 ng/ml bo‘lganlar ulushi esa 47,9% ni tashkil etgan.

O‘zbekiston hududi, jumladan, Qashqadaryo viloyati iqlimi quyosh nuri yetarli bo‘lishiga qaramay, kiyinish an’analari, ovqatlanish odatlari va tashxisga murojaat qilingan guruhlarda asosan ayollar ko‘pligi sababli vitamin D yetishmovchiligi sezilarli darajada uchrashi ehtimoli mavjud. Shuning uchun hududiy miqyosda vitamin D darajasini o‘rganish epidemiologik monitoring uchun muhim ahamiyatga ega.[10]; [11]; [15]

Ushbu tadqiqotning maqsadi — Qashqadaryo viloyati bo‘yicha 2025-yil 1-yanvardan 30-noyabrgacha o‘tkazilgan 25-OH D laborator tahlillari natijalarini tahlil qilish va ularni global epidemiologik ko‘rsatkichlar bilan taqqoslashdan iborat.

Material va metodika. Tadqiqot retrospektiv kesim (cross-sectional) ko‘rinishda bo‘lib, Qashqadaryo viloyati hududida 2025-yil 1-yanvardan 30-noyabrgacha laboratoriyalarga 25-OH D tahlili topshirgan 1497 nafar shaxsning natijalari tahlil qilindi. Tahlil uchun serumdagi 25-gidroksivitamin D darajasi ng/ml birlikda o‘lchangan.[1];[3];[5]

Natijalar quyidagi tasnif asosida guruhlarga ajratildi:

- < 12 ng/ml — to‘liq defitsit
- 13–20 ng/ml — normadan past daraja
- 20–30 ng/ml — nisbiy normal (insuffitsit)
- 30–100 ng/ml — optimal normal
- >100 ng/ml — yuqori daraja (toksik darajaga yaqin)

Ma’lumotlar foizlarda ifodalandi va global meta-tahlil ko‘rsatkichlari bilan taqqoslandi.

Natijalar va muhokama. Umumiy 1497 nafar tekshiriluvchining 25-OH D ko‘rsatkichlari quyidagi taqsimotda kuzatildi, natijalar 1-jadvalda ko‘rsatilgan**.**

1-jadval

Guruh	Mutlaq son (n)	Ulushi (%)	Daraja
0–12 ng/ml	210	14,02 %	Defitsit
13–20 ng/ml	475	31,73 %	Normadan past
20–30 ng/ml	458	30,59 %	Nisbiy normal
30–100 ng/ml	335	22,37 %	Normal
>100 ng/ml	19	1,26 %	Normadan yuqori
Jami	1497	100 %	—

Vitamin D <20 ng/ml bo‘lganlar jami 45,75% (685 kishi) ni tashkil etdi. Shundan 14,02% to‘liq defitsitga to‘g‘ri keladi. Normal (30–100 ng/ml) darajaga ega shaxslar — 22,37%, yuqori ko‘rsatkich (>100 ng/ml) qayd etilganlar — 1,26%.

Olingan natijalar Qashqadaryo viloyati aholisi orasida vitamin D yetishmovchiligi keng tarqalganligini ko‘rsatdi. Tekshiriluvchilar orasida 20 ng/ml dan past darajalar ulushi 45,75% ni tashkil etdi, bu global meta-tahlil natijalari (47,9%) bilan deyarli bir xil ekanini ko‘rsatadi. To‘liq defitsit holati (<12 ng/ml) 14,02% ulushni tashkil etib, global daraja (15,7%) bilan mos keladi.

Hududda 20–30 ng/ml oralig‘idagi nisbiy normal ko‘rsatkichlarning yuqori bo‘lishi (30,59%) quyosh nuri yetarli bo‘lishiga qaramay, D vitamini balansining to‘liq ta’minlanmasligi mumkinligini ko‘rsatadi. Bu holat ovqatlanish, tashqi muhit, kiyinish an’analari, qishda quyosh ta’sirining kamayishi yoki ayollarda hijob va yopiq kiyim ko‘p bo‘lishi kabi omillar bilan bog‘lanishi ehtimoldan xoli emas.

Yuqori daraja (>100 ng/ml) 1,26% hollarda aniqlandi. Bu global epidemiologiyada kam uchraydigan (odatda <1%) holat bo‘lib, aholining o‘z-o‘zini davolash maqsadida yuqori doza vitamin D qo‘shimchalarini nazoratsiz qabul qilayotganidan dalolat beradi. Bu klinik xavf tug‘diradi, chunki vitamin D toksikligi giperkalsemiya, nefrokalsinoz va yurak ritm buzilishlariga olib kelishi mumkin.

Natijalar shuni ko‘rsatadiki, Qashqadaryo viloyatida vitamin D yetishmovchiligi bo‘yicha epidemiologik holat global tendensiyalar bilan to‘liq uyg‘un. Hududiy sog‘liqni saqlash amaliyotida vitamin D yetishmovchiligi bo‘yicha muntazam skrining, xavf guruhlarini aniqlash va profilaktik qo‘shimchalar bo‘yicha standart protokollar ishlab chiqilishi maqsadga muvofiq.

Xulosa. 1. 2025-yil davomida Qashqadaryo viloyatida 25-OH D tahlili o‘tkazilgan 1497 nafar shaxsning 45,75% da vitamin D yetishmovchiligi aniqlandi.

2. 14,02% holatlar to‘liq defitsit (<12 ng/ml)ni ko‘rsatgan bo‘lsa, 31,73% da esa normadan past daraja (13–20 ng/ml) aniqlangan.

3. Hududiy ko‘rsatkichlar global epidemiologik natijalarga mos keladi (global <20 ng/ml ≈ 47,9%).

4. 1,26% hollarda yuqori darajalar (>100 ng/ml) qayd etildi, bu nazoratsiz qo‘shimcha iste’molini ko‘rsatadi.

5. Vitamin D yetishmovchiligi hududda jiddiy sog‘liq muammosi bo‘lib, skrining dasturlari, profilaktika va xavf guruhlari bilan ishlash zarur.

6. Mahalliy sharoitda vitamin D qo‘shimchalarini qabul qilish bo‘yicha tibbiy tavsiyalarni standartlashtirish va aholida xabardorlikni oshirish muhim hisoblanadi.

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YAKKA KURASH SPORTCHILARIDA LAKTAT METABOLIZMI VA FIZIOLOGIK KO‘RSATKICHLARNING STATISTIK TAHLILI

Nazarov Sobir Usmonovich, p.f.b.f.d.(PhD), dotsent
Jismoniy tarbiya va sport bo‘yicha mutaxassislarni qayta tayyorlash va malakasini oshirish instituti
Xaydarova Shaxnoza Elmuratovna
Qarshi davlat universiteti Fiziologiya kafedrasi o‘qituvchisi
xshaxnoza711@gmail.com
ORCID 0009-0007-1799-7694
UDK 796.01:612

Annotatsiya. Mazkur tadqiqotda yakka kurash sport turlari (kurash, boks, dzyudo) bilan shug‘ullanuvchi sportchilarda jismoniy yuklama paytida laktat metabolizmining fiziologik xususiyatlari o‘rganildi. Tadqiqotda 60 nafar yuqori malakali sportchi ishtirok etdi. Asosiy fiziologik ko‘rsatkichlar sifatida mushak kuchi, 30 metr sprint vaqti, VO_2max va qondagi laktat konsentratsiyasi baholandi. Olingan ma’lumotlar SPSS dasturi orqali tahlil qilinib, ANOVA, korrelyatsiya va regressiya tahlillari amalga oshirildi. Natijalar mushak kuchi va laktat konsentratsiyasi o‘rtasida ijobiy korrelyatsiya mavjudligini ($r=0.41$), VO_2max ko‘rsatkichi esa laktatni bartaraf etish jarayoniga manfiy bog‘liqlik orqali ta’sir ko‘rsatishini ($r=-0.36$) ko‘rsatdi.

Shuningdek, tadqiqot natijalari sportchilarda jismoniy yuklamaga moslashuv darajasi va tiklanish tezligi laktat almashinuvi bilan bog‘liqligini ko‘rsatdi hamda funksional holatni yaxshilashda muhim omil ekanligi aniqlandi.

Kalit so‘zlar: laktat metabolizmi, yakka kurash, sport fiziologiyasi, VO_2max, anaerob glikoliz, statistik tahlil.

STATISTICAL ANALYSIS OF LACTATE METABOLISM AND PHYSIOLOGICAL INDICATORS IN WRESTLING ATHLETES

Abstract. This study investigates the physiological characteristics of lactate metabolism in athletes engaged in combat sports (wrestling, boxing, and judo) under physical нагрузка. A total of 60 highly qualified athletes participated in the study. The primary physiological indicators assessed included muscle strength, 30-meter sprint time, maximal oxygen uptake (VO_2max), and blood lactate concentration.

Statistical analysis was performed using SPSS software, applying analysis of variance (ANOVA), correlation, and regression analyses. The results revealed a significant positive correlation between muscle strength and lactate concentration ($r = 0.41$), while VO_2max demonstrated a negative relationship with lactate levels ($r = –0.36$), indicating its important role in lactate clearance processes. Additionally, the results of the study showed that athletes’ adaptation to physical нагрузка and recovery rate are associated with lactate metabolism and are important factors in improving functional condition.

Keywords: lactate metabolism, combat sports, sports physiology, VO_2max, anaerobic glycolysis, statistical analysis.

Kirish. Zamonaviy sport fiziologiyasida laktat metabolizmi jismoniy ish qobiliyatini baholashda muhim ko‘rsatkichlardan biri hisoblanadi, chunki anaerob glikoliz jarayonida hosil bo‘ladigan laktat yuqori intensivlikdagi mashqlar paytida mushaklarda to‘planadi. Ayniqsa, kurash, boks va dzyudo kabi yakka kurash sport turlari qisqa vaqt ichida maksimal kuch va

tezlikni namoyon etishni talab qilgani sababli, bu jarayonda anaerob energiya ta’minoti tizimi faollashib, laktat konsentratsiyasi keskin oshadi. So‘nggi ilmiy tadqiqotlar laktatni faqat charchash omili sifatida emas, balki energiya almashinuvida muhim metabolit sifatida talqin etib, uning qayta ishlatilish imkoniyatlarini asoslab bermoqda. Xususan, George A. Brooks tomonidan ilgari surilgan laktat almashinuvi nazariyasiga ko‘ra, laktat organizmda energiya manbayi sifatida qayta foydalanilishi mumkin. Shu jihatdan, laktat metabolizmini chuqur o‘rganish sportchilarning funksional holatini aniqlash, ularning jismoniy imkoniyatlarini baholash hamda mashg‘ulot yuklamalarini ilmiy asosda optimallashtirishda muhim ahamiyat kasb etadi.

Mazkur tadqiqotda yakka kurash sport turlari bilan shug‘ullanuvchi sportchilarda jismoniy yuklama sharoitida laktat metabolizmining fiziologik xususiyatlarini aniqlash, uning mushak kuchi, tezkorlik va maksimal kislorod iste’moli (VO_2max) kabi asosiy funksional ko‘rsatkichlar bilan o‘zaro bog‘liqligini statistik jihatdan baholashga alohida e’tibor qaratildi. Shu maqsadda sportchilarda mushak kuchi, sprint tezligi, VO_2max va laktat konsentratsiyasi kabi asosiy fiziologik ko‘rsatkichlar aniqlanib, jismoniy yuklama ta’sirida laktat metabolizmining o‘zgarish dinamikasi o‘rganildi. Shuningdek, kurash, boks va dzyudo bilan shug‘ullanuvchi sportchilar o‘rtasida laktat konsentratsiyasidagi farqlar statistik jihatdan tahlil qilinib, mushak kuchi bilan laktat darajasi o‘rtasidagi bog‘liqlik hamda VO_2max ko‘rsatkichining laktatni bartaraf etish jarayoniga ta’siri baholandi.

Tadqiqot doirasida yakka kurash sport turlari bilan shug‘ullanuvchi yuqori malakali sportchilarning funksional holati va ularda jismoniy yuklama sharoitida kechadigan fiziologik jarayonlar o‘rganilib, laktat metabolizmining xususiyatlari, uning mushak kuchi, VO_2max va tezkorlik ko‘rsatkichlari bilan o‘zaro aloqadorligi hamda organizmning yuklamaga javob reaksiyasi sifatidagi dinamikasi tahlil etildi.

Adabiyotlar tahlili. Bugungi sport fiziologiyasida olib borilgan tadqiqotlarga ko‘ra, laktat metabolizmi masalasi anaerob energiya ta’minoti doirasidagina emas, balki hujayralararo energetik integratsiya, signal uzatish va metabolik adaptatsiya jarayonlari bilan uzviy bog‘liq kompleks tizim sifatida qaralmoqda. Ilgari laktat metabolizmning “charchash markeri” sifatida talqin etilgan bo‘lsa, hozirgi ilmiy qarashlarda u markaziy energetik substrat va metabolik regulyator sifatida baholanadi [5; 9].

Laktat hosil bo‘lishi asosan anaerob glikoliz jarayonida piruvatning laktatdegidrogenaza (LDH) fermenti orqali reduksiyalanishi natijasida amalga oshadi. Bu jarayon NAD^+/NADH redoks juftligi muvozanatini saqlashda hal qiluvchi ahamiyatga ega bo‘lib, yuqori intensivlikdagi mushak ishi sharoitida glikolitik oqimning uzluksiz davom etishini ta’minlaydi [12]. Shu nuqtayi nazardan, laktat hosil bo‘lishi patologiya emas, balki hujayra energetikasining fiziologik adaptatsiya mexanizmi sifatida qaraladi.

George A. Brooks tomonidan ilgari surilgan “lactate shuttle theory” konsepsiyasi laktatning lokal metabolit emas, balki sistemaviy energiya tashuvchi sifatidagi rolini ilmiy asoslab berdi. Unga ko‘ra, laktat mushak tolalaridan qon oqimi orqali yurak mushagi, jigar va oksidativ mushak tolalariga tashilib, qayta oksidlanadi yoki glyukoneogenez jarayonida ishtirok etadi [5]. Bu konsepsiya sport fiziologiyasida “metabolik kooperatsiya” tushunchasini shakllantirdi.

Lawrence B. Gladden (2004) tadqiqotlarida laktatning mitoxondrial oksidlanish jarayonida bevosita substrat sifatida ishlatilishi isbotlangan. Muallif laktatni “dynamic metabolic intermediate” sifatida tavsiflab, uning mushak hujayralarida energiya ishlab chiqarishda faol ishtirok etishini ta’kidlaydi [9].

Bioximik nuqtayi nazardan, laktatning hujayralararo transporti monokarboksilat transporterlar (MCT1 va MCT4) orqali amalga oshadi. MCT1 asosan oksidativ tolalarda, MCT4 esa glikolitik tolalarda ekspressiyalanadi. Sportchilarda mashg‘ulotlar ta’sirida ushbu transporterlarning ekspressiyasi oshishi laktat klirensini tezlashtiradi va bu adaptatsiya yuqori darajadagi jismoniy ish qobiliyatini ta’minlaydi.

Shuningdek, laktat metabolizmi faqat energetik jarayon emas, balki signal molekulasi sifatida ham faol ishtirok etadi. So‘nggi tadqiqotlarda laktatning PGC-1α (peroxisome proliferator-activated receptor gamma coactivator 1-alpha) orqali mitoxondrial biogenezni

rag‘batlantirishi, shuningdek, gen ekspressiyasiga ta’sir ko‘rsatishi aniqlangan. Bu holat laktatni “metabokine” sifatida qarashga asos bo‘ladi.

Yakka kurash sport turlarida (kurash, dzyudo, boks) laktat metabolizmi ayniqsa muhim ahamiyatga ega. Chunki ushbu sport turlari yuqori intensivlikdagi interval yuklamalar bilan xarakterlanib, anaerob glikoliz tizimi faollashadi. Franchini va hammualliflar (2013) tadqiqotlariga ko‘ra, dzyudo bellashuvlaridan so‘ng qondagi laktat konsentratsiyasi 12–16 mmol/L gacha yetishi mumkin [7]. Shuningdek, Smith (2006) bokschilarda 10–14 mmol/L darajada laktat qayd etilganini ko‘rsatgan [14].

Xulosa qilib aytganda, zamonaviy ilmiy adabiyotlar laktat metabolizmini:

– energiya tashuvchi substrat,
– redoks muvozanat regulyatori,
– signal molekulasi,
– adaptatsiya mexanizmi sifatida ko‘rib chiqadi. Bu esa uni yakka kurash sport turlarida sportchilarning funksional holatini baholash va mashg‘ulot jarayonini individuallashtirishda muhim biomarker sifatida qo‘llash imkonini beradi.

Tadqiqot metodologiyasi. Mazkur tadqiqot yakka kurash sport turlari bilan shug‘ullanuvchi sportchilarda metabolik javob reaksiyalarining fiziologik xususiyatlarini kompleks tahlil qilishga qaratilgan bo‘lib, u ko‘p guruhli hamda tajribaga asoslangan tadqiqot usullarini integratsiyalashtirgan holda shakllantirilgan ilmiy tadqiqot tuzilishi asosida amalga oshirildi.

Natija va muhokama. Tadqiqot konsepsiyasi sport fiziologiyasida keng qo‘llaniladigan sistemali yondashuv asosida shakllantirilib, unda yakka kurash sport turlariga xos yuqori intensivlikdagi yuklamalar sharoitida organizmda kechadigan metabolik jarayonlar, xususan, laktat metabolizmining funksional xususiyatlari kompleks tarzda baholandi. Tahlil jarayonida laktatga ta’sir qiluvchi asosiy omillar sifatida mushak kuchi, aerob ish qobiliyatini ifodalovchi VO_2max ko‘rsatkichi hamda tezkorlik xususiyatlarini aks ettiruvchi sprint natijalari inobatga olindi. Shu bilan birga, bog‘liq o‘zgaruvchi sifatida organizmda anaerob glikolitik jarayonlarning integral indikatori hisoblangan qondagi laktat konsentratsiyasi qabul qilinib, uning yuqoridagi omillar bilan o‘zaro bog‘liqligi va dinamik o‘zgarishlari ilmiy asosda tahlil etildi.Tadqiqot tuzilishini ishlab chiqishda biologik tizimlarga xos bo‘lgan individual variabellikni hisobga olish va uning ta’sirini minimallashtirishga alohida ahamiyat berildi. Shuningdek, natijalarning ishonchliligi va interpretatsiya aniqligini ta’minlash maqsadida ehtimoliy **konfundirlovchi omillar** (yosh, jismoniy tayyorgarlik darajasi, mashg‘ulot staji, tiklanish holati va boshqalar) maksimal darajada nazorat qilindi yoki standartlashtirildi.

Ushbu yondashuv tadqiqot natijalarining ichki validligini oshirish, shuningdek, turli sport turlari o‘rtasidagi fiziologik farqlarni ilmiy asoslangan holda taqqoslash imkonini berdi.

Respondentlar. Mazkur tadqiqotda 60 nafar yuqori malakali yakka kurash sportchilari ishtirok etdi. Tadqiqot tanlanmasi maqsadli tanlash (maqsadga yo‘naltirilgan saralash) usuli asosida shakllantirildi, bu esa tadqiqot vazifalariga maksimal darajada mos keluvchi kontingentni qamrab olish imkonini berdi. **Respondentlar** sport turlari kesimida taqsimlandi (1-jadval)

1-jadval

Respondentlar kontingentining sport turlari kesimidagi taqsimoti

Sport turi	**n**	**Yosh (yil)**	**Sport staji**
Kurash	20	21.3 ± 2.1	≥5 yil
Boks	20	20.8 ± 1.9	≥5 yil
Dzyudo	20	21.1 ± 2.0	≥5 yil

Tadqiqotga jalb etilgan respondentlarni saralash jarayonida aniq ilmiy mezonlarga asoslanildi. Jumladan, quyidagi mezonlar belgilandi:

– yosh jihatdan 18–25 yosh oralig‘ida bo‘lishi;
– yuqori sport malakaligi (kamida sport ustasiga nomzod yoki undan yuqori daraja);
– tibbiy ko‘rikdan o‘tgan holda sog‘lom deb topilganligi.

Shu bilan birga, tadqiqot natijalarining xolisligi va ishonchliligini ta’minlash maqsadida quyidagi **mezonlar** qo‘llanildi:

– metabolik yoki yurak-qon tomir tizimi kasalliklarining mavjudligi;

– tadqiqotdan oldingi 48 soat davomida yuqori intensivlikdagi jismoniy yuklamalarni bajarganlik;

– dori vositalari yoki ergogen ta’sirga ega bo‘lgan qo‘shimchalarni qabul qilgan holatlar.

Tadqiqotni o‘tkazish jarayonida barcha ishtirokchilardan ixtiyoriy ravishda yozma rozilik olindi. Ilmiy tadqiqot inson ishtirokida o‘tkaziladigan tadqiqotlar uchun belgilangan bioetik tamoyillar va xalqaro me’yoriy talablarga to‘liq rioya qilingan holda amalga oshirildi.

Fiziologik o‘lchash usullari

Mushak kuchini baholash

Mushak kuchini aniqlashda **bir marta maksimal takrorlash (1RM — one repetition maximum)** usulidan foydalanildi. Mazkur usul neyromushak tizimining maksimal kuch ishlab chiqarish qobiliyatini baholashda eng ishonchli va keng qo‘llaniladigan standart usullardan biri hisoblanadi.

1RM testi jarayonida ishtirokchi belgilangan mashqni maksimal og‘irlik bilan faqat bir marta bajara oladigan darajagacha bosqichma-bosqich yuklama oshirib borildi. Olingan natijalar mushak tizimining kuch potensialini va funksional tayyorgarlik darajasini baholashda asosiy ko‘rsatkich sifatida qabul qilindi.

Sprint tezligini baholash

30 metr masofaga sprint vaqti yuqori aniqlikka ega bo‘lgan fotoelementli elektron taymerlar yordamida qayd etildi. O‘lchashlar millisekund darajasida aniqlik bilan amalga oshirildi, bu esa tezkorlik qobiliyatini ishonchli baholash imkonini berdi.

VO_2max ni baholash

Aerob ish qobiliyatining asosiy ko‘rsatkichi hisoblangan VO_2max kosvennыy gazoanaliz usuli asosida, pog‘onama-pog‘ona ortib boruvchi yuklama (incremental treadmill protocol) sharoitida baholandi.

VO_2max quyidagi fiziologik munosabat orqali ifodalanadi:

$$V02max = Q \cdot (a - v02)/m$$

Bu yerda:

Q — yurak chiqarishi (cardiac output);

$(a - vO_2)$ — arteriovenoz kislorod farqi;

m — tana massasi.

Mazkur ko‘rsatkich organizmning maksimal kislorod iste’mol qilish qobiliyatini aks ettirib, aerob energiya ta’minoti samaradorligini baholashda muhim mezon hisoblanadi.

Laktat konsentratsiyasini aniqlash.

Qondagi laktat konsentratsiyasini aniqlashda qon namunasi (barmoq uchidan) olish orqali, portativ va laboratoriya tipidagi biokimyoviy analizatorlar (Lactate Pro, Biosen)dan foydalanildi. Jumladan, dala sharoitida tezkor baholashni amalga oshirish maqsadida Lactate Pro portativ analizatoridan, yuqori aniqlik talab etilgan holatlarda esa Biosen C-Line laboratoriya analizatoridan foydalanildi.

Shu tariqa, ikki turdagi analizatorlardan kompleks foydalanish tadqiqot natijalarining ishonchliligini oshirish va laktat metabolizmini har tomonlama baholash imkonini berdi.

Mazkur qurilmalar fermentativ-amperometrik usul asosida ishlab, qondagi laktat konsentratsiyasini qisqa vaqt ichida aniqlash imkonini beradi. Portativ analizatorlar tadqiqotning amaliy qismlarida, ya’ni mashq jarayonidan keyin tezkor monitoring olib borishda samarali hisoblansa, laboratoriya analizatorlari yuqori darajadagi aniqlik va takrorlanuvchanlikni ta’minlashi bilan ilmiy tahlillar uchun muhim ahamiyat kasb etadi.

O‘lchashlar quyidagi vaqt nuqtalarida amalga oshirildi:

– dam olish holatida;

– jismoniy yuklamadan keyin 3-daqiqada;

– jismoniy yuklamadan keyin 5-daqiqada.

Ushbu yondashuv laktat metabolizmining dinamikasini, ya’ni uning hosil bo‘lish va

bartaraf etilish jarayonlarini kompleks baholash imkonini beradi.

Biokimyoviy va fiziologik asoslar

Laktat hosil bo‘lishi anaerob glikoliz jarayonida piruvatning reduksiyalanishi bilan bog‘liq bo‘lib, ushbu reaksiya laktatdegidrogenaza fermenti ishtirokida amalga oshadi. Mazkur jarayon hujayra ichidagi redoks muvozanatni ta’minlash va glikolitik energiya ta’minotini uzluksiz davom ettirishda muhim ahamiyatga ega.

Laktat hosil bo‘lish reaksiyasi quyidagi tenglama orqali ifodalanadi:

Pyruvate+**NADH**+**H**$^+$↔**Lactate**+**NAD**$^+$

Ushbu biokimyoviy reaksiya:

– hujayra ichidagi NAD$^+$/NADH redoks muvozanatini saqlashga xizmat qiladi;

– anaerob sharoitda glikolitik ATP sintezining uzluksizligini ta’minlaydi;

– yuqori intensivlikdagi jismoniy yuklamalarda energiya ta’minotining muhim mexanizmi hisoblanadi.

Shu bilan birga, laktat metabolizmi organizmda energiya tashuvchi va qayta ishlanuvchi substrat sifatida ham ishtirok etib, uning ahamiyati faqat anaerob glikoliz doirasi bilan cheklanib qolmaydi.

Statistik tahlil

Tadqiqot davomida olingan ma’lumotlar **SPSS 26.0** statistik dasturi yordamida qayta ishlandi. Ma’lumotlarni tahlil qilishda bir nechta zamonaviy statistik usullardan kompleks foydalanildi.

Qo‘llanilgan asosiy statistik usullar quyidagilardan iborat:

– tavsifiy statistika (o‘rtacha qiymat va standart og‘ish — Mean ± SD);

– ma’lumotlarning taqsimotini baholash uchun normallikni tekshirish (Shapiro–Wilk test);

– guruhlar o‘rtasidagi farqlarni aniqlash uchun bir omilli dispersion tahlil;

– o‘zgaruvchilar o‘rtasidagi bog‘liqlikni baholash uchun Pirson korrelyatsiya tahlili;

– laktat konsentratsiyasiga ta’sir etuvchi omillarni baholash uchun ko‘p omilli chiziqli regressiya tahlili.

Bir omilli dispersion tahlil modeli quyidagi munosabat orqali ifodalanadi:

$$F = \frac{MSwithin}{MSbetween}$$

Ko‘p omilli chiziqli regressiya modeli esa quyidagi ko‘rinishga ega:

$$Y=\beta0+\beta1X1+\beta2X2+\varepsilon$$

Bu yerda:

- Y — qondagi laktat konsentratsiyasi;
- X_1 — mushak kuchi;
- X_2 — VO_2max ko‘rsatkichi;
- β_0, β_1, β_2 — regressiya koeffitsiyentlari;
- ε — tasodifiy xatolik.

Barcha statistik gipotezalarni tekshirishda ishonchlilik darajasi $p<0.05$ sifatida qabul qilindi. Bu esa olingan natijalarning statistik jihatdan ahamiyatliligini ta’minlaydi.

Ilmiy ishonchlilik va validlik

Tadqiqot natijalarining ishonchliligi va ilmiy asoslanganligini ta’minlash maqsadida bir qator metodik chora-tadbirlar amalga oshirildi. Xususan, o‘lchashlarning ichki ishonchliligi (test–retest reliability) ta’minlanib, barcha ko‘rsatkichlar bir xil sharoitlarda takroriy o‘lchash orqali tekshirildi.

Qo‘llanilgan o‘lchov asboblari tadqiqotdan oldin tekshiruvdan o‘tkazilib, ularning metrologik aniqligi va ishonchliligi doimiy nazorat ostida ta’minlandi. Shuningdek, inson omilining ta’sirini minimallashtirish maqsadida barcha testlar yagona uslubiy yondashuvga asoslangan holda, qat’iy standartlashtirilgan tartibda amalga oshirildi.

Tadqiqotda validlikning quyidagi turlari ta’minlandi:

– **ichki validlik** — tadqiqotni nazorat qilingan sharoitlarda tashkil etish va ehtimoliy tashqi ta’sirlarni cheklash orqali;

– **tashqi validlik** — tadqiqotga jalb etilgan ishtirokchilarning real sport populyatsiyasini ifodalashi hisobiga natijalarni amaliyotga tatbiq etish imkoniyati orqali.

Axloqiy masalalar.

Tadqiqot inson ishtirokida o‘tkaziladigan ilmiy izlanishlar uchun belgilangan bioetik tamoyillarga to‘liq rioya qilingan holda amalga oshirildi. Barcha ishtirokchilar tadqiqot maqsadi va mazmuni bilan oldindan tanishtirilib, ulardan ixtiyoriy ravishda yozma rozilik) olindi.

Shuningdek, ishtirokchilarga oid shaxsiy ma’lumotlarning maxfiyligi ta’minlandi va ulardan faqat ilmiy maqsadlarda foydalanildi. Tadqiqot jarayoni ishtirokchilar salomatligiga zarar yetkazmaydigan xavfsiz sharoitlarda tashkil etildi.

Tadqiqotning ilmiy ahamiyati

Ishlab chiqilgan metodik yondashuv sportchilarning funksional holatini har tomonlama baholash imkonini beradi. Xususan, mazkur metodologiya:

– fiziologik ko‘rsatkichlarni kompleks tahlil qilish;

– metabolik jarayonlarni ilmiy asosda modellashtirish;

– sport tayyorgarligini individuallashtirish

imkoniyatlarini kengaytirishga xizmat qiladi.

Muhokama

Olingan natijalar yakka kurash sport turlarida anaerob energiya ta’minoti tizimining ustunligini tasdiqlaydi. Xususan, kurash va dzyudo sportchilarida laktat konsentratsiyasining yuqori darajada kuzatilishi ushbu sport turlariga xos bo‘lgan portlovchi kuch, yuqori intensivlik va qisqa muddatli maksimal yuklamalar ustunligi bilan izohlanadi [7].

Shu bilan birga, VO_2max ko‘rsatkichining yuqori bo‘lishi laktatning qayta ishlanishi va neytrallashtirilish jarayonlarini tezlashtirishi aniqlandi. Bu holat aerob va anaerob energiya ta’minoti tizimlarining o‘zaro funksional bog‘liqligini va bir-birini to‘ldirishini ko‘rsatadi [8].

Natijalar shuni ko‘rsatadiki, yakka kurash sport turlarida yuqori sport natijalariga erishish uchun anaerob quvvat bilan bir qatorda aerob imkoniyatlarni ham rivojlantirish muhim ahamiyat kasb etadi.

Xulosa. Tadqiqot natijalari quyidagilarni ko‘rsatdi:

– yakka kurash sport turlarida laktat konsentratsiyasi yuqori darajada namoyon bo‘ladi;

– mushak kuchi laktat hosil bo‘lishiga ijobiy ta’sir ko‘rsatadi;

– VO_2max ko‘rsatkichi laktatni bartaraf etishda muhim omil hisoblanadi;

– qo‘llanilgan statistik tahlil usullari sportchilarning funksional holatini aniq va ishonchli baholash imkonini beradi.

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STZ DIABETDA KALAMUSH JIGAR MITOXONDRIYASI MEMBRANASI LIPIDLARINING PEREKISLI OKSIDLANISH JARAYONIGA GOSSIPOLNING DIAZAMINO HOSILALARINING TA'SIRI

Sattorova Iroda Yangiboyevna
Turon universiteti dotsenti v.b.
iroda8724@gmail.com
ORCID 0009-0007-2825-4837
UDK 611.36 (045).

Annotatsiya. Streptozototsin (STZ) diabet sharoitida jigar mitoxondriyasiga YAN-2 (4:1) va YAN-2 (6:1) polifenol birikmalarning ta'siri in vitro va in vivo tajribalarda o'rganildi. Kalamushlarning jigar mitoxondriyasi differensial sentrifugalash usuli yordamida ajratib olindi. STZ diabet bilan bog'liq mitoxondrial disfunksiyalarni biologik faol birikmalar yordamida korreksiyalash mumkin. STZ diabet sharoitida kalamush jigar mitoxondriyasining Fe^{2+}/sitrat yordamida chaqirilgan LPO jarayoniga polifenollarning ta'siri o'rganildi. STZ glyukozaning toksik analoglari bo'lib, ular asosan GLUT2 glyukoza tashuvchisi orqali oshqozonosti bezi β-hujayralarida to'planadi. STZ diabet sharoitida jigar mitoxondriyasining bo'kishi o'z navbatida ichki va tashqi membranada joylashgan lipidlarni gidrolizga uchratishi mumkin. STZ hozirda ko'plab ilmiy tadqiqotlar tajriba hayvonlarida qandli diabet modelini hosil qilishda qo'llaniladigan antibiotik bo'lib, oshqozon osti bezining β-hujayrasidan insulin sekretsiyasini ingibirlash orqali ta'sirini namoyon qiladi.

