ISSN (Print) 2616-6771
ISSN (Online) 2617-9962

Л.Н. Гумилев атындағы Еуразия ұлттық университетінің

ХАБАРШЫСЫ

BULLETIN
of L.N. Gumilyov Eurasian National University

ВЕСТНИК
Евразийского национального университета имени Л.Н. Гумилева

ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ сериясы

CHEMISTRY. GEOGRAPHY. ECOLOGY Series

Серия ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ

3(144)/ 2023

1995 жылдан бастап шығады
Founded in 1995
Издается с 1995 года

Жылына 4 рет шығады
Published 4 times a year
Выходит 4 раза в год

Астана, 2023
Astana, 2023

Редакцияның мекенжайы: 010008, Қазақстан, Астана қ., Сәтбаев к-сі, 2,
Л.Н. Гумилев атындағы Еуразия ұлттық университеті, 402 б.
Тел.: +7 (7172) 709-500, (ішкі 31-413). **E-mail:** vest_chem@enu.kz
Техникалық хатшы: Изтелеуова Е.А.

Л.Н. Гумилев атындағы Еуразия ұлттық университетінің хабаршысы. Химия. География. Экология сериясы
Меншіктенуші: КеАҚ "Л.Н. Гумилев атындағы Еуразия ұлттық университеті"
Мерзімділігі: жылына 4 рет
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінде 02.02.2021 ж.
№ KZ81VPY00031939 тіркеу куәлігімен тіркелген
Типографияның мекенжайы: 010008, Қазақстан, Астана қ., Қажымұқан к-сі 13/1
Л.Н. Гумилев атындағы Еуразия ұлттық университеті
Тел: +7 (7172)709-500 (ішкі 31-413). Сайт: http://bulchmed.enu.kz

Editorial address: 2, Satpayev str., of. 402,
L.N. Gumilyov Eurasian National University, Astana, Kazakhstan,
010008 **Tel.:** +7 (7172) 709-500 (ext. 31-413), **E-mail:** vest_chem@enu.kz
Technical secretary: Yelena Izteleuova

Bulletin of L.N. Gumilyov Eurasian National University.
Chemistry. Geography. Ecology Series
Owner: Non-profit joint-stock company «L.N. Gumilyov Eurasian National University»
Periodicity: 4 times a year
Reistered by the Ministry of Information and Communication of the Republic of Kazakhstan Reistration certificate № KZ81VPY00031939 from 02.02.2021
Address of Printin Office: 13/1 Kazhimukan str., L.N. Gumilyov Eurasian National University, Astana, Kazakhstan 010008
Tel: +7 (7172) 709-500 (ext. 31-413). Website: http://bulchmed.enu.kz

Адрес редакции: 010008, Казахстан, г. Астана, ул. Сатпаева, 2,
Евразийский национальный университет имени Л.Н. Гумилева, каб. 402
Тел.: +7(7172) 709-500, (вн. 31-413). **E-mail:** vest_chem@enu.kz
Технический секретарь: Изтелеуова Е.

Вестник Евразийского национального университета имени Л.Н. Гумилева.
Серия Химия. География. Экология
Собственник: НАО «Евразийский национальный университет имени Л.Н. Гумилева»
Периодичность: 4 раза в год
Зарегистрирован Министерством информации и коммуникаций Республики Казахстан Регистрационное свидетельство № KZ81VPY00031939 от 02.02.2021 г.
Адрес типографии: 010008, Казахстан, г. Астана, ул. Кажымукана, 13/1, Евразийский национальный университет имени Л.Н. Гумилева
Тел.: +7(7172)709-500 (вн.31-413). Сайт: http://bulchmed.enu.kz

Л.Н. ГУМИЛЕВ АТЫНДАҒЫ ЕУРАЗИЯ ҰЛТТЫҚ УНИВЕРСИТЕТІНІҢ ХАБАРШЫСЫ.
СЕРИЯ ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ
BULLETIN OF L.N. GUMILYOV EURASIAN NATIONAL UNIVERSITY.
SERIES CHEMISTRY. GEOGRAPHY. ECOLOGY
ВЕСТНИК ЕВРАЗИЙСКОГО НАЦИОНАЛЬНОГО УНИВЕРСИТЕТА ИМЕНИ
Л.Н.ГУМИЛЕВА. СЕРИЯ ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ
№3(144)/2023

МАЗМҰНЫ/ CONTENTS/ СОДЕРЖАНИЕ

ХИМИЯ/ CHEMISRY

Л.Н. ГУМИЛЕВ АТЫНДАҒЫ ЕУРАЗИЯ ҰЛТТЫҚ УНИВЕРСИТЕТІНІҢ ХАБАРШЫСЫ.
СЕРИЯ ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ
BULLETIN OF L.N. GUMILYOV EURASIAN NATIONAL UNIVERSITY.
SERIES CHEMISTRY. GEOGRAPHY. ECOLOGY
ВЕСТНИК ЕВРАЗИЙСКОГО НАЦИОНАЛЬНОГО УНИВЕРСИТЕТА ИМЕНИ
Л.Н.ГУМИЛЕВА. СЕРИЯ ХИМИЯ. ГЕОГРАФИЯ. ЭКОЛОГИЯ
№3(144)/2023

МАЗМҰНЫ/ CONTENTS/ СОДЕРЖАНИЕ

ГЕОГРАФИЯ. ЭКОЛОГИЯ/ GEOGRAPHY. ECOLOGY

МНРТИ 31.15.25

О.В. Соболь[1], С.А. Фролова[1], А.М. Моржухин[2]

[1]ФГБОУ ВО «Донбасская национальная академия строительства и архитектуры», Макеевка, Россия

[2]ФГБОУ ВО «Университет «Дубна», Дубна, Россия
(автор для корреспонденции: cluck@mail.ru[2])

Анализ термодинамических параметров кристаллизации эвтектического состава в системе $H_2O – Na_2S_2O_3·5H_2O$

Аннотация. *При разработке холодоаккумуляторов на основе фазовых переходов (ХА ФП) в настоящее время основные усилия направлены на расчет различных конструкционных устройств и таких параметров, как объем, площадь поверхности ХА, коэффициент теплопередачи (или термическое сопротивление) на границе холодоаккумулирующего материала (ХАМ) с материалом аккумулятора, температура и время зарядки и разрядки, энергетический КПД. Вместе с тем, слабо освещается физическая и химическая проблемы учета процессов самих фазовых переходов и их влияние на эффективную работу ХА. В данной работе по экспериментально полученным термограммам проведен анализ кинетических и термодинамических параметров плавления и кристаллизации эвтектического состава в системе* H_2O – $Na_2S_2O_3·5H_2O$ *(ТСН-5), который можно использовать как ХАМ, работающий при T=262±1 K (-11±1°С). Выявлено, что в зависимости от величины прогрева жидкой фазы относительно температуры плавления и дальнейшего охлаждения имеют место два вида кристаллизации. Первый вид – это квазиравновесная кристаллизация (КРК), которая происходит при температуре* T_S, *совпадающей с температурой* $T_L = T_E$. *Второй вид является неравновесно-взрывной кристаллизацией (НРВК), которая начинается после достижения определенных предкристаллизационных переохлаждений* $\Delta T_{LS}^{-} = T_L - T_{\min}$. *Были рассчитаны активности* $a_E^{H_2O}$, a_E^{TCH-5}, *коэффициенты активностей* $\gamma_E^{H_2O}$, γ_E^{TCH-5} *и энергии активации* $W_E^{H_2O}$, W_E^{TCH-5} *в эвтектике как при температуре* T_E' *т.е. при равновесной кристаллизации (КРК), так и в области переохлаждения при температуре* T_{min} *на начало неравновесно-взрывной кристаллизации (НРВК).*

Ключевые слова: *холодоаккумулирующий материал, термический анализ, раствор, эвтектика, плавление, кристаллизация, вода.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-10-23

Введение. Транспортировка скоропортящихся продуктов питания, а также хранение и транспортировка медицинских препаратов на данный момент являются одной из основных задач логистики городского хозяйства [1,2]. Эффективное решение данной проблемы заключается в использовании аккумуляторов холода, которые называются эвтектическими плитами или зероторами.