Kalit so'zlar: jigar, mitoxondriya, kversetin,LPO, polifenol birikmalar.

EFFECT OF DIAZAMINO DERIVATIVES OF GOSSYPOL ON PEROXIDATION OF LIPIDS IN RAT LIVER MITOCHONDRIA MEMBRANE IN STZ DIABETES

Abstract. The effects of polyphenolic compounds YAN-2 (4:1) and YAN-2 (6:1) on liver mitochondria in streptozotocin (STZ) diabetes were studied in vitro and in vivo experiments. Rat liver mitochondria were isolated using differential centrifugation. Mitochondrial dysfunctions associated with STZ diabetes can be corrected by biologically active compounds. The effects of polyphenols on the Fe2+/citrate-induced LPO process in rat liver mitochondria in STZ diabetes were studied. STZ are toxic analogues of glucose, which accumulate mainly in pancreatic β-cells via the GLUT2 glucose transporter. The damage to liver mitochondria in STZ diabetes can, in turn, hydrolyze lipids located in the inner and outer membranes. STZ may inhibit hepatic mitochondria in diabetic conditions, which in turn hydrolyzes lipids located in the inner and outer membranes. STZ is currently an antibiotic used in many scientific studies to produce a model of diabetes in experimental animals, and it exerts its effects by inhibiting insulin secretion from pancreatic β-cells.

Keywords: liver, mitochondria, quercetin, LPO, polyphenol compounds.

Kirish. Qandli diabet tez sura'tlar bilan rivojlanib borayotgan sivilizatsiya kasalligi bo'lib, hozirda Yevropa aholisining taxminan 8,6% ni tashkil qiladi. Qandli diabet ichki muhit doimiyligini jiddiy ravishda buzilishi bilan namoyon bo'ladigan va turli organlarning shikastlanishiga yoki disfunksiyasiga olib keladigan endokrin kasalliklar qatoriga kiritiladi. Hozirda ilmiy tadqiqotlarda tajriba hayvonalarida qandli diabetni o'rganish uchun ko'plab ekspermental qandli diabet modellari yaratilgan.

Qandli diabetni tadqiqotlarda tajriba hayvonlarida jarrohlik yo'li bilan, genetik manipulyatsiya, yuqori ratsionli yog'li mahsulotlar yoki maxsus kimyoviy moddalarni kiritish orqali qo'zg'atish mumkin. Insulin ishlab chiqaradigan me'daosti bezi β-hujayralarini yo'q qiladigan kimyoviy birikmalarni qo'llash orqali chaqiriladigan qandli diabet kasalligi boshqa usullarga qaraganda ikki yoki uch baravar samarali model bo'lib, nisbatan sodda, iqtosodiy jihatdan arzon usul hisoblanadi [1].

Hujayra ichidagi tiollar, ayniqsa glutation mavjud bo'lganda, alloksan o'zining

qaytarilish mahsuloti dialurik kislota bilan siklik qaytarilish reaksiyasida kislorodning faol shakllarini (KFSH) hosil qiladi. Dialurik kislotaning avtooksidlanishi natijasida superoksid radikallari, vodorod peroksid va temir bilan katalizlanadigan reaksiyaning oxirgi bosqichida gidroksil radikallari hosil bo‘ladi. Ushbu gidroksil radikallar, ayniqsa, antioksidant himoya xossasiga ega bo‘lgan β-hujayralarining o‘limiga va insulinga bog‘liq “alloksan diabet”ning keyingi holatiga javob beradi. [7].

Tiol reagenti sifatida alloksan, shuningdek, β-hujayra glyukoza sensori glyukokinazasini ingibirlash xossasi orqali insulin sekretsiyasini tanlab ingibirlaydi. STZ β-hujayralarda, glyukoza va metilnitrozomochevina qismiga bo‘linadi. [8].

O‘zining alkillovchi xususiyatlari tufayli, ikkinchisi biologik makromolekulalarni o‘zgartiradi, DNKni parchalaydi va β-hujayralarini nobud qiladi, bu esa insulinga bog‘liq diabet holatini keltirib chiqaradi. Mitoxondrial DNKning nishonga olinishi bilan β-hujayra mitoxondrial metabolizmining signalizatsiya funksiyasini buzadi, shuningdek, STZning glyukoza bilan bog‘liq insulin sekretsiyasini qanday ingibirlashini ham tushuntiradi [2].

STZ diabet sharoitida jigar (mPTP) konformatsiyasining ochiq holatga kelishi membrana lipidlarining peroksidatsiya jarayoni bilan bog‘liq bo‘lishi mumkin. Ushbu taxminni aniqlash maqsadida navbatdagi tajribamizda STZ diabet sharoitida kalamush jigar mitoxondriyasining Fe^{2+}/sitrat yordamida chaqirilgan LPO jarayoniga polifenollarning ta’siri o‘rganildi. Bizga ma’lumki, mitoxondrial lipidlar mitoxondriya membranasi yaxlitligini va funksiyasini saqlash uchun ajralmas hisoblanadi. Temir va temir komplekslari LPOni rag‘batlantiradi [3].

Tajribamizda mitoxondriya membranasida lipoperoksidatsiya jarayonini amalga oshirish uchun LPOni induktori hisoblangan Fe^{2+}/sitratdan foydalanildi.

Jigar mitoxondriyasining Fe^{2+}/sitrat yordamida chaqirilgan LPO jarayonini aniqlash va usulning to‘g‘ri amalga oshirilayotganligiga ishonch hosil qilish maqsadida tajriba uchun tayyorlangan inkubatsiya muhiti tarkibiga Fe^{2+}/sitrat kiritilmagan vaqtda jigar mitoxondriyasining LPO jarayoni tekshirildi. [9].

Bunda, inkubatsiya muhiti tarkibida Fe^{2+}/sitrat mavjud bo‘lmagan sharoitda LPO jarayoni amalga oshmadi. Demak, eksperimental sharoitda Fe^{2+}/sitrat ishtirokisiz (induktorsiz) mitoxondrial shishish orqali sodir bo‘luvchi LPO jarayoni amalga oshmadi. Bu holat 1-rasmning intakt egri chizig‘i orqali qayd etildi va mitoxondriya membranasining buzilishi kuzatilmadi.

Inkubatsiya muhiti tarkibida Fe^{2+}/sitrat mavjud bo‘lmagan sharoitda LPO jarayoni amalga oshmadi. Demak, STZ diabet sharoitda Fe_2+/sitrat ishtirokisiz mitoxondrial shishish orqali sodir bo‘luvchi LPO jarayoni amalga oshmadi. Bu holat 1-rasmning intakt egri chizig‘i orqali qayd etildi va mitoxondriya membranasining buzilishi kuzatilmadi.

Tadqiqot metodologiyasi. Tajribalar zotsiz vazni 180-200 gr bo‘lgan oq kalamushlarda o‘tkazildi. Laboratoriya hayvonlarini vivariy sharoitida standart ratsional sharoitda oziqlantirildi. Tadqiqot kalamushlarida diabet chaqirish uchun streptozotosindan foydalanildi. Streptozotosin(STZ) diabet chaqirilgan kalamushlarga YAN-2 (4:1) va YAN-2 (6:1) polifenol birikmalar peroral yuborilgan.

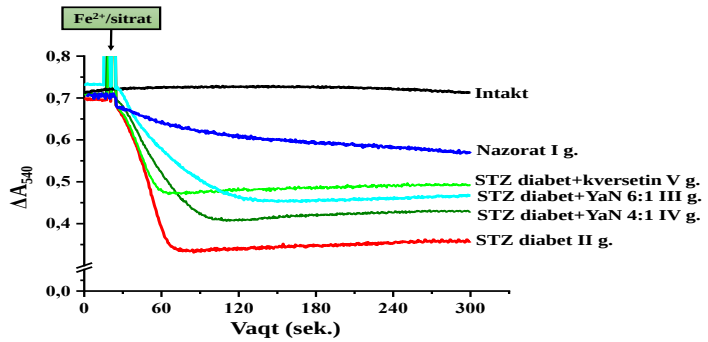
STZ diabet sharoitida kalamush jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPOga polifenollarning diazamino hosilalarining suvda eruvchan YaN 6:1 va YaN 4:1 supramolekulyar komplekslarining ta’sirini o‘rganishdan iborat.

Natijalar va muhokama. Kalamush jigaridan mitoxondriyalar differensial sentrifugalash W.C. Schneider usuli yordamida ajratib olindi. Tajriba hayvonlari guruhlarga ajratildi: I guruh – nazorat, II guruh – tajriba (STZ-diabet), III guruh – tajriba (STZ-diabet+ YAN-2 (4:1)) va IV guruh (STZ diabet+ YAN-2 (6:1)). II, III va IV guruh kalamushlarda diabet chaqirish uchun bir kunlik ochlikdan so‘ng, bir marta STZ 50 mg/kg (0,1 mol/l sitrat buferi, 0,2 ml, pH 4,5) [4] eritmasi qorin bo‘shlig‘i teriosti sohasiga yuborildi. STZ-diabet chaqirilgan hayvonlardan har 3 kunda qon olinib, glyukoza miqdori aniqlab borildi. Kalamushlarga STZ inyeksiya qilingandan so‘ng qonda glyukoza miqdori 11 mmol/l dan oshgandan so‘ng (12 kun), sutkasiga bir marta II guruh hayvonlariga 0,2 ml 0,9% li NaCl eritmasi, tajribaning III guruhiga YAN-2 (4:1) kompleksidan 30 mg/kg, IV guruhga YAN-2

(6:1) kompleksi 30 mg/kg dozada peroral usulda sutkasiga bir marta 10 kun davomida yuborildi. Farmakoterapiya qilingan STZ diabetli hayvonlarni (qonda glyukoza miqdori 11 mmol/l dan kamayganda) jigar mitoxondriyasining Fe^{2+}/sitrat yordamida chaqirilgan LPO jarayoni aniqlandi. Qondagi glyukoza miqdori glyukooksidaza usuli yordamida aniqlandi. [10].

Olingan natijalarni statistik qayta ishlash Origin 6.1 (AQSH) kompyuter dasturi yordamida amalga oshirildi. Natijalar 4 ta turli tajribalarning o‘rtacha arifmetik qiymatini hisoblash tarzida amalga oshirildi. In vivo tajribalarda olingan qiymatlar o‘ptasidagi farq t-tect bo‘yicha hisoblab chiqildi. Bunda *P<0,05 va **P<0,01 qiymatlar statistik ishonchlilikni ifodalaydi.

Nazorat sifatida olingan I guruh sog‘lom kalamushlarning jigar mitoxondriyasini Fe^{2+}/ sitrat bilan chaqirilgan LPO jarayoni bo‘kishining optik zichlik ko‘rsakichi 0,135 ΔA_{540}min. ni tashkil etdi. STZ diabet chaqirilgan II guruh kalamushlarning jigar mitoxondriyasini Fe^{2+}/sitrat yordamida bo‘kishining optik zichlik ko‘rsatkichi 0,339 ΔA_{540}min. ni tashkil etib, nazoratga (sog‘lomga) nisbatan 151,1% ga ortganligi aniqlandi (1 va 2-rasmlar).

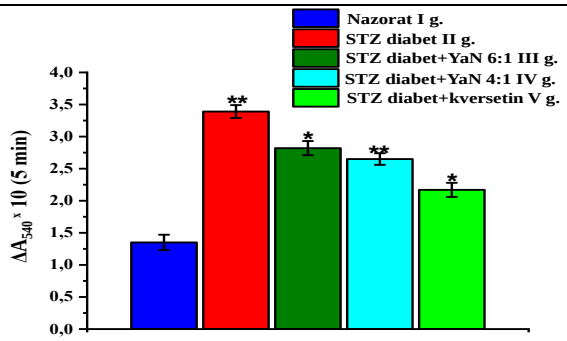


1-rasm. STZ diabet sharoitida kalamush jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPOga polifenollarning diazamino hosilalarining suvda eruvchan YaN 6:1 va YaN 4:1 supramolekulyar komplekslarini ta’siri (original yozuv).

Ordinata o‘qida ΔA_{540} to‘lqin uzunligidagi yorug‘likning yutilishi va absissa o‘qida esa o‘tkazuvchanlikning vaqtning sekund birligidagi ifodasi keltirilgan.

LPO, odatda, KFSH tomonidan qo‘zg‘atilgan biomembranalarni shikastlanishining asosiy mexanizmi hisoblanadi va bu jarayonda ishtirok etadigan ko‘plab reaksiyalarni katalizlaydigan o‘tish metallari tomonidan kuchli ta’sirlanadi [4]. Temir komplekslari Fenton reaksiyasi [5] orqali hosil bo‘lgan KFSH tomonidan boshlangan mitoxondriya membranasining keng qamrovli LPOni keltirib chiqaradi. Bunday sharoitda mitoxondriya membrana potensialining pasayishi, mitoxondriya ichki membranasining o‘tkazuvchanligini oshishi, mitoxondrial shish va matriks komponentlarining yo‘qolishi kabi bir qator o‘zgarishlar sodir bo‘ladi [6]. Ushbu kuzatishlar oksidlovchi stress ostida mitoxondriya disfunksiyasida membrana LPOning muhim rolini ko‘rsatadi.

Gossipolning diazamino hosilasini suvda eruvchan YaN 6:1 supramolekulyar kompleksi yuborilgan STZ diabetli III guruh kalamushlarni jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPO jarayoni 0,282 ΔA_{540} min. ni tashkil etib, STZ diabetga (II guruh) nisbatan 16,9% ga kamayganligi aniqlandi. Gossipolning diazamino hosilasini suvda eruvchan YaN 4:1 supramolekulyar kompleksi yuborilgan STZ diabetli IV guruh kalamushlarni jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPO jarayoni0,325 ΔA_{540} min. ni tashkil etib, STZ diabetga (II guruh) nisbatan 21,8% ga kamayganligi aniqlandi (2-rasm). Demak, gossipolning diazamino hosilasini suvda eruvchan supramolekulyar komplekslari STZ diabet sharoitida jigar mitoxondriyasining ichki va tashqi membranasida joylashgan LPOni kamaytirdi. STZ diabetli V guruh kalamushlarni mavjud gipoglikemik birikma kversetin flavonoidi bilan 10 kun davomida farmakoterapiya qilindi. Shundan so‘ng kalamushlar jigaridan mitoxondriya ajratildi va uning LPO jarayoni o‘rganildi. Bunda, STZ diabetli kalamushlarga kversetin yuborilishi natijasida ularning jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPO jarayoni0,217 ΔA_{540} min. ni tashkil etib, STZ diabetga (II guruh) nisbatan 35,9% ga ortganligi aniqlandi (2-rasm).



2-rasm. STZ diabet sharoitida kalamush jigar mitoxondriyasining Fe^{2+}/sitrat bilan chaqirilgan LPOga gossipolning diazamino hosilalarining suvda eruvchan YaN 6:1 va YaN 4:1 supramolekulyar komplekslarini ta'siri (*P<0,05; **P<0,01; n=5).

Ordinata o'qida ΔA_{540} to'lqin uzunligidagi yorug'likning yutilishi va absissa o'qida esa tajriba guruhlari keltirilgan.

Xulosa va takliflar. Gossipolning diazamino hosilalari STZ diabet sharoitida jigar mitoxondriyasining ichki va tashqi membranasida joylashgan LPOni kamaytirdi. Kversetin kuchli standart antioksidant birikma bo'lganligi uchun ularning mitoxondriya membranasi LPO jarayonini ingibirlovchi xossasi gossipolning diazamino hosilalariga nisbatan faol ekanligi aniqlandi.

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QORAQALPOG'ISTON RESPUBLIKASIDA YASHOVCHI SPORTCHI, HAVASKOR VA SPORT BILAN SHUG'ULLANMAYDIGAN QIZLARDA MORFOFUNKSIONAL KO'RSATKICHLARNING QIYOSIY TAHLILI

Shirliyeva Guncha Davletgeldiyevna
Qoraqalpoq davlat universiteti tayanch doktoranti
shgd.111988@gmail.com
ORCID 0009-0004-0774-0439
UDK 796.015:572.087-055.2

Annotatsiya. Tadqiqotning maqsadi Qoraqalpog'iston Respublikasida yashovchi sportchi, havaskor va sport bilan shug'ullanmaydigan qizlarning morfofunksional ko'rsatkichlarini qiyosiy baholashdan iborat. Materiallar va usullar sifatida jami 355 nafar qiz tekshiruvdan o'tkazildi, shundan 140 nafari sportchi, 64 nafari havaskor va 151 nafari sport bilan shug'ullanmaydigan guruhni tashkil etdi.

Olingan natijalar sportchi qizlarda o‘pkaning hayotiy sig‘imi va qo‘l mushak kuchi nisbatan yuqoriroq, teri-yog‘ qavati qalinligi va yurak urish tezligi esa nisbatan pastroq ekanini ko‘rsatdi. Xulosa qilib aytganda, muntazam sport faoliyati qizlar organizmining morfofunksional holatiga ijobiy ta’sir ko‘rsatadi va olingan ma’lumotlar tibbiy nazorat, jismoniy tarbiya jarayonini individuallashtirish hamda profilaktik tadbirlarni ishlab chiqishda muhim ahamiyat kasb etadi.

Kalit so‘zlar: morfofunksional ko‘rsatkichlar, sportchi qizlar, havaskor qizlar, sport bilan shug‘ullanmaydigan qizlar, antropometriya, o‘pkaning hayotiy sig‘imi, mushak kuchi, arterial bosim, yurak urish tezligi, qiyosiy tahlil.

COMPARATIVE ANALYSIS OF MORPHOFUNCTIONAL INDICATORS IN ATHLETES, AMATEURS AND NON-SPORTS GIRLS LIVING IN THE REPUBLIC OF KARAKALPAKSTAN

Abstract. The purpose of the study is to conduct a comparative assessment of the morphofunctional indicators of athletes, amateurs and non-athletes living in the Republic of Karakalpakstan. Materials and methods A total of 355 girls were examined, of which 140 were athletes, 64 were amateurs and 151 were non-athletes. The results showed that in female athletes, vital capacity of the lungs and arm muscle strength were relatively higher, while skin-fat layer thickness and heart rate were relatively lower. In conclusion, regular sports activities have a positive effect on the morphofunctional state of the girls' body, and the data obtained are of great importance in the development of medical supervision, individualization of the physical education process, and preventive measures.

Keywords: morphofunctional indicators, female athletes, female amateurs, female non-athletes, anthropometry, vital capacity of the lungs, muscle strength, arterial pressure, heart rate, comparative analysis.

Kirish Zamonaviy sport fiziologiyasi va yoshga oid morfologiya fanida qizlar organizmining jismoniy rivojlanishi hamda funksional holatini kompleks baholash masalasi alohida ahamiyat kasb etadi[1]. Ayniqsa, muntazam sport bilan shug‘ullanish, havaskor darajadagi jismoniy faollik yoki aksincha, kamharakat turmush tarzining yosh organizmning morfologik va funksional ko‘rsatkichlariga ta’sirini aniqlash dolzarb ilmiy-amaliy vazifalardan biridir[8]. So‘nggi yillarda qizlar o‘rtasida sport bilan shug‘ullanish ko‘lami kengayib borayotgan bo‘lsa-da, ularning morfofunksional ko‘rsatkichlarini hududiy xususiyatlar asosida qiyosiy o‘rganish yetarli darajada yoritilmagan[4]. Qoraqalpog‘iston Respublikasi sharoitida yashovchi qizlarning tana tuzilishi, nafas olish tizimi faoliyati, mushak kuchi va gemodinamik ko‘rsatkichlari o‘rtasidagi farqlarni aniqlash nafaqat nazariy, balki amaliy jihatdan ham muhimdir[3].

Tadqiqot metodologiyasi. Tadqiqot 2024–2025-yillarda Qoraqalpog‘iston Respublikasida yashovchi qizlar orasida olib borildi. Tekshiruvga jami 355 nafar respondent jalb etildi. Ular jismoniy faollik darajasiga ko‘ra uch guruhga ajratildi. Birinchi guruh muntazam sport bilan shug‘ullanuvchi sportchi qizlardan, ikkinchi guruh havaskor darajada sport va jismoniy mashqlar bilan shug‘ullanuvchi qizlardan, uchinchi guruh esa sport bilan shug‘ullanmaydigan qizlardan iborat bo‘ldi.

Tekshiruvlar standart antropometrik va fiziologik usullar asosida olib borildi. Dastlab morfologik ko‘rsatkichlar aniqlandi. Antropometrik ko‘rsatkichlarni baholashda umumqabul qilingan o‘lchash tamoyillariga amal qilindi[9].

Funksional ko‘rsatkichlardan o‘pkaning hayotiy sig‘imi, o‘ng va chap qo‘l panjasi mushak kuchi, sistolik arterial bosim, diastolik arterial bosim hamda yurak qisqarishlari soni baholandi[2].

Olingan natijalar guruhlar kesimida qiyosiy tahlil qilindi. Ma’lumotlar o‘rtacha qiymat va standart og‘ish ko‘rinishida ifodalandi[11]. Guruhlararo farqlarni aniqlashda no parametrik statistik yondashuvdan foydalanildi[12]. Bir nechta mustaqil guruh ko‘rsatkichlarini taqqoslash uchun Kruskal Uollis mezoni, zarur hollarda juft guruhlar o‘rtasidagi tafovutlarni aniqlash uchun Mann Uitni mezoni qo‘llanildi[13]. Statistik ahamiyatlilik darajasi $p<0,05$ deb qabul qilindi.

Natijalar va muhokama. Tadqiqot guruhlarida morfofunksional ko‘rsatkichlarning qiyosiy tahlili sportchi, havaskor va sport bilan shug‘ullanmaydigan qizlar o‘rtasida muayyan farqlar mavjudligini ko‘rsatdi. Teri-yog‘ qavati qalinligi ko‘rsatkichlari, aksincha, sport bilan shug‘ullanmaydigan qizlarda yuqoriroq bo‘ldi. Olingan natijalar sport bilan muntazam shug‘ullanish qizlarning morfofunksional holatini yaxshilashi, ayniqsa nafas olish tizimi,

mushak kuchi va tana kompozitsiyasiga ijobiy ta’sir ko‘rsatishini tasdiqlaydi[7].

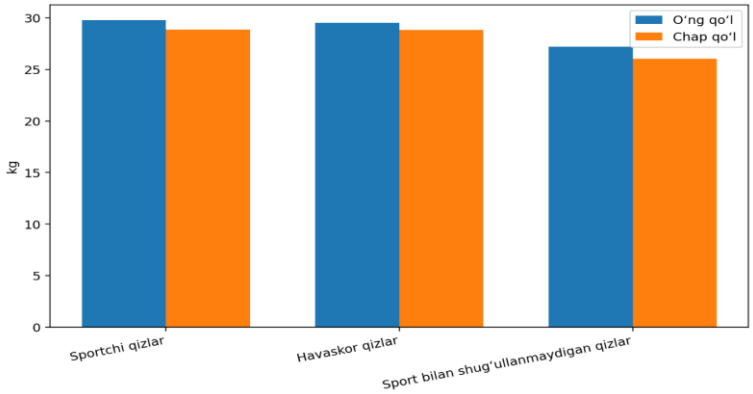
Jadval 1.

Sportchi, havaskor va sport bilan shug‘ullanmaydigan qizlarning asosiy morfofunksional ko‘rsatkichlari

Ko‘rsatkich	Sportchi qizlar	Havaskor qizlar	Sport bilan shug‘ullanmaydigan qizlar
Bo‘y uzunligi, sm	164,00±6,09	163,57±5,73	161,17±5,79
Tana vazni, kg	60,51±11,13	58,84±8,52	54,95±9,76
Ko‘krak qafasi aylanasi, sm	81,44±6,37	81,62±5,50	80,11±6,10
Ko‘krak qafasi ekskursiyasi, sm	7,53±2,01	7,84±2,08	7,31±1,95
O‘pkaning hayotiy sig‘imi, ml	3008,98±602,49	2963,66±461,43	2810,74±486,02
KSM o‘ng, kg	29,78±5,11	29,55±4,72	27,21±5,38
KSM chap, kg	28,89±4,72	28,84±4,79	26,04±5,50
SAD, mm.sim.ust.	113,96±12,47	114,30±14,42	117,10±11,29
DAD, mm.sim.ust.	75,31±10,55	76,69±9,07	77,71±10,71
ChSS, marta/min	78,98±12,94	83,36±12,02	83,17±12,59
KJQ yelka orqa yuzasi, mm	2,70±1,11	3,11±1,36	3,49±0,82
KJQ qorin yon qismi, mm	3,86±1,07	4,04±0,98	4,86±1,21

Jadvalda keltirilgan ma’lumotlar sportchi qizlarda funksional ko‘rsatkichlar, ayniqsa JEL va qo‘l panjasi mushak kuchi yuqoriroq ekanini ko‘rsatadi. Shu bilan birga, teri-yog‘ qavati qalinligi sport bilan shug‘ullanmaydigan qizlarda nisbatan yuqori ekanligi aniqlandi. Bu holat sport faoliyatining tana kompozitsiyasi va funksional imkoniyatlarga ijobiy ta’sirini tasdiqlaydi[5].

Morfologik va funksional rivojlanishni baholashda qo‘l panjasi mushak kuchi muhim ko‘rsatkichlardan biri hisoblanadi. Ushbu mezon mushak tizimining rivojlanish darajasini, kuch imkoniyatlarini hamda organizmning umumiy funksional tayyorgarligini tavsiflaydi. Tadqiqotda o‘ng va chap qo‘l panjasi mushak kuchi alohida o‘rganilib, guruhlar bo‘yicha qiyoslandi. Olingan natijalar quyidagi diagrammada aks ettirilgan.

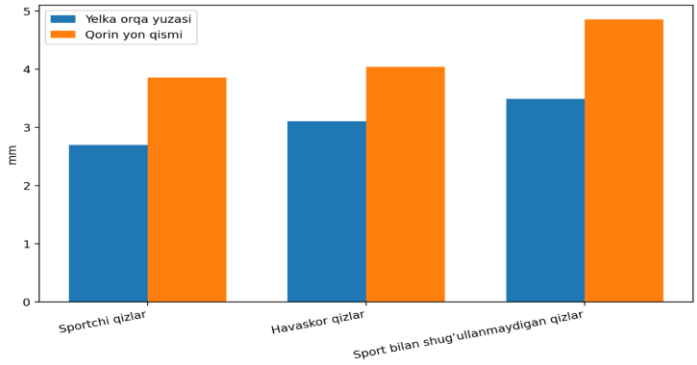


1-rasm. Tadqiqot guruhlarida qo‘l panjasi mushak kuchi ko‘rsatkichlarining qiyosiy ifodalanishi

Diagramma natijalari sportchi qizlarda ham o‘ng, ham chap qo‘l panjasi mushak kuchi ko‘rsatkichlari yuqoriroq ekanini ko‘rsatadi. Havaskor qizlarda mazkur ko‘rsatkichlar sportchi guruhga yaqin bo‘lib, sport bilan shug‘ullanmaydigan qizlarga nisbatan yuqoriroq qayd etilgan. Sport bilan shug‘ullanmaydigan qizlarda esa mushak kuchi ko‘rsatkichlari nisbatan past bo‘lib, bu ularning funksional tayyorgarligi hamda mushak tizimi rivojlanish darajasi sustroq ekanini anglatadi. Olingan ma’lumotlar sport mashg‘ulotlari mushak kuchini shakllantirish va saqlashda muhim omil ekanini ko‘rsatadi.

Tana kompozitsiyasini baholashda teri-yog‘ qavati qalinligi alohida ahamiyatga ega. Mazkur ko‘rsatkich organizmdagi yog‘ komponentining rivojlanish darajasini tavsiflaydi va jismoniy faollik bilan chambarchas bog‘liq bo‘ladi. Tadqiqotda teri-yog‘ qavati qalinligi yelkaning orqa yuzasi va qorin yon qismi sohalarida o‘lchandi. Guruhlararo qiyosiy natijalar

quyidagi diagrammada berilgan.



2-rasm.Tadqiqot guruhlarida teri-yog‘ qavati qalinligi ko‘rsatkichlarining qiyosiy ifodalanishi

Diagrammadan ko‘rinadiki, teri-yog‘ qavati qalinligi sportchi qizlarda eng past ko‘rsatkich bilan tavsiflangan. Havaskor qizlarda ushbu ko‘rsatkich sportchi guruhga nisbatan biroz yuqoriroq, biroq sport bilan shug‘ullanmaydigan qizlarga nisbatan pastroq darajada qayd etilgan. Sport bilan shug‘ullanmaydigan qizlarda esa teri-yog‘ qavati qalinligining eng yuqori qiymatlari aniqlandi. Bu holat muntazam sport faoliyati organizmda yog‘ komponenti miqdorining kamayishiga, tana kompozitsiyasining nisbatan maqbul shakllanishiga xizmat qilishini ko‘rsatadi.

Tadqiqot guruhlarida ayrim morfofunksional ko‘rsatkichlarning darajalar bo‘yicha taqsimlanishi ham o‘rganildi. Shu maqsadda o‘pkaning hayotiy sig‘imi, qo‘l panjasi mushak kuchi va teri-yog‘ qavati qalinligi ko‘rsatkichlari past, o‘rtacha va yuqori darajalarga ajratilib, guruhlar bo‘yicha qiyosiy tahlil qilindi. Olingan natijalar quyidagi jadvalda keltirilgan.

Jadval 2

Tadqiqot guruhlarida ayrim morfofunksional ko‘rsatkichlarning darajalar bo‘yicha taqsimlanishi

Ko‘rsatkich	Daraja	Sportchi qizlar abs/%	Havaskor qizlar abs/%	Sport bilan shug‘ullanmaydigan qizlar abs/%	χ^2	p
JEL	Past	41 / 29,3%	19 / 29,7%	59 / 39,1%	7,05	0,133
JEL	O‘rtacha	45 / 32,1%	20 / 31,2%	53 / 35,1%	7,05	0,133
JEL	Yuqori	54 / 38,6%	25 / 39,1%	39 / 25,8%	7,05	0,133
Qo‘l panjasi mushak kuchi o‘rtacha ko‘rsatkichi	Past	34 / 24,3%	14 / 21,9%	73 / 48,3%	25,27	<0,001
Qo‘l panjasi mushak kuchi o‘rtacha ko‘rsatkichi	O‘rtacha	53 / 37,9%	26 / 40,6%	46 / 30,5%	25,27	<0,001
Qo‘l panjasi mushak kuchi o‘rtacha ko‘rsatkichi	Yuqori	53 / 37,9%	24 / 37,5%	32 / 21,2%	25,27	<0,001
Teri-yog‘ qavati qalinligi o‘rtacha ko‘rsatkichi	Past	79 / 56,4%	28 / 43,8%	13 / 8,6%	88,66	<0,001
Teri-yog‘ qavati qalinligi o‘rtacha ko‘rsatkichi	O‘rtacha	47 / 33,6%	20 / 31,2%	69 / 45,7%	88,66	<0,001
Teri-yog‘ qavati qalinligi o‘rtacha ko‘rsatkichi	Yuqori	14 / 10,0%	16 / 25,0%	69 / 45,7%	88,66	<0,001

Jadval ma’lumotlari shuni ko‘rsatdiki, o‘pkaning hayotiy sig‘imi bo‘yicha sportchi va havaskor qizlarda yuqori darajali ko‘rsatkichlar ulushi sport bilan shug‘ullanmaydigan

qizlarga nisbatan ko‘proq uchradi. Qo‘l panjasi mushak kuchi bo‘yicha ham xuddi shunday tendensiya kuzatilib, sport bilan shug‘ullanmaydigan qizlarda past darajadagi ko‘rsatkichlar ulushi ancha yuqori bo‘ldi. Teri-yog‘ qavati qalinligi bo‘yicha esa aksincha holat kuzatildi: sportchi qizlarda past darajadagi ko‘rsatkichlar ustun bo‘lsa, sport bilan shug‘ullanmaydigan qizlarda yuqori darajadagi ko‘rsatkichlar ulushi sezilarli darajada yuqori ekanligi aniqlandi. Bu holat muntazam sport faoliyati qizlar organizmida funksional imkoniyatlarning ortishi va tana kompozitsiyasining nisbatan maqbul shakllanishiga xizmat qilishini ko‘rsatadi.

Darajalash mezonlari: JEL: past ≤ 2651 ml, o‘rtacha 2652–3139 ml, yuqori ≥ 3140 ml. Qo‘l panjasi mushak kuchi o‘rtacha ko‘rsatkichi: past ≤ 26,5 kg, o‘rtacha 26,6–30,0 kg, yuqori > 30,0 kg. Teri-yog‘ qavati qalinligi o‘rtacha ko‘rsatkichi: past ≤ 3,0 mm, o‘rtacha 3,1–4,0 mm, yuqori > 4,0 mm.