Транспортное средство (ТС) для перевозки замороженных продуктов или медицинских препаратов должно быть оснащено изотермической будкой и приспособлениями для холодильного агрегата, который подключается к зероторам. Эвтектические плиты, в свою очередь, устанавливаются внутри изотермической будки на её потолке, что позволяет поддерживать постоянную температуру во всем объеме изотермического отсека. Эвтектические плиты имеют ряд преимуществ:

- эвтектические плиты не имеют подвижных частей, поэтому их надежность намного больше, чем у систем вентилируемого обдува;
- при выключенном двигателе грузовика или открытых дверях изотермической будки холод заполняет весь объем рефрижераторного отсека и поддерживает постоянную отрицательную температуру;
- если влага будет намерзать на поверхности эвтектических плит, это не ухудшает эффективность охлаждения, в отличие от продувной системы, для которой данный аспект является критическим;
- учитывая более длительный срок службы и минимальные расходы на обслуживание, средняя стоимость эвтектической системы будет ниже системы вентилируемого обдува;
- зарядка эвтектических плит в ночное время позволяет снизить расходы на электроэнергию;
- в эвтектической системе полностью отсутствуют шум, вибрации и загрязняющие выбросы в окружающую среду, что особенно важно для развоза продукции в центральной части городов.

При разработке холодоаккумуляторов на основе фазовых переходов (ХАФП) в настоящее время основные усилия направлены на расчет различных конструкционных устройств и таких параметров, как объем, площадь поверхности ХА, коэффициент теплопередачи (или термическое сопротивление) на границе холодоаккумулирующего материала (ХАМ) с материалом аккумулятора, температура и время зарядки и разрядки, энергетический КПД. Вместе с тем, слабо освещается физическая и химическая проблемы учета процессов самих фазовых переходов и их влияние на эффективную работу ХА [3,4]. Для аккумулирования холода, необходимого при транспортировке скоропортящихся продуктов и медицинских препаратов, хорошим выбором являются кристаллогидраты солей натрия с добавками, предотвращающими или снижающими предкристаллизационные переохлаждения. Однако на фоне недостатков индивидуальных кристаллогидратов их эвтектические смеси выгодно отличаются высокой устойчивостью к длительному термоциклированию и низкими значениями переохлаждений. В данной работе на примере экспериментально полученных термограмм проведен анализ кинетических и термодинамических параметров плавления и кристаллизации эвтектического состава в системе $H_2O - Na_2S_2O_3{\cdot}5H_2O$ (ТСН-5), который можно использовать как ХАМ, работающий при T=262±1 K (-11±1°C).

Методы исследования. Управление процессами нагрева-охлаждения, а также запись кривых в методе циклического термического анализа (ЦТА) и методе дифференциального термического анализа (ДТА) производилось при помощи регулятора-измерителя THERMOMETR UNIT-325 с ХА-термопарами и выходом на ПК. Все образцы массами по 1 г, помещали в стеклянные пробирки с притёртыми крышечками. Раствор эвтектического состава готовили путем смешивания 47,8 вес. % пентагидрата тиосульфата натрия и 52,2 вес. % воды. В мольных концентрациях $X_E^{H_2O} = 0{,}927$ и $X_E^{TCH-5} = 0{,}072$ моль соответственно. Для приготовления раствора использовалась дважды перегнанная дистиллированная вода и $Na_2S_2O_3{\cdot}5H_2O$ марки ЧДА. Образцы нагревали и охлаждали с помощью печи-сопротивления в диапазоне температур от 248 до 298 K. С этой целью печь помещали в морозильную камеру BEKO FSE 1010, работающую при 243 K. Погрешность измерения температуры составляла 1 градус. Скорости нагрева и охлаждения были приблизительно одинаковыми и варьировали от 0,1 до 0,2 K/c. Изучено три образца, на каждом из которых проведено более десятка последовательных термоциклов нагрева и охлаждения. Достоверность полученных результатов и надежность основывались на совпадении реперных точек со справочными данными и многократном повторении соответствующих экзо- и эндотермических эффектов при непрерывном термоциклировании.

Переход от КРК к НРВК при охлаждении зависел от величины предварительного перегрева расплава ΔT^{+} до некоторого критического значения $T_{к}^{+}$=293±1 K.

В методе ЦТА источником информации является группа параметров, которые характеризуют процессы плавления и кинетику кристаллизации переохлажденных растворов, т.е. фазовые превращения, сопровождающиеся экзо- и эндотермическими эффектами. Такими параметрами являются:

T_{L} – температура плавления образца;

T_{S} – температура равновесной кристаллизации образца;

$T_{к}^{+}$ – величина перегрева жидкой фазы относительно температуры плавления T_{L};

$T_{\min}$ – граница метастабильности;

$\Delta T_{LS}^{-} = T_{L} - T_{\min}$ – степень предкристаллизационного переохлаждения;

ΔH_{LS} – энтальпия плавления;

ΔH_{SL} – энтальпия кристаллизации;

v и τ – скорость и время плавления, либо кристаллизации;

τ_{1} – инкубационный период зарождения твердой фазы;

τ_{2} и $v_{к}$ – время и скорость коагуляции зародышей твердой фазы;

τ_{3} – время затвердевания после коагуляции зародышей;

η – степень кристалличности;

$v_{нагр}$, $v_{охл}$ – скорости нагрева и охлаждения и др.

Приведем некоторые теплофизические свойства воды и тиосульфата натрия пятиводного [5].

Таблица 1. Значения молярной массы μ, температуры плавления T_{L}, поверхностного натяжения σ_{LS}, энтальпии плавления ΔH_{LS}, плотностей твердой фазы ρ_{S}, жидкой фазы ρ_{L}, разности плотностей $\Delta\rho$, удельных теплоемкостей твердой C_{PS} и жидкой C_{PL} фаз

	μ, г/моль	T_{L}, K	σ_{LS}, мДж/м^2	ΔH_{LS}, Дж/моль	ρ_{S}, кг/м^3	ρ_{L}, кг/м^3	$\Delta\rho$, кг/м^3	C_{PS}, Дж/кг·K	C_{PL}, Дж/кг·K
H_2O	18	273	32	6025	900	1000	100	4190	2100
$Na_2S_2O_3 \cdot 5H_2O$	248	321	≈70	49848	1730	1670	60	1460	2400-3050

Результаты и обсуждение. Результаты экспериментальных исследований процессов плавления и кристаллизации эвтектики свидетельствуют о том, что, как и у чистых компонентов (H_2O и $Na_2S_2O_3 \cdot 5H_2O$) в зависимости от величины прогрева жидкой фазы относительно температуры плавления T_L и дальнейшего охлаждения, имеют место два вида кристаллизации [6,7]. Первый вид – это квазиравновесная кристаллизация (КРК), которая происходит при температуре T_S, практически совпадающей с температурой T_L. Причем, $T_L \approx T_S \approx T_E \approx 263 \pm 1K$. Время плавления составляет $\tau_S \approx 3$ мин, время кристаллизации $\tau_L \approx 7$ мин.

Второй вид – это неравновесно-взрывная кристаллизация (НРВК), которая начинается при $T_{\min} < T_L \approx 256 \pm 1K$, т.е. после достижения определенных предкристаллизационных переохлаждений ($\Delta T_{LS}^{-} = T_L - T_{\min}$), $\Delta T_{LS}^{-} = 7^{\circ}$, при прогреве образца до. На рис. 1 приведены термограммы, характеризующие оба вида кристаллизации КРК (I) и НРВК (II) в координатах температура T – время τ.

При изучении кинетики фазовых превращений растворов особый интерес представляют неравновесные процессы (рис. 1, термограмма II) для устранения условий, вызывающих НРВК, что является нежелательным для ХАМ.

С учетом фазового превращения кривая охлаждения *abcdef* дает достаточную информацию о кинетических параметрах затвердевания: скорости массовой кристаллизации *dm/dt*, степени переохлаждения ΔT_{LS}^{-}, инкубационном периоде зародышеобразования τ_1, времени коагуляции зародышей τ_2, времени изотермической докристаллизации τ_3, времени затвердевания τ_S, где $\tau_S = \tau_1 + \tau_2 + \tau_3$. По термограммам получили значения: $\tau_1 \approx 8$ мин, $\tau_2 \approx 1$ сек, $\tau_3 \approx 3$ мин. Общее время затвердевания τ_S = 661 сек.

При охлаждении жидкой фазы из точки *a* до точки *c* за время τ_1 на термограмме никакие экзотермические эффекты не фиксируются. В растворе при охлаждении до температуры T_L (от точки *a* до точки *b*), конечно, могут происходить гидратационные процессы по восстановлению стехиометрического состава до насыщенного состояния. Этот процесс продолжается и в метастабильной области от точки *b* до точки *c*. Затем температура со скоростью ~50°/с за время τ_2 быстро поднимается от температуры $T_{\min}$ до температуры плавления T_L. Быстрый подъем температуры свидетельствует о некотором адиабатном процессе, происходящем в переохлажденном растворе, в результате которого последний прогревается от $T_{\min}$ до T_L.

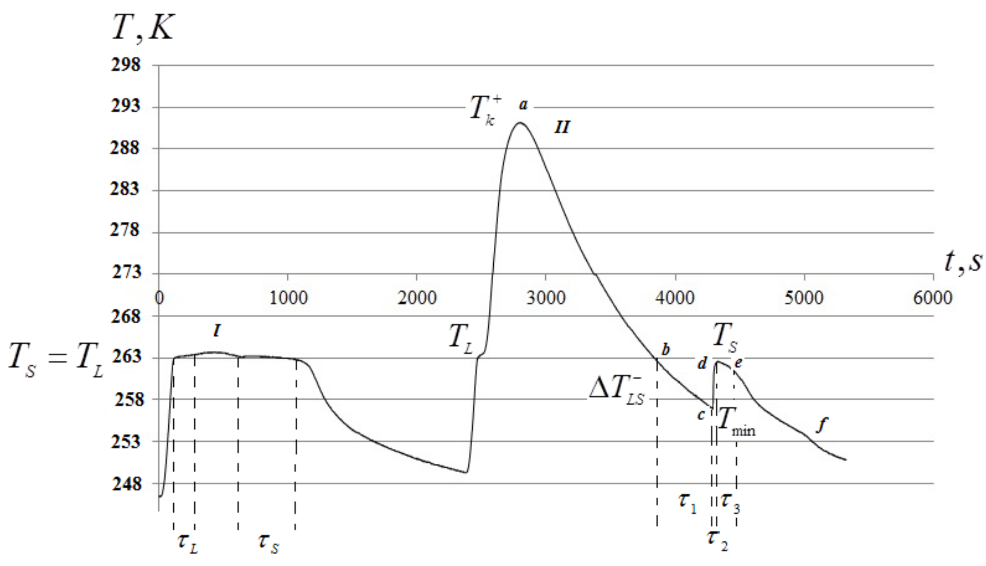


Рисунок 1 – Экспериментальные термограммы эвтектики, характеризующие переход от КРК (I) к НРВК (II)

Полученные методом ДТА энтальпии плавления и неравновесно-взрывной кристаллизации образца оказались равными ΔH_{LS} =193,7 кДж/кг, ΔH_{SL} =168,0 кДж/кг соответственно. Видно, что энтальпия кристаллизации на 20% меньше, чем энтальпия плавления.

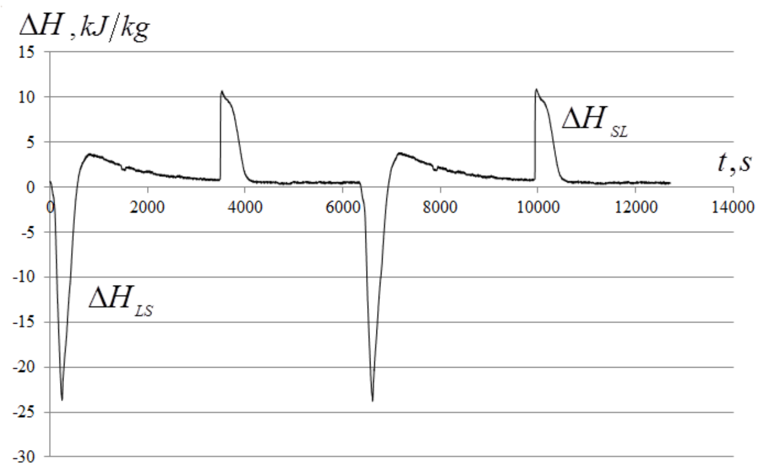


Рисунок 2 – Экспериментальные термограммы эвтектического состава, полученные методом ДТА

Причина этого расхождения, скорее всего, заключается в следующем: плавление происходит очень медленно, так, что выполняется условие квазиадиабатичности, при котором тепловой эффект пропорционален площади соответствующего эндо-пика на кривой ДТА. Кристаллизация же реализовывалась в условиях значительного переохлаждения по схеме «взрывного» типа на начальном этапе. В этой ситуации условие квазиадиабатичности не выполняется, в связи с чем нарушается линейность между количеством теплоты и площадью экзо-эффекта, что, возможно, и приводит к гистерезису эндо- и экзоэффектов на кривых ДТА. При квазиравновесной кристаллизации подобных эффектов не наблюдается.

В процессе кристаллизации эвтектики в системе $H_2O - Na_2S_2O_3 \cdot 5H_2O$ участвуют два компонента: вода и пентагидрат тиосульфата натрия, поэтому представляет интерес расчет активностей обоих компонентов как при температуре T_E, т.е. на момент начала равновесной кристаллизации (КРК), так и в области переохлаждения при температуре $T_{\min}$.

Активности воды $a_E^{H_2O}$ и пентагидрата тиосульфата натрия a_E^{TCH-5} в жидкой эвтектике на момент начала КРК при эвтектической температуре T_E рассчитывали по уравнению Шредера [8].

$$a_E^{H_2O} = \exp[\frac{\Delta H_{LS}^{H_2O}}{R}(\frac{1}{T_L^{H_2O}} - \frac{1}{T_E})] \quad (1)$$

$$a_E^{TCH-5} = \exp[\frac{\Delta H_{LS}^{TCH-5}}{R}(\frac{1}{T_L^{TCH-5}} - \frac{1}{T_E})] \quad (2)$$

где $\Delta H_{LS}^{H_2O}$ и ΔH_{LS}^{TCH-5} – энтальпии плавления льда и пентагидрата тиосульфата натрия, $T_L^{H_2O}$ и T_L^{TCH-5} – температуры плавления льда и тиосульфата натрия пятиводного.