Xulosa va takliflar. Qoraqalpog‘iston Respublikasida yashovchi sportchi, havaskor va sport bilan shug‘ullanmaydigan qizlarning morfofunksional ko‘rsatkichlarini qiyosiy o‘rganish natijalari shuni ko‘rsatdiki, jismoniy faollik darajasi organizmning morfologik va funksional holatiga bevosita ta’sir ko‘rsatadi. Tadqiqot davomida sportchi qizlarda o‘pkaning hayotiy sig‘imi, qo‘l panjasi mushak kuchi, ko‘krak qafasi ekskursiyasi kabi funksional ko‘rsatkichlar nisbatan yuqori ekani, teri-yog‘ qavati qalinligi esa pastroq darajada qayd etilgani aniqlandi. Havaskor qizlarda ko‘rsatkichlar ko‘p hollarda oraliq holatni egallab, ular sportchi va sport bilan shug‘ullanmaydigan guruhlar orasidagi o‘tish bosqichini ifodaladi. Sport bilan shug‘ullanmaydigan qizlarda esa ayrim funksional imkoniyatlarning pastligi hamda yog‘ komponentiga oid ko‘rsatkichlarning yuqoriroqligi kuzatildi. Olingan natijalar muntazam sport mashg‘ulotlari qizlar organizmida nafas olish tizimi, mushak tizimi va umumiy funksional tayyorgarlikning yaxshilanishiga xizmat qilishini tasdiqlaydi. Tadqiqot natijalari qizlar salomatligini monitoring qilish, jismoniy yuklamalarni ilmiy asosda individuallashtirish, sport seleksiyasi ishlarini takomillashtirish hamda profilaktik sog‘lomlashtirish dasturlarini ishlab chiqishda muhim amaliy ahamiyatga ega.

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O‘ZBEKISTON FLORASIDA TARQALGAN *ACONITUM TALASSICUM* POPOV POPULIYATSIYASINING ZAMONAVIY HOLATI

Qodirov U.H.
O‘zbekiston Respublikasi Fanlar akademiyasi
Botanika instituti, katta ilmiy xodim
Abduraimov O.S.
O‘zbekiston Respublikasi Fanlar akademiyasi
Botanika instituti, katta ilmiy xodim
Qosimov Z.Z.
O‘zbekiston Respublikasi Fanlar akademiyasi
Botanika instituti, kichik ilmiy xodim
Po‘latov S.O.
O‘zbekiston Respublikasi Fanlar akademiyasi
Botanika instituti, kichik ilmiy xodim
Abduraimov A.S.
Guliston davlat universiteti, o‘qituvchi
qodirovu86@mail.ru
ORCID 0000-0003-1346-9636
Bo‘ranova M.O.
Qarshi davlat universiteti, dotsent
muhayyoxon@bk.ru
Saidmurodova Inoyat Ilhom qizi
QarDU tayanch doktoranti
ORCID 0000-0003-4701-4322
UDK 581.4:55

Annotatsiya. Markaziy Osiyoning Tyan-Shan va Pomir-Oloy tog‘ tizimlari global biologik xilmaxillik markazlaridan biri hisoblanadi. Ushbu hududlarda tarqalgan noyob va endem o‘simlik turlarining populyatsion holatini o‘rganish muhim ilmiy va amaliy ahamiyatga ega. Mazkur tadqiqotda O‘zbekiston florasining kamyob vakillaridan biri – *Aconitum talassicum* senopopulyatsiyalarining ontogenetik va demografik tuzilishi tahlil qilindi. Tadqiqotlar natijasida tur ishtirokida 4 ta senopopulyatsiya ajratilib, ularning ontogenetik spektrlari chap tomonlama (SP1, SP3), markazlashgan (SP2) hamda bimodal (SP4) tiplarga xos ekanligi aniqlandi. Demografik ko‘rsatkichlar populyatsiyalarda yosh individlarning yuqori ulushi mavjudligini ko‘rsatib, turning tabiiy tiklanish salohiyati yetarli darajada ekanligini tasdiqlaydi. Delta-omega klassifikatsiyasiga ko‘ra senopopulyatsiyalar yosh (SP1, SP3) va o‘tuvchi (SP2, SP4) tiplarga mansubligi qayd etildi. Shu bilan birga ayrim hududlarda antropogen omillar ta’siri natijasida populyatsiya tuzilishida regressiv o‘zgarishlar kuzatilishi aniqlangan.

Kalit so‘zlar: senopopulyatsiya, ontogenetik struktura, demografik ko‘rsatkichlar, kamyob turlar, Ranunculaceae, O‘zbekiston.

THE CURRENT STATE OF THE POPULATION OF *ACONITUM TALASSICUM* POPOV DISTRIBUTED IN THE FLORA OF UZBEKISTAN

Abstract. The Tien Shan and Pamir-Alai mountain systems of Central Asia represent one of the global centers of biodiversity. The study of the population status of rare and endemic plant species occurring in this region is of significant scientific and practical importance. In the present study, the ontogenetic and demographic structure of coenopopulations of *Aconitum talassicum*, a rare species of the flora of Uzbekistan, was analyzed. Four coenopopulations of the species were identified, exhibiting left-sided (CP1, CP3), centered (CP2), and bimodal (CP4) ontogenetic spectra. Demographic parameters revealed a high

proportion of juvenile individuals within the populations, indicating a considerable natural regeneration potential of the species. According to the delta–omega classification, the studied coenopopulations belong to the young (CP1, CP3) and transitional (CP2, CP4) types. At the same time, in some habitats anthropogenic impacts lead to regressive changes in the population structure.

Keywords: coenopopulation, ontogenetic structure, demographic indicators, rare species, Ranunculaceae, Uzbekistan.

Kirish. Markaziy Osiyoning Tyan-Shan va Pomir-Oloy tog‘ tizimlari biologik xilmaxillikning global o‘choqlaridan biriga kiradi va ularni muhofaza qilish ustuvor ahamiyatga ega [11]. Ekotizimlarga antropogen bosimning izchil ortib borishi natijasida zaif, endem va noyob o‘simlik turlarini, shuningdek, ular tarkibiga kiruvchi fitotsenozlarni maqsadli hamda kompleks o‘rganish masalasi zamonaviy botanika va ekologiyada alohida ilmiy-amaliy ahamiyat kasb etmoqda. O‘simlik populyatsiyasining ontogenetik tuzilishi uning eng muhim demografik ko‘rsatkichlaridan biri bo‘lib, populyatsiya tarkibidagi turli ontogenetik holatlarning nisbatini aks ettiradi. [3]. Shu bois populyatsiyaning ontogenetik strukturasi va yosh tarkibini tahlil qilish o‘simlik turlari populyatsiyalarining demografik holatini baholash, regeneratsiya jarayonlari samaradorligini aniqlash hamda ularning kelgusi rivojlanish dinamikasini ilmiy asosda bashorat qilish imkonini beradi [6].

So‘nggi yillarda insonlar tomonidan dorivor o‘simliklarga bo‘lgan ta’sirlarning ortishi natijasida, ularning populyatsiyalariga bo‘lgan bosim ortib bormoqda [5]. Bu holat mazkur kuchayib borayotgan ta’sir ostidagi turlarning tarqalish maydonlarini aniqlash hamda ularning zamonaiy holatini baholashni taqozo etmoqda. Aynan shunday turlar qatoriga *Aconitum* L. (Ranunculaceae) turkumini kiritishimiz mumkin. Dunyo miqyosida turkumning 343 turi, O‘zbekistonda 3 turi (*A. rotundifolium* Kar. & Kir., *A. seravschanicum* Steinb., *A. talassicum* Popov) uchraydi (http://www.plantsoftheworldonline.org/).

Turkum vakillarining aksariyati biologik faol, biroq kuchli zaharli birikmalar bilan boy bo‘lib, zamonaviy farmatsevtikada juda keng miqyosda foydalaniladi. Turlar tarkibida asosan diterpenoid alkaloidlar (akonitin, mezakonitin, gipakonitin va ularga yaqin birikmalar), shuningdek flavonoidlar, fenol birikmalari va organik kislotalar mavjudligi ochiq ilmiy manbalarda qayd etilgan. Ushbu alkaloidlar yuqori farmakologik faollikka ega bo‘lib, ayni paytda kuchli neyro- va kardiotoksik ta’sir ko‘rsatadi, shu sababli turning xo‘jalikda qo‘llanilishi keskin cheklangan [5]. Tadqiqotlarimiz 2025–2026-yillarda O‘zbekistonning turli botanik-geografik hududlarida olib borildi.

Tadqiqot obyekti va metodlari. Tadqiqot obyekti O‘zbekiston florasida tarqalgan *Aconitum talassicum* Popov hisoblanadi. *A. talassicum* o‘simligi O‘zbekiston Respublikasi Qizil kitobiga kiritilgan bo‘lib, mamlakat hududida nodir va yo‘qolib borish xavfi ostidagi turlar qatoriga kiradi. Bo‘yi 1,5 m ga yetadigan, ko‘p yillik, tugunak ildizpoyali o‘t. Ildizpoyasi tugunaklarning yonma-yon qo‘shilishidan hosil bo‘lgan. Poyalari oddiy, tik o‘suvchi. Poyaning yuqori qismidagi barglari bandsiz, qolganlari bandli, yaprog‘i asosigacha yirik tishli bo‘laklarga ajralgan. Yorqin ko‘k rangli gullari poyaning yuqori qismida yirik to‘pgul hosil qiladi. Iyun-iyulda gullaydi, mevasi iyul-avgust oylarida yetiladi. Urug‘idan ko‘payadi.

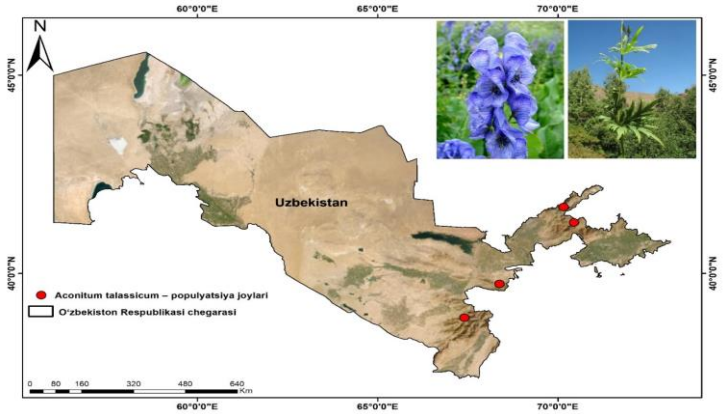
Tur ishtirokidagi fitotsenozlarda geobotanik qaydnomalar 100 m^2 maydonda umumqabul qilingan metodlar yordamida yuritildi [7]. O‘simlikning nomlari http://www.plantsoftheworldonline.org/ saytiga muvofiq keltirildi. Senopopulyatsiyalar strukturasi umumqabul qilingan metodlar yordamida o‘rganildi. Buning uchun turlarning har bir senopopulyatsiyasida kamida 3 ta transekt tashlandi [4]. Transekt uzunligi 10 metrdan iborat bo‘lib, har bir kvadratdagi tuplar miqdori hisobga olindi. Senopopulyatsiyalarning ontogenetik strukturasi senopopulyatsiyadagi har xil ontogenetik holatdagi tuplar nisbatiga ko‘ra aniqlandi. O‘lchov birligi sifatida tup olindi. Populyatsion strukturani tavsiflashda turlarning xarakterli ontogenetik spektri to‘g‘risidagi qarashlarga tayanildi [3]. Taqsimlanish xarakteriga ko‘ra ontogenetik guruhlar 4 ta spektrga bo‘linadi: chap tomonlama, markazlashgan, o‘ng tomonlama va bimodal. Turlarning xarakterli spektri uning biologik xususiyatlaridan kelib chiqadi. Senopopulyatsiyalar qaydnomasi A.A. Uranov va O.V. Smirnova [8] hamda L.A. Jivotovskiylarning “delta-omega” [2] tasniflariga ko‘ra amalga oshirildi. Delta – yosh indeksi bo‘lib, har bir o‘rganilgan vaqtdagi senopopulyat-siyaning yosh

darajasini baholaydi, omega – *i* ontogenetik holatdagi o‘simlikning samaradorligini anglatadi. Ushbu tasnifga ko‘ra senopopulyatsiyalar yosh, yetilayotgan, yetilgan, o‘tuvchi, qariyotgan va qari tiplarga bo‘linadi.

Tadqiqotlar davomida tur ishtirokida 4 ta senopopulyatsiya ajratildi. Dastlabki senopopulyatsiyalar (SP1, SP2) G‘arbiy Tyon-shon hududidan ajratildi (*1-rasm*).

Olingan natijalar va ularning muhokamasi. G‘arbiy Tyan-shan hududlarida tuproqning o‘simliklar bilan qoplanish darajasi 50-55 % atrofida bo‘lishi qayd etilib, 30 dan ortiq yuksak o‘simliklar aniqlandi. Navbatdagi senopopulyatsiya (SP3) Turkiston tog‘ tizmasi hududidan ajratildi. Tuproqning o‘simliklar bilan qoplanish darajasi 60 % ni tashkil qilib, hududda 29 tur ro‘yxatga olindi. To‘rtinchi senopopulyatsiya (SP4) Qashqadaryo botanik-geografik rayonidan ajratildi. Tuproqning o‘simliklar bilan qoplanish darajasi 40 % ni tashkil qildi. Mazkur hududda 24 tur ro‘yxatga olindi.

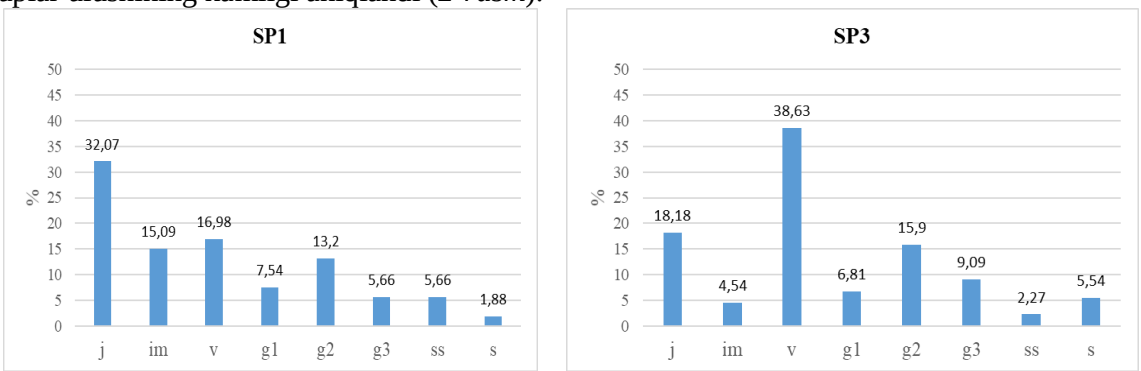
Turkum vakillari senopopulyatsiyalari borasida ayrim tadqiqotlar amalga oshirilgan. Ushbu tadqiqotlarda turkum vakillari uchun xarakterli spektr chap tomonlama ekanligi qayd etilgan [1, 9]. Buning asosi sifatida ularning urug‘ mahsuldorligining yuqori bo‘lishi hamda vegetativ ravishda ham ko‘paya olishi qayd etilgan.



1-rasm. Tadqiqot olib borilgan hudud xaritasi

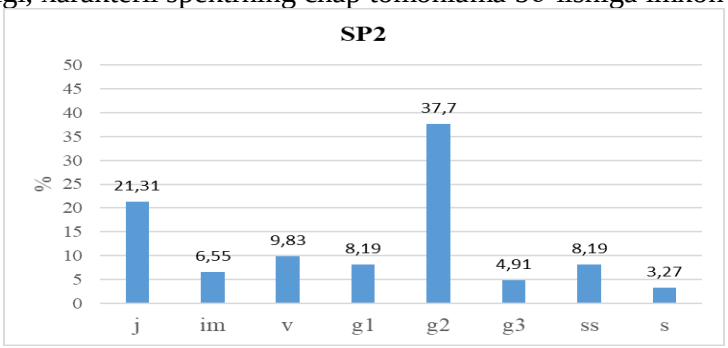
Qayd etilgan senopopulyatsiyalar quyidagi spektrlarga xos ekanligi aniqlandi: Chap tomonlama (SP1, SP3), markazlashgan (SP2) va bimodal (SP4).

Chap tomonlama ontogenetik spektr. Ushbu senopopulyatsiya asosan bir cho‘qqili bo‘lib, yuvenil va virginil bosqichdagi tuplarning ulushi yuqori ekanligini ko‘rsatdi. Xususan 1 senopopulyatsiyada yuvenil (32,07 %) tuplar, 3 senopopulyatsida virginil (38,63 %) bosqichdagi tuplarning ulushi yuqoriligi qayd etildi. Bu holat birinchi navbatda turkum vakillari urug‘ mahsuldorligining yuqori ekanligi bilan izohlanadi. Mavjud adabiy manbalar tahlili shuni ko‘rsatadiki, bitta o‘simlik tupida 360 tadan 6000 tagacha potensial urug‘lar shakllanadi. Ularning haqiqiy urug‘ mahsuldorligi tabiiy sharoitda 200-2000 tani tashkil qiladi. Yillik yog‘in miqdorining yetarli bo‘lishi va haroratning orib borishi, senopopulyatsiyalarda yosh tuplarning yoppasiga ko‘payishiga sabab bo‘ladi. Turning vegetativ ravishda ham ko‘paya olishi natijasida, senopopulyatsiyada virginil tuplarning to‘planib qolishi kuzatilgan (SP3). Senopopulyatsiyalar to‘liq a’zoli bo‘lib, senil va subsenil tuplar ulushining kamligi aniqlandi (*2-rasm*).



2-rasm. Chap tomonlama ontogenetik spektr

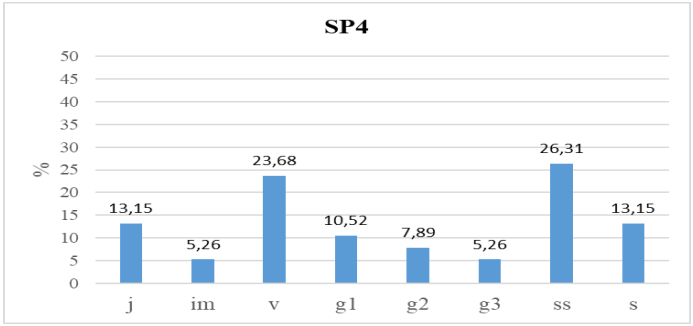
Markazlashgan ontogenetik spektr. Mazkur senopopulyatsiyada (SP2) asosiy cho‘qqi o‘rta generativ (g2) bosqichdagi tuplar ulushiga to‘g‘ri kelib, ularning ulushi 37,7 % ni tashkil qildi. Bu holat, birinchi navbatda, turning ontogenezi bilan bog‘liq hisoblanadi. L.V. Volkova [1] tomonidan olib borilgan tadqiqot natijalari shuni ko‘rsatadiki, turkum vakillari katta hayotiy siklga (30-35 yil) ega. Turkum vakillarining aynan o‘rta generativ holati davomiyligi 12-16 yilni o‘z ichiga oladi. Bu esa senopopulyatsiyalarda bir necha yillar davomida ularning turg‘unligini hamda tur uchun xarakterli spektr markazlashgan bo‘lishini ta’minlaydi (*3-rasm*). Yuqorida keltirilgandek, turning vegetativ ko‘payishi hamda yuqori urug‘ mahsuldorligi, xarakterli spektrning chap tomonlama bo‘lishiga imkon beradi.



3-rasm. Markazlashgan ontogenetik spektr

Bimodal ontogenetik spektr. Bimodal spektr ikki cho‘qqili bo‘lib, yuqori ulush virginil (23,68) va subsenil (26,31) bosqichiga to‘g‘ri keldi (SP4). Bimodal ontogenetik spektrlar, odatda, ikki xil ekologik holatda namoyon bo‘ladi: birinchidan, tuplar uchun optimal sharoit shakllanganda, ikkinchidan esa, aksincha, noqulay ekologik omillar ta’siri kuchayganda. Bizning tadqiqotlarda ikkinchi holatning ustunlik qilishi kuzatildi. Xususan gullagan o‘simliklar, aholi tomonidan terib ketish holatlari kuzatildi (*4-rasm*). Bu esa turning urug‘ yordamida ko‘payishiga salbiy ta’sir qiladi. Natijada tur, o‘z-o‘zini tabiiy tiklash maqsadida, vegetativ ravishda ko‘payishga harakat qiladi va senopopulyatsiyada virginil tuplarning to‘planishiga sabab bo‘ladi.

Generativ tuplarning bir necha yillar davomida zararlanishi hamda ma’lum miqdorda tashqi bosimlar ta’sirida qolishi natijasida, subsenil tuplar ulushining to‘planishiga olib kelgan. Mazkur hudud aholi yashash maskanlariga juda yaqin joylashgan bo‘lib, chorva mollarining muntazam boqilishi natijasida tuproqning payhonlanish darajasi yuqori bo‘lgani aniqlandi.



4-rasm. Bimodal ontogenetik spektr

Demografik ko‘rsatkichlar senopopulyatsiyalarning hozirgi holatini baholash va ularning kelajakdagi rivojlanish istiqbollarini prognozlashda muhim ahamiyatga ega hisoblanadi. Demografik tahlil natijalariga ko‘ra, senopopulyatsiyalardagi umumiy tuplar soni 38-61 ta oralig‘ida ekanligi ma’lum bo‘ldi. 1 m^2 maydondagi tuplar zichligi 1,9-3,05 hamda ekologik zichligi 2,11-3,81 tani tashkil qiladi. Turlarning tiklanish indeksi 0,74 dan 2,42 gacha bo‘lgan diapazonda qayd etildi. Senopopulyatsiyalarda generativ oldi (juvenil, immatur va virginil) bosqichdagi tuplarning yuqori ulushi tiklanish indeksining yuqori qiymatlari bilan bevosita bog‘liqligi aniqlandi. Xususan, bunday holat 1-senopopulyatsiyada yaqqol namoyon bo‘ldi. Chap tomonlama ontogenetik spektrga xos bo‘lgan ushbu senopopulyatsiyada generativ davrgacha bo‘lgan tuplarning ulushi 64,14 % ni tashkil etdi. Aksincha, markazlashgan spektrli 2-senopopulyatsiyada generativ davrgacha bo‘lgan tuplar ulushining

eng quyi ko‘rsatkichi qayd etildi va atigi 37,69 % ga teng bo‘ldi.

Qarish indeksi bo‘yicha olingan natijalardan ko‘rsatkichlar biri-biridan keskin farq qilishi aniqlandi (0,08-0,65). Bu holat ayrim senopopulyatsiyalarda qarish jarayonlari nisbatan sust kechayotganini, ayrim senopopulyatsiyalarda esa turli omillar ta’sirida jadallik bilan rivojlanayotganligini ko‘rsatadi (SP4). Individual optimum indeksi generativ bosqichdagi tuplar hamda virginil va generativ bosqichlar nisbati asosida hisoblandi. *Aconitum talassicum* senopopulyatsiyalarida mazkur ko‘rsatkich 0,45 dan 0,82 gacha bo‘lgan nisbat oralig‘ida o‘zgarib turishi qayd etildi. Samaradorlik indeksi esa o‘z navbatida senopopulyatsiyalardagi umumiy tuplar soni bilan izohlanadi. Bu holatda ko‘rsatkichlar 16,72 dan 35,38 gacha bo‘lishi kuzatildi.

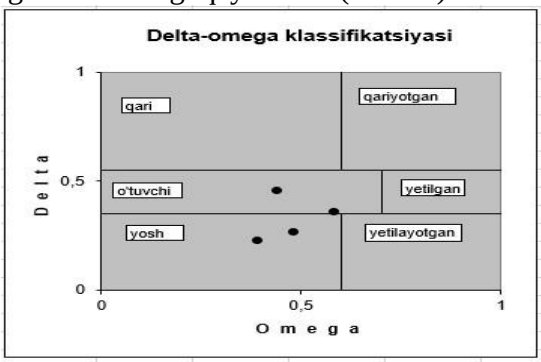
1-jadval

***Aconitum talassicum* senopopulyatsiyalarining demografik ko‘rsatkichlari**

№ ЦП	I_t	I_q	I_{io}	I_s	Tuplar zichligi, 1m2	Pekol ($1m^2$)	ω	Δ	Umumiy tuplar soni, dona	SP tipi
1	2,42	0,08	0,60	20,67	2,65	3,11	0,39	0,23	53	Yosh
2	0,74	0,12	0,82	35,38	3,05	3,81	0,58	0,36	61	O‘tuvchi
3	1,92	0,08	0,45	21,12	2,2	2,75	0,48	0,27	44	Yosh
4	1,77	0,65	0,49	16,72	1,9	2,11	0,44	0,46	38	O‘tuvchi

Izoh: I_t – *tiklanish indeksi*; I_q – *qarish indeksi*; I_{io} – *individual optimum indeksi;* I_s – *samaradorlik indeksi;* P_{ekol} – *ekologik zichlik*; Δ - *yosh indeksi*; ω – *samaradorlik indeksi* (delta-omega klassifkatsiyasi bo‘yicha); SP – *senopopulyatsiya*

Delta-omega klassifikatsiyasiga ko‘ra senopopulyatsiyalar yosh (SP1, SP3) va o‘tuvchi (SP2, SP4) tiplarga xos ekanligi qayd etildi (*5-rasm*).



5-rasm. Senopopulyatsiyalarning tipi

Xulosa. O‘tkazilgan tadqiqotlar *A. talassicum* senopopulyatsiyalarining ontogenetik tuzilishi va demografik ko‘rsatkichlari hududiy ekologik sharoitlar hamda antropogen omillar ta’sirida sezilarli darajada farqlanishini ko‘rsatdi. Chap tomonlama ontogenetik spektrga ega bo‘lgan senopopulyatsiyalar (SP1 va SP3) yosh individlarning yuqori ulushi bilan tavsiflanib, turning tabiiy regeneratsiya jarayonlari faol kechayotganini va populyatsiyaning barqaror rivojlanish salohiyatini aks ettiradi. Markazlashgan spektrga ega senopopulyatsiyada (SP2) o‘rta generativ bosqichdagi individlarning ustunligi turning uzoq ontogenetik sikli bilan bog‘liq bo‘lib, populyatsiyaning nisbatan barqaror demografik holatini ta’minlaydi. Bimodal spektrga ega senopopulyatsiyada (SP4) esa generativ individlarning kamayishi va subsenil bosqichdagi tuplarning ortishi antropogen bosim (o‘simliklarni terib olish va chorva payhonlashi) natijasida yuzaga kelgan regressiv jarayonlarni ko‘rsatadi.

Delta-omega klassifikatsiyasi senopopulyatsiyalarning yosh va o‘tuvchi tipga mansubligi turning ayrim hududlarda barqaror tiklanish imkoniyatiga ega ekanini, biroq populyatsiyalarning bir qismida ekologik va antropogen omillar ta’siri kuchayib borayotganini ko‘rsatadi.

Mazkur tadqiqotlar O‘zbekiston Respublikasi Fanlar akademiyasi Botanika institutining 2025–2029- yillarga mo‘ljallangan **“**Raqamli tabiat” mavzusidagi davlat dasturi va FL-9024093685-sonli “O‘zbekistonning transchegaraviy hududlari bioxilmaxillik markazlari va ularning zamonaviy holati” mavzusidagi fundamental loyihalari doirasida amalga oshirildi.

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MARKAZIY OSIYO FLORASI MISOLIDA *OXYTROPIS* TURKUMI TURLARINI *IN VITRO* KO‘PAYTIRISH VA SAQLASH

Jamalova Dilafruz Ne‘matilla qizi
O‘zbekiston Respublikasi Fanlar akademiyasi botanika instituti, kichik ilmiy xodim
dilafruz.bel.91@mail.ru
ORCID 0000-0003-2035-7560
Xaydarova Nilufar Nodirjon qizi
O‘zbekiston Respublikasi Fanlar akademiyasi botanika instituti, kichik ilmiy xodim
Yusupov Ziyoviddin Olimjon o‘g‘li
O‘zbekiston Respublikasi Fanlar akademiyasi botanika instituti, katta ilmiy xodim
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Annotatsiya. Oxytropis turkumi turlari biotexnologik jihatdan muhim salohiyatga ega bo‘lgan turli turlarni o‘z ichiga oladi, biroq ularning in vitro ko‘paytirish va saqlash bo‘yicha tadqiqotlar bir xil darajada rivojlanmagan. Ayrim turlar uchun samarali mikroklonal ko‘paytirish va regeneratsiya protokollari ishlab chiqilgan bo‘lsa-da, ko‘pchilik turlar in vitro sharoitida yetarlicha o‘rganilmagan, bu esa ularni keng miqyosda ko‘paytirish va ex situ saqlash imkoniyatlarini cheklaydi. Ushbu muammo ayniqsa biologik xilmaxillik yuqori bo‘lgan hududlar, jumladan, O‘zbekiston uchun dolzarb bo‘lib, bu yerda biotexnologik tadqiqotlar va saqlash strategiyalari hali boshlang‘ich bosqichda. Shu sababli, mavjud in vitro ma’lumotlarni kompleks tahlil qilish, tadqiqot bo‘shliqlarini aniqlash hamda Oxytropis turlarini mikroklonal ko‘paytirish, genofondni saqlash va barqaror foydalanish bo‘yicha samarali biotexnologik yondashuvlarni ishlab chiqish zarur.

Tayanch so‘zlar: mikroklonal ko‘paytirish, Oxytropis, morfogenez, kallusogenez, organogenez, sterilizatsiya, fitogormonlar, urug‘larning unishi, yashovchanlik

РАЗМНОЖЕНИЕ И СОХРАНЕНИЕ ВИДОВ РОДА *OXYTROPIS IN VITRO* С АКЦЕНТОМ НА ФЛОРУ ЦЕНТРАЛЬНОЙ АЗИИ

Аннотация. Род Oxytropis включает разнообразную группу видов, обладающих значительным биотехнологическим потенциалом; однако исследования их культивирования in vitro и сохранения остаются крайне неравномерными. Хотя для некоторых видов разработаны эффективные протоколы микроклонального размножения и регенерации, большинство видов остаются недостаточно изученными в условиях in vitro, что ограничивает их массовое размножение и ex situ сохранение. Эта проблема особенно актуальна для регионов с высоким уровнем биоразнообразия, таких как Узбекистан, где систематические биотехнологические исследования и стратегии сохранения находятся на начальном этапе развития. В связи с этим необходим комплексный анализ существующих данных по культивированию in vitro для выявления пробелов в исследованиях и

разработки эффективных биотехнологических подходов для микроклонального размножения, сохранения генетических ресурсов и устойчивого использования видов рода Oxytropis.

Ключевые слова: микроклональное размножение, Oxytropis, морфогенез, каллусогенез, органогенез, стерилизация, фитогормоны, прорастание семян, жизнеспособность

Введение. В условиях продолжающихся экологических кризисов во многих регионах сохранение растительного разнообразия и предотвращение исчезновения видов стали приоритетными глобальными экологическими задачами. В этой связи применение современных биотехнологических подходов считается как эффективным, так и необходимым. Среди них методы культуры *in vitro* широко признаны одними из наиболее оптимальных для сохранения и размножения редких и находящихся под угрозой исчезновения видов растений. Данный подход позволяет использовать ограниченное количество семян эндемичных или уязвимых видов для получения высококачественных, свободных от заболеваний растений-регенерантов. В результате это способствует формированию жизнеспособных растений с высокой продуктивностью и поддержанию экологической устойчивости.

Настоящее исследование посвящено разработке протоколов *in vitro* размножения представителей рода *Oxytropis*. Род Oxytropis DC., относящийся к семейству Fabaceae, включает около 310 видов, распространённых по всему миру. Основной ареал этих видов сосредоточен в Центральной и Восточной Азии, при этом почти половина видов встречается в Китае [1]. На территории Узбекистана выявлено около 63 видов *Oxytropis*, преимущественно произрастающих в засушливых регионах и на горных склонах. Из них восемь видов являются эндемиками Узбекистана, а шесть видов занесены в Красную книгу Республики Узбекистан [2].

Виды рода *Oxytropis* имеют важное экологическое и хозяйственное значение. Некоторые из них используются в качестве кормовых растений, тогда как другие относятся к так называемым «locoweeds» из-за их токсичных свойств. Кроме того, виды *Oxytropis* широко применяются в традиционной медицине для лечения простудных заболеваний, воспалений, отёков, болевых синдромов и различных видов кровотечений. Фармакологические исследования показали, что данные растения обладают противоопухолевой, антисептической, противовоспалительной, гемостатической, нейроэндокринной и иммуносупрессивной активностью [3].

С учётом этих ценных свойств были проведены исследования *in vitro* для ряда видов *Oxytropis*, включая *O. scheludjakovae, O. erecta, O. pilosa* [4], *O. chankaensis* [5], *O. gmelinii, O. uralensis, O. ambigua* [6] и *O. glabra* [7]. В основном данные исследования были направлены на изучение прорастания семян, а в некоторых случаях также рассматривались процессы морфогенеза с использованием питательной среды Мурасиге и Скуга (MS)[8].

Успешное размножение *in vitro* зависит от ряда ключевых факторов, включая предварительную обработку семян, эффективную стерилизацию и тщательный подбор питательных сред с добавлением соответствующих регуляторов роста растений. Совокупность этих факторов обеспечивает оптимальное прорастание семян, жизнеспособность растений и контролируемый морфогенез.

Методы исследования. В данной работе применены методы аналитического обзора и сравнительного анализа научной литературы, посвящённой вопросам микроклонального размножения представителей рода *Oxytropis* в условиях *in vitro*.

Поиск и отбор научных источников осуществлялся с использованием международных научных баз данных (Scopus, Web of Science, Google Scholar и др.). В анализ были включены публикации, отражающие современные подходы к введению в культуру *in vitro*, стерилизации эксплантов, индукции каллусогенеза и органогенеза, а также особенности применения фитогормонов и условий культивирования.

Проведён сравнительный анализ полученных данных с целью выявления наиболее эффективных протоколов микроклонального размножения, факторов, влияющих на морфогенез, а также проблем и перспектив дальнейших биотехнологических исследований представителей рода *Oxytropis*.

Обобщение результатов позволило систематизировать имеющиеся данные и определить направления для будущих исследований.

Результаты и обсуждение. *Прорастание семян и жизнеспособность видов Oxytropis в условиях in vitro*

Исследования различных представителей рода *Oxytropis* показали, что успешное прорастание семян в условиях *in vitro* во многом зависит от методов предпосевной обработки. Семена видов данного рода характеризуются плотной и водонепроницаемой семенной оболочкой, препятствующей проникновению воды, поэтому перед введением в культуру необходимы скарификация и последующая стерилизация.

В исследовании Berdasova и соавт. [5] изучалось прорастание семян эндемичного вида *Oxytropis chankaensis* с использованием различных методов предпосевной обработки: химической скарификации концентрированной серной кислотой, механической скарификации, температурного воздействия и стратификации. Наиболее эффективным методом оказалась химическая скарификация, при которой прорастание начиналось уже на второй день, а итоговая всхожесть достигала 93%. Механическая скарификация обеспечила 66% всхожести, стратификация — 46%, а температурная обработка — только 13%. Полученные результаты свидетельствуют о высокой эффективности химической обработки для преодоления физического покоя семян.

Аналогичные результаты были получены для видов *O. scheludjakovae, O. erecta* и *O. pilosa* [9]. После обработки семян концентрированной серной кислотой в течение 25 минут показатели всхожести составили 53,3%, 45% и 41,6% соответственно. Первые проростки *O. scheludjakovae* и *O. erecta* появились на второй день, тогда как у *O. pilosa* — на десятый. Жизнеспособность сеянцев варьировала между видами и достигала максимального значения у *O. pilosa* (40,4%). Сходные результаты были получены и в исследованиях микроклонального размножения данного вида [4].

Kruglova и Kruglova [6] исследовали прорастание семян *O. gmelinii, O. uralensis* и реликтового вида *O. ambigua*. Несмотря на отсутствие подробного описания методов скарификации, наблюдалась высокая всхожесть семян: массовое прорастание происходило на 4–5-е сутки и достигало 70%, 80% и 95% соответственно. Для *O. glabra*, несмотря на наличие исследований по микроклональному размножению [7], конкретные показатели всхожести в литературе не приводятся.

Таким образом, анализ литературных данных показывает, что химическая скарификация является наиболее эффективным методом предпосевной обработки семян видов *Oxytropis*, обеспечивающим высокие показатели всхожести и ускоренное прорастание в условиях *in vitro*.

Таблица 1

Показатели прорастания и жизнеспособности видов *Oxytropis* при оптимальных методах скарификации

Plant species	Scarification method	Germination rate (%)	Viability (%)	Germination start (days)	Mass germination (days)	References
O. pilosa	Concentrated H_2SO_4 25 min	41.6	40.4	10	12	Nikiforova & Berdasova, 2023; Gal'kina & Zueva, 2018
O. scheludjakovae	Concentrated H_2SO_4 25 min	53.3	15.8	6	12	Androsova & Danilova, 2018
O. erecta	Concentrated H_2SO_4 25 min	45	30.2	6	10	Androsova & Danilova, 2018
O. gmelinii	½ MS	70	–	4	4–5	Berdasova et al., 2023
O. uralensis	½ MS	80	–	4	4–5	Berdasova et al., 2023
O. ambigua	½ MS	95	–	4	4–5	Berdasova et al., 2023

O. glabra	Concentrated H_2SO_4 10 min	>85	–	2	2	Zhao et al., 2007; Yang et al., 2012

Морфогенетические реакции видов Oxytropis в условиях in vitro

Культура растительных тканей представляет собой современный биотехнологический метод, позволяющий культивировать изолированные ткани и органы растений на искусственных питательных средах в стерильных условиях [10]. В качестве эксплантов могут использоваться апикальные меристемы, каллусные ткани, зародыши, семена и листовые сегменты, способные к регенерации полноценных растений при соответствующих условиях культивирования.

Среди различных питательных сред наиболее широко применяется среда Мурасиге и Скуга (MS) благодаря сбалансированному составу макро- и микроэлементов [8]. Добавление фитогормонов, в частности ауксинов и цитокининов, играет ключевую роль в регуляции процессов каллусогенеза, органогенеза, пролиферации побегов и ризогенеза.

В исследованиях *Oxytropis pilosa* [4] изучалось влияние различных комбинаций фитогормонов на процессы каллусообразования и регенерации побегов. Наибольший коэффициент размножения был получен на среде MS с добавлением 0,1015 мг/л ИМК (IBA), что свидетельствует о высокой эффективности данной концентрации ауксина для микроклонального размножения.

Kruglova и Kruglova [6] исследовали микроклональное размножение *O. gmelinii, O. uralensis* и *O. ambigua* с использованием упрощённых комбинаций регуляторов роста. Установлено, что оптимальной средой для индукции побегообразования является среда MS с добавлением 1 мг/л БАП, тогда как укоренение наиболее эффективно происходило на среде с 1 мг/л ИУК.

Наиболее детально морфогенетические процессы были изучены у *O. glabra* [7]. Авторы исследовали влияние различных комбинаций ТДЗ, БАП и НУК на процессы органогенеза, каллусогенеза и накопления алкалоидов. Среди 20 протестированных комбинаций несколько вариантов обеспечили частоту регенерации побегов свыше 80%. Максимальное количество побегов наблюдалось на среде с 10 мкМ БАП и 1 мкМ НУК. Дополнительная холодовая обработка листовых эксплантов при 4 °C в течение 7 суток значительно повышала регенерационную способность, обеспечивая формирование в среднем 12,6 побегов на эксплант при частоте регенерации 88,4%. Более длительное охлаждение приводило к снижению этих показателей.

Для укоренения побегов длиной более 4 см наиболее эффективной оказалась среда с добавлением 1,0 мкМ ИМК, где формировалось в среднем 12,2 корня на растение. Гистологический анализ подтвердил, что регенерация у O. glabra происходит по типу непрямого органогенеза через образование каллусной ткани и развитие адвентивных побегов.

В исследованиях *Oxytropis myriophylla* [3] установлено, что оптимальное развитие проростков наблюдается на среде MS с добавлением 0,1 мг/л БАП и 0,1 мг/л НУК, тогда как максимальный коэффициент размножения достигался на среде с 0,5 мг/л БАП и 0,2 мг/л НУК. Полученные результаты подтверждают важную роль сбалансированного соотношения ауксинов и цитокининов в эффективном микроклональном размножении видов рода *Oxytropis.*

Таблица 2

Влияние фитогормонов на образование побегов, каллуса и корней у видов *Oxytropis* в условиях *in vitro*

Species	Medium	Hormone combination (mg L^{-1})	Explant	Response	Morphogenesis	Reference
O. pilosa	MS	—	Seedling	1.25 (coef.)	Gemmogenesis	Nikiforova et al.
	MS	BAP 0.5	Seedling	1.7 (coef.)	Gemmogenesis	Nikiforova et al.
	MS	TDZ 0.23	Seedling	1.45 (coef.)	Gemmogenesis	Nikiforova et al.

	MS	NAA 0.5	Seedling	1.22 (coef.)	Callogenesis	Nikiforova et al.
	MS	BAP 1.0 + NAA 1.0 + IBA 0.5	Seedling	-	Organogenesis	Nikiforova et al.
	MS	IBA 0.1015	Seedling	2.0 (coef.)	Rhizogenesis	Nikiforova et al.
O. glabra	MS	BAP 2.22 + NAA 0.186	Leaf	85.6%	Gemmogenesis	Wei et al.
	MS	TDZ 1.0	Leaf	82.2%	Gemmogenesis	Wei et al.
	MS	TDZ 1.0 + BAP 2.22	Leaf	86.8%	Gemmogenesis	Wei et al.
	MS	TDZ 1.0 + BAP 4.44	Leaf	84.4%	Gemmogenesis	Wei et al.
	MS (+4°C)	BAP 2.22 + NAA 0.186	Leaf	88.4%	Gemmogenesis	Wei et al.
	½ MS	—	Shoot	23.6%	Rhizogenesis	Wei et al.
	½ MS	IBA 0.20	Shoot	86.8%	Rhizogenesis	Wei et al.
O. myriophylla	MS	BAP 0.1 + NAA 0.1	Seedling	-	Organogenesis	Dan Li Hui
	MS	BAP 0.5 + NAA 0.2	Stem	7.3 (coef.)	Gemmogenesis	Dan Li Hui
	½ MS	NAA 0.1	Shoot	-	Rhizogenesis	Dan Li Hui

Выводы и предложения. Несмотря на высокое видовое разнообразие представителей рода *Oxytropis* на территории Узбекистана, включающее значительное число редких и эндемичных видов, степень их научной изученности остаётся крайне ограниченной. Проведённые к настоящему времени исследования носят фрагментарный характер: биотехнологические работы, направленные на разработку эффективных протоколов *in vitro* культивирования, микроклонального размножения и сохранения генетических ресурсов, практически отсутствуют. В то же время фитохимические и фармакологические исследования охватывают лишь 3–4 вида, что не позволяет в полной мере оценить потенциал всего рода.

Учитывая, что значительная часть видов *Oxytropis* относится к категории редких, эндемичных и находящихся под угрозой исчезновения, возникает объективная необходимость в проведении системных и комплексных исследований. Особую актуальность приобретают разработки биотехнологических подходов, включающих оптимизацию условий стерилизации, прорастания семян, индукции морфогенеза и регенерации растений в условиях *in vitro*. Параллельно требуется расширение фитохимических исследований с целью выявления биологически активных соединений и оценки их фармакологического потенциала.

Таким образом, интеграция биотехнологических и химико-биологических исследований представляется ключевым направлением для сохранения генофонда видов рода *Oxytropis*, разработки эффективных стратегий их *ex situ* консервации и обеспечения рационального использования в будущем.

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HARORATNING KUZGI YUMSHOQ BUG‘DOY ILDIZ TIZIMI RIVOJLANISHIGA TA’SIRI

Yo‘ldasheva Shaxnoza Xasanboy qizi
Xorazm Ma’mun akademiyasi, tayanch doktorant
ORCID 0009-0001-1990-1103
shahnozayuldashuva@gmail.com
Xamrayev Nurbek Ulug‘bekovich
Don va dukkakli ekinlar ilmiy tadqiqot instituti, b.f.f.d., k.i.x.
ORCID 0000-0002-9349-3048
nurbek.hamraev@gmail.com
UDK 633.111.1; 551.524

Annotatsiya. Ushbu maqolada bug‘doy namunalarini turli haroratlarda stressga bardoshliligi o‘rganilgan. Navlar 25°C va 35°C da 7 kun davomida KKS 115 Smart pro rusumli harorat va namlikni nazorat qiluvchi iqlim kamerasida o‘stirilgan va 7 kundan so‘ng o‘simliklarning ildiz uzunligi, ildiz soni va haroratga chidamlilik indeks ko‘rsatkichlari aniqlangan va tahlil qilingan.

Ildiz uzunligi tahliliga ko‘ra 35°C da MV-Nemere va Ultra navlarida yuqori ekanligi, Ravnaq va Bobur navlarida esa nisbatan past ekanligi kuzatilgan. Ildiz uzunligi bo‘yicha haroratga chidamlilik indeksi (HCHI) Drujba navida eng yuqori natijani, Vassa navida esa eng past natijani qayd etgan. Ildiz soni bo‘yicha Andijon-2, Drujba va Brigada 35°C sharoitda yuqori ekanligi, MV-Nemere, Ravnaq va Grom navlarida esa 35°C da ildiz sonining keskin kamayishi kuzatilgan. Haroratga chidamlilik indeksi (HCHI) yuqori bo‘lgan bug‘doy navlarini ota-ona formalari sifatida olib, seleksiya ishlariga jalb qilingan va F_2 duragaylari olingan.

Kalit so‘zlar: Bug‘doy navlari, yuqori harorat, ildiz uzunligi, ildiz soni, nazorat, chidamlilik indeksi va unuvchanlik.

EFFECT OF TEMPERATURE ON ROOT SYSTEM DEVELOPMENT OF AUTUMN SOFT WHEAT

Abstract. In this article, the tolerance of wheat samples to stress under different temperature conditions was studied. The varieties were grown at 25°C and 35°C for 7 days in a KKS 115 Smart Pro climate chamber that controls temperature and humidity, and after 7 days, the root length, root number, and heat tolerance index indicators of the plants were determined and analyzed.

According to the analysis of root length, it was observed that at 35°C it was higher in MV-Nemere and Ultra varieties, while it was relatively lower in Ravnaq and Bobur varieties. According to the heat tolerance index (HTI) based on root length, the highest result was recorded in the Drujba variety, while the lowest result was recorded in the Vassa variety. In terms of root number, it was observed that Andijon-2, Drujba, and Brigada were high under 35°C conditions, while a sharp decrease in root number at 35°C was observed in MV-Nemere, Ravnaq, and Grom varieties. Wheat varieties with a high heat tolerance index (HTI) were taken as parental forms, involved in breeding work, and F_2 hybrids were obtained.

Keywords: Wheat varieties, high temperature, root length, root number, control, heat tolerance index and germination.

Kirish. Bug‘doy (*Triticum aestivum L.*) dunyo miqyosida muhim oziq-ovqat ekini

bo‘lib, aholi uchun asosiy kaloriya va oqsil manbalaridan biri hisoblanadi [16]. Ammo bug‘doy yetishtirish global iqlim o‘zgarishi sababli qiyinchiliklarga duch kelmoqda, ayniqsa, haroratning oshishi muammo tug‘dirmoqda [3]. Bug‘doy o‘sishi uchun ideal harorat oralig‘i 22/14°C (kun/tun) atrofida bo‘ladi [12]. Yuqori harorat vegetativ o‘sish va biomassa hosil bo‘lishiga salbiy ta’sir ko‘rsatib, organ va to‘qimalarning rivojlanishi hamda shakllanish jarayonlarini o‘zgartiradi. Reproduktiv bosqichda yuqori harorat bug‘doy umumiy biomassasining 44% gacha kamayishiga olib kelishi mumkin [15]. Issiqlik stressi bug‘doyda fotosintez, xlorofill miqdorini saqlash va hujayra metabolizmi kabi muhim fiziologik jarayonlarga salbiy ta’sir ko‘rsatishi aniqlangan [4].

Fotosintez issiqlik stressiga eng sezgir fiziologik ko‘rsatkichlardan biri bo‘lib, bu bug‘doyning o‘sish samaradorligining pasayishiga olib keladi [6]. Issiqlik stressining asosiy ta’sirlaridan biri fotosintez jarayonining kamayishi bo‘lib, bu barg yuzasining kengayishining susayishi, fotosintetik apparatning zararlanishi hamda barglarning erta qarishi natijasida yuzaga keladi va oxir-oqibat bug‘doy hosildorligining kamayishiga olib keladi [2, 9].

Harorat oshishi bilan nafas olish tezligi ortadi, biroq ma’lum bir harorat darajasidan so‘ng nafas olish apparatining zararlanishi tufayli bu jarayon sekinlashadi yoki kamayadi [13]. Tadqiqotlar shuni ko‘rsatadiki, bug‘doy o‘simliklarida 30-35°C da nafas olish tezligi tez ortadi, shu bilan birga fotosintez tezligi keskin kamayadi [8]. Issiqlik stressi (IS) sharoitida bug‘doy endospermidagi kraxmal miqdori sezilarli darajada kamayadi [18]. Don quruq massasining 65% dan ortig‘ini kraxmal tashkil etishi sababli, kraxmal miqdorining pasayishi natijasida hosildorlik kamayadi [14]. Shu bilan birga, don to‘lish davrida issiqlik stressi donlardagi oqsil miqdoriga salbiy ta’sir ko‘rsatishi mumkin, chunki kraxmalning yig‘ilishi kamayadi [7]. IS bug‘doy donlaridagi azot va kraxmal muvozanatini buzadi, natijada nisbatan ko‘proq azot oqsil hosil bo‘lishiga yo‘naltiriladi, bu esa oqsil konsentratsiyasining oshishiga olib keladi [17]. Shuning uchun iqlim o‘zgarishi sharoitida oziq-ovqat xavfsizligini ta’minlash uchun issiqqa chidamli bug‘doy navlarini yaratish juda muhim hisoblanadi [11].

Tadqiqot metodologiyasi. Tadqiqotlarda kuzgi yumshoq bug‘doyning 21 ta (Andijon-4, ASR, Gomer, Bobur, Karavan, Brigada, Durdona, Drujba, Zimnitsa, Grom, Jiva, Ravnaq, Aziz, Ultra, MV-Nemere, Andijon-2, Step, Vostorg, Vassa, Kroshka va Krasnodar-99) navlari obyekti sifatida olindi.

Bug‘doy urug‘lari 5 daqiqa davomida 1% natriy gipoxlorit bilan sterilizatsiya qilindi, distillangan suv bilan yaxshilab yuvildi va keyin qorong‘ida 25°C da 24 soat davomida distillangan suvda namlanadi. Bir tekis unib chiqqan urug‘lar filtr qog‘oz qo‘yilgan petri idishlariga solindi. O‘simliklar 7 kun davomida KKS 115 Smart pro rusumli harorat va namlikni nazorat qiluvchi iqlim kamerasida o‘stirildi. Navlar ikki xil harorat rejimida o‘stirildi: nazorat sharoiti (25°C) va issiqlik stressi sharoiti (35°C). 35°C harorat issiqlik stressini yuzaga keltirish uchun tanlandi, chunki u bug‘doy nihollarida sezilarli stress reaksiyalarini hosil qilishi ilmiy manbalarda isbotlangan [1,10]. 7 kundan so‘ng o‘simliklarning ildiz uzunligi, ildiz soni va haroratga chidamlilik indeks ko‘rsatkichlari aniqlandi.

Natijalar va muhokama. Issiqqa chidamlilik 7 kunlik tajriba oxirida ildiz uzunligi va ildiz sonini o‘lchash orqali baholandi. Ushbu tadqiqot asosan issiqlik stressiga javob beruvchi muhim ko‘rsatkichlarga qaratilgan bo‘lib, ildiz uzunligi chizg‘ich yordamida o‘lchandi, ildizlar soni esa qo‘lda sanaldi. Ildiz ko‘rsatkichlari tanlanishining sababi – ularning issiqlik stressiga juda sezgirligi va o‘simlikning suv hamda oziqa moddalarini o‘zlashtirish qobiliyatini bevosita aks ettirishidir [5].

Tadqiqot natijalariga ko‘ra, o‘rganilgan 21 ta bug‘doy navida haroratning oshishi ildiz o‘sishiga sezilarli ta’sir ko‘rsatgan. 25°C sharoitda barcha navlarda ildiz uzunligi yuqori bo‘lgan bo‘lsa, 35°C da bu ko‘rsatkichlarning kamayishi kuzatilgan. Har bir bug‘doy namunasi uchun yuqori haroratga chidamlilik indeksi (HCHI) quyidagi formula asosida hisoblandi:

HCHI= (ildiz uzunligi (35°C) / ildiz uzunligi (25°C)) * 100%

Krasnodar-99 (nazorat) navida ildiz uzunligi 25°C da 13,4 sm dan 35°C da 4,9 sm gacha kamaygan bo‘lib, haroratga chidamlilik indeksi (HCHI) 36,6 % ni tashkil etdi. Andijon-

2 navida ildiz uzunligi 12,9 sm dan 5,0 sm gacha kamayib, HCHI 38,8 % ni tashkil etdi. ASR navida ildiz uzunligi 10,3 sm dan 5,0 sm gacha kamayib, HCHI 48,5 % bo‘lgan.

Aziz navida ildiz uzunligi 14,9 sm dan 6,2 sm gacha kamayib, HCHI 41,6 % ni tashkil etdi. Durdona navida ildiz uzunligi 12,8 sm dan 5,3 sm gacha kamayib, HCHI 41,4 % bo‘lgan. Bobur ildiz uzunligi 12,3 sm dan 4,5 sm gacha kamayib, HCHI 36,6 % ni tashkil etdi (1-jadval).

1-jadval

25ºC va 35ºC harorat ostida o‘stirilgan kuzgi yumshoq bug‘doy navlarining ildiz uzunligi, sm

№	Nav nomi	Ildiz uzunligi, sm (25ºC)	Ildiz uzunligi, sm (35ºC)	HCHI, %
1.	Krasnodar-99 (nazorat)	13,4±0,4	4,9±0,2	36,6
2.	Andijon-2	12,9±0,9	5,0±0,5	38,8
3.	ASR	10,3±0,5	5,0±0,2	48,5
4.	Aziz	14,9±0,9	6,2±0,2	41,6
5.	Durdona	12,8±0,6	5,3±0,4	41,4
6.	Bobur	12,3±0,7	4,5±0,2	36,6
7.	Andijon-4	12,2±0,7	4,7±0,3	38,5
8.	Drujba	8,3±0,3	5,5±0,3	66,3
9.	Grom	15,7±0,8	5,4±0,2	34,4
10.	Zimnitsa	14,0±1,0	4,8±0,3	34,3
11.	Vassa	15,2±0,6	5,0±0,2	32,9
12.	Brigada	12,2±0,6	6,5±0,5	53,3
13.	Kroshka	16,4±0,8	7,3±0,4	44,5
14.	Ultra	14,8±0,7	7,4±0,6	50,0
15.	Ravnaq	9,8±0,5	4,2±0,5	42,9
16.	Karavan	15,9±0,8	7,1±0,5	44,7
17.	Step	12,6±1,1	4,9±0,4	38,9
18.	Gomer	14,3±0,8	6,1±0,4	42,7
19.	Jiva	14,5±0,8	6,5±0,7	44,8
20.	MV-Nemere	15,4±0,6	7,7±0,8	50,0
21.	Vostorg	11,9±0,5	5,0±0,8	42,0

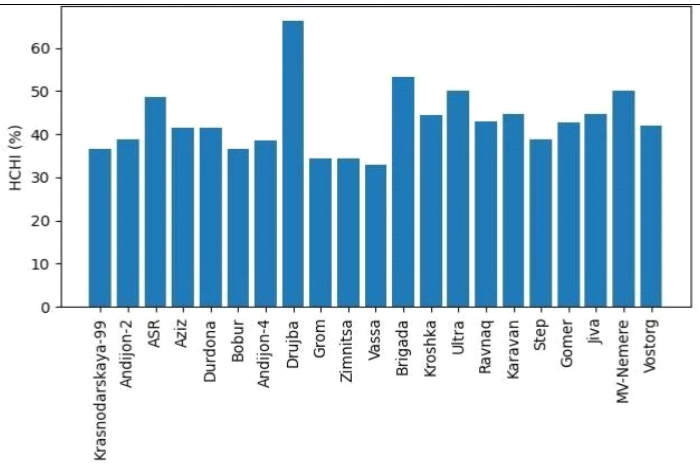
Andijon-4 navida ildiz uzunligi 12,2 sm dan 4,7 sm gacha kamayib, HCHI 38,5% bo‘lgan. Drujba navida ildiz uzunligi 8,3 sm dan 5,5 sm gacha kamayib, nisbatan yuqori HCHI 66,3% qayd etilgan. Grom navida ildiz uzunligi 15,7 sm dan 5,4 sm gacha kamayib, HCHI 34,4% bo‘lgan.

Zimnitsa navida ildiz uzunligi 14,0 sm dan 4,8 sm gacha kamayib, HCHI 34,3% ni tashil qilgan. Vassa navida ildiz uzunligi 15,2 sm dan 5,0 sm gacha kamayib, HCHI 32,9% bo‘lib, nisbatan past ko‘rsatkich qayd etilgan. Brigada navida ildiz uzunligi 12,2 sm dan 6,5 sm gacha kamayib, HCHI 53,3% ni tashkil etgan.

Kroshka navida ildiz uzunligi esa 16,4 sm dan 7,3 sm gacha kamayib, HCHI 44,5% bo‘lgan. Ultra navida ildiz uzunligi 14,8 sm dan 7,4 sm gacha kamayib, HCHI 50% ni tashkil etgan. Ravnaq navida ildiz uzunligi 9,8 sm dan 4,2 sm gacha kamayib, HCHI 42,9% bo‘lgan.

Karavan navida ildiz uzunligi 15,9 sm dan 7,1 sm gacha kamayib, HCHI 44,7% ni tashkil etgan. Step navida ildiz uzunligi esa 12,6 sm dan 4,9 sm gacha kamayib, HCHI 38,9% bo‘lgan. Gomer navida ildiz uzunligi 14,3 sm dan 6,1 sm gacha kamayib, HCHI 42,7% ni tashkil etgan.

Jiva navida ildiz uzunligi 14,5 sm dan 6,5 sm gacha kamayib, HCHI 44,8% bo‘lgan. MV-Nemere navida ildiz uzunligi 15,4 sm dan 7,7 sm gacha kamayib, HCHI 50% ni tashkil etgan. Vostorg navida ildiz uzunligi 11,9 sm dan 5,0 sm gacha kamayib, HCHI 42% ga kamaygan (1-rasm).



1-rasm. Haroratga chidamlilik indeksi (HCHI)

Tadqiqotimiz davomida kuzgi bug‘doy navlarining 25°C (nazorat) va 35°C (issiqlik stressi) sharoitlarida ildiz sonidagi ozgarishlar ham tahlil qilindi va natijalariga ko‘ra, 35°C da aksariyat navlarda ildiz sonining kamayishi kuzatilgan, biroq ayrim navlarda ortish yoki o‘zgarishsiz qolish holatlari ham qayd etilgan.

Krasnodar-99 (nazorat) navida 25°C da ildiz soni 5,2 dona bo‘lgan bo‘lsa, 35°C da 3,7 donaga tushgan. Andijon-2 navida esa 25°C da 4,4 dona bo‘lib, 35°C da 4,8 donagacha oshgan. ASR navida 25°C da 4,4 dona bo‘lib, 35°C da 3,8 donagacha kamaygan (2-jadval).

2-jadval

25ºC va 35ºC harorat ostida o‘stirilgan kuzgi bug‘doy navlarining ildiz soni, dona

№	Nav nomi	Ildiz soni, dona (25ºC)	Ildiz soni, dona (35ºC)
1.	Krasnodarskaya-99 (nazorat)	5,2±0,2	3,7±0,2
2.	Andijon-2	4,4±0,3	4,8±0,3
3.	ASR	4,4±0,2	3,8±0,2
4.	Aziz	4,9±0,2	4,4±0,4
5.	Durdona	4,3±0,3	3,4±0,3
6.	Bobur	4,9±0,2	3,8±0,2
7.	Andijon-4	5,3±0,1	4,6±0,3
8.	Drujba	3,6±0,2	4,8±0,2
9.	Grom	4,5±0,2	3,2±0,3
10.	Zimnitsa	4,2±0,2	3,8±0,5
11.	Vassa	4,7±0,4	4,0±0,3
12.	Brigada	4,7±0,3	4,9±0,4
13.	Kroshka	4,2±0,2	3,9±0,3
14.	Ultra	4,9±0,3	4,8±0,4
15.	Ravnaq	3,5±0,2	3,2±0,3
16.	Karavan	4,7±0,4	4,2±0,2
17.	Step	4,7±0,2	4,3±0,3
18.	Gomer	4,1±0,3	3,7±0,2
19.	Jiva	4,6±0,3	4,6±0,3
20.	MV-Nemere	5,0±0,2	3,1±0,2
21.	Vostorg	4,8±0,1	4,4±0,2

Aziz navida 25°C da 4,9 dona, 35°C da 4,4 dona; Durdona navida 4,3 donadan 3,4 donagacha kamaygan. Bobur navida 25°C da 4,9 dona bo‘lib, 35°C da 3,8 donaga tushgan. Andijon-4 navida esa 25°C da 5,3 dona, 35°C da 4,6 dona bo‘lgan.

Drujba navida 25°C da 3,6 dona ildiz kuzatilgan bo‘lsa, 35°C da 4,8 donagacha oshgan. Grom navida 25°C da 4,5 dona bo‘lib, 35°C da 3,2 donagacha kamaygan. Zimnitsa navida 4,2 dan 3,8 donagacha, Vassa navida 4,7 dan 4,0 donagacha pasaygan.

Brigada navida 25°C da 4,7 dona bo‘lib, 35°C da 4,9 donagacha oshgan. Kroshka navida 4,2 dan 3,9 donagacha kamaygan. Ultra navida 25°C da 4,9 dona bo‘lib, 35°C da 4,8 dona bo‘lib deyarli o‘zgarmagan.

Ravnaq navida 25°C da 3,5 dona bo‘lib, 35°C da 3,2 donagacha kamaygan. Karavan navida 4,7 dan 4,2 donagacha, Step navida 4,7 dan 4,3 donagacha kamaygan. Gomer navida 4,1 dan 3,7 donagacha pasaygan.

Jiva navida 25°C va 35°C sharoitlarda ildiz soni bir xil-4,6 dona bo‘lib qolgan. MV-Nemere navida 25°C da 5,0 dona bo‘lib, 35°C da 3,1 donagacha keskin kamaygan. Vostorg navida esa 4,8 donadan 4,4 donagacha pasaygan.

Xulosa va takliflar. Tadqiqot natijalariga ko‘ra, kuzgi bug‘doy navlarida haroratning 25°C dan 35°C gacha oshishi ildiz uzunligining sezilarli darajada kamayishiga olib kelgan. Barcha o‘rganilgan navlarda ildiz uzunligi qisqargan bo‘lib, bu yuqori haroratning o‘simlik rivojlanishiga salbiy ta’sir ko‘rsatishini tasdiqlaydi.

Nazorat varianti bo‘lgan Krasnodar-99 navida ildiz uzunligi 13,4 sm dan 4,9 sm gacha kamaygan. 25°C sharoitida eng yuqori ildiz uzunligi Kroshka (16,4 sm) va Karavan (15,9 sm) navlarida aniqlangan. Shu bilan birga, ayrim navlar yuqori harorat sharoitida ildiz uzunligini nisbatan yaxshi saqlab qolganligi kuzatildi. Jumladan, MV-Nemere (7,7 sm), Aziz (7,4 sm) va Kroshka (7,3 sm) navlari 35°C sharoitida ham nisbatan yuqori ildiz uzunligi ko‘rsatkichlarini namoyon etdi. 35°C da esa ayrim navlar boshqa navlarga nisbatan kamroq kamayish ko‘rsatib, issiqlikka nisbatan chidamliligini namoyon qilgan. Bundan tashqari tadqiqotimizda haroratga chidamlilik indeksi (HCHI) ko‘rsatkichlari ham aniqlandi. Ushbu ko‘rsatkich navlar kesimida turlicha bo‘lib, eng yuqori natijani Drujba (66,3%) va Brigada (53,3%) navlari qayd etgan. Bu esa ularning yuqori haroratga nisbatan chidamli ekanligini anglatadi. Aksincha, HCHI ko‘rsatkichi nisbatan past bo‘lgan navlar qatoriga Vassa (32,9%) va Zimnitsa (34,3%) kiritilib, ular yuqori haroratga sezgir ekanligi kuzatildi.

25°C dan 35°C ga o‘tganda ildiz sonining kamayishi aksariyat navlarga xos bo‘ldi. Biroq ayrim navlar, xususan Andijon-2, Drujba va Brigada 35°C sharoitda ildiz sonining ortishi yoki barqaror saqlanishi kuzatilib, bu ularning issiqlik stressiga nisbatan yuqori moslashuvchanligini ko‘rsatadi. MV-Nemere, Ravnaq va Grom navlarida esa 35°C da ildiz sonining keskin kamayishi kuzatilib, ular issiqlikka sezgir navlar sifatida baholandi.