Коэффициенты активности воды $\gamma_E^{H_2O}$ и пентагидрата γ_E^{TCH-5} в тех же условиях находили из отношений активностей к мольным концентрациям компонентов в эвтектике ($X_E^{H_2O}, X_E^{TCH-5}$):

$$\gamma_E^{H_2O} = a_E^{H_2O} / X_E^{H_2O}\ ;\ \gamma_E^{TCH-5} = a_E^{TCH-5} / X_E^{TCH-5}\ . \tag{3}$$

Дальше в работе оценивались энергии активации в эвтектике как со стороны воды $W_E^{H_2O}$, так и со стороны тиосульфата натрия W_E^{TCH-5}: [9]

$$W_E^{H_2O} = \frac{\Delta H_{LS}^{H_2O}(1-\frac{T_E}{T_L^{H_2O}}) + RT_E \ln X_E^{H_2O}}{(1 - X_E^{H_2O})^2}\ , \tag{4}$$

$$W_E^{TCH-5} = \frac{\Delta H_{LS}^{TCH-5}(1-\frac{T_E}{T_L^{TCH-5}}) + RT_E \ln X_E^{TCH-5}}{(1 - X_E^{TCH-5})^2}\ . \tag{5}$$

Анализ перечисленных выше параметров в переохлажденной метастабильной области на момент начала «взрывной» кристаллизации представляет особый интерес. Обозначим энергии активации $\omega_E^{H_2O}$, ω_E^{TCH-5} соответственно.

В данном случае работает «логарифмика Шредера» [8] и уравнения (1), (2), (4), (5) можно записать в виде:

$$\alpha_E^{H_2O} = \exp[\frac{\Delta H_{LS}^{H_2O}}{R}(\frac{1}{T_{\min}^{H_2O}} - \frac{1}{T_{\min}^{E}})], \tag{6}$$

$$\alpha_E^{TCH-5} = \exp[\frac{\Delta H_{LS}^{TCH-5}}{R}(\frac{1}{T_{\min}^{TCH-5}} - \frac{1}{T_{\min}^{E}})], \tag{7}$$

$$\omega_E^{H_2O} = \frac{\Delta H_{LS}^{H_2O}(1-\frac{T_{\min}^{E}}{T_{\min}^{H_2O}}) + RT_{\min}^{E} \ln X_E^{H_2O}}{(1 - X_E^{H_2O})^2}\ , \tag{8}$$

$$\omega_E^{TCH-5} = \frac{\Delta H_{LS}^{TCH-5}(1-\frac{T_{\min}^{E}}{T_{\min}^{TCH-5}}) + RT_{\min}^{E} \ln X_E^{TCH-5}}{(1 - X_E^{TCH-5})^2}\ . \tag{9}$$

где $T_{\min}^{H_2O} = 265$ K и $T_{\min}^{TCH-5} = 277$ K – температуры плавления льда и тиосульфата натрия пятиводного при «взрывной» кристаллизации.

В таблице 2 приведены значения активностей $\alpha_E^{H_2O}$, α_E^{TCH-5}, коэффициентов активности $\gamma_E^{H_2O}$, γ_E^{TCH-5} и энергий активации $W_E^{H_2O}$, W_E^{TCH-5} $\omega_E^{H_2O}$, ω_E^{TCH-5} компонентов системы.

Таблица 2. Значения активностей $\alpha_E^{H_2O}$, α_E^{TCH-5}, коэффициентов активности $\gamma_E^{H_2O}$, γ_E^{TCH-5} и энергий активации $W_E^{H_2O}$, W_E^{TCH-5} $\omega_E^{H_2O}$, ω_E^{TCH-5} компонентов системы

Вид кристал-лизации	$\alpha_E^{H_2O}$	α_E^{TCH-5}	$\gamma_E^{H_2O}$	γ_E^{TCH-5}	$W_E^{H_2O}$ кДж/моль	W_E^{TCH-5} кДж/моль	$\omega_E^{H_2O}$ кДж/моль	ω_E^{TCH-5} кДж/моль
КРК	0,885	0,013	0,951 *(0,950)*	0,187 *(0,189)*	23,172	4,194	-	-
НРВК	0,853	0,091	0,916 *(0,911)*	1,26 *(1,34)*	-	-	40,443	-0,706

Значения энергии $W_E^{H_2O}$ и W_E^{TCH-5} были использованы для проверки коэффициентов активностей $\gamma_E^{H_2O}$ и γ_E^{TCH-5} по методике [10] (см. таблица 1 выделено курсивом):

$$\gamma_E^{H_2O} = \exp[-(1 - X_E^{H_2O})^2 \cdot W_E^{H_2O} / RT_E], \quad (10)$$

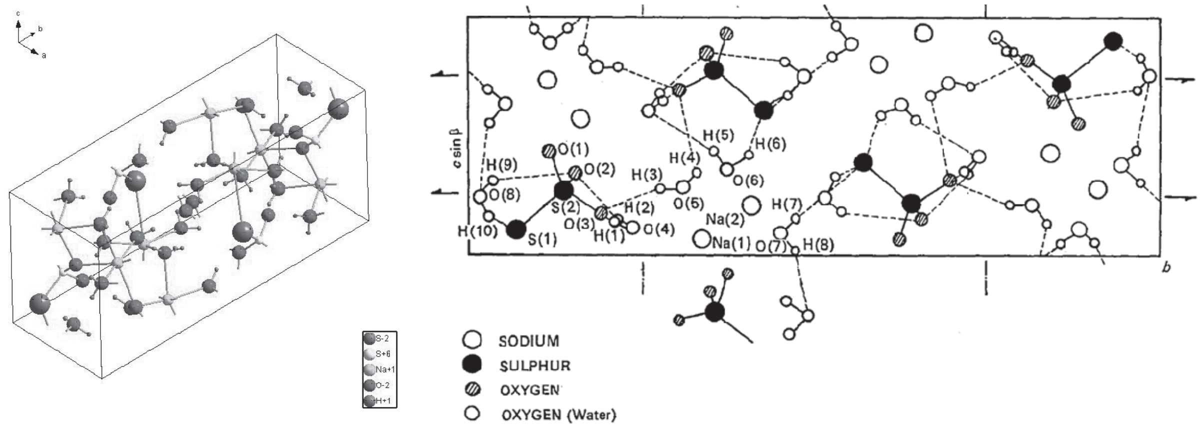
$$\gamma_E^{TCH-5} = \exp[-(1 - X_E^{TCH-5})^2 \cdot W_E^{TCH-5} / RT_E] \cdot \quad (11)$$

Кристаллизация эвтектики имеет особый характер и в настоящее время является актуальной научной задачей [11-14]. Действительно, температура начала и конца затвердевания такого раствора совпадает, эвтектика затвердевает при низшей температуре, и в ней практически при одной температуре выделяются оба вида кристаллов.

Система водородных связей в структуре моноклинных кристаллов ТСН-5 разбита на четыре класса: две сильные (H_2O – кислород молекулы $Na_2S_2O_3$), две $H_2O – H_2O$ и три $H_2O – S$ [15]. Один из атомов водорода при этом не участвует в водородной связи. На рис. 3 показана структура кристаллогидрата $Na_2S_2O_3{\cdot}5H_2O$, свидетельствующая о достаточно сложном переплетении различных связей между атомами Na+, ионами $S_2O_3^{2-}$ и молекулами воды – от ковалентных и ионных до водородных и ван-дер-ваальсовых.

Кристаллы $Na_2S_2O_3{\cdot}5H_2O$ образуют моноклинную решётку с координационным числом Z = 8 и параметрами решётки a = 5,94, b = 21,57, c = 7,53 Å. Наличие анизотропии связей свидетельствует о том, что при плавлении сначала разрушаются слабые связи с сохранением ближнего порядка между отдельными молекулами, либо происходит частичная дегидратация ТСН-5 за счет слабосвязанных молекул H2O с образованием гидрата с меньшим количеством воды $Na_2S_2O_3{\cdot}nH_2O$, где n<5.