Umuman olganda, kuzgi bug‘doy navlari yuqori haroratga turlicha munosabat bildiradi va ildiz tizimining rivojlanish darajasi ularning issiqlikka moslashuvchanligini baholashda muhim ko‘rsatkich hisoblanadi.

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QASHQADARYO VILOYATIDAGI *ACHILLEA* L. TURKUMI AYRIM TURLARI SENOPOPULYATSIYALARINING SISTEMATIK TARKIBI TAHLILI

Bo‘ranova M.O.
Iqtisodiyot va pedagogika universiteti, dotsent
muhayyoxon@bk.ru
ORCID 0000-0003-4701-4322,
Toshpulotova S.A.
Qarshi davlat universiteti, magistrant
setoratoshpolatova338@gmail.com
UDK 58.009

Annotatsiya. Ushbu maqolada *Achillea* L. turkumiga mansub *A. wilhelmsii* K. Koch. ва *A. filipendulina* Lam. turlarining senopopulyatsiyalaridagi o‘simliklarning sistematik tarkibi, hayotiy shakllari va Drude shkalasi bo‘yicha mo‘llik darajalari tahlil qilingan. Tadqiqot natijalariga ko‘ra, *A. wilhelmsii* senopopulyatsiyasida 39 tur (22 oila), *A. filipendulina* senopopulyatsiyasida esa 43 tur (24 oila) tarqalganligi aniqlandi. *A. wilhelmsii* senopopulyatsiyasida *Asteraceae* oilasi (7 tur, 17,9%) yetakchi o‘rinda bo‘lsa, *A. filipendulina* senopopulyatsiyasida *Fabaceae* oilasi (7 tur, 18,2%) turlar rang-barangligi bo‘yicha yaqqol dominantlik qiladi. Drude shkalasi bo‘yicha *A. wilhelmsii* senopopulyatsiyasida *Poa bulbosa* (6 ball) eng yuqori mo‘llikka ega. *A. filipendulina* senopopulyatsiyasida esa *Trigonella cancellata* (7 ball) mo‘lligi bo‘yicha eng yuqori ko‘rsatkichga ega bo‘lib, ushbu turning asosiy dominant ekanligi aniqlangan.

Kalit so‘zlar: *Achillea*, senopopulyatsiya, sistematik tahlil, Drude shkalasi, hayotiy shakl, dominant tur, bioxilmaxillik.

SYSTEMATIC STRUCTURE ANALYSIS OF COENOPOPULATIONS OF SOME SPECIES OF THE GENUS *ACHILLEA* L. IN KASHKADARYA REGION

Abstract. This article analyzes the systematic composition, life forms, and abundance levels according to the Drude scale of plants in coenopopulations of species belonging to the genus *Achillea* L. – *A. wilhelmsii* K. Koch and *A. filipendulina* Lam. According to the research results, 39 species (22 families) were identified in the coenopopulation of *A. wilhelmsii*, while 43 species (24 families) were recorded in the coenopopulation of *A. filipendulina*. In the coenopopulation of *A. wilhelmsii*, the Asteraceae family is dominant (7 species, 17.9%), whereas in the coenopopulation of *A. filipendulina*, the Fabaceae family (7 species, 18.2%) shows clear dominance in terms of species diversity. According to the Drude scale, *Poa bulbosa* (6 points) exhibits the highest abundance in the *A. wilhelmsii* coenopopulation. In the *A. filipendulina* coenopopulation, *Trigonella cancellata* (7 points) was found to have the highest abundance, indicating that this species is the main dominant.

Keywords: *Achillea*, coenopopulation, systematic analysis, Drude scale, life form, dominant

species, biodiversity.

Kirish. O‘zbekiston florasi o‘zining boy turlar tarkibi va noyob ekologik tizimlari bilan ajralib turadi. Mamlakatimizning tog‘li hududlari, adirlar va vohalari turli xil dorivor, ozuqabop va manzarali o‘simliklarga boy. Shulardan biri – *Achillea* L. (Bo‘ymodaron) turkumi bo‘lib, ushbu turkum vakillari xalq tabobatida qadimdan foydalanilib kelinadi va ularning fitotsenozlardagi o‘rni muhimdir. *Achillea* turlari keng ekologik moslashuvchanlikka ega bo‘lib, turli landshaft-geografik zonalarda – tog‘ yonbag‘irlaridan tortib, toshloq va shag‘alli yerlar, yo‘l yoqalari va o‘tloqzorlarda uchraydi [2].

Senopopulyatsiya tushunchasi bir turning ma’lum bir fitotsenoz doirasidagi barcha individlari majmuini anglatadi. Ushbu senopopulyatsiyalar tarkibida boshqa turlarning mavjudligi, ularning miqdoriy ko‘rsatkichlari va sistematik mansubligi mazkur ekotopning ekologik sharoiti, antropogen ta’sir darajasi va suksession holati haqida muhim ma’lumotlar beradi.

Tadqiqotning maqsadi – *A. wilhelmsii* K. Koch. va *A. filipendulina* Lam. turlarining senopopulyatsiyalaridagi o‘simliklarning sistematik tarkibini tahlil qilish va mo‘lligini baholashdan iborat.

Tadqiqot usullari. Tadqiqot obyekti sifatida *Achillea* turkumiga mansub ikki turning senopopulyatsiyalari tanlab olindi:

1. *Achillea wilhelmsii* K. Koch. – tobulg‘ibargli bo‘ymodaron, dastarbosh – ko‘p yillik o‘t o‘simlik. Lyossimon, mayda tuproqli, shag‘alli, toshli yonbag‘irlar, shag‘al toshloq yerlar, daryo va soy vodiylari, ekilmay yotgan yerlar, dalalarning chekkalari, bog‘larda tarqalgan. Tog‘oldi hududlari, tog‘larning quyi va o‘rta mintaqalarida uchraydi. Qashqadaryo viloyatining Urgut, Qashqadaryo, Torqopchig‘ay botanik-geografik rayonlarida o‘sadi [2]. Asosan O‘rta Osiyo, Eron va Afg‘onistonning tog‘li hududlarida uchraydi. Qurg‘oqchilikka chidamli. Dorivor o‘simlik hisoblanadi [3, 5, 7, 8].
2. *Achillea filipendulina* Lam. – Vilgelms bo‘ymodaroni (Karmana bo‘ymodaroni), boshog‘riq o‘ti – ko‘p yillik o‘t o‘simlik. Qumli, gilli, shag‘alli cho‘llar, tog‘ oldi tekisliklari, sho‘rxok joylar, lyossli yonbag‘irlar, ariq va kanallar qirg‘oqlari, dalalar chekkalari, ekin ekilmay yotgan yerlarda tarqalgan. Tekislik, tog‘ oldi hududlari, tog‘larning quyi mintaqasida uchraydi. Qashqadaryo viloyatining Urgut, Qashqadaryo, Torqopchig‘ay va Qarshi-Qarnobcho‘l botanik-geografik rayonlarida o‘sadi [2]. Manzarali va dorivor o‘simlik sifatida qadrlanadi [4]. So‘nggi tadqiqotlarda saratonning ayrim turlarida qo‘llanilishi aniqlangan [9]. Urug‘lari tarkibida efir moylari mavjud [10].

Tadqiqot davomida quyidagi metodlar qo‘llanildi:

1. Marshrutli usul: *Achillea* turlarining har bir senopopulyatsiyasi joylashgan hududlarda marshrutli kuzatishlar olib borilib, o‘simliklarning umumiy ro‘yxati tuzildi.
2. Hisobga olish maydonchalari usuli: senopopulyatsiyalar doirasida 10×10 m o‘lchamdagi hisobga olish maydonchalari qo‘yilib, u yerda uchraydigan barcha turlar ro‘yxatga olindi va ularning soni baholandi [1].
3. Sistematik tahlil: aniqlangan barcha turlarning oila va turkumlarga mansubligi zamonaviy sistematik klassifikatsiya asosida aniqlandi. O‘simliklarning lotincha nomlari Halqaro o‘simlik nomlari indeksi (IPNI) bo‘yicha keltirildi [6].
4. Mo‘llikni baholash: har bir turning senopopulyatsiyadagi mo‘lligi Drude shkalasining 7 ballik tizimi asosida baholandi. Ballar quyidagi ma’nolarni anglatadi:

– 7 ball (Socialis – Soc): o‘simlik juda ko‘p, fon yaratadi, umumiy qoplamning asosiy qismini tashkil qiladi.
– 6 ball (Copiosae 3 – Cop3): o‘simlik juda ko‘p.
– 5 ball (Copiosae 2 – Cop2): o‘simlik ko‘p.
– 4 ball (Copiosae 1 – Cop1): o‘simlik anchagina ko‘p.
– 3 ball (Sparsae – Sp): o‘simlik siyrak, kam miqdorda uchraydi.
– 2 ball (Solitariae – Sol): o‘simlik yakka-yakka holda uchraydi.
– 1 ball (Unicum – Un): o‘simlik bir nusxada uchraydi.

Natijalar va muhokama. *A. wilhelmsii* senopopulyatsiyasi tarkibida 39 tur (1-jadval) tarqalganligi aniqlandi. Bu turlar 22 oilaga mansub.

1-jadval

***Achillea wilhelmsii* ning senopopulyatsiyasi joylashgan o‘simliklarning oilalar bo‘yicha joylashishi**

№	Tur nomi	Oilasi
1	*Achillea wilhelmsii* K. Koch.	*Asteraceae*
2	*Aegilops cylindrica* Host.	*Poaceae*
3	*Allium drepanophyllum* Vved.	*Alliaceae*
4	*Althaea cannabina L.*	*Malvaceae*
5	*Alyssum szovitsianum* Fisch. & C.A. Mey.	*Brassicaceae*
6	*Artemisia baldshuanica* Krasch. & Zopr.	*Asteraceae*
7	*Arum korolkowii Regel*	*Araceae*
8	*Bromus tectorum* L.	*Poaceae*
9	*Chardinia orientalis* (L.) Kuntze	*Asteraceae*
10	*Convolvulus subhirsutus* Regel et Schmalh.	*Convolvulaceae*
11	*Cryptospora omissa* Botsch.	*Brassicaceae*
12	*Elaeagnus angustifolia L.*	*Elaeagnaceae*
13	*Equisetum ramosissimum Desf.*	*Equisetaceae*
14	*Garhadiolus papposus* Boiss. & Buhse	*Asteraceae*
15	*Gentiana olivieri* Griseb.	*Gentianaceae*
16	*Goldbachia laevigata* DC.	*Brassicaceae*
17	*Haplophyllum perforatum* Kar. & Kir.	*Rutaceae*
18	*Heteranthelium piliferum* Hochst. ex Jaub. & Spach	*Poaceae*
19	*Hypericum perforatum L.*	*Hypericaceae*
20	*Ixiolirion tataricum* (Pall.) Herb. & Traub	*Ixioliriaceae*
21	*Juglans regia L.*	*Juglandaceae*
22	*Nepeta olgae Regel*	*Labiatae*
23	*Nigella bucharica* Schipcz.	*Ranunculaceae*
24	*Perovskia scrophulariefolia Bunge*	*Labiatae*
25	*Phlomis spinidens* Nevski	*Lamiaceae*
26	*Phlomoides kaufmanniana* (Regel) Adylov, Kamelin & Makhm.	*Lamiaceae*
27	*Poa bulbosa* L.	*Poaceae*
28	*Populus alba L.*	*Salicaceae*
29	*Ranunculus arvensis L*	*Ranunculaceae*
30	*Salvia sclarea L.*	*Labiatae*
31	*Scorzonera circumflexa* Krasch. & Lipsch.	*Asteraceae*
32	*Strigosella africana* (L.) Botsch.	*Brassicaceae*
33	*Taraxacum officinale F.H. Wigg.*	*Asteraceae*
34	*Thalictrum isopyroides* C.A. Mey.	*Ranunculaceae*
35	*Trifolium pratense L.*	*Fabaceae*
36	*Trigonella cancellata* Desf.	*Fabaceae*
37	*Turgenia latifolia* Hoffm.	*Apiaceae*
38	*Ziziphora tenuior* L.	*Labiatae*
39	*Zoegea baldschuanica* C. Winkl.	*Asteraceae*

A. wilhelmsii senopopulyatsiyasida turlar soni bo‘yicha yetakchi o‘rinlarni quyidagi oilalar egallaydi:

– Asteraceae oilasi – 7 tur (17,9%);
– Labiatae, Poaceae va Brassicaceae oilalari – 4 tadan tur (10,3% dan);
– Ranunculaceae oilasi – 3 tur (7,7%);
– Fabaceae va Lamiaceae oilalari – 2 tadan tur (5,1% dan);
– Alliaceae, Apiaceae, Araceae, Convolvulaceae, Elaeagnaceae, Equisetaceae, Gentianaceae, Hypericaceae, Ixioliriaceae, Juglandaceae, Malvaceae, Rutaceae va Salicaceae oilalari – 1 tadan tur (2,6% dan).

Bu yerda Asteraceae (Murrakkaguldoshlar) oilasining roli sezilarli darajada yuqori. Shuningdek, bu senopopulyatsiyada daraxtlar (*Elaeagnus angustifolia*, *Juglans regia*, *Populus alba*) va chala butalar (*Perovskia scrophulariefolia*) uchraydi, bu esa mazkur senopopulyatsiyaning turli yaruslardan iborat murakkabroq tuzilishga ega ekanligini ko‘rsatadi.

39 turning 21 tasi (53,8%) ko‘p yillik o‘tlar, 12 tasi (30,8%) bir yillik o‘tlar, 1 tasi

(2,6%) ikki yillik o‘t, 1 tasi chala buta (2,6%), 1 tasi lianasimon buta (2,6%) va 3 tasi (7,7%) daraxtlardir. Daraxt va butalarning mavjudligi bu fitotsenozning ekologik sharoiti (namlik, tuproq unumdorligi) nisbatan qulayroq ekanligidan dalolat beradi.

Tadqiqotlarimiz davomida bu senopopulyatsiyada o‘simliklarning mo‘lligi quyidagichaligi aniqlandi:

– Cop3 (6 ball): *Poa bulbosa* (1 tur).

– Cop2 (5 ball): *Nepeta olgae, Ranunculus arvensis, Phlomoides kaufmanniana* (3 tur).

– Cop1 (4 ball): *Achillea wilhelmsii, Allium drepanophyllum, Arum korolkowii, Hypericum perforatum, Juglans regia, Trigonella cancellata, Zoegea baldschuanica* (7 tur).

– Sp (3 ball): *Althaea cannabina, Convolvulus subhirsutus, Cryptospora omissa, Equisetum ramosissimum, Garhadiolus papposus, Heteranthelium piliferum, Perovskia scrophulariefolia, Phlomis spinidens, Salvia sclarea, Scorzonera circumflexa, Strigosella africana, Taraxacum officinale, Ziziphora tenuior* (13 tur).

– Sol (2 ball): *Aegilops cylindrica, Alyssum szovitsianum, Artemisia baldshuanica, Bromus tectorum, Chardinia orientalis, Gentiana olivieri, Goldbachia laevigata, Haplophyllum perforatum, Ixiolirion tataricum, Nigella bucharica, Populus alba, Thalictrum isopyroides, Trifolium pratense, Turgenia latifolia* (14 tur).

– Un (1 ball): *Elaeagnus angustifolia* (1 tur).

A. wilhelmsii senopopulyatsiyasida *Poa bulbosa* juda yuqori mo‘llikka ega (6 ball). *Nepeta olgae* va *Ranunculus arvensis* ham faol turlardir. *Trigonella cancellata* bu senopopulyatsiyada Cop1 darajasida, *Trifolium pratense* esa Sol darajasida uchraydi.

A. filipendulina senopopulyatsiyasi eng boy turlar tarkibiga ega bo‘lib, unda 24 oilaga mansub 43 tur aniqlandi (2-jadval). Uning senopopulyatsiyasida turlar soni bo‘yicha yetakchi o‘rinlarni quyidagi oilalar egallaydi:

– Fabaceae oilasi – 7 tur (15,9%);

– Labiatae oilasi – 5 tur (11,4%);

– Asteraceae va Rosaceae oilalari – 4 tadan tur (9,1% dan);

– Boraginaceae, Brassicaceae, Poaceae va Ranunculaceae oilalari – 2 tadan tur (4,5% dan);

– Apiaceae, Araceae, Asphodelaceae, Convolvulaceae, Cyperaceae, Elaeagnaceae, Equisetaceae, Hypecoaceae, Hypericaceae, Ixioliriaceae, Juglandaceae, Lamiaceae, Papaveraceae, Rubiaceae, Rutaceae va Tamaricaceae oilalari – 1 tadan tur (2,3% dan).

A. wilhelmsii senopopulyatsiyasidan farqli ravishda, bu senopopulyatsiyada Fabaceae oilasining dominantligi kuzatiladi (7 tur). Shuningdek, Labiatae, Asteraceae va Rosaceae oilalari ham yuqori ko‘rsatkichga ega. Daraxt va butalarning turli-tumanligi (*Amygdalus*, *Crataegus*, *Elaeagnus*, *Juglans*, *Tamarix*, *Hulthemia*) mazkur senopopulyatsiya joylashgan hududning landshaft xilma-xilligi va ekologik imkoniyatlari kengligidan dalolat beradi.

2-jadval

***Achillea filipendulina* ning senopopulyatsiyasi joylashgan o‘simliklarning oilalar bo‘yicha joylashishi**

№	Tur nomi	Oilasi
1	*Achillea filipendulina* Lam.	*Asteraceae*
2	*Alhagi pseudalhagi* (M.Bieb.) Desv.	*Fabaceae*
3	*Alyssum szovitsianum* Fisch. & C.A. Mey.	*Brassicaceae*
4	*Amygdalus spinosissima* Bunge	*Rosaceae*
5	*Arum korolkowii Regel*	*Araceae*
6	*Astragalus campylotrichus* Bunge	*Fabaceae*
7	*Astragalus filicaulis* Fisch. & C.A. Mey. ex Kar.	*Fabaceae*
8	*Astragalus maverranagri* Popov	*Fabaceae*
9	*Astragalus rumpens* V.V.Meffert	*Fabaceae*
10	*Bromus tectorum* L.	*Poaceae*
11	*Carex pachystylis* J. Gay	*Cyperaceae*
12	*Convolvulus subhirsutus* Regel et Schmalh.	*Convolvulaceae*
13	*Crambe kotschyana* Boiss.	*Brassicaceae*

№	Tur nomi	Oilasi
14	*Crataegus pontica C. Koch.*	*Rosaceae*
15	*Elaeagnus angustifolia L.*	*Elaeagnaceae*
16	*Equisetum ramosissimum Desf.*	*Equisetaceae*
17	*Eremurus luteus* Baker	*Asphodelaceae*
18	*Galium tricornutum* Dandy	*Rubiaceae*
19	*Haplophyllum perforatum* Kar. & Kir.	*Rutaceae*
20	*Hulthemia persica* Bornm.	*Rosaceae*
21	*Hypecoum trilobum* Trautv.	*Rosaceae*
22	*Hypericum perforatum L.*	*Hypericaceae*
23	*Inula macrophylla* Kar. & Kir.	*Hypecoaceae*
24	*Ixiolirion tataricum* (Pall.) Herb. & Traub	*Ixioliriaceae*
25	*Juglans regia L.*	*Juglandaceae*
26	*Nepeta olgae Regel*	*Labiatae*
27	*Origanum tytthanthum Gontsch.*	*Labiatae*
28	*Perovskia scrophulariefolia Bunge*	*Labiatae*
29	*Phlomis thapsoides* Bunge	*Lamiaceae*
30	*Poa bulbosa* L.	*Poaceae*
31	*Ranunculus arvensis L*	*Ranunculaceae*
32	*Ranunculus baldshuanicus Regel*	*Ranunculaceae*
33	*Rochelia cardiosepala* Bunge	*Boraginaceae*
34	*Roemeria refracta (Stev.) DC.*	*Papaveraceae*
35	*Salvia sclarea L.*	*Labiatae*
36	*Scorzonera circumflexa* Krasch. & Lipsch.	*Asteraceae*
37	*Tamarix arceuthoides Bunge*	*Tamaricaceae*
38	*Taraxacum officinale F.H. Wigg.*	*Asteraceae*
39	*Trichodesma incanum* Bunge	*Boraginaceae*
40	*Trifolium pratense L.*	*Fabaceae*
41	*Trigonella cancellata* Desf.	*Fabaceae*
42	*Turgenia latifolia* Hoffm.	*Apiaceae*
43	*Ziziphora tenuior L.*	*Labiatae*

43 turning 25 tasi (56,8%) ko‘p yillik o‘tlar, 12 tasi (27,3%) bir yillik o‘tlar, 4 tasi (9,1%) daraxtlar, 2 tasi (4,5%) butalar, 1 tasi (2,3%) chala buta. Daraxt-buta qatlami (6 tur) mavjudligi bu fitotsenozning yaruslar bo‘yicha murakkab tuzilganligini ko‘rsatadi.

Bu senopopulyatsiyada o‘simliklarning mo‘lligi quyidagilarni ko‘rsatdi:

– Soc (7 балл): *Trigonella cancellata* (1 тур).

– Cop3 (6 балл): *Crambe kotschyana, Poa bulbosa, Roemeria refracta* (3 тур).

– Cop2 (5 балл): *Achillea filipendulina, Hulthemia persica, Nepeta olgae, Phlomis thapsoides, Ranunculus arvensis* (5 тур).

– Cop1 (4 балл): *Alyssum szovitsianum, Arum korolkowii, Astragalus rumpens, Eremurus luteus, Hypericum perforatum, Juglans regia, Origanum tytthanthum* (7 тур).

– Sp (3 балл): *Astragalus campylotrichus, Astragalus maverranagri, Carex pachystylis, Equisetum ramosissimum, Inula macrophylla, Perovskia scrophulariefolia, Ranunculus baldshuanicus, Rochelia cardiosepala, Salvia sclarea, Scorzonera circumflexa, Taraxacum officinale, Turgenia latifolia, Ziziphora tenuior* (13 тур).

– Sol (2 балл): *Alhagi pseudalhagi, Amygdalus spinosissima, Astragalus filicaulis, Bromus tectorum, Convolvulus subhirsutus, Crataegus pontica, Galium tricornutum, Haplophyllum perforatum, Hypecoum trilobum, Ixiolirion tataricum, Tamarix arceuthoides, Trichodesma incanum, Trifolium pratense* (13 тур).

– Un (1 балл): *Elaeagnus angustifolia* (1 тур).

A. filipendulina senopopulyatsiyasida *Trigonella cancellata* eng yuqori mo‘llikka ega (7 ball). *Crambe kotschyana*, *Poa bulbosa* va *Roemeria refracta* ham Cop3 darajasida. Avvalgi senopopulyatsiyalardan farqli jihati shundaki, *Trifolium pratense* bu senopopulyatsiyada kam uchraydi (Sol), *Trigonella cancellata* esa asosiy dominantga aylangan.

Xulosa va takliflar. *A. filipendulina* senopopulyatsiyasi turlar boyligi va daraxt-buta qatlamining mavjudligi bilan ajralib turadi. *A. wilhelmsii* senopopulyatsiyasida Lamiaceae va

Brassicaceae oilalarining roli yuqori.

Umumiy turlar sifatida barcha senopopulyatsiyalarda uchraydigan va yuqori mo‘llikka ega bo‘lgan *Poa bulbosa* fitotsenozlarning asosiy edifikatorlaridan biri ekanligini ko‘rsatdi. *Trigonella cancellata* va *Trifolium pratense* kabi turlarning mo‘llik darajalaridagi keskin farqlar esa ularning tor ekologik optimumga ega ekanligidan dalolat beradi.

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NERIUM OLEANDER L. NAVLARINING QARSHI VOHASI SHAROITIDA O‘SISH XUSUSIYATLARI VA FENOLOGIYASI

Samatova Shoxista Azamatovna
Qarshi davlat universiteti, Botanika kafedrasi dotsenti
ORCID 0009-0001-6828-8130
canna_luiza@mail.ru
Sharipov Abdunazar Eshqobil o‘g‘li
Termiz davlat universiteti katta o`qituvchisi
ORCID 0000-0001-9602-0855
iqtidor1990@mail.ru
Choriyeva Kumush Faxriddin qizi,
Turon universiteti magistranti
UDK 581.1:581.52:581.543

Annotatsiya. Maqolada Qarshi vohasi sharoitiga introduksiya qilingan *Nerium oleander* L.ning *“Album”, “Hardi red”, “Petite pink”, “Petit salmon”* navlarining o‘sish xususiyatlari va fenologiyasini o‘rganish natijalari keltirilgan. Navlarning o‘sishi aprel oyining II-III dekadasida, o‘rtacha +18,4…+20,5 ºC haroratda boshlanishi, sentyabr oyining II-III dekadasida yakunlanishi aniqlangan. Novdalarning o‘sishi asosan bir to‘lqinli bo‘lib, eng jadal rivojlanish may-iyun oylariga to‘g‘ri kelgan. Maksimal o‘sish may oyida, minimal o‘sish sentyabr oyida sodir bo‘lgan. “Hardy red” va “Petit salmon” navlarining jadal,

“Album” navining sekin o‘sishi qayd etilgan. Barcha navlar Qarshi vohasi sharoitida rivojlanishning barcha bosqichlarini o‘tashi, ularning rivojlanish bosqichlari asosan harorat va namlik omillariga bog‘liq holda kechishi aniqlangan.

Kalit so‘zlar: gullash, nav, novda, introduksiya, fenologiya, o‘sish.

GROWTH CHARACTERISTICS AND PHENOLOGY OF NERIAM OLEANDER L. VARIETIES IN THE KARSHI OASIS

Abstract. The article presents the results of a study of the growth and phenology characteristics of the Nerium oleander L. cultivars ‘Album’, ‘Hardi Red’, ‘Petite Pink’, and ‘Petit Salmon’, introduced to the Karshi Oasis. It was established that the growth of the cultivars begins in the second and third ten-day periods of April at an average temperature of +18.4…+20.5 °C and ends in the second and third ten-day periods of September. Shoot growth is predominantly uniwave, with the most intensive development observed in May–June. Maximum growth was noted in May, and minimum growth in September. It was revealed that the ‘Hardi Red’ and ‘Petit Salmon’ cultivars are characterized by rapid growth, while the ‘Album’ cultivar is slower. It was established that all cultivars go through all stages of development in the Karshi Oasis, and their phenological phases mainly depend on temperature and humidity factors.

Keywords: flowering, variety, stem, introduction, phenology, growth.

Kirish. Qarshi vohasi sharoitiga introduksiya qilingan ekzotik doimiy yashil o‘simliklar orasida yuqori manzaralilik xususiyatiga ega bo‘lgan *Nerium oleander* L. navlari alohida o‘rin tutadi. Ushbu manzarali butadan Abxaziya, Ozarbayjon, Qrim shaharlarining markaziy ko‘chalari va kurort hududlarini ko‘kalamzorlashtirishda keng foydalaniladi [1; 2]. *Nerium* L. turkumi ayrim manbalarga ko‘ra ikki tur bilan ifodalanadi: butun O‘rta Yer dengizi sohillaridan Fors ko‘rfazigacha tarqalgan *Nerium oleander* L. (sinonimi – *N. laurifolium* Lam) va shimoli-g‘arbiy Hindistondan Xitoygacha bo‘lgan hududlarni o‘z ichiga olgan hind oleandri yoki xushbo‘y oleandr – *N. indicum* L. (sinonimi – *N. odorum* Soland.) [3]. Biroq, APG III taksonomik tizimiga muvofiq, *Nerium* L. turkumi faqat bitta turni – *N. oleander* ni o‘z ichiga oladi, *N. indicum* L. esa turning sinonimi hisoblanadi. Hozirgi kunda mavjud bo‘lgan bog‘ navlarining aksariyati tabiatda uchramaydigan duragaylar va formalardan iborat bo‘lib, [4], kelib chiqishi noaniq yoki aralash bo‘lgan madaniy navlar hisoblanadi va *Nerium* × *hybridum* hort. deb nomlanadi [5] (“×” belgisi duragay ekanligini, hort. esa o‘simlikning tabiiy emas, balki bog‘dorchilik amaliyotida qo‘llanilishini bildiradi [10]).

Introduksiya qilingan o‘simliklar ishtirokida manzarali kompozitsiyalar yaratish ularning o‘sishi va rivojlanishi xususiyatlarini o‘rganishni taqozo qiladi. *N. oleander* o‘sishi va rivojlanish xususiyatlari R.V. Galushkoning Qrim sharoitida yetishtirilgan o‘simliklar ustida olib borilgan tadqiqotlari natijalarida keltirilgan [6]. Biroq O‘zbekistonning janubiy sharoitlarida uning o‘sish jarayonlari o‘rganilmagan. Shunga ko‘ra, Qarshi vohasi sharoitida *N. oleander* duragaylari va navlarini o‘sishi va rivojlanish xususiyatlarini o‘rganish maqsad qilindi.

Tadqiqot obyektlari va usullari. *Nerium oleander* L. – Apocynaceae oilasiga mansub doim yashil buta bo‘lib, 4 m gacha o‘sadi. Gullari ikki jinsli, novdalarni uchki qismida soyabonsimon shingil to‘pgulda joylashgan. Mevasi ko‘p urug‘li bargak meva, uzunligi 20 sm gacha, ikki tomondan ochiladi. Urug‘lari popukli. Kseromezofit [7].

2024–2025- yillarda olib borilgan tadqiqotlar uchun material sifatida Qarshi davlat universiteti hududidagi oleandr kolleksiyasi xizmat qildi. Fenologik kuzatuvlar botanika bog‘larida ishlab chiqilgan metodikalar asosida olib borildi [8]. O‘lchash uchun tanlangan tuplarning har biri katta yoshli bo‘lib, muntazam sug‘oriladigan uchastkalarda bir xil sharoitda o‘sgan. Ushbu o‘simliklarning har bir navidan 5 tadan tup tanlab olindi. Har 5 kunda ularni beshta o‘sib kelayotgan novdasining uzunligi o‘lchab borildi.

Tadqiqotga *Nerium* × *hybridum* hort. ning to‘rtta navi jalb etildi: ‘*Album’* – oq rangda gullaydi, *“Hardi red”* – alvon rangda gullaydi, *“Petite pink”* – pushti rangda gullaydi, *“Petit salmon”* – novvot rangida gullaydi [11].

Natija va muhokama. O‘simlikning o‘sishi simpodial bo‘lib, to‘pgul bilan yakunlanadigan monokarp novdalar hosil qiladi. Tabiiy arealida o‘simlik bir vegetatsiya davri mobaynida faqat bitta – bahordan yozgacha bo‘lgan o‘sish davriga ega [4]. Qarshi vohasi sharoitida novdalarning o‘sishi bir to‘lqinli bo‘lib, aprel oyining II dekadasidan sentyabr oyining II dekadasigacha davom etadi.

O‘rganilgan o‘simliklarda novdalar tizimining shakllanishi barg qo‘ltiqlarida joylashgan kurtaklar orqali hamda novdalarning mexanik shikastlanishi ro‘y berganda yoki ular kesilganda, butalanganda uxlovchi kurtaklar hisobiga amalga oshadi. Uxlovchi kurtaklardan hosil bo‘lgan novdalarning jadalroq o‘sishi kuzatildi.

Har bir novdaning barg qo‘ltiqlaridagi kurtaklaridan 2-3 ta yangi novda rivojlanadi, lekin ularning barchasi ham hosil bo‘lgan yili gullamaydi. Kuzatishlar davomida havo harorati va nisbiy namligi qulay bo‘lgan davrda o‘sgan novdalarning apikal qismida to‘pgul shakllanishi aniqlandi.

Vegetatsiya davrida mexanik zararlangan yoki shoxlari qisqartirilgan, shuningdek, zaif o‘sgan novdalar o‘sish jarayonini to‘liq yakunlay olmadi. Bunday novdalarda kelgusi yil kuzgacha barg tizimi shakllanadi. Ya’ni, ushbu novdalardan yon novda o‘sib chiqmaydi. Shu sababli ular qisqaroq o‘sadi. Navbatdagi bahor kelishi bilan ushbu novdalarda rivojlanish davom etadi. Yangi mavsumda ularning meristema faoliyati tiklanadi, to‘pgul va yon novdalar hosil qiladi.

2024-yilda olib borilgan kuzatishlarga ko‘ra, “*Petite pink”, “Album”* navlarining yillik novdalari gulladi, ammo shu novdalardan chiqqan yon shoxlar gullashga ulgurmadi. “*Hardy red”* navida esa ayrim yon novdalarning ham gullashga ulgurganligi kuzatildi va shu novdalardan navbatdagi tartibli novdalar ham hosil bo‘ldi. *“Petit salmon”* navida bunday novda hosil bo‘lmadi. “*Album”* navida vegitatsiya davri 152 kunni tashkil qildi, novdalar o‘sishi 20-apreldan boshlandi. *“Hardy red”*da vegetatsiya davri 149 kunni tashkil qildi, novdalar o‘sishi esa 15-apreldan boshlanishi qayd etildi. “*Petite pink*” va “*Petit salmon”*da vegetatsiya davri 157 kunni tashkil qildi va novdalar o‘sishi “*Petite pink*” da 22-apreldan, “*Petit salmon”* da esa 12-apreldan boshlandi.

“*Album”* novdalarining o‘sishi 20-aprelda o‘n kunlik o‘rtacha harorat +18,4 ºC bo‘lgan paytdan boshlanib, harorat 20.5 ºC bo‘lgan aprelning III dekadasiga kelib o‘sish jadallashdi. Jadal o‘sish mayning oxirigacha davom etdi (o‘n kunlik o‘rtacha harorat 23.9 ºC). Iyun oyining dastlabki o‘n kunligida o‘rtacha harorat 28.8ºCga ko‘tarilganda novdalarning o‘sishi biroz sekinlashdi. Yon novdalarning hosil bo‘lishi 20-apreldan iyun oyining o‘rtalarigacha davom etdi. Iyul oyining dastlabki kunlarida o‘sish biroz to‘xtagandek bo‘ldi, ammo ko‘p o‘tmay – iyul oyining ikkinchi dekadasidan yana o‘sishni boshladi. May oyining oxiri – iyun oyining boshida ushbu yon novdalardan yangi tartibli yon novdalar hosil bo‘ldi. Novdalarning o‘sishi avgustda sekinlashib, sentyabrda to‘xtadi.

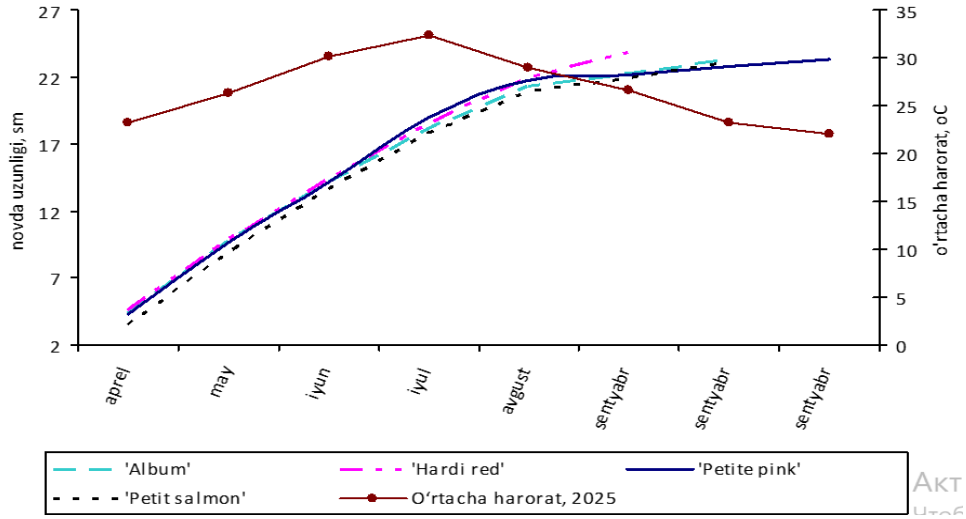
“*Hardy red*” navi novdalarining o‘sishi 15-apreldan boshlandi. May-iyun oylari davomida, novdalarning o‘sishi jadallashdi. Iyul oyidan o‘sish tezligi biroz sekinlashdi va shu tariqa 10-sentyabrgacha o‘sdi. Eng yuqori o‘sish ko‘rsatkichi aprel-iyun oylariga to‘g‘ri keldi. Ushbu navda III tartibli novdalar may oyining oxirida hosil bo‘lib, ayrimlari gullashga ham ulgurdi.

“*Petite pink*” o‘tgan yilda shakllangan novdalari 15-apreldan o‘sishni boshladi (harorat +18,4°C). Butun aprel oyi mobaynida va may oyining 1-o‘nkunligida jadal o‘sish kuzatildi. Mayning II dekadasidan o‘sish sekinlashdi va iyun oyining boshida to‘xtadi. Yangi yon novdalar 22-apreldan o‘sa boshladi va eng yuqori o‘sish may-iyul oyiga to‘g‘ri keldi. Avgust oyining 2-o‘nkunligidan o‘sish sekinlashdi va 25-sentyabrda to‘xtadi. May oyining 2-o‘nkunligida III tartibli novdalar ham hosil bo‘ldi. Bu novdalar avgust oyining 2-o‘nkunligigacha o‘sdi, lekin gul hosil qilmadi.

“*Petit salmon”* novdalarining o‘sishi “*Petite pink”*ga nisbatan 10 kun oldin – 12-apreldan boshlandi (rasm). Aprel oyining 3-o‘nkunligidan boshlab o‘sish tezlashdi, (o‘nkunlik o‘rtacha harorat +20,5°C) iyun oyining oxirgi 10-kunligida sekinlashdi (+30,7°C) va 15-sentyabrda o‘sish to‘xtadi. Ushbu nav III tartibli novdalar hosil qilmadi.

Kuzatuv natijalarini tahlil qilish asosida quyidagilar aniqlandi: o‘rganilgan navlarda o‘sish aprel oyining II–III dekadasida boshlandi, bu paytda o‘rtacha dekadlik harorat +18,4…+20,5ºC atrofida bo‘ldi. Shu vaqtda kunlik o‘sishlar nisbatan sekin bo‘lib, oy oxiriga borib, tezlashdi. Kunlik o‘rtacha harorat +21ºC dan yuqoriga ko‘tarilganda jadal o‘sish qayd etildi. Aprelning II dekadasida o‘sa boshlagan *“Album”* va *“Petite pink”* o‘sishning ilk kunlaridanoq faol rivojlandi. O‘sishning eng yuqori nuqtasi may oyida kuzatildi. Navlarning

barchasida o‘sish dastlab bir yillik novdalarda boshlanib, yangi novdalar 5-7 kun keyin o‘sishni boshlashi aniqlandi.



Rasm. Qarshi vohasi sharoitida *Nerium* × *hybridum* hort. navlari novdalarining o‘sishi

Vegetativ usulda ko‘paytirilgan o‘simliklar, 5 yoshgacha juda faol o‘sib, ko‘p miqdorda shox-shabba hosil qildi. 2025-yilda 2 yoshli shunday o‘simliklarning 60-70 sm, 3 yoshligining 40-50 sm, 4 yoshligining 30 sm o‘sganligi kuzatildi. Katta yoshli yirik butalar yiliga 15-20 sm o‘sdi.

Fenologik kuzatuv natijalariga ko‘ra, kurtakning bo‘rtishi eng erta “Petit salmon” navida kuzatildi. Unda kurtaklar 5 aprelda bo‘rta boshlagan. “Hardy red” navida bu jarayon 8 aprelda, “Album” va “Petite pink” navlarida esa 10 aprelda qayd etildi (Jadval).

Barglarning paydo bo‘lishi fazasi ham navlarga qarab turlicha kuzatildi. “Petit salmon” navida barglar 12 aprelda paydo bo‘lgan bo‘lsa, “Hardy red” navida 13 aprelda, “Album” navida 15 aprelda va “Petite pink” navida 18 aprelda kuzatildi.

Jadval

Qarshi vohasi sharoitida *Nerium* × *hybridum* hort. navlarining fenologiyasi (2025 y.)

№	O‘simliklar nomi	Kurtakning bo‘rtishi	Barglarning paydo bo‘lishi	O‘sishi		G‘uncha-lash	Gullash	
				Boshlanishi	tugashi		boshlanishi	tugashi
1.	*Album*	10.04	15.04	20.04	18.09	28.04	15.05	15.10
2.	*Hardy red*	8.04	13.04	15.04	10.09	24.04	10.05	10.10
3.	*Petite pink*	10.04	18.04	22.04	25.09	20.04	1.05	20.09
4.	*Petit salmon*	5.04	12.04	12.04	15.09	25.04	10.05	25.09

O‘simliklarning o‘sish davri ham turlicha davom etdi. Masalan, “Hardy red” navida o‘sish davri 15-apreldan boshlanib 10-sentyabrgacha davom etgan бўлса, “Album” navida o‘sish 20-apreldan boshlanib 18-sentyabrgacha davom etgan. “Petite pink” va “Petit salmon” navlarida o‘sish davri biroz uzoqroq – oktyabrni birinchi yarmigacha davom etgan.

G‘unchalash fazasi ham navlar o‘rtasida farq qilgan. “Petite pink” navida g‘unchalash 20 aprelda boshlangan bo‘lib, bu boshqa navlarga nisbatan ertaroq hisoblanadi. “Hardy red” navida g‘unchalash 24 aprelda, “Album” navida 28 aprelda va “Petit salmon” navida 25 aprelda boshlangan.

Gullash davri ham navlarga qarab farq qilgan. Masalan, “Hardy red” navida gullash 10 maydan boshlanib 10 oktyabrgacha davom etgan. “Album” navida esa gullash 15 maydan boshlanib 15 oktyabrgacha kuzatilgan. “Petite pink” navida gullash 1 maydan boshlanib 20 sentyabrgacha, “Petit salmon” navida esa 10 maydan boshlanib 25 sentyabrgacha davom etgan.

Olingan ma’lumotlar tahlili shuni ko‘rsatadiki, Nerium × hybridum hort. navlarining fenologik rivojlanish bosqichlari asosan bahor faslida boshlanadi. Aprel oyining birinchi o‘n kunligida kurtaklarning bo‘rtishi kuzatilib, shu oyning ikkinchi yarmiga kelib barglar paydo bo‘ladi.

Eng erta fenologik rivojlanish “Petit salmon” navida kuzatildi. Bu navda kurtaklar

boshqa navlarga nisbatan ertaroq bo‘rta boshlagan. Bu holat ushbu navning iqlim sharoitiga tez moslashish xususiyatiga ega ekanligini ko‘rsatadi.

Gullash muddatiga ko‘ra eng uzoq davom etgan navlar “Album” va “Hardy red” hisoblanadi. Ularda gullash oktyabr oyigacha davom etgan. Bu esa ularning manzaralilik qiymatini oshiradi.

Pakana navlar hisoblangan “Petite pink” va “Petit salmon” navlarida gullash davri biroz qisqaroq bo‘lib, sentyabr oyida tugagan. Bu holat ushbu navlarning biologik xususiyatlari bilan bog‘liq bo‘lishi mumkin.

Fenologik kuzatuvlar natijalari *Nerium* × *hybridum* hort. navlarining Qarshi shahri iqlim sharoitiga yaxshi moslashganligini ko‘rsatdi. Aprel oyida vegetatsiya boshlanishi va may oyida gullashning faollashishi ushbu o‘simlikning subtropik tabiatga ega ekanligini tasdiqlaydi. Shuningdek, gullash davrining uzoq davom etishi ushbu navlarni shahar ko‘kalamzorlashtirish ishlarida qo‘llash uchun istiqbolli ekanligini ko‘rsatadi. Ayniqsa, “Album” va “Hardy red” navlari uzoq muddat gullashi bilan ajralib turadi.

Qrim sharoitida may oyidan sentyabrgacha gullaydi. Sutkalik musbat haroratlar yig‘indisi (+5ºC) 1148 ± 117 ga yetganda g‘unchalash, 1483 ± 104 ga yetganda gullash boshlanadi. Musbat haroratlar yig‘indisi 3644 ºC ga yetganda gullash yakunlanadi [9]. Qarshi vohasi sharoitida 2024-yilda musbat haroratlar yig‘indisi (+5ºC) 400 ºC ga yetganda vegetatsiya boshlandi. Novdalarning o‘sishi 500 ºC ga, g‘unchalash 600 ºC ga, gullash 800 ºC ga yetganda boshlandi.

Xulosa. Qarshi vohasi sharoitida *Nerium* × *hybridum* hort. navlarining o‘sishi aprel oyining II-III dekadasida, o‘rtacha +18,4…+20,5 ºC haroratda boshlanib, sentyabr oyining II-III dekadasida yakunlanishi aniqlandi. Novdalarning o‘sishi asosan bir to‘lqinli bo‘lib, eng jadal rivojlanish may-iyun oylariga to‘g‘ri keldi. Novdalar tizimi barg qo‘ltiqlaridagi kurtaklar hamda mexanik ta’sir natijasida faollashgan uxlovchi kurtaklar hisobiga shakllandi va uxlovchi kurtaklardan hosil bo‘lgan novdalar kuchliroq o‘sdi. Har bir novdada 2-3 ta yon novda rivojlandi, biroq ularning barchasi bir vegetatsiya davrida gullashga ulgurmadi. Navlarning oylik o‘sish ko‘rsatkichlari barcha navlar uchun mavsumiy o‘zgaruvchanlikka egaligini ko‘rsatdi. Maksimal o‘sish may oyida, minimal o‘sish sentyabr oyida sodir bo‘ldi. “Hardy red” va “Petit salmon” navlari tezroq o‘sadi va ularning umumiy o‘sish ko‘rsatkichlari nisbatan yuqori. “Album” navi esa past o‘sish ko‘rsatkichiga ega.

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KUZGI YUMSHOQ BUG‘DOY NAVLARINING BARG HUJAYRA SHIRASIDAGI ALBUMINLAR KOAGULYATSIYASI

Xamrayev Nurbek Ulug‘bekovich
b.f.f.d., k.i.x., Don va dukkakli ekinlar ilmiy tadqiqot instituti,
ORCID 0000-0002-9349-3048
nurbek.hamraev@gmail.com
UDK 633.111.1; 577.112

Annotatsiya. Ushbu maqolada kuzgu yumshoq bug‘doy navlarining boshoqlash davrida barg hujayra shirasi tarkibidagi albumin oqsillarining ivish (koagullanish) harorati P.A.Genkel uslubi yordamida o‘rganilgan.

Tadqiqot uchun tanlab olingan kuzgi yumshoq bug‘doy nav namunalari ikki yil davomida tadqiq qilindi. Navlar 2025–2026-yillarda Xorazm viloyati tuproq-iqlim sharoitida, hudud uchun qabul qilingan agrotexnik tadbirlarni qo‘llab yetishtirildi.

Olib borilgan tadqiqot natijalariga ko‘ra, navlarning bargdagi albumin oqsillarning ivish harorati 2025-yilda eng yuqori ko‘rsatkich Yonbosh navida 63,2ºC ni, 2026-yilda esa Bo‘zqal‘a navida 63,5ºC ni tashkil qilgan. Bu esa mazkur navlarning yuqori haroratga chidamli ekanligini ko‘rsatadi. Ushbu navlardan seleksiya jarayonida ota-ona shakllari sifatida foydalanish yuqori harorat stresiga va suv tanqisligiga bardoshli va don sifati yuqori yangi navlarni yaratishga imkon beradi.

Kalit so‘zlar: Kuzgi yumshoq bugdoy, nav, albumin oqsili, barg hujayra shirasi, koagulyatsiya harorati.

COAGULATION OF ALBUMINS IN LEAF CELL SAP OF AUTUMN SOFT WHEAT VARIETIES

Abstract. In this article, the coagulation temperature of albumin proteins in leaf cell sap during the heading period of soft winter wheat varieties was studied using the P.A.Genkel method.

The varieties were grown in 2025-2026 in the soil and climatic conditions of the Khorezm region, using agrotechnical measures adopted for the region.

According to the results of the research, the highest coagulation temperature of albumin proteins in 2025 in the leaves of the Yonbosh variety was 63.2ºC, and in 2026 it was 63.5ºC in the Bozkala variety. This indicates that these varieties are resistant to high temperatures. Using these varieties as parental forms in the breeding process will allow the creation of new varieties that are tolerant to high temperature stress and water shortage and have high grain quality.

Keywords: Bread wheat, variety, albumin protein, leaf cell sap, coagulation temperature.

Kirish. Havo harorati o‘simlik hayoti va mahsuldorligiga eng kuchli ta’sir ko‘rsatadigan asosiy ekologik omillardan biridir [11]. O‘simliklarining yuqori haroratga chidamliligini oshirish butun dunyo bo‘ylab qishloq xo‘jaligi uchun jiddiy muammo hisoblanadi. Bug‘doy eng muhim don ekinlari, asosiy oziq-ovqat manbayi va inson oziqlanishi manbayi bo‘lib hisoblanadi [8]. Bug‘doy issiqlik stressiga juda sezgir hisoblanadi. Haroratning har 1°C oshishi bug‘doy ishlab chiqarishning 6% ga kamayishiga olib keladi [10]. Bug‘doyning generative organlarining shakillanish bosqichda haroratning 1°C ga oshishi ham don hosilini yo‘qotishiga olib kelishi mumkin [6]. Yuqori harorat bug‘doyda turli xil fiziologik, biologik va biokimyoviy jarayonlarni o‘zgartiradi [9]. A.To‘xtayev ma’lumotlariga ko‘ra bug‘doyning issiqlikka chidamliligi barglarning hujayra shirasidagi suvda eriydigan oqsillarning koagulyatsiya harorati bilan chambarchas bog‘liq [4].

O‘sish davrining birinchi yarmida bug‘doy o‘simliklari ko‘pincha qurg‘oqchilik, issiqlik va sovuq kabi noqulay ekologik sharoitlardan aziyat chekadi. Natijada o‘simlik unumdorligini pasayishiga va fiziologik jarayonlarning buzilishiga olib keladi [12]. O‘simliklarning issiqlik stressiga chidamliligi turli xil fiziologik, biokimyoviy va molekulyar-genetik o‘zgarishlar, shu jumladan membranalarning fizik xususiyatlarining o‘zgarishi bilan bog‘liq [7].

Issiqlikka chidamlilik, genetik nuqtayi nazardan, poligenik xususiyat bo‘lib, u nafaqat bir nechta genlar, balki o‘simlikning butun genotipi tomonidan nazorat qilinadi [3].

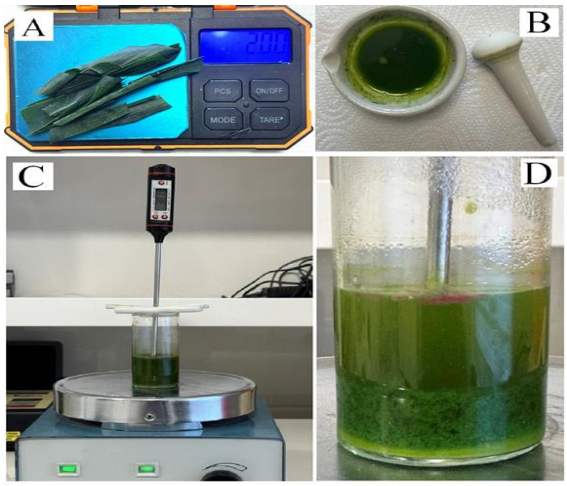
M. Amanov ta’kidlaganidek, hujayra shirasi konsentratsiyasi, oqsil ivish harorati, stress sharoitda suvni ushlab turish qobiliyati, xlorofill miqdori va fotosintez intensivligi navning mahsuldorlikka nisbatan barqarorligini tavsiflovchi asosiy fiziologik belgilardir. Ushbu belgilar bo‘yicha seleksion manbalarni baholash suv ta’minoti yetarli bo‘lmagan

sharoitda amalga oshirilishi tadqiqotlarni ishonchliligini yanada oshiradi [2].

Yuqorida keltirib o‘tilgan fikrlarga tayangan holda, biz o‘z tajribalarimizda ayrim kuzgi yumshoq bug‘doy navlarining barg hujayra shirasidagi albuminlar koagulyatsiyasini baholash bo‘yicha laboratoriya tadqiqotlarini o‘tkashni va pishish davrida yuzaga keladigan yuqori hororatga chidamli navlarni aniqlashni maqsad qildik.

Tadqiqot metodologiyasi. Tadqiqot obyekti sifatida kuzgu yumshoq bug‘doyning 6 ta (Yaksart, Bo‘zqal‘a, Pamyat, Yonbosh, Kroshka, Kate-A1) nav namunalari olindi.

Tadqiqot uslublari. **N**avlar boshoqlash davrida barg hujayra shirasi tarkibidagi suvda eruvchi albumin oqsillarining ivish (koagullanish) harorati P.A.Genkel uslubi yordamida o‘rganildi. Mazkur uslub yordamida albuminlar koagulyatsiyasini aniqlash uchun 2,0 gramm barg namunasi olinib, olingan namuna ustiga 25 ml distil suv quyib chinni havonchada yaxshilab eziladi. Barg hujayra shirasi ajratib olinib, filtrlanadi. Filtrlangan eritma elektr plitka ustiga qo‘yilib qizdiriladi (1-rasm). Albumin oqsillarining ivish (koagullanish) harorati aniqlanadi va jadvalga tushiladi [5].



1-rasm. P.A.Genkel uslubi yordamida albumin oqsillarining koagullanish harorati aniqlash jarayoni. A) kerakli barg namunasini o‘lchash, B) barg hujayra shirasini ajratib olish, C)barg shirasi ekstraktiga harorat ta’sir qildirish jarayoni, D)koagulyatsiyaga uchragan albumin oqsillari.

Natijalar va muhokama. 2025–2026- yillarda olib borilgan laboratoriya tadqiqotlarida navlarning bargdagi suvda eruvchan albumin oqsillarning ivish harorati o‘lchandi. Unga ko‘ra, 2025-yilda navlarning bargdagi suvda eruvchan albumin oqsilining ivish harorati o‘rtacha 57,9ºC dan 63,2ºC gacha oraliqda bo‘lib, eng yuqori natija Bo‘zqal‘a (62,8ºC) va Yonbosh (63,2ºC) navlarida qayd qilindi (1-jadval).

2026-yilda navlarning oqsil koagulyatsiyasi aniqlanganda eng past natija Kate-A1 navida kuzatilib 56,6ºC ga teng bo‘ldi. Qolgan navlarda Kate-A1 naviga nisbatan oqsil koagulyatsiyasi ±0,3 dan 6,9ºC gacha yuqori ko‘rsatkichni qayd qildi. Eng yuqori natija Bo‘zqal‘a navida (63,5ºC) kuzatildi.

1-jadval

Navlar barg hujayra shirasidagi albumin oqsillarining ivish harorati, ºC

T/r	Nav nomi	Bargdagi suvda eruvchan albumin oqsilining ivish harorati, ºC		
		2025	2026	O‘rtacha
1	Yaksart	59,6	58,4	59,0
2	Bo‘zqal‘a	62,8	63,5	63,2
3	Pamyat	61,1	61,6	61,4
4	Yonbosh	63,2	62,5	62,9
5	Kroshka	58,4	56,9	57,7
6	Kate-A1	57,9	56,6	57,3

M. Amanov tadqiqotlarida bug‘doy protoplazmasida oqsil koagulyatsiyasi O‘rta

Osiyoda 61°C dan boshlanishini aytib o‘tgan. O.Gladishev ma’lumotlariga ko‘ra, boshqa bug‘doy ekotiplari uchun bu ko‘rsatkich 55,0-58,0°C dan oshmaydi [1]. Xorazm viloyati tuproq-iqlim sharoitida bu qiymat biz o‘rganayotgan navlarda o‘rtacha 57,3-63,2°C gacha oraliqda o‘zgarib turdi. Navlar kesimida hujayra shirasidagi albumin oqsillarining ivish harorati o‘rganilganda Kate-A1 navida 57,3°C, Kroshka navida 57,7°C, Yaksart navida 59,0°C, Pamyat navida 61,4°C, Yonbosh navida 62,9°C va Bo‘zqal‘a navida 63,2°C natijaga ega bo‘ldi.

Qiziqarli jihati shundaki, deyarli barcha navlarda 2025-yilga nisbatan 2026-yilda oqsil ivish harorati biroz o‘zgargan (ayrimlarida pasaygan, ayrimlarida esa ko‘tarilgan). Masalan, Bo‘zqal‘a navida 2026-yilda chidamlilik ko‘rsatkichi (63,5 ºC) oshgan bo‘lsa, Kroshka va Kate-A1 navlarida pasayish kuzatilgan. Bu o‘sha yillardagi ob-havo sharoiti va o‘simlikning moslashuvchanlik xususiyatlari bilan bog‘liq bo‘lishi mumkin.

Xulosa va takliflar. Kuzgi yumshoq bug‘doy navlarining barg hujayra shirasidagi albuminlar koagulyatsiyasini aniqlash bug‘doy navlarining pishish davrida yuzaga keladigan yuqori harorat stresiga va suv tanqisligiga bardoshliligini baholashga imkon beradi.

Olib borilgan tadqiqot natijalariga ko‘ra, navlarning bargdagi albumin oqsillarning ivish harorati 2025-yilda eng yuqori ko‘rsatkich Yonbosh navida (63,2ºC), 2026-yilda esa Bo‘zqal‘a navida (63,5ºC) kuzatildi. Bu esa mazkur navlarning yuqori haroratga chidamli ekanligini ko‘rsatadi. Ushbu navlardan seleksiya jarayonida ota-ona shakllari sifatida foydalanish yuqori harorat stresiga va suv tanqisligiga bardoshli va don sifati yuqori yangi navlarni yaratishga imkon beradi.

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ОСОБЕННОСТИ ФОРМЫ ТЕЛА ОБЫКНОВЕННОГО ЛЕЩА, *ABRAMIS BRAMA*, ТУДАКУЛЬСКОГО ВОДОХРАНИЛИЩА УЗБЕКИСТАНА

Умаралиева Гузал
Навоийский государственный университет, докторант
Umaraliyeva0995@gmail.com
Юлдашов Мансур
Ташкентский государственный аграрный университет, профессор
yuldashovmansur1964@gmail.com
Ташкенбаева Аружан
Филиал Астраханского государственного технического университета в Ташкентской области, студент
Камилов Бахтияр
Институт зоологии Академии наук Узбекистана, профессор
ORCID 0000-0002-1597-6132
УДК 597.55: 639.3

Аннотация. Во второй половине XX века в низовьях Зарафшана было создано Тудакульское водохранилище для ирригационных нужд, а также акклиматизирован европейский лещ, Abramis brama, из реки Урал. Вид натурализовался, стал промысловым. В апреле 2025 и 2026 годов анализировали репрезентативную выборку леща из водохранилища. В выборке (n = 50 экз.) были особи леща общей длиной 13,2 – 32,5 см, стандартной длиной 9,4 – 24,0 см, общей массой 25,2 – 1054,0 г. Определяли пластические признаки по классической для карповых рыб схеме промеров и по методу геометрической морфометрии по 10 ориентирам по периметру формы тела. Факторный анализ абсолютных значений параметров выявил влияние 1 латентного фактора, который объясняет 87,3 % общей дисперсии. В отношении относительных показателей (индексов от стандартной длины тела) выявлено влияние 8 латентных факторов, влияющих на признаки по классической схеме промеров карповых (суммарно 84,56 % общей дисперсии) и 7 латентных факторов на индексы геометрической морфометрии (суммарно объясняют 78,97 % общей дисперсии). Выявлено влияние 3 латентных факторов (72,853 % общей дисперсии) на индексы показателей геометрической морфометрии чешуи леща.

Ключевые слова. Европейский лещ, Abramis brama, морфометрический анализ, геометрическая морфометрия рыб, Тудакульское водохранилище, Узбекистан.

TO‘DAKO‘L SUV OMBORIDAGI (O‘ZBEKISTON) ODDIY OQCHA (*ABRAMIS BRAMA*) BALIG‘I TANASI SHAKLINING TASNIFI

Annotatsiya. XX asrning ikkinchi yarmida Zarafshon daryosining quyi oqimida irrigatsiya ehtiyojlari uchun To‘dako‘l suv ombori barpo etildi shuningdek, Urol daryosidan Yevropa oqchasi Abramis brama, iqlimlashtirildi. Tur bu yerga moslashib ovlanish ahamiyatiga ega bo‘lgan baliqlar qatoriga kirdi. 2025 va 2026-yillar aprel oyida suv omboridan to‘plangan reprezentativ namunalar tahlil qilindi. Namunalar (n = 50 dona) tanasining umumiy uzunligi – 13,2 - 32,5 sm, standart uzunligi – 9,4 - 24,0 sm, umumiy og‘irligi – 25,2 - 1054,0 g bo‘lgan oqcha balig‘i vakillaridan tashkil topdi. Plastik belgilarini karpsimon baliqlarni o‘lchashning klassik chizmasi va tanasi bo‘ylab 10 ta mo‘ljal nuqtani geometrik morfometriya usuli bo‘yicha aniqladik. Ko‘rsatkichlarning mutlaq miqdori bo‘yicha o‘tkazilgan omilli tahlil 1 ta yashirin (latent) omil ta’siri borligini aniqladi va u umumiy dispertsiyaning 87,3 % bilan izohlanadi. Nisbiy ko‘rsatkichlar (standart uzunligiga nisbatan) bo‘yicha karpsimon baliqlarni o‘lchashning klassik chizmasi bo‘yicha aniqlangan ko‘rsatkichlarga 8 ta (ularning yig‘indisi umumiy dispersiyaning 84,56 % ini tashkil etadi) yashirin omil ta’siri borligini va geometrik morfometriya ko‘rsatkichlariga 7 ta (ularning yig‘indisi umumiy despersiyaning 78,97 % ni tashkil qiladi) ta’siri borligi aniqlandi. Oqcha balig‘i tangachasi geometrik morfometriya ko‘rsatkichlariga 3 ta yashirin (umumiy despersiyaning 72,853 %) ta’siri borligi aniqlandi.

Kalit so‘zlar. Yevropa oqchasi, Abramis brama, morfometrik tahlil, baliqlarning geometrik morfometriyasi, To‘dako‘l suv ombori, O‘zbekiston

Введение Обыкновенный или европейский лещ, *Abramis brama* (Linnaeus, 1758), представитель семейства Leuciscidae (Minnows, Ельцовые) – пресноводная и солоноватоводная бентопелагическая тепловодная экологически пластичная рыба, хорошо приспосабливающаяся к разным условиям. В квазистационарном состоянии Аральского моря лещ обитал в самом Арале, где был ценной промысловой рыбой, но не обитал в равнинных участках таких крупных рек бассейна как Зарафшан, Кашкадарья в Узбекистане [1,2,3]. После крупномасштабных ирригационных преобразований

гидрографии бассейна и создания новых водохранилищ в бассейн Зарафшана и Кашкадарьи вселяли леща из реки Урал [5]. В крупном Тудакульском водохранилище лещ адаптировался, натурализовался и стал важной промысловой рыбой. Основные биологические показатели леща в водоеме мало исследованы. Целью данной работы было дать оценку морфологических признаков леща Тудакульского водохранилища.

Тудакульское водохранилище (39°51'15"N 64°50'29"E) гидрографически расположено в нижнем течении реки Зарафшан, при этом заполняется большей частью водой из среднего течения Амударьи. Это пустынная зона. Климат умеренный, резко-континентальный с жарким летом (среднесуточная температура летом достигает 29ºС и выше, воздух часто прогревается днем выше 40ºС) и относительно холодной зимой (среднемесячная температура в январе опускается ниже -2ºС). Водохранилище крупное, общая площадь достигает 22000 га, средняя глубина около 5 м, максимальная глубина до 22 м. Водохранилище - важный в Узбекистане рыбохозяйственный водоем.

Материалы и методы. Материал собирали в апреле 2025 и 2026 года в Тудакульском водохранилище ставными разноячейными сетями. После определения вида [5] рыб фиксировали целиком в 4%-ном растворе формалина, в лаборатории измеряли общую (TL, см) и стандартную длину тела до конца чешуйного покрова (SL, см) с точностью до 1 мм. Подсчитывали меристические признаки. Рыб тщательно распрямляли и делали цифровые фото. В микроскопе делали фото чешуй. Пластические признаки измеряли по схеме промеров для карповых рыб (*an* - длина туловища, *ad* – длина рыла, *np* – диаметр глаза, *po* – заглазничный отдел, *ao* – длина головы, *lm* – высота головы у затылка, *gh* – наибольшая высота тела, *ik* – наименьшая высота тела, *aq* – антедорсальное расстояние, *sd* – наименьшая высота тела, *fd* – длина хвостового стебля, *qs* – длина основания спинного плавника, *tu* – высота спинного плавника, *yy1* – длина основания анального плавника, *ej* – высота анального плавника, *vx* – длина грудного плавника, *zz1* – длина брюшного плавника, *vz* – пектовентральное расстояние, *zy* – вентроанальное расстояние) [4], а также выделили 10 ориентиров по однозначно определяемым точкам по периметру тела рыб (рис. 2) для измерений по методу геометрической морфометрии [9]. Линии промеров (по т.н. «truss»-протоколу) указаны в формате «*a*–*b*» (расстояние между ориентирами *a* и *b* по прямой. Рассчитывали индексы (%) пластических признаков тела по отношению к стандартной длине тела. Использовали методы многомерной статистической оценки числовых данных компьютерными программами.