В небольшом интервале температур (выше TL) в растворе сосуществуют молекулярные фракции различного состава, в том числе и кристаллоподобные кластеры. При охлаждении раствора слабые связи могут быстро восстанавливаться, а молекулы $Na_2S_2O_3{\cdot}nH_2O$ за счет перегидратации должны восстанавливать стехиометрию ТСН-5.



а) б)

Рисунок 3 – Структура $Na_2S_2O_3·5H_2O$: а) кристаллическая решетка;
б) проекция вдоль оси b

В кристаллической структуре льда (рис. 4) [16] каждая молекула воды окружена четырьмя ближайшими к ней молекулами, которые находятся на одинаковых расстояниях от нее, равных 2,76 Å и размещенных в вершинах правильного тетраэдра.

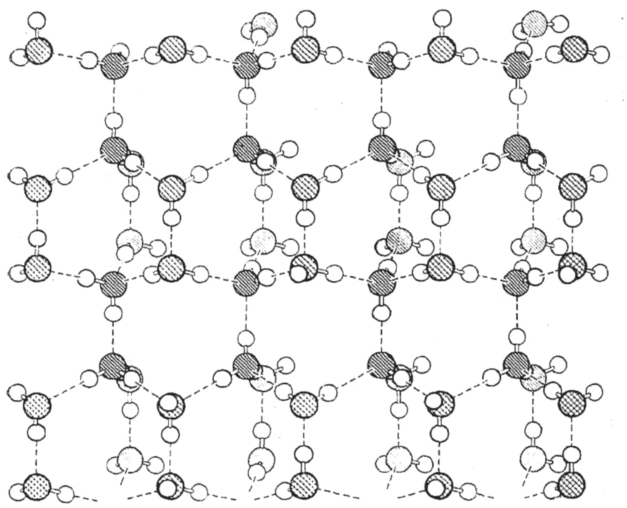


Рисунок 4 – Структура льда

В кристаллах льда задействованы все четыре водородные связи на каждую молекулу, т.е. все молекулы оказываются жестко соединенными между собой системой связей в виде регулярной пространственной решетки. Структурным отличием жидкой воды от кристаллического льда является пространственно-временная хаотическая незавершенность системы связей. В каждый момент времени в ней присутствуют молекулы, охваченные всеми возможными (от 0 до 4) количествами водородных связей.

Согласно кластерно-коагуляционной модели кристаллизации [6], при незначительных перегревах кристаллизация эвтектики идет как бы на собственных затравках, и затвердевание носит равновесный характер.

При кристаллизации сначала выделяется кристаллик одного компонента, а когда рядом в жидкости остается много молекул другого компонента, образуется его кристалл и т. д. Следовательно, есть компонент, ведущий кристаллизацию. Он создает основу (скелет), а второй компонент, кристаллизующийся за ним, остается в межосных пространствах этого скелета. Ведущим компонентом в этой системе, скорее всего, является $Na_2S_2O_3{\cdot}5H_2O$, т.к. имеет более высокую температуру плавления.

Рассмотрим теперь кристаллизацию типа НРВК. За время τ_1 во всем объёме образца V (массой m) идет процесс накопления кристаллоподобных образований. В реальном метастабильном состоянии распределение этих частиц (образований) неоднородно. В наиболее «благоприятной» области образца объёмом V_x (массой m_x) концентрация кластеров–зародышей достигает критического значения $\eta_\kappa = V_x / V = m_x / m$. Близость частиц способствует их быстрому объединению, т.е. коагуляции за время с образованием первичной твердой массы m_x. Дальше затвердевание за время τ_2 происходит как бы на собственных затравках, сформировавшихся за время τ_1 и τ_2, и носит изотермический характер при температуре плавления T_L. Массовая кристаллизация происходит путем присоединения к начальному остову объёмом V_x (массой m_x) оставшихся в образце молекул, кластеров, вторичных зародышей, новых коагуляционных очагов и т.д. На этом этапе за время τ_3 затвердевает оставшаяся часть $m' = m - m_x$ (или $1-\eta_k$) образца.

Следовательно, по мере повышения температуры в жидкой фазе происходит «дробление» молекулярных группировок с одновременным образованием комплексов $Na_2S_2O_3{\cdot}nH_2O$, $Na_2S_2O_3$, ионов Na^+, $S2O32^-$ и молекул H_2O. Естественно, что для восстановления связей хотя бы до размеров зародышей требуется инкубационный период, а система переходит в метастабильное переохлажденное состояние. «Взрывная» кристаллизация происходит за счет коагуляции зародышей при их сближении [17-24].

Активность можно рассматривать как величину, которая характеризует степень связанности частиц. Активность воды $\alpha_E^{H_2O}$ в эвтектике больше, чем активность α_E^{TCH-5} ТСН-5. Однако при НРВК активность воды немного падает, а активность ТСН-5 увеличивается. Это объясняется, скорее всего, тем, что вода представляется в виде модели, в которой 70% молекул занимают льдообразующие участки. Они имеют гидрофобный характер, т.к. связаны водородными связями. Гидрофильные (т.е. активные) молекулы воды, которые составляют примерно 30% всех молекул, обладают большой кинетической энергией и, подобно частицам газа, находятся в беспорядочном хаотическом движении. Под действием этих молекул кластеры (льдообразные ассоциаты, гидраты и т.д.) разрушаются. Степень разрушения зависит от кинетической энергии свободных молекул воды и их количества [25], а так как НРВК возникает при значительных перегревах, то как раз и увеличивается энергия и количество свободных молекул воды.

Энергия активации – это избыточное количество энергии (по сравнению со средней величиной), которым должна обладать частица в момент столкновения, чтобы быть способной к какому-либо взаимодействию. Молекулы, которые обладают таким количеством энергии, называются активными. Повышение температуры приводит к увеличению числа активных молекул в системе. Для воды при КРК энергия активации соизмерима с энергией активации процесса разрыва водородных связей ≈4,0 ккал/моль (≈17 кДж/моль). При НРВК значение энергии активации увеличилось в -≈2 раза. Скорее всего, это объясняется тем, что в растворе повысилось количество молекул свободной воды, т.к. добавились молекулы кристаллизационной воды гидрата тиосульфата. Например, в работе при изучении кинетики экстракции воды трибутилфосфатом (ТБФ) было получено значение энергии активации диффузии воды ≈9,2±0,6 ккал/моль (≈37 кДж/моль) [26]. Можно предположить, что диффузия молекул воды связана с одновременным разрывом нескольких водородных связей, т.е. с временным нарушением структуры раствора, что и может служить объяснением высокого значения энергии активации, причем, чем выше энергия активации, тем медленнее протекает процесс, а чем меньше – тем быстрее.

При НРВК $Na_2S_2O_3{\cdot}5H_2O$ имеет отрицательное значение энергии активации. Это означает, что для успешного протекания процесса энергия должна не подводиться к реагирующим частицам, а отводиться от них. Появление отрицательных значений энергии активации может рассматриваться как кинетический критерий участия молекул молекулярных комплексов в химическом процессе. В случае ТСН-5 при значительных переохлаждениях уже образовались комплексы $Na_2S_2O_3{\cdot}4H_2O$ и для завершения процесса необходима одна молекула воды, которая и заберет избыточную энергию комплекса:

$$\beta–Na_2S_2O_3{\cdot}4H_2O\ (мет.) + H_2O\ {\cdot}\alpha–Na_2S_2O_3{\cdot}5H_2O.$$

Таким образом, гидратация *Na2S2O3·5H2O* последней молекулой воды является экзотермическим процессом.

Коэффициент активности - это величина, отражающая все имеющиеся в данной системе явления, вызывающие изменения подвижности ионов. Он зависит не только от концентрации данного вещества, но и от концентрации посторонних ионов, присутствующих в данном растворе [27]. У воды коэффициент активности незначительно уменьшается при НРВК. А у $Na_2S_2O_3{\cdot}5H_2O$ он увеличивается в -≈7 раз. Возможно, что увеличение значения коэффициента активности и связано с присоединением последней молекулы воды, чтобы получился стехиометрический состав $Na_2S_2O_3{\cdot}5H_2O$.

Выводы. При изучении теплофизических свойств циклическим термическим анализом (ЦТА) и совмещенным методом ЦТА и ДТА на примере эвтектики в системе $H_2O – Na_2S_2O_3{\cdot}5H_2O$ были обнаружены «критические» границы перегрева жидкой фазы *Тк+* относительно температуры плавления, разграничивающие последующие процессы кристаллизации от «взрывной» (после ощутимых переохлаждений) к квазиравновесной с незначительным переохлаждением, что важно для ФП ХАМ. Также были определены значения энтальпии плавления и кристаллизации. И хотя энтальпия эвтектики всегда меньше энтальпий каждого из компонентов, она всегда значительна, а вместе с низкой переохлаждаемостью и высокой стабильностью, эвтектический состав является оптимальным выбором для создания ФП ХАМ.

Список литературы

1. Официальный сайт. Международные перевозки скоропортящихся грузов – основные аспекты и необходимые документы. [Электронный ресурс]. URL:https://vedinform.com/freight/skoroport (Дата обращения: 25.08.2023).
2. Официальный сайт. Транспортирование скоропортящейся продукции. [Электронный ресурс]. URL: https://znaytovar.ru/s/Transportirovanie-skoroportyashhe.html (Дата обращения: 25.08.2023).
3. Искендеров Э.Г. Вариативность значений энтальпии плавления льда и льдосодержащих смесей // Известия вузов. Северо-Кавказский регион. Технические науки. 2021. - № 1. – С. 85-90.
4. Абрамов Г.А., Шестаков Д.В., Жуманбаев С.М. и др. Выбор наиболее эффективного охлаждающего агента методом определения показателей температурного поля в стендовом эксперименте на биологических тканях // Вестник КАЗНМУ № 4. – 2020. – С. 429-432.
5. Мозговой А.Г., Шпильрайн Э.Э. и др. Обзоры по теплофизическим свойствам. – М. – №2 (82). – 1990. – 105 с.
6. Александров В.Д. Кинетика зародышеобразования и массовой кристаллизации переохлажденных жидкостей и аморфных сред / В.Д. Александров. – Донецк: Донбасс, 2011. – 591 с.
7. Александров В.Д. Экспериментальное исследование влияния перегрева жидкой фазы относительно температуры плавления TL на процесс кристаллизации натрия тиосульфата пятиводного. // Наукові праці Донецького національного технічного університету. Серія: Хімія і хімічна технологія. – 2005. -№ 108(8). – С. 65-71.
8. Крестовников А.Н., Вигдорович В.Н. Химическая термодинамика. – М.: Металлургия, 1974. –256 с.
9. Александров В.Д., Фролова С.А., Амерханова Ш.К. Особенности кристаллизации эвтектического сплава в системе галлий-олово. – Металлы. – Москва. – 2016. – №3. – С. 47-52.
10. Уббелоде А.Р. Расплавленное состояние вещества. – М.: Металлургия, 1982. – 376 с.

11. Ahmad Alhadid, Christian Jandl. Estimating the nonideality of eutectic systems containing thermally unstable substances // The Journal of Chemical Physics- 159(9).- September 2023. DOI:10.1063/5.0158985.

12. James D. Martin, Angela M. Shipma. Deep Dive into Eutectics: On the Origin of Deep and Elevated Eutectics // Journal of The Electrochemical Society -170(6).- June 2023. DOI:10.1149/1945-7111/acdd27

13. Ivan Klbik, Katarína Čechová. Cryoprotective Mechanism of DMSO Induced by the Inhibitory Effect on Eutectic NaCl Crystallization // The Journal of Physical Chemistry Letters- 13(1):11153–11159. - November 2022. DOI:10.1021/acs.jpclett.2c03003.

14. Mohammadreza Akbarkermani. Fatma Elif Genceli Güner. Eutectic freeze crystallization in the boric acid–water system // Chemical Papers.- 77(1). -June 2023. DOI:10.1007/s11696-023-02907-z

15. Hiroshi, Kimura Nucleation of molten $Na_2S_2O3{\bullet}5H_2O$ and some other similar hydrates. A termodynamic observation. // Ind. And Eng. Chem. Fundam, 1980. – V.19. – №3. – P. 251 – 253.

16. Маленков Г.Г. Вода. // Химическая энергия недр. – М.: Советская энциклопедия, 1988. –763–769с.

17. Современная кристаллография (в четырех томах). Т. 3. Образование кристаллов. А.А. Чернов, Е.И. Гиваргизов, Х.С. Багдасаров и др. – М.: Наука, 1980. – 302 с.

18. Фольмер М. Кинетика образования новой фазвы. – М.: Наука, 1986. – 206 с.

19. Козлова О.Г. Рост и морфология кристаллов 3-е изд. – М.: МГУ, 1980. – 357 с.

20. Портнов В.Н. Возникновение и рост кристаллов. – М.: Физматлит. 2006. – 328 с.

21. Яценко О.Б. Особенности кристаллизации и плавления компонентов в водных растворах // Конденсированные среды и межфазные границы. – 1999. – Т. 1. № 4. – С.328-333.

22. Таран Ю.Н. Парный рост кристаллов в славах эвтектического типа. // Расширенные тезисы 6 международной конференции по росту кристаллов НКРК. – Москва. – 1980 – С. 46-48.

23. Алиханов В.А., Худоян М.В. Методика получения направленно-кристаллизованных эвтектик // Известия вузов. Северо-Кавказский регион. – 2019. – № 1. – С.77-81.

24. Гуськов А.П. Самоорганизация распределения компонент при эвтектической кристаллизации. // Тезисы докладов XII национальной конференции по росту кристаллов НКРК 2006. – Москва. – 2006. – С. 86.

25. Овчинников В.П., Вяхирев В.И., Кузнецов Ю.С. Солевая композиция для цементирования скважин и вскрытия продуктивных пластов. – М. ИРЦ Газпром – 1996. – 28 с.

26. Последние достижения в области жидкостной экстракции. Под редакцией Хансона К.М.// Химия. - 1974.- 448 с.

27. Крешков А.П. Основы аналитической химии. - М.: Из-во «Химия», 1976.- 400 с.