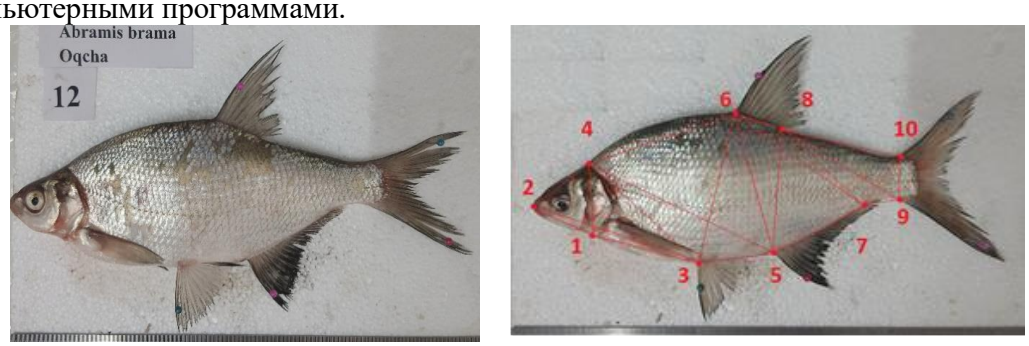

Рис. 2. Лещ: общий вид (слева) и ориентиры по периметру формы тела со схемой промеров для геометрической морфометрии, Тудакульское водохранилище

Результаты. В выборке (n = 50 экз.) были особи леща общей длиной 13,2 – 32,5 см, стандартной длиной 9,4 – 24,0 см, общей массой 25,2 – 1054,0 г.

У леща Тудакульского водохранилища были выявлены следующие меристические признаки: D III, 9 лучей, A III, 22 – 26 (в среднем 23,6) лучей, в боковой линии 49 – 55 (51,8) чешуй.

Индексы морфометрических показателей плотвы в выборке представлены в Таблице 1. Мера адекватности выборки Кайзера – Майера – Олкина (КМО) (0,822) и критерий сферичности Бартлетта (стремится к нулю) показали адекватность проведения факторного анализа выборки.

Таблица 1. Индексы пластических признаков леща Тудакульского водохранилища ($X_{ср}$ – среднее, S_x – ошибка среднего)

Индекс	Мин. – Макс.	$X_{ср.} \pm S_x$	Индекс	Мин. – Макс.	$X_{ср.} \pm S_x$
TL	115,9 – 128,5	121,28 ± 0,6	1-2	13,0 – 19,4	16,94 ± 0,27
an	4,0 – 5,4	4,61 ± 0,08	1-3	27,7 – 45,0	31,19 ± 0,68
ad	94,6 – 96,0	95,39 ± 0,08	2-3	43,6 – 49,5	46,37 ± 0,32
np	4,3 – 7,4	5,06 ± 0,13	2-4	16,6 – 19,7	18,13 ± 0,18
po	9,1 – 11,6	10,36 ± 0,13	3-4	36,0 – 41,1	37,93 ± 0,25
ao	18,6 – 21,6	20,23 ± 0,17	3-5	18,5 – 37,6	21,23 ± 0,80
lm	17,8 – 22,2	19,47 ± 0,21	3-6	36,0 – 42,1	39,38 ± 0,28
gh	33,9 – 39,3	37,12 ± 0,27	4-5	36,7 – 57,0	52,76 ± 0,71
ik	7,3 – 11,2	10,18 ± 0,16	4-6	36,5 – 41,6	39,63 ± 0,28
aq	53,9 – 59,5	57,24 ± 0,25	5-6	34,6 – 39,8	37,45 ± 0,25
sd	27,4 – 34,7	30,53 ± 0,31	5-7	19,3 – 31,6	28,44 ± 0,47
fd	5,8 – 13,0	9,04 ± 0,32	6-7	37,8 – 43,7	40,61 ± 0,29
qs	11,7 – 14,7	13,23 ± 0,16	6-8	12,1 – 15,1	13,45 ± 0,17
tu	18,5 – 29,8	25,70 ± 0,44	7-8	12,3 – 32,1	27,06 ± 0,91
yy1	13,5 – 32,6	27,79 ± 0,69	7-9	6,2 – 12,8	8,86 ± 0,28
ej	15,6 – 20,4	17,75 ± 0,26	7-10	11,9 – 16,5	13,79 ± 0,22
vx	7,3 – 23,1	20,48 ± 0,62	8-9	29,1 – 37,1	34,58 ± 0,31
zz1	6,4 – 15,9	12,43 ± 0,36	8-10	23,7 – 33,7	30,20 ± 0,40
vz	16,2 – 26,7	22,81 ± 0,56	9-10	9,0 – 28,0	11,06 ± 0,72
zy	12,3 – 19,9	15,24 ± 0,40			

Факторный анализ индексов морфометрических признаков плотвы исследуемого водоема провели для абсолютных промеров леща (рис. 3), а также для относительных показателей – индексов параметров геометрической морфометрии (в % от SL) (рис. 4). Видно, что на абсолютные значения морфометрических признаков определяющее влияние оказывает один латентный фактор, объясняющий 87,1 % общей дисперсии. Можно уверенно предположить, что это рост тела рыб. В отношении индексов пластических промеров выявлено влияние 8 латентных признаков на показатели формы тела по классчисекой схеме (факторы суммарно объясняют 84,56 % общей дисперсии) и 7 латентных факторов (78,97 %) по методам геометрической морфометрии. Повернутые матрицы компонентов для обоих анализов, объясняющих на какие индексы пластических признаков влияют выявленные латентные признаки, приведены в таблицах 2 и 3.

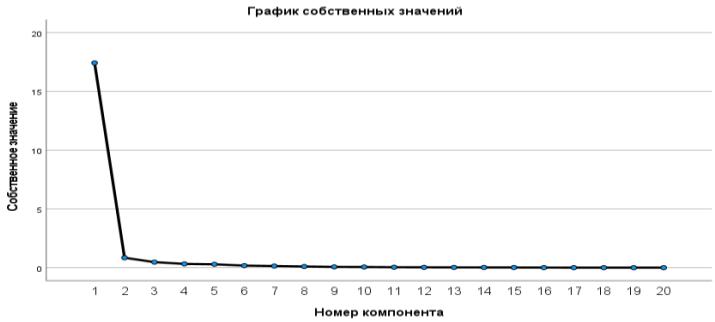

Рис. 3. График собственных значений латентных признаков леща при факторном анализе абсолютных промеров леща, Тудакульское водохранилище

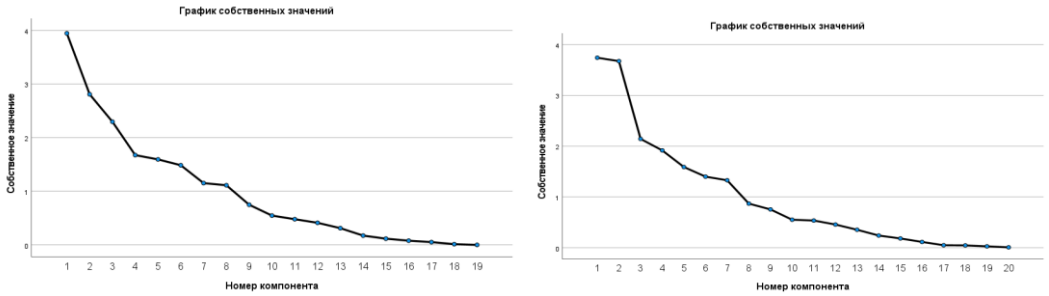

Рис. 4. График собственных значений латентных факторов леща при факторном анализе индексов промеров тела (% от SL): по классической схеме (слева) и геометрической морфометрии(справа), Тудакульское водохранилище

Таблица 2. Повернутая матрица латентных факторов, влияющих на индексы пластических признаков (% от SL) леща по классической схеме карповых

Признак	*Компонент*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
an			-0,980					
ad			0,980					
np	0,822							
po						0,875		
ao	0,566					0,510		
lm	0,839							
gh		0,593						
ik		0,816						
aq								0,510
sd					0,735			
fd		-0,853						
qs								0,880
tu					0,845			
yy1							0,882	
ej	0,637							
vx				0,533			0,595	
zz1								
vz				0,906				
zy	0,571	-0,598						
Метод выделения факторов: метод главных компонент. Метод вращения: варимакс с нормализацией Кайзера.								
a. Вращение сошлось за 13 итераций.								

Таблица 3. Повернутая матрица латентных факторов, влияющих на индексы пластических признаков (% от SL) геометрической морфометрии леща

	Латентный фактор						
	1	*2*	*3*	*4*	*5*	*6*	*7*
TL				0,618			
1 - 2					0,716		
1 - 3		0,527					
2 - 3		0,834					
2 - 4				0,586		0,517	
3 - 4		0,888					
3 - 5			0,736				
3 - 6			0,684				
4 - 5		0,507			0,503		
4 - 6						-0,922	
5 - 6			0,778				
5 - 7				0,577			
6 - 7							0,809
6 - 8					0,599		
7 - 8							0,719
7 - 9	0,671						
7 - 10				-0,858			
8 - 9	0,893						
8 - 10	0,852						
9 - 10	-0,832						
Метод выделения факторов: метод главных компонент. Метод вращения: варимакс с нормализацией Кайзера.							
a. Вращение сошлось за 10 итераций.							

Результаты и обсуждение. Вид рыб, особенно обладающий широким ареалом, имеет сложную структуру и существует в виде популяций. В оценках структуры вида важно разделение популяций. Фенотипически это можно делать по изменчивости морфометрических признаков. Однако эта изменчивость включает внутригрупповую (внутрипопуляционную) и межгрупповую (межпопуляционную). Одним из методов стала геометрическая морфометрия [6,7,8]. Наши исследования проведены для обыкновенного леща Тудакульского водохранилища. Можно предположить, что физическими преградами

ограничены само водохранилище и система подающего канала, включающая 13 насосных станций (поднимающих воды из среднего течения Амударьи более чем на 100 м), через которые рыбы не могут более проникать. По мере сбора данных по различным водоемам структура вида в бассейне Аральского моря в современном его состоянии будет проясняться, а также будут получены данные по адаптивной способности этого пластичного вида рыб.

Заключение. Ранее для водоемов Узбекистана для леща отмечали следующие меристические признаки: в спинном плавнике III 9-10, в анальном III 23-28 лучей, чешуй в боковой линии 49 – 58 чешуй. У леща Тудакульского водохранилища были выявлены следующие меристические признаки: D III, 9 лучей, A III, 22 – 26 лучей, в боковой линии 49 – 55 чешуй. Исследуемое стадо леща в водоеме находится в благополучном состоянии, испытывает влияние пресса лова, которое на популяцию отрицательного влияния не оказывает. Собственно, лещ и был вселен в водоем для увеличения рыбопродуктивности водоема за счет искусственного создания промысловой ихтиофауны!

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DENGIZKO'L, QORAQIR VA ZAMONBOBO KO'LLARIDAGI *RUTILUS ARALENSIS*NING YOSH TUZILMASI, O'SISH XUSUSIYATLARI HAMDA UZUNLIK-OG'IRLIK MUNOSABATLARI

Namozov S.M.
O'zR FA Zoologiya instituti, kichik ilmiy xodim,
sirojiddin.namozov.90@mail.ru
Sobirov B.J.
O'zR FA Zoologiya instituti, tayanch doktorant
Atamuratova M.Sh.
O'zR FA Zoologiya instituti, katta ilmiy xodim
Sobirov J.J.
O'zR FA Zoologiya instituti, katta ilmiy xodim
Kamilov B.G.
O'zR FA Zoologiya instituti, professor
ORCID 0000-0001-8549-1846
UDK 597.554.3

Annotatsiya. Ushbu maqolada Buxoro viloyatining Dengizko'l, Qoraqir va Zamonbobo ko'llarida

uchraydigan *Rutilus aralensis* populyatsiyalarining yosh tuzilmasi, o‘sish xususiyatlari va uzunlik–og‘irlik munosabatlari tahlil qilindi. Ilmiy tadqiqot ishlari 2025-yilda ovlangan namunalar asosida olib borilib, baliqlarning umumiy va standart uzunligi, tana og‘irligi, yosh tarkibi hamda holat indeksi ko‘rsatkichlari aniqlandi. Natijalarga ko‘ra, Dengizko‘l va Qoraqir ko‘llarida asosan 2+ va 3+ yoshli individlar ustunlik qilgan, Zamonbobo ko‘lida esa 1+ dan 6+ gacha bo‘lgan yosh guruhlari qayd etilgan. Barcha suv havzalarida tana uzunligi va vazni o‘rtasida yuqori darajadagi musbat bog‘liqlik kuzatildi, determinatsiya koeffitsiyenti 0,971–0,978 oralig‘ida bo‘ldi. *b* ko‘rsatkichining 3 ga yaqin qiymatlari turning o‘sishi asosan izometrik xarakterga ega ekanini ko‘rsatdi. Holat indeksi natijalari populyatsiyalarning biologik holati barqarorligini, Zamonbobo ko‘lida esa yashash sharoiti nisbatan qulayroq ekanini tasdiqladi.

Kalit so‘zlar: *Rutilus aralensis*, yosh tarkibi, uzunlik–og‘irlik munosabatlari, o‘sish xususiyatlari, holat indeksi, Dengizko‘l, Qoraqir, Zamonbobo, Buxoro viloyati.

AGE STRUCTURE, GROWTH CHARACTERISTICS, AND LENGTH-WEIGHT RELATIONSHIPS OF RUTILUS ARALENSIS IN DENGIZKUL, QORAQIR, AND ZAMONBOBO LAKES

Abstract. This article analyzes the age structure, growth characteristics, and length-weight relationship of Aral roach (*Rutilus aralensis*) populations inhabiting lakes Dengizkul, Karakir, and Zamonbobo in the Bukhara region. The scientific research was based on material collected in 2025; the total and standard length, body weight, age composition, and condition factor of the fish were determined. According to the results obtained, individuals aged 2+ and 3+ predominated in lakes Dengizkul and Karakir, whereas in Lake Zamonbobo, age groups from 1+ to 6+ were noted. A strong positive correlation between body length and weight was observed in all water bodies, with the coefficient of determination ranging from 0.971 to 0.978. The values of the "b" parameter, close to 3, indicate that the species' growth is predominantly isometric. The analysis of the condition factor confirmed the stability of the populations' biological state and also pointed to relatively more favorable habitat conditions in Lake Zamonbobo.

Keywords: *Rutilus aralensis*, age structure, length-weight relationship, growth patterns, condition factor, Dengizkul, Karakir, Zamanbaba, Bukhara region.

Kirish. O‘zbekistonning tabiiy va kollektor-zovur asosida shakllangan ichki suv havzalari ixtiofauna hamda baliq resurslarini saqlashda muhim ahamiyatga ega. Ushbu ekotizimlarda *Rutilus aralensis* populyatsiyasining yosh tarkibi, o‘sish sur’ati va biologik holatini o‘rganish suv havzalarining ekologik farqlarini aniqlash hamda resurslardan oqilona foydalanish choralarini ishlab chiqishga xizmat qiladi.

Rutilus aralensis (Berg) Cyprinidae oilasiga mansub bo‘lib, Orol havzasi ixtiofaunasiga xos baliq turlaridan biridir. Ushbu tur O‘zbekistonning turli ichki suv havzalarida uchraydi hamda ayrim ko‘l va suv omborlarida ovlanish ahamiyatiga ega populyatsiyalarni shakllantirgan. FAO ma’lumotlariga ko‘ra, O‘zbekiston ichki suv havzalarida Rutilus urug‘i muhim xo‘jalik ahamiyatiga ega baliqlar qatoriga kiradi, mamlakatdagi ko‘llar va suv omborlari esa baliqchilik resurslarini shakllantirishda alohida o‘rin tutadi [9]. So‘nggi yillarda *Rutilus aralensis*ning ayrim suv havzalaridagi populyatsion va morfobiologik xususiyatlarini o‘rganishga bag‘ishlangan tadqiqotlar ko‘paymoqda. Xususan, Aydar-Arnasoy ko‘llar tizimida ushbu turning zamonaviy holati, yosh-o‘lcham tuzilishi va o‘sish sur’atlari tahlil qilinib, populyatsiyada asosan 1+–5+ yoshli baliqlar uchrashi, bunda 2+ va 3+ yoshli individlar ustunligi qayd etilgan; shuningdek, o‘sish ko‘rsatkichlari sezilarli darajada barqaror ekanligi ko‘rsatilgan [2, 3, 10]. Xususan, Tuzkon ko‘lida ushbu turning yosh tarkibi, tana vazni va qator morfometrik belgilari tahlil qilinib, populyatsiyaning yosh tuzilmasi hamda asosiy biometrik ko‘rsatkichlari tavsiflangan [12]. Shuningdek, Zamonbobo ko‘lida o‘tkazilgan tadqiqotlarda *Rutilus aralensis*ning uzunlik–og‘irlik munosabatlari va holat ko‘rsatkichlari aniqlanib, tana uzunligi bilan vazn o‘rtasida kuchli musbat bog‘liqlik mavjudligi ko‘rsatilgan [4, 11, 13]. Mazkur ma’lumotlar turli suv havzalarida *Rutilus aralensis* populyatsiyalarining yosh tuzilmasi, o‘sish xususiyatlari va biologik holatini qiyosiy baholash zarurligini ko‘rsatadi. Biroq Buxoro viloyatining Dengizko‘l, Qoraqir va Zamonbobo ko‘llarida *Rutilus aralensis*ning yosh tarkibi hamda uzunlik-og‘irlik ko‘rsatkichlarini qiyosiy yorituvchi ma’lumotlar yetarli darajada emas.

Baliqlarning yosh tarkibi populyatsiya barqarorligi va tiklanish jarayonlarini, uzunlik-og‘irlik munosabatlari esa o‘sish sur’ati hamda yashash sharoiti qulayligini baholashga xizmat qiladi. Shu bois Dengizko‘l, Qoraqir va Zamonbobo ko‘llarida *Rutilus aralensis* populyatsiyalarining yosh tuzilmasi, o‘lcham-og‘irlik ko‘rsatkichlari va biologik holatini

qiyosiy o‘rganish dolzarb hisoblanadi.

Material va metodika. Tadqiqot materiali sifatida Buxoro viloyatining Dengizko‘l, Zamonbobo va Qoraqir ko‘llaridan 2025-yilda ovlangan *Rutilus aralensis* namunalari olindi. Namunalar dala tadqiqotlari jarayonida yig‘ilib, laboratoriya sharoitida umumqabul qilingan ixtiologik va biometrik usullar asosida tahlil qilindi [5].

Baliqlarning umumiy uzunligi (TL, sm), standart uzunligi (SL, sm) va tana og‘irligi (W, g) o‘lchandi. Uzunlik ko‘rsatkichlari 0,1 sm aniqlikda ixtiologik o‘lchov taxtachasi yordamida, tana og‘irligi esa 0,1 g aniqlikda elektron tarozida aniqlandi [5].

Yosh tangachalar asosida aniqlanib, ular tananing yon chizig‘i ustki qismidan, orqa suzgichi oldi sohasidan olindi. Tangachalar tozalanib, mikroskop ostida ko‘rib chiqildi va yillik halqalar soniga ko‘ra yosh guruhlari belgilandi [6].

Uzunlik-og‘irlik munosabatlari $W = aL^b$ tenglamasi asosida baholandi; bu yerda W — tana og‘irligi (g), L – tana uzunligi (sm), a va b – regressiya koeffitsiyentlari. Regressiya parametrlarini aniqlash uchun ma’lumotlar logarifmlanib, logW = loga + b logL tenglamasi asosida tahlil qilindi. Determinatsiya koeffitsiyenti (R^2) hisoblandi, b ko‘rsatkichiga ko‘ra o‘sish tipi izometrik (b = 3) yoki allometrik (b ≠ 3) sifatida baholandi [7, 8, 14].

Har bir suv havzasi bo‘yicha yosh guruhlari tarkibi, uzunlik va tana og‘irligining minimal, maksimal hamda o‘rtacha qiymatlari aniqlandi. Statistik ishlov berishda variatsion statistika usullari qo‘llanilib, o‘rtacha arifmetik qiymat (M), xatolik ko‘rsatkichi (±m), standart og‘ish (SD) va variatsiya koeffitsiyenti (CV, %) hisoblandi [1].

Olingan natijalar Dengizko‘l, Zamonbobo va Qoraqir ko‘llaridagi *Rutilus aralensis* populyatsiyalarining yosh tarkibi hamda uzunlik-og‘irlik ko‘rsatkichlarini qiyosiy baholash asosida tahlil qilindi.

Natijalar va muhokama. Buxoro viloyatining Dengizko‘l, Zamonbobo va Qoraqir ko‘llarida uchragan *Rutilus aralensis* populyatsiyasining yosh tarkibi tahlili ushbu turning mazkur suv havzalarida turli avlod guruhlari bilan ifodalanganini ko‘rsatdi. Tadqiqot materiallarida asosan bir necha yosh guruhlariga mansub individlar qayd etilib, populyatsiya tarkibida o‘rta yoshli baliqlar ustunlik qilishi aniqlandi. Yosh guruhlarining bunday taqsimlanishi turning ushbu ko‘llardagi populyatsiyasi nisbatan barqaror shakllanganini va suv havzalari sharoiti uning yashashi hamda o‘sishi uchun qulay ekanini ko‘rsatadi. Shu bilan birga, alohida ko‘llarda ayrim yosh guruhlarining ustunligi yoki kamroq uchrashi trofik sharoit, gidrologik rejim, ov bosimi va tabiiy ko‘payish samaradorligi bilan izohlanishi mumkin. *Rutilus aralensis*ning yosh tarkibi bo‘yicha kuzatilgan tafovutlar har bir ko‘lning ekologik xususiyatlari bilan chambarchas bog‘liq bo‘lib, bu holat turning populyatsion holatini qiyosiy baholashda muhim ahamiyat kasb etadi.

Tadqiqot natijalariga ko‘ra, *Rutilus aralensis*ning yosh guruhlari bo‘yicha uzunlik va tana vazni ko‘rsatkichlari suv havzalar kesimida farqlanishi aniqlandi (1-jadval).

1-jadval

Buxoro viloyati ko‘llarida *Rutilus aralensis*ning yosh tarkibi va o‘lcham–og‘irlik ko‘rsatkichlari

Yosh guruhi	Tana uzunligi (l), sm	Tana vazni, g	N, dona
Dengizko‘l ko‘li			
2+	13,0 – 16,7	43 – 99	41
3+	16,5 – 18,1	89 – 135	37
Qoraqir ko‘li			
1+	11,0 – 12,7	23 – 48	5
2+	12,5 – 18,0	39 – 100	44
3+	16,5 – 18,8	89 – 159	29
Zamonbobo ko‘li			
1+	8,7–12,5	10–45	19
2+	13,0–17,0	45–110	18
3+	17,0–20,0	95–190	26
4+	21,5–23,0	205–265	5
5+	23,0–25,0	250–360	8
6+	26,5–26,5	365–370	2

Jadval ma’lumotlaridan ko‘rinadiki, Buxoro viloyatining turli ko‘llarida *Rutilus aralensis* populyatsiyasining yosh tarkibi va o‘lcham-og‘irlik ko‘rsatkichlari bir-biridan

sezilarli farq qildi. Dengizko‘l ko‘lida mazkur tur faqat 2+ va 3+ yosh guruhlari bilan ifodalangan bo‘lib, bunda 2+ yoshli individlar son jihatdan biroz ustunlik qildi. Ushbu ko‘lda 2+ yoshli baliqlarning tana uzunligi 13,0–16,7 sm, tana vazni 43–99 g, 3+ yoshli baliqlarda esa mos ravishda 16,5–18,1 sm va 89–135 g oralig‘ida bo‘ldi. Bu holat Dengizko‘l populyatsiyasida asosan o‘rta yoshli individlar ustunligini ko‘rsatadi.

Qoraqir ko‘lida *Rutilus aralensis*ning yosh tarkibi nisbatan kengroq bo‘lib, 1+, 2+ va 3+ yosh guruhlari qayd etildi. Bunda 2+ yoshli baliqlar asosiy ulushni tashkil etib, ularning soni 44 dona, 3+ yoshli individlar soni 29 dona, 1+ yoshli baliqlar esa 5 donani tashkil qildi. Tana uzunligi va vazni yosh ortishi bilan izchil oshib bordi: 1+ yoshda 11,0–12,7 sm va 23–48 g, 2+ yoshda 12,5–18,0 sm va 39–100 g, 3+ yoshda esa 16,5–18,8 sm va 89–159 g.

Zamonbobo ko‘lida esa populyatsiya eng keng yosh diapazoni bilan tavsiflanib, 1+ dan 6+ gacha bo‘lgan yosh guruhlari uchradi. Son jihatdan 3+ yoshli individlar ustun bo‘ldi. Bu suv havzasida tana uzunligi 8,7–26,5 sm, tana vazni esa 10–370 g oralig‘ida qayd etildi. Umuman, Dengizko‘l va Qoraqirda 2+–3+ yoshli baliqlar ustun bo‘lsa, Zamonboboda ko‘p yoshli tuzilmaning shakllanishi yashash sharoitlarining nisbatan barqarorligini ko‘rsatadi.

Rutilus aralensisning uzunlik-og‘irlik munosabatlarini tahlil qilish uning o‘sish xususiyatlarini baholashda muhim ahamiyatga ega. Tadqiqotlar shuni ko‘rsatdiki, Dengizko‘l, Qoraqir va Zamonbobo ko‘llarida tana uzunligi bilan vazn o‘rtasida barqaror musbat bog‘liqlik mavjud, ya’ni uzunlik ortishi bilan vazn ham izchil oshib borgan. Bu holat turning o‘sishi tabiiy biologik qonuniyatlar asosida kechishini tasdiqlaydi. Biroq uzunlik–og‘irlik ko‘rsatkichlari suv havzalari bo‘yicha bir xil emas, chunki ular oziqa bazasi, gidrologik rejim, yashash muhiti va populyatsiyaning yosh tarkibiga bog‘liq. Zamonbobo ko‘lida 1+ dan 6+ gacha bo‘lgan yosh guruhlarining uchrashi regressiya ko‘rsatkichlarini to‘liqroq ifodalash imkonini berdi. Dengizko‘l va Qoraqir ko‘llarida esa yosh diapazoni torroq bo‘lgani sababli mazkur bog‘liqlik asosan o‘rta yoshli individlar doirasida shakllandi. Shunday qilib, uzunlik-og‘irlik tenglamalari va determinatsiya koeffitsiyentlari Rutilus aralensis populyatsiyalarining biologik holatini qiyosiy baholashda muhim mezon hisoblanadi.

*Rutilus aralensis*ning Buxoro viloyatidagi o‘rganilgan suv havzalarida o‘lcham ko‘rsatkichlari, umumiy uzunlik va standart uzunlik o‘rtasidagi bog‘liqlik, uzunlik–og‘irlik munosabatlari hamda holat indeksi ko‘rsatkichlari 2–6-jadvallarda keltirilgan.

2-jadval.

O‘rganilgan suv havzalaridagi *Rutilus aralensis* balig‘ining o‘lcham ko‘rsatkichlari (min.–maks.)

Suv havzasi / ko‘rsatkichlar	**TL, sm**	**SL, sm**	**W, g**	**N, ekz.**
Qoraqir ko‘li	6,8–21,5	5,4–17,9	5–126	54
Zamonbobo ko‘li	7,2–23,1	5,8–19,2	6–148	47
Dengizko‘l ko‘li	5,5–20,4	4,5–16,4	3–102	39

2-jadval ma’lumotlaridan ko‘rinadiki, Buxoro viloyatining o‘rganilgan suv havzalarida *Rutilus aralensis*ning o‘lcham ko‘rsatkichlari muayyan darajada farqlangan. Qoraqir ko‘lida ushbu turning umumiy uzunligi (TL) 6,8–21,5 sm, standart uzunligi (SL) 5,4–17,9 sm va tana vazni 5–126 g oralig‘ida qayd etildi. Zamonbobo ko‘lida o‘lcham diapazoni nisbatan kengroq bo‘lib, TL 7,2–23,1 sm, SL 5,8–19,2 sm va tana vazni 6–148 g ni tashkil etdi. Dengizko‘l ko‘lida esa *Rutilus aralensis*ning umumiy uzunligi 5,5–20,4 sm, standart uzunligi 4,5–16,4 sm va tana vazni 3–102 g chegarasida bo‘ldi. Mazkur natijalar Zamonbobo ko‘lida yirikroq individlar, Dengizko‘lda esa nisbatan maydaroq baliqlar uchrashini ko‘rsatadi.

3-jadval.

O‘rganilgan suv havzalaridagi *Rutilus aralensis* balig‘i tanasining standart uzunligi (SL) va umumiy uzunligi (TL) o‘rtasidagi to‘g‘ri chiziqli bog‘liqlik hamda ularning korrelyatsiya koeffitsiyenti qiymati

Suv havzasi/ko‘rsatkichlar	**Regressiya tenglamasi**	**r**	**N, ekz.**
Qoraqir ko‘li	SL = 0,25 + 0,812·TL	0,993	54
Zamonbobo ko‘li	SL = 0,31 + 0,807·TL	0,992	47
Dengizko‘l ko‘li	SL = 0,19 + 0,815·TL	0,994	39

3-jadval natijalariga ko‘ra, *Rutilus aralensis*da umumiy uzunlik (TL) va standart uzunlik (SL) o‘rtasida barcha tekshirilgan havzalarda juda yuqori darajadagi musbat to‘g‘ri chiziqli bog‘liqlik kuzatildi. Qoraqir ko‘lida ushbu bog‘liqlik SL = 0,25 + 0,812·TL tenglamasi bilan ifodalanib, korrelyatsiya koeffitsiyenti r = 0,993 ga teng bo‘ldi. Zamonbobo

ko‘lida bu ko‘rsatkich SL = 0,31 + 0,807·TL va r = 0,992, Dengizko‘l ko‘lida esa SL = 0,19 + 0,815·TL va r = 0,994 ni tashkil etdi. Bu ko‘rsatkichlar *Rutilus aralensis*da umumiy va standart uzunlik orasidagi bog‘liqlik barcha suv havzalarida juda barqaror ekanini ko‘rsatadi.

4-jadval.

O‘rganilgan suv havzalari *Rutilus aralensis* balig‘i populyatsiyalarining namuna hajmlari va o‘lcham–vazn bog‘liqligining aniq ko‘rsatkichlari

Suv havzasi	**N, ekz.**	**a**	**95% CL of a**	**b**	**95% CL of b**	**R^2**
Qoraqir ko‘li	*54*	*0,00962*	–4,206; –3,982	3,071	2,998; 3,143	0,975
Zamonbobo ko‘li	*47*	*0,01014*	–4,186; –3,955	3,041	2,961; 3,121	0,971
Dengizko‘l ko‘li	*39*	*0,00888*	–4,263; –4,012	3,082	2,995; 3,170	0,978

4-jadval ma’lumotlariga ko‘ra, barcha suv havzalarida *Rutilus aralensis*ning uzunlik–og‘irlik munosabatlari yuqori ishonchlilik bilan tavsiflandi. Qoraqir ko‘lida namuna hajmi 54 ta bo‘lib, a koeffitsiyenti 0,00962, b ko‘rsatkichi 3,071 va determinatsiya koeffitsiyenti R^2 = 0,975 ga teng bo‘ldi. Zamonbobo ko‘lida 47 ta namunada a = 0,01014, b = 3,041 va R^2 = 0,971 aniqlangan bo‘lsa, Dengizko‘l ko‘lida 39 ta namunada a = 0,00888, b = 3,082 va R^2 = 0,978 qayd etildi. Determinatsiya koeffitsiyentlarining barcha hollarda juda yuqori bo‘lishi tana uzunligi ortishi bilan vaznning muntazam ravishda oshib borishini tasdiqlaydi.

5-jadval.

O‘rganilgan suv havzalaridagi *Rutilus aralensis* balig‘ining o‘lcham va og‘irlik ko‘rsatkichlari logarifmlanganidan keyingi bog‘liqligi

Suv havzasi/ko‘rsatkichlar	**Regressiya tenglamasi**	**R^2**
Qoraqir ko‘li	$log_{10}W = –2,017 + 3,071 \cdot log_{10}TL$	*0,975*
Zamonbobo ko‘li	$log_{10}W = –1,994 + 3,041 \cdot log_{10}TL$	*0,971*
Dengizko‘l ko‘li	$log_{10}W = –2,051 + 3,082 \cdot log_{10}TL$	*0,978*

5-jadvalda keltirilgan logarifmlangan regressiya tenglamalari ham uzunlik va vazn o‘rtasidagi bog‘liqlikning yuqori darajada ekanini ko‘rsatdi. Qoraqir ko‘lida bu tenglama $log_{10}W = –2,017 + 3,071 \cdot log_{10}TL$, Zamonbobo ko‘lida $log_{10}W = –1,994 + 3,041 \cdot log_{10}TL$, Dengizko‘l ko‘lida esa $log_{10}W = –2,051 + 3,082 \cdot log_{10}TL$ ko‘rinishida ifodalandi. B ko‘rsatkichining barcha suv havzalarida 3 ga yaqin bo‘lishi tekshirilgan populyatsiyalarda o‘sish asosan izometrik xarakterga ega ekanini ko‘rsatadi. Shu bilan birga, Dengizko‘l va Qoraqir ko‘llarida b ko‘rsatkichining 3 dan biroz yuqoriroq bo‘lishi musbat allometrik o‘sish elementlari mavjudligini bildiradi, Zamonbobo ko‘lida esa ushbu ko‘rsatkich izometriyaga eng yaqin bo‘ldi.