О.В. Соболь[1], С.А. Фролова[1], А.М. Моржухин[2]

[1] «Донбасс ұлттық құрылыс және архитектура академиясы» ФМБЖОО, Макеевка, Ресей

[2] «Дубна» Университеті» ФМБЖОО, Дубна, Ресей

$H_2O – Na_2S_2O_3{\cdot}5H_2O$ жүйесінде эвтектикалық құрамның кристалдануының термодинамикалық параметрлерін талдау

Аңдатпа. Фазалық ауысуларға (ФА ТА) негізделген тоңазытқыш аккумуляторларын әзірлеуде қазіргі уақытта негізгі күш әртүрлі құрылымдық құрылғылар мен тоңазытқыш аккумулятордың көлемі, бетінің ауданы, жылу беру коэффициенті (немесе жылу кедергісі), салқындатқыш материалдың (САМ) батарея материалымен интерфейсі, температура және зарядтау және разрядтау уақыты, энергия тиімділігі сияқты параметрлерді есептеуге бағытталған. Сонымен қатар фазалық ауысу процестерінің өзін және олардың химиялық агенттердің тиімді жұмыс істеуіне әсерін есепке алудың физикалық-химиялық мәселелері нашар қамтылған. Бұл жұмыста тәжірибелік түрде алынған термограммаларды пайдалана отырып, $H_2O – Na_2S_2O_3{\cdot}5H_2O$ (ТСН-5) жүйесіндегі эвтектикалық құрамды балқу және кристалданудың кинетикалық және термодинамикалық параметрлерін талдадық, оны Т=- 11°C кезінде жұмыс істейтін САМ ретінде пайдалануға болады. Сұйық фазаның балқу температурасына қатысты қызу мөлшеріне және одан әрі салқындатуға байланысты кристалданудың екі түрі жүретіні анықталды. Бірінші түрі – T_L=T_E температурасымен сәйкес келетін температурада болатын квази тепе-теңдік кристалдану (КТТК). Екінші түрі -

белгілі бір кристалдану алдындағы асқын салқындатуларға жеткеннен кейін басталатын тепе-теңдіксіз жарылғыш кристалдану (ТТЖК). Эвтектикада белсенділік, белсенділік коэффициенттері және активтену энергиялары T_E температурасында, яғни тепе-теңдік кристалдану (ТТК) кезінде және де салқындату аймағындағы температурада T_{min} тепе-теңдіксіз жарылғыш кристалдану (ТТЖК) басталғанда да есептелді.

Түйін сөздер: салқындатқыш материал, термиялық талдау, ерітінді, эвтектика, балқу, кристалдану, су.

O. Sobol[1], S. Frolova[1], A. Morzhukhin[2]

[1]Donbas National Academy of Civil Engineering and Architecture, Makeevka, Russia

[2]Dubna University, Dubna, Russia

Analysis of thermodynamic parameters of crystallization of eutectic composition in the H_2O - $Na_2S_2O_3·5H_2O$ system

Abstract. In the development of cold accumulators based on phase transitions (CA PT), the main efforts are currently aimed at calculating various structural devices and parameters such as volume, surface area of the CA, heat transfer coefficient (or thermal resistance) at the boundary of the cold storage material (CSM) with the battery material, charging and discharge temperature and time, energy efficiency. At the same time, the physical and chemical problems of accounting for the processes of phase transitions themselves and their impact on the effective operation of CA are poorly covered. In this work, the analysis of kinetic and thermodynamic parameters of melting and crystallization of eutectic composition in the H_2O- $Na_2S_2O_3·5H_2O$ system (TSN-5) was carried out using experimentally obtained thermograms. Depending on the amount of heating of the liquid phase with respect to the melting temperature and further cooling, there are two types of crystallization. The first kind is quasi-equilibrium crystallization (QEC), which occurs at a temperature coinciding with that of $T_L = T_E$. The second species is non-equilibrium-explosive crystallization (NEC), which begins after certain pre-crystallization $\Delta T_{LS}^{-} = T_L - T_{min}$ hypothermia have been achieved. Activities $\grave{a}_E^{H_2O}$, α_E^{TCH-5}, activity coefficients $\gamma_E^{H_2O}$, γ_E^{TCH-5}, and activation energy $W_E^{H_2O}$, W_E^{TCH-5} were calculated in eutectics, both at T_E, i.e., equilibrium crystallization (QEC), and in the supercooling region at Tmin at the onset of non-equilibrium-explosive crystallization (NEC).

Keywords: cold storage material, thermal analysis, solution, eutectics, melting, crystallization, water.

References

1. Oficial'nyj sajt. Mezhdunarodnye perevozki skoroportyashchihsya gruzov – osnovnye aspekty i neobhodimye dokumenty [Official website. International perishable goods transportation - basic aspects and necessary documents]. Available at: https://vedinform.com/freight/skoroport, free. (accessed: 25.08.2023).

2. Oficial'nyj sajt. Transportirovanie skoroportyashchejsya produkcii [Official website. Transportation of perishable products]. Available at: https://znaytovar.ru/s/Transportirovanie-skoroportyashhe.html (accessed: 25.08.2023).

3. Iskenderov E.G. Variativnost' znachenij ental'pii plavleniya l'da i l'dosoderzhashchih smesej. Izvestiya vuzov. Severo-Kavkazskij region. Tekhnicheskie nauki [Variability of values of the enthalpy of melting ice and ice-containing mixtures. Bulletin of universities. North Caucasus region. Technical sciences],1, 85-90(2021).

4. Abramov G.A., Shestakov D.V., Zhumanbaev S.M., et al. Vybor naibolee effektivnogo ohlazhdayushchego agenta metodom opredeleniya pokazatelej temperaturnogo polya v stendovom

eksperimente na biologicheskih tkanyah. Vestnik KAZNMU [Selection of the most effective cooling agent by the method of determining the temperature field parameters in the bench experiment on biological tissues. Vestnik VZALMU], 4, 429-432(2020).

5. Mozgovoy A.G., Shpilrein E.E., et al. Obzory po teplofizicheskim svojstvam [Reviews on thermophysical properties]. 2 (82).105 (1990).

6. Aleksandrov V.D. Kinetika zarodysheobrazovaniya i massovoj kristallizacii pereohlazhdennyh zhidkostej i amorfnyh sred [Kinetics of nucleation and mass crystallization of supercooled liquids and amorphous media] (Donetsk, Donbass, 2011, 591 p.)

7. Aleksandrov V.D. Eksperimental'noe issledovanie vliyaniya peregreva zhidkoj fazy otnositel'no temperatury plavleniya TL na process kristallizacii natriya tiosul'fata pyativodnogo. Naukovi praci Donec'kogo nacional'nogo tekhnichnogo universitetu. Seriya: Himiya i himichna tekhnologiya [A pilot study of impact of overheating of a liquid phase concerning temperature of melting of TL on process of crystallization of sodium of thiosulphate five-water]. Donetsk. 108(8). 65-71(2005).

8. Krestovnikov A.N., Vigdorovich V.N. Himicheskaya termodinamika [Chemical thermodynamics]. (M.: Metallurgy, 1974, 256 p.)

9. Aleksandrov V.D., Frolova S.A., Amerkhanova S.K. Osobennosti kristallizacii evtekticheskogo splava v sisteme gallij-olovo. Metally [Features of crystallization of eutectic alloy in gallium-tin system. Metals]. 3. 47-52(2016).

10. Ubelode A.R. Rasplavlennoe sostoyanie veshchestva [Molten state of matter]. (M., Metallurgy, 1982, 376 p.)

11. Ahmad Alhadid, Christian Jandl. Estimating the nonideality of eutectic systems containing thermally unstable substances. The Journal of Chemical Physics 159(9). September 2023. DOI:10.1063/5.0158985

12. James D. Martin, Angela M. Shipma. Deep Dive into Eutectics: On the Origin of Deep and Elevated Eutectics. Journal of The Electrochemical Society 170(6). June 2023. DOI:10.1149/1945-7111/acdd27.

13. Ivan Klbik, Katarína Čechová. Cryoprotective Mechanism of DMSO Induced by the Inhibitory Effect on Eutectic NaCl Crystallization. The Journal of Physical Chemistry Letters. 13(1):11153–11159. November 2022. DOI:10.1021/acs.jpclett.2c03003.

14. Mohammadreza Akbarkermani. Fatma Elif Genceli Güner. Eutectic freeze crystallization in the boric acid–water system. Chemical Papers. 77(1). June 2023. DOI:10.1007/s11696-023-02907-z.

15. Hiroshi, Kimura Nucleation of molten $Na_2S_2O_3 \bullet 5H_2O$ and some other similar hydrates. A termodynamic observation. Ind. And Eng. Chem. Fundam. 19(3). 251 – 253(1980).

16. Malenkov G.G. Water. Chemical energy of the subsoil. (Moscow, Soviet Encyclopedia, 1988. 763-769).

17. Sovremennaya kristallografiya [Modern crystallography] (in four volumes). T. 3. Crystal formation. A.A. Chernov, E.I. Givargizov, H.S. Bagdasarov and others. (Moscow, Nauka, 1980, 302 p.)

18. Folmer M. Kinetika obrazovaniya novoj fazvy [Kinetics of new phase formation]. (Moscow, Science, 1986. 206 p.)

19. Kozlova O.G. Rost i morfologiya kristallov 3-e izd [Crystal Growth and Morphology 3rd ed]. (Moscow, MSU, 1980. 357 p.)

20. Portnov V.N. Vozniknovenie i rost kristallov [Crystal origin and growth]. (Moscow, Fizmatlit, 2006, 328 p.)

21. Yatsenko O.B. Osobennosti kristallizacii i plavleniya komponentov v vodnyh rastvorah. Kondensirovannye sredy i mezhfaznye granicy [Features of crystallization and melting of components in aqueous solutions. Condensed media and interfacial boundaries].1(4).328-333(1999).

22. Ram Yu.N. Parnyj rost kristallov v slavah evtekticheskogo tipa. Rasshirennye tezisy 6 mezhdunarodnoj konferencii po rostu kristallov NKRK [Paired crystal growth in eutectic glory. Extended theses of the 6th international conference on crystal growth of the NKRK]. Moscow. 46-48(1980).

23. Alikhanov V.A., Khudoyan M.V. Metodika polucheniya napravlenno-kristallizovannyh evtektik [Procedure for obtaining directional crystallized eutectics. / News of universities. North Caucasus region]. 1. 77-81(2019).

24. Guskov A.P. Samoorganizaciya raspredeleniya komponent pri evtekticheskoj kristallizacii. Tezisy dokladov XII nacional'noj konferencii po rostu kristallov NKRK [Self-organization of component distribution during eutectic crystallization. Abstracts of reports of the XII National Conference on Crystal Growth of the NKRK]. Moscow. 86(2006).

25. Ovchinnikov V.P., Vyakhirev V.I., Kuznetsov Y.S. Solevaya kompoziciya dlya cementirovaniya skvazhin i vskrytiya produktivnyh plastov [Salt composition for cementing wells and penetrating productive formations]. (M. IRC Gazprom, 28 (1996).

26. Poslednie dostizheniya v oblasti zhidkostnoj ekstrakcii [Recent advances in liquid extraction]. Edited by Hanson K.M. (Chemistry, 1974, 448 p.)

27. Kreshkov A.P. Obzory po teplofizicheskim svojstvam [Fundamentals of analytical chemistry. From Chemistry]. (M.,1976, 400)

Сведения об авторах:

Соболь Оксана Викторовна – кандидат химических наук, доцент кафедры физики и прикладной химии, Донбасская национальная академия строительства и архитектуры, ул. Державина, 2, Макеевка, Россия.

Фролова Светлана Александровна – кандидат химических наук, доцент, заведующая кафедрой физики и прикладной химии, Донбасская национальная академия строительства и архитектуры, ул. Державина, 2, Макеевка, Россия.

Моржухин Артём Маркович – аспирант, старший преподаватель кафедры химии, новых технологий и материалов, Федеральное государственное бюджетное образовательное учреждение высшего образования «Университет «Дубна», ул. Университетская, 19, Дубна, Россия.

Sobol Oksana – PhD, Associate Professor, Department of Physics and Applied Chemistry, Donbas National Academy of Civil Engineering and Architecture, Derzhavin str., 2, Makeevka, Russia.

Frolova Svetlana – PhD, Associate Professor, Head of the Department of Physics and Applied Chemistry, Donbas National Academy of Civil Engineering and Architecture, 2 Derzhavin str., Makeevka, Russia.

Morzhukhin Artyom – graduate student, Senior Lecturer, Department of Chemistry, Federal State Budgetary Educational Institution of Higher Education Dubna University, 19 Universitetskaya str., Dubna, Russia.

IRSTI 62.35.00:44.01.91

Ye. Zhatkanbayev[1,2], K. Kurtibay[1], Zh. Zhatkanbayeva[2], A. Kayubaliyeva[1], A. Ussenova[1], A. Kappassuly[1], Sh. Turarbek[1], D. Sembaeva[1], E. Moldagulova[1]

[1]*Scientific and Production Center for Ecological and Industrial Biotechnology LLP, Astana, Kazakhstan*
[2]*L.N. Gumilyov Eurasian National University, Astana, Kazakhstan*
(E-mail: kurtibayqb@gmail.com)
Corresponding author: [1,2]*erlan.ntp@mail.ru*

Wastewater treatment systems based on plant-microbial fuel cells

Abstract. *The article presents data on the current state of using combined engineered wetlands and microbial fuel cells and on the factors that provide wastewater treatment and power generation. Wastewater treatment is one of the energy-intensive industries, with most of this energy being used to supply oxygen from the atmosphere to biological reactors to oxidize effluent organic matter. Both classical and new water purification methods, including biological post-treatment, are used to increase the degree of purification and reduce energy losses. The simplest and most effective way is soil cleaning using the technology of irrigation and filtration fields, as well as wetlands.*
Data are presented on plant-microbial fuel cells that perform wastewater treatment and are a way to generate electricity through microbiological oxidation of organic substances with oxygen. Fuel cells based on «Constructed Wetlands» sedimentary type, which received widespread use in recent years. Even though «Wetlands» have been widely used for wastewater treatment since the 70s of the last century, the modern use of Constructed Wetlands is an imitation of a swamp with aquatic plants, soil, and associated microorganisms due to the possibility of generating electricity in such systems.
Presented results of experimental plant-microbial fuel cells from plants (PMFCs) of various natures. As a result of the conducted studies of experimental systems with PMFCs, stainless steel, and graphite electrodes were selected, developing the highest potential, the optimal distance between the electrodes in the plant was determined, which was 10 cm and was established, that of plants more effective were plants of pistia, then rice and eihornia, which have a well-developed root system, the smallest indicators of the current generation were in the reed.
Keywords: *wetlands, plant-microbial fuel cells, purification, wastewater, electricity generation, microorganisms, electrode.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-24-41

Introduction

The sharp increase in the demand for water and energy, while simultaneously increasing their scarcity, increases the likelihood of a humanitarian crisis. In the next decade, the shortage of available fresh water and the growth in energy consumption are expected to be 40% and 36%, respectively, which will require sustainable solutions to these problems. Existing wastewater treatment methods suffer from an imbalance in the work-to-energy ratio in providing treatment standards [1]. It is now generally accepted that wastewater is a renewable energy source, holding in the chemical bonds of organic matter several times more energy than is required for their purification [2].

Thus, the concepts of converting waste to energy and developing less energy-intensive wastewater management technologies have evolved and been widely researched worldwide. Developing economical and energy-neutral technologies is currently the most demanded approach [3].

Reservoirs that have received excess organic matter (for example, from sewers or runoff from cattle farms) become a "dead zone": water blooms in them and fish and fauna die. To prevent this, it is necessary to purify water from organic contaminants. On average, developed countries annually spend up to 3% of all energy generated on such events. Conventional wastewater treatment processes consume large amounts of energy, and energy demand in these systems is expected to increase by as much as 20% over the next 15 years. The leading technologies for treating urban, agricultural, and industrial wastewater operate based on energy-intensive aerobic biological processes developed more than a century ago. Aeration