6-jadval.

Tekshirilgan suv havzalaridagi *Rutilus aralensis* baliqlarining holat indeksi ko‘rsatkichlari

Suv havzasi / ko‘rsatkichlar	**W amaliy.**	**W nazariy**	**Fulton bo‘yicha semizlik koeffitsiyenti**	**Nisbiy holat koeffitsiyenti (Kn)**	**N, ekz.**
Qoraqir ko‘li	5–126 42 ± 4,3	4–120 41 ± 4,1	0,94–1,52 1,21 ± 0,02	0,92–1,11 1,00 ± 0,015	54
Zamonbobo ko‘li	6–148 55 ± 5,1	5–145 54 ± 4,9	0,97–1,48 1,26 ± 0,03	0,93–1,10 1,01 ± 0,014	47
Dengizko‘l ko‘li	3–102 38 ± 3,7	3–99 37 ± 3,5	0,89–1,43 1,18 ± 0,02	0,91–1,09 1,00 ± 0,013	39

6-jadval ma’lumotlari *Rutilus aralensis*ning holat indeksi ko‘rsatkichlari suv havzalari kesimida ma’lum darajada farqlanishini ko‘rsatdi. Qoraqir ko‘lida amaliy vazn 5–126 g, nazariy vazn 4–120 g oralig‘ida bo‘lib, Fulton bo‘yicha semizlik koeffitsiyenti 0,94–1,52, o‘rtacha 1,21 ± 0,02 ni tashkil etdi. Nisbiy holat koeffitsiyenti 0,92–1,11 oralig‘ida qayd etilib, uning o‘rtacha qiymati 1,00 ± 0,015 ga teng bo‘ldi. Zamonbobo ko‘lida amaliy vazn 6–148 g, nazariy vazn 5–145 g bo‘lib, Fulton koeffitsiyenti 0,97–1,48, o‘rtacha 1,26 ± 0,03 ni tashkil etdi, nisbiy holat koeffitsiyenti esa 0,93–1,10 oralig‘ida, o‘rtacha 1,01 ± 0,014 bo‘ldi. Dengizko‘l ko‘lida amaliy vazn 3–102 g, nazariy vazn 3–99 g, Fulton koeffitsiyenti 0,89–1,43, o‘rtacha 1,18 ± 0,02, nisbiy holat koeffitsiyenti esa 0,91–1,09 oralig‘ida, o‘rtacha 1,00 ± 0,013 ni tashkil etdi. Umuman, barcha havzalarda nisbiy holat koeffitsiyentining o‘rtacha qiymati 1,00–1,01 atrofida bo‘lib, populyatsiyalarning umumiy biologik holati barqaror ekanini ko‘rsatdi. Zamonboboda Fulton koeffitsiyentining yuqoriroq bo‘lishi yashash sharoiti va oziqa bazasining nisbatan qulayligini bildiradi.

Olingan natijalar Buxoro viloyatining Dengizko‘l, Qoraqir va Zamonbobo ko‘llarida *Rutilus aralensis* populyatsiyalarining yosh tarkibi, o‘sish ko‘rsatkichlari va biologik holati suv havzalarining ekologik sharoitlariga bog‘liq holda farqlanishini ko‘rsatdi. Yosh tarkibi bo‘yicha Dengizko‘l va Qoraqir ko‘llarida asosan 2+ va 3+ yoshli individlar ustunlik qilgani holda, Zamonbobo ko‘lida 1+ dan 6+ gacha bo‘lgan yosh guruhlarining uchrashi mazkur havzada populyatsiya tuzilmasi nisbatan to‘liqroq shakllanganini bildiradi. Bu holat, odatda, yashash muhitining barqarorligi, tabiiy ko‘payish jarayonlarining muntazamligi hamda oziqa sharoitlarining qulayligi bilan izohlanadi. Aksincha, yosh tarkibining nisbatan tor bo‘lishi ayrim havzalarda populyatsiyaning tuzilmasi soddaroq ekanini ko‘rsatadi.

Tadqiqot davomida *Rutilus aralensis*ning o‘lcham ko‘rsatkichlari ham suv havzalari o‘rtasida ma’lum tafovutlarga ega ekanligi aniqlandi. Eng yuqori umumiy uzunlik va tana vazni Zamonbobo ko‘lida qayd etilib, bu yerda yirik o‘lchamli individlar ulushi ko‘proq ekanligi kuzatildi. Dengizko‘l ko‘lida esa umumiy uzunlik va tana vazni ko‘rsatkichlarining nisbatan pastroq bo‘lishi populyatsiyada yosh diapazonining torroq ekanligi va maydaroq individlar ulushining yuqoriligi bilan bog‘liq bo‘lishi mumkin. Qoraqir ko‘li bu jihatdan oraliq holatni egallab, o‘lcham tarkibi bo‘yicha Dengizko‘l va Zamonbobo ko‘rsatkichlari orasidagi holatni namoyon etdi.

Umumiy uzunlik (TL) va standart uzunlik (SL) o‘rtasidagi juda yuqori korrelyatsiya koeffitsiyentlari (r=0,992–0,994) barcha o‘rganilgan populyatsiyalarda tana proporsiyalarining barqaror ekanini ko‘rsatdi. Bu esa turning morfometrik tuzilishi turli ekologik sharoitlarda ham sezilarli o‘zgarishga uchramasligini bildiradi. Shuningdek, uzunlik–og‘irlik munosabatlari bo‘yicha determinatsiya koeffitsiyentining yuqori darajada bo‘lishi (R^2 = 0,971–0,978) tana uzunligi va vazni o‘rtasida zich hamda biologik jihatdan ishonchli bog‘liqlik mavjudligini tasdiqladi. B ko‘rsatkichining barcha holatlarda 3 ga yaqin bo‘lishi o‘sishning asosan izometrik xarakterga ega ekanini ko‘rsatdi. Dengizko‘l va Qoraqir ko‘llarida bu qiymatning 3 dan biroz yuqori bo‘lishi musbat allometrik o‘sish elementlari mavjudligini anglatadi, Zamonbobo ko‘lida esa o‘sish izometriyaga eng yaqin bo‘ldi.

Holat indeksi ko‘rsatkichlari ham populyatsiyalarning ekologik holatini baholashda muhim mezon bo‘ldi. Fulton bo‘yicha semizlik koeffitsiyentining Zamonbobo ko‘lida nisbatan yuqoriroq bo‘lishi ushbu havzada oziqa bazasi va yashash sharoitlari qulayroq ekanini ko‘rsatadi. Qoraqirda bu ko‘rsatkich biroz pastroq, Dengizko‘lda esa eng past qiymatlar qayd etildi. Shunga qaramay, nisbiy holat koeffitsiyentining barcha havzalarda 1,00 atrofida bo‘lishi *Rutilus aralensis* populyatsiyalarining umumiy biologik holati barqaror ekanidan dalolat beradi. Umuman, o‘rganilgan ko‘llarda tur muvaffaqiyatli moslashgan bo‘lsa-da, Zamonbobo ko‘li yoshi katta, yirik va semizroq individlar ulushi bilan eng qulay ekologik sharoitga ega havza sifatida ajralib turdi.

Xulosa. Buxoro viloyatining Dengizko‘l, Qoraqir va Zamonbobo ko‘llarida *Rutilus aralensis* populyatsiyalarining yosh tarkibi, o‘lcham ko‘rsatkichlari, uzunlik-og‘irlik munosabatlari hamda holat indekslari o‘rganildi va ularning suv havzalarining ekologik sharoitlariga bog‘liq holda farqlanishi aniqlandi. Dengizko‘l va Qoraqir ko‘llarida asosan 2+ va 3+ yoshli individlar ustunlik qilgan bo‘lsa, Zamonbobo ko‘lida 1+ dan 6+ gacha bo‘lgan yosh guruhlari qayd etilib, bu havzada populyatsiya yosh tuzilmasining nisbatan to‘liqroq shakllangani kuzatildi. O‘lcham ko‘rsatkichlari bo‘yicha eng yirik individlar Zamonbobo ko‘lida, nisbatan maydaroq namunalar esa Dengizko‘l ko‘lida uchradi, Qoraqir ko‘li esa oraliq holatni egalladi. Umumiy uzunlik va standart uzunlik o‘rtasida barcha ko‘llarda juda yuqori musbat bog‘liqlik aniqlandi (r=0,992–0,994). Uzunlik–og‘irlik munosabatlari yuqori ishonchlilik bilan tavsiflanib, determinatsiya koeffitsiyenti 0,971–0,978 oralig‘ida bo‘ldi, b ko‘rsatkichining 3 ga yaqin qiymatlari esa o‘sishning asosan izometrik xarakterga ega ekanini ko‘rsatdi. Nisbiy holat koeffitsiyentining o‘rtacha 1,00–1,01 atrofida bo‘lishi populyatsiyalarning umumiy biologik holati barqarorligini, Fulton koeffitsiyentining Zamonbobo ko‘lida nisbatan yuqoriroq bo‘lishi esa ushbu suv havzasida oziqa bazasi va yashash sharoitlari qulayroq ekanini bildirdi. Olingan natijalar tur populyatsiyalarini monitoring qilish va baliq resurslaridan oqilona foydalanishda muhim ahamiyatga ega.

Mazkur tadqiqot ishi O‘zbekiston Respublikasi Fanlar akademiyasi Zoologiya institutining 2025–2029- yillarga mo‘ljallangan “1.2. Buxoro va Navoiy viloyatlari hayvonot dunyosining raqamli axborot tizimini yaratish” davlat byudjetidan moliyalashtiriladigan ilmiy-tadqiqot ishlari dasturi doirasida bajarilgan, shuningdek, mualliflar rejalashtirilgan ish hajmini bajarish uchun yaratilgan shart-sharoitlar uchun Institut rahbariyatiga o‘z minnatdorchiligini bildiradi.

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РОЛЬ АМФИБИЙ В ФОРМИРОВАНИИ И РЕАЛИЗАЦИИ ЖИЗНЕННЫХ ЦИКЛОВ ГЕЛЬМИНТОВ В УСЛОВИЯХ УЗБЕКИСТАНА

Икромов Эркин Файзуллаевич
Наманганский государственный университет,
кандидат биологических наук, доцент
ORCID 0000-0002-2748-731X
erkin-ikromov1@mail.ru
Икромов Элмурод Эркинович
Наманганский государственный университет,
старший преподаватель, PhD
ORCID 0000-0003-4652-9703
hansem@list.ru
Акмурадова Лейло Гуванчовна
Навоийский государственный университет, докторант
akmuradovaleyla255@gmail.com
УДК 576.895.1:597.8(575.1)

Аннотация. В статье представлены результаты анализа гельминтологических и экологических исследований, проведённых в 2000–2025 гг. на территории 11 областей Узбекистана и Республики Каракалпакстан. Изучена гельминтофауна шести видов амфибий родов *Bufotes* и *Pelophylax*, включая гибридные формы. Методами полного и неполного гельминтологического

вскрытия (К. И. Скрябин) зарегистрировано 68 видов гельминтов различных таксономических групп. Анализ их жизненных циклов позволил выделить 22 варианта биологической циркуляции. Установлено, что амфибии выполняют функции окончательных, промежуточных, вторых промежуточных, резервуарных (паратенических) и в ряде случаев амфиксенических хозяев. Отмечена их роль как экологических «тупиков» для отдельных гельминтов парнокопытных. Показано, что амфибии являются важным звеном в передаче паразитов между трофическими уровнями. Полученные данные подчёркивают их значительную экологическую роль в поддержании устойчивости паразитарных систем и имеют важное значение для паразитологии, экологии и оценки эпизоотологических рисков.

Ключевые слова: амфибии, гельминты, жизненный цикл, экологический тупик, экология

O‘ZBEKISTON SHAROITIDA GELMINTLAR HAYOT SIKLLARINI SHAKLLANTIRISH VA AMALGA OSHIRISHDA AMFIBIYALARNING ROLI

Annotatsiya. Mazkur maqolada 2000–2025-yillarda O‘zbekistonning 11 viloyati va Qoraqalpog‘iston Respublikasi hududida o‘tkazilgan gelmintologik va ekologik tadqiqotlar natijalarining tahlili keltirilgan. Bufotes va Pelophylax avlodlariga mansub, jumladan, gibrid shakllarni ham o‘z ichiga olgan olti tur amfibiyalarning gelmintofaunasi o‘rganildi. K.I. Skryabin usuli bo‘yicha to‘liq va qisman gelmintologik yorish usullari yordamida turli taksonomik guruhlarga mansub 68 tur gelmintlar qayd etildi. Ularning hayot sikllarini tahlil qilish natijasida biologik sirkulyatsiyaning 22 ta varianti ajratildi. Aniqlanishicha, amfibiyalar yakuniy, oraliq, ikkinchi oraliq, rezervuar (paratenik) va ayrim hollarda amfiksenik xo‘jayin vazifasini bajaradi. Shuningdek, ularning ayrim juft tuyoqli hayvonlar gelmintlari uchun ekologik „tupik“ sifatidagi roli qayd etildi. Amfibiyalar parazitlarni turli trofik darajalar o‘rtasida uzatishda muhim zveno ekanligi ko‘rsatildi. Olingan natijalar parazitar tizimlar barqarorligini ta’minlashda amfibiyalarning muhim ekologik ahamiyatini ta’kidlaydi hamda parazitologiya, ekologiya va epizootologik xavflarni baholash uchun muhim ahamiyat kasb etadi.

Kalit so‘zlar: amfibiyalar, gelmintlar, hayot sikli, ekologik tupik, ekologiya.

Введение. Амфибии занимают важное место в фауне Узбекистана, являясь ключевой экологической группой, связывающей водные и наземные экосистемы. Двух средовая природа их жизненного цикла определяет участие амфибий в различных трофических цепях и их значимую роль в поддержании устойчивости природных биоценозов.

Экологические и биологические особенности амфибий обусловливают их участие в жизненных циклах многочисленных паразитических организмов, в том числе гельминтов. Амфибии могут выполнять функции окончательных, промежуточных, вторых промежуточных и резервуарных (паратенических) хозяев, что подчёркивает их многофункциональную роль в циркуляции паразитов. Изучение жизненных циклов гельминтов амфибий имеет важное научное значение для понимания механизмов формирования и устойчивого функционирования паразитарных систем в природных экосистемах.

Через амфибий гельминты передаются на более высокие трофические уровни — птицам, рептилиям и млекопитающим, обеспечивая стабильность природных очагов инвазий [1]. Наряду с этим амфибии выступают в роли биологических регуляторов численности беспозвоночных организмов и рассматриваются как важные биоиндикаторы состояния экосистем. Гельминтозы оказывают существенное влияние на физиологическое состояние, репродуктивный потенциал и выживаемость амфибий, что делает изучение паразитарной нагрузки актуальным инструментом экологической оценки.

Гельминтологические исследования амфибий имеют также практическое значение в контексте охраны здоровья человека и животных, поскольку ряд гельминтов, ассоциированных с амфибиями, обладает зоонозной и эпизоотологической значимостью [2]. Несмотря на это, сведения о жизненных циклах гельминтов амфибий на территории Узбекистана остаются ограниченными и фрагментарными, что обусловливает необходимость проведения систематических комплексных исследований.

В связи с этим целью настоящей работы является анализ жизненных циклов гельминтов амфибий, определение роли амфибий в системе «паразит–хозяин–среда» и

выявление экологических, а также эпизоотологических закономерностей функционирования данных паразитарных систем в условиях Узбекистана.

Материалы и методы исследования

Исследования проводились в период 2000–2025 гг. на территории 11 областей: Андижанской, Наманганской, Ферганской, Сырдарьинской, Ташкентской, Джизакской, Самаркандской, Бухарской, Навоийской, Сурхандарьинской и Кашкадарьинской областей, а также Республики Каракалпакстан.

Объектом исследования служили 6 видов амфибий, а именно: жаба Перрини — *Bufotes perrini* Mazepa, Litvinchuk, Jablonski, Dufresnes, 2019; жаба Певцова — *B. pewzowi* (Bedriaga, 1898); жаба туранская — *B. turanensis* Hemmer, Schmidtler & Böhme, 1978; лягушка Терентьева — *Pelophylax terentievi* (Mezhzherin, 1992); сырдарьинская лягушка — *Pelophylax* sp. Mazepa, 2013, а также гибридная форма *P. terentievi* × *Pelophylax* sp. Видовая принадлежность амфибий определялась в соответствии с современными таксономическими исследованиями G. Mazepa [3], S.N. Litvinchuk et al.[4] и D. Ualiyeva et al. [5].

Для эвтаназии амфибий в вентральную часть брюшной полости вводили 20% раствор гидрохлорида бензокаина. Данная процедура проводилась в соответствии с рекомендациями *AVMA Guidelines for the Euthanasia of Animals**. Гельминтологический материал извлекался из амфибий методом полного гельминтологического вскрытия по К.И.Скрябину [6]. Собранные гельминты фиксировались в 70% этаноле и соответствующим образом маркировались для дальнейшей обработки.

Идентификация обнаруженных гельминтов до видового уровня осуществлялась на основе фундаментальной монографии К. М. Рыжикова в соавторстве [7], а также соответствующих научных публикаций отечественных и зарубежных специалистов [8,9]. Таксономическая принадлежность паразитов уточнялась с использованием данных, представленных на сайте Global Biodiversity Information Facility (https://www.gbif.org/).

Часть собранного гельминтологического материала была передана для хранения в лабораторию экологии и паразитологии гидробионтов Центра научно-практических инноваций по аквакультуре при Наманганском государственном университете, а также в лабораторию общей паразитологии Института зоологии Академии наук Республики Узбекистан.

Результаты и обсуждение

В результате проведённых комплексных исследований у шести видов амфибий, обитающих на территории Узбекистана, было зарегистрировано 68 видов гельминтов, относящихся к 8 классам животного мира. Жизненные циклы выявленных гельминтов были проанализированы на основе собственных исследований и ранее опубликованных нами научных работ [10-15], что позволило выделить 22 пути циркуляции, а также определить место и роль амфибий в реализации данных жизненных циклов.

В частности:

1. Амфибия (дефинитивные хозяева) — внешняя среда — головастик — амфибия. Такая биоциркуляция характерна для моногенеи *Polystoma integerrimum* (Frölich, 1798).

2. Амфибия (вторые промежуточные хозяева) — плотоядные млекопитающие (дефинитивные хозяева) — внешняя среда — членистоногие (первые промежуточные хозяева) — амфибия (вторые промежуточные хозяева). Такой путь развития установлен для цестод *Spirometra erinaceieuropaei* (Rudolphi, 1819) и *Mesocestoides lineatus* (Goeze, 1782).

3. Амфибия (амфиксенические: вставочные и резервуарные хозяева) — хищные млекопитающие (дефинитивные хозяева) — внешняя среда — пресноводные моллюски (первые промежуточные хозяева) — амфибия (вставочные и резервуарные хозяева). Такая циркуляция характерна для трематоды *Alaria alata* (Goeze, 1782).

4. Амфибия (вторые промежуточные и резервуарные хозяева) — голенастые птицы (выпи) (дефинитивные хозяева) — внешняя среда — пресноводные моллюски

(первые промежуточные хозяева) — амфибия (вторые промежуточные и резервуарные хозяева). Такой путь развития характерен для *Codonocephalus urnigerus* (Rudolphi, 1819) Lühe, 1909.

5. Амфибия (вторые промежуточные хозяева) — хищные птицы (дефинитивные хозяева) — внешняя среда — пресноводные моллюски (первые промежуточные хозяева) — амфибия (вторые промежуточные хозяева). Такой путь развития характерен для *Tylodelphys excavata* (Rudolphi, 1803) и *Echinostoma revolutum* (Frölich, 1802).

6. Амфибия (вставочные, дополнительные и резервуарные хозяева) — хищные птицы (дефинитивные хозяева) — внешняя среда — пресноводные моллюски (первые промежуточные хозяева) — амфибия (вставочные, дополнительные и резервуарные хозяева). Такой путь развития характерен для *Strigea strigis* (Schrank, 1788) Abildgaard, 1790.

7. Амфибия (дефинитивные хозяева) — внешняя среда — брюхоногие моллюски (промежуточные хозяева) — внешняя среда — амфибия (дефинитивные хозяева). Такая биологическая циркуляция характерна для трематоды *Diplodiscus subclavatus* (Pallas, 1760).

8. Амфибия (дефинитивные хозяева) — внешняя среда — дождевые черви, наземные моллюски (резервуарные хозяева) — амфибия (дефинитивные хозяева). Данная циркуляция наблюдается у нематод *Rhabdias bufonis* (Schrank, 1788) и *Rhabdias rubrovenosa* (Schneider, 1866) Semenov, 1929.

9. Амфибия (дефинитивные хозяева) — внешняя среда — амфибия (дефинитивные хозяева). Такой жизненный цикл развития наблюдается у нематод *Oswaldocruzia filiformis* (Goeze, 1782), *O. biolata* (Molin, 1880) Travassos, 1917, *O. ukreinae* Iwanitzky, 1928, *Gyrinicola tba* Dinnik, 1930, *Gyrinicola* sp., *Aplectana acuminata* (Schrank, 1788), *A. multipapillosa* Ivanitzky, 1940, *Neoxysomatium brevicaudatum* (Zeder, 1800), *Neoxysomatium* sp., *Subulascaris* sp., *Strongyloides spiralis* (Grabda-Kazubska, 1978), *Strongyloides* sp. 1, 2, *Cosmocerca commutata* (Diesing, 1851), *C. ornata* (Dujardin, 1845), *Cosmocercoides skryabini* (Ivanitzky, 1940), *Cosmocercoides* sp. и *Spironoura govacus* Ikromov et Azimov, 2004.

10. Амфибия (вторые промежуточные хозяева) — змеи (дефинитивные хозяева) — внешняя среда — моллюски (промежуточные хозяева) — амфибия (вторые промежуточные хозяева). Такой жизненный цикл развития наблюдается у трематоды *Encyclometra colubrimurorum* (Rudolphi, 1819) Dollfus in Joyeux & Houdemer, 1928.

11. Амфибия (дефинитивные хозяева) — внешняя среда — водные моллюски (промежуточные хозяева) — внешняя среда — членистоногие (личинки и имаго) (вторые промежуточные хозяева) — амфибия (дефинитивные хозяева). Данная биологическая циркуляция наблюдается у трематод *Gorgodera cygnoides* (Zeder, 1800), *G. asiatica* Pigulevsky, 1945, *G. dollfusi* Pigulevsky, 1945, *G. media* Strom, 1940, *G. pagenstecheri* Ssinitzin, 1905, *Haematoloechus (Pneumonoeces) variegatus*, *Skrjabinoeces similis* (Looss, 1899) и *Pleurogenoides medians* Olsson, 1876.

12. Амфибия (дефинитивные хозяева) — внешняя среда — водные моллюски (первые промежуточные хозяева) — внешняя среда — головастики лягушек (вторые промежуточные хозяева) — амфибия (дефинитивные хозяева). Такой путь развития характерен для трематоды *Gorgoderina vitelliloba* (Olsson, 1876).

13. Амфибия (амфиксенический хозяин: окончательный и дополнительный) — внешняя среда — водные моллюски (первый промежуточный хозяин) — внешняя среда — амфибия (амфиксенический хозяин: окончательный и дополнительный). Такой жизненный цикл характерен для трематод *Haplometra cylindracea*, *Opisthioglyphe ranae* (Frölich, 1791) и *Opisthioglyphe koisarensis* Dunganova, 1974.

14. Амфибия (дефинитивные хозяева) — внешняя среда — первый промежуточный хозяин (моллюски рода *Planorbis*) — вторые промежуточные хозяева (личинки комаров) — амфибия (дефинитивные хозяева). Такой путь развития наблюдается у трематод *Haematoloechus (Pneumonoeces) variegatus* (Rudolphi, 1819) и *Haematoloechus variegatus abbreviatus* Bykhovsky, 1932.

15. Амфибия (резервуарные хозяева) — водяной уж (дефинитивные хозяева) — внешняя среда — моллюски (промежуточные хозяева) — амфибия (резервуарные хозяева). Данный путь развития характерен для трематоды *Telorchis assula* (Dujardin, 1845).

16. Амфибия (резервуарные хозяева) — млекопитающие (дефинитивные хозяева) — внешняя среда — жуки (промежуточные хозяева) — амфибия (резервуарные хозяева). Такой жизненный цикл характерен для архиакантоцефала *Macracanthorhynchus catulinus* Kostylev, 1927.

17. Амфибия (дефинитивные хозяева) — внешняя среда — мокрицы (промежуточные хозяева) — амфибия (дефинитивные хозяева). Такой жизненный цикл характерен для палеакантоцефалов *Acanthocephalus falcatus* (Frölich, 1789) Lühe, 1911, *A. ranae* (Schrank, 1788) Lühe, 1911, *Pseudoacanthocephalus bufonis* (Shipley, 1903) и *P. bufonincola* (Kostylew, 1941).

18. Амфибия (резервуарные хозяева) — птицы (дефинитивные хозяева) — внешняя среда — мокрицы (промежуточные хозяева) — амфибия (резервуарные хозяева). Такой жизненный цикл характерен для палеакантоцефалов *Centrorhynchus globocaudatus* (Zeder, 1800) Lühe, 1911, *Sphaerirostris picae* (Rudolphi, 1819) Golvan, 1958 и *Plagiorhynchus (Prosthorhynchus) transversus* (Rudolphi, 1819).

19. Амфибия (резервуарные хозяева) — птицы (дефинитивные хозяева) — внешняя среда — жуки (промежуточные хозяева) — амфибия (резервуарные хозяева). Данный цикл развития характерен для архиакантоцефала *Mediorhynchus papillosus* Van Cleave, 1916.

20. Амфибия (дефинитивные хозяева) — внешняя среда — (экспериментально) дождевые черви, наземные моллюски, тритоны (резервуарные/транспортные хозяева) — амфибия (дефинитивные хозяева). Такой путь биологического развития характерен для *Rhabdias bufonis* (Schrank, 1788) и *Rhabdias rubrovenosa* (Schneider, 1866) Semenov, 1929.

21. Амфибия (резервуарные хозяева) — водные птицы (дефинитивные хозяева) — внешняя среда — олигохеты (промежуточные хозяева) — амфибия (резервуарные хозяева). Данный жизненный цикл характерен для нематоды *Hystrichis tricolor* Dujardin, 1845.

22. Амфибия (резервуарные хозяева) — рептилии (дефинитивные хозяева) — внешняя среда — амфибия (резервуарные хозяева). Такой жизненный цикл характерен для нематоды *Ophidascaris schikhobalovi* Mosgovoy, 1950 (личиночные стадии).

Полученные в ходе исследования данные подтверждают, что амфибии играют ключевую роль в функционировании паразитарных систем природных экосистем Узбекистана. Их биологические и экологические особенности, прежде всего двухсредовый образ жизни, обусловливают активное участие в циркуляции гельминтов между водными и наземными экосистемами. Благодаря тесной связи амфибий с различными компонентами биотопа, они выступают важным связующим звеном в системе «паразит–хозяин–среда», обеспечивая устойчивость и непрерывность жизненных циклов многих паразитических организмов.

Результаты проведённых исследований показали, что у шести видов амфибий, распространённых на территории Узбекистана, зарегистрировано 68 видов гельминтов, принадлежащих к различным таксономическим группам. Анализ их жизненных циклов позволил выделить 22 варианта биологической циркуляции паразитов. Подобное разнообразие жизненных стратегий свидетельствует о значительной экологической роли амфибий в поддержании сложных паразитарных систем. Установлено, что амфибии могут выступать в качестве окончательных, промежуточных, вторых промежуточных и резервуарных хозяев, а в некоторых случаях — амфиксенических хозяев, выполняя одновременно несколько функций в жизненном цикле паразитов, а также выступать экологическими «тупиками» для некоторых гельминтов парнокопытных животных — *Gongylonema pulchrum* (Molin, 1857), *Ascarops strongylina* (Rudolphi, 1819), *Physocephalus sexalatus* (Molin, 1860) и *Spirocerca lupi* (Rudolphi, 1819).

Анализ структуры гельминтофауны амфибий показал, что паразиты, связанные с этой группой позвоночных, характеризуются различными типами жизненных циклов. Наиболее простыми являются моноксенные циклы, характерные для ряда нематод, развитие которых происходит без участия промежуточных хозяев.

Такие паразиты способны завершать весь жизненный цикл в пределах одной популяции амфибий, используя внешнюю среду лишь как этап передачи инвазионных личинок. Наличие подобных циклов обусловлено экологическими особенностями среды обитания амфибий, включая повышенную влажность, высокую плотность популяций и постоянный контакт животных с субстратом и водой. Эти факторы создают благоприятные условия для распространения паразитов с прямым типом развития.

В то же время значительная часть выявленных паразитов характеризуется сложными гетероксенными жизненными циклами. Особенно это характерно для трематод, в жизненном цикле которых участвуют один или два промежуточных хозяина. Как правило, первым промежуточным хозяином выступают пресноводные моллюски, а амфибии выполняют роль вторых промежуточных или дополнительных хозяев. В организме амфибий происходит развитие личиночных стадий паразита, после чего инвазионные формы передаются окончательным хозяевам — птицам, рептилиям или млекопитающим. Подобные циклы характерны для таких видов, как *Alaria alata, Codonocephalus urnigerus, Tylodelphys excavata* и ряда других трематод.

Особое значение имеет роль амфибий в качестве резервуарных (паратенических) хозяев. В этом случае личинки паразитов способны длительное время сохраняться в организме амфибий без дальнейшего развития, ожидая попадания в организм окончательного хозяина. Такая стратегия позволяет паразитам поддерживать устойчивость популяции даже при низкой плотности окончательных хозяев. Резервуарная функция амфибий характерна для ряда цестод и скребней, личинки которых накапливаются в тканях амфибий и передаются хищным птицам, рептилиям или млекопитающим при их поедании. Таким образом, амфибии выполняют роль своеобразного «биологического аккумулятора» паразитов в экосистеме.

Экологический анализ показал, что амфибии играют важную роль в передаче паразитов между различными трофическими уровнями. С одной стороны, они активно питаются беспозвоночными организмами — моллюсками, насекомыми и другими потенциальными промежуточными хозяевами паразитов. С другой стороны, сами амфибии служат объектом питания для многих позвоночных хищников, включая птиц, змей и млекопитающих. Такая трофическая позиция делает амфибий важным элементом пищевых цепей, обеспечивающим передачу паразитов от низших звеньев экосистемы к высшим.

Не менее важным является тот факт, что амфибии могут выступать в роли так называемых экологических «тупиков» для некоторых гельминтов. В подобных случаях личинки паразитов попадают в организм амфибий, однако дальнейшее развитие не происходит, поскольку амфибия не является подходящим окончательным хозяином. Тем не менее подобные ситуации имеют большое значение для понимания структуры паразитарных систем, поскольку они отражают сложные взаимодействия между различными компонентами биоценоза и свидетельствуют о наличии потенциальных путей передачи паразитов в природных экосистемах.

Результаты проведённого исследования также подчёркивают важность амфибий как биоиндикаторов состояния экосистем. Известно, что структура гельминтофауны в значительной степени зависит от экологических условий среды, включая гидрологический режим водоёмов, состав беспозвоночной фауны и степень антропогенного воздействия. Изменения в составе паразитов амфибий могут отражать трансформации природных экосистем, обусловленные хозяйственной деятельностью человека, изменением климата или деградацией водных биотопов. В связи с этим паразитологические исследования амфибий могут служить важным инструментом экологического мониторинга.

Кроме того, изучение гельминтофауны амфибий имеет существенное

эпизоотологическое и эпидемиологическое значение. Некоторые паразиты, ассоциированные с амфибиями, способны заражать домашних и диких животных, а в отдельных случаях — и человека. Поэтому анализ жизненных циклов таких паразитов позволяет выявлять потенциальные источники инвазий и разрабатывать меры профилактики паразитарных заболеваний. В этом контексте амфибии могут рассматриваться как важный элемент природных очагов паразитарных инфекций.

Таким образом, проведённые исследования демонстрируют, что амфибии являются одним из ключевых компонентов паразитарных систем природных экосистем Узбекистана. Их участие в жизненных циклах гельминтов определяется сложными экологическими взаимодействиями между различными группами организмов и отражает тесную взаимосвязь водных и наземных биотопов. Понимание роли амфибий в циркуляции паразитов имеет важное значение для развития паразитологии, экологии и охраны биоразнообразия, а также для оценки эпизоотологической и эпидемиологической ситуации в природных экосистемах региона.

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*https://www.gbif.org/

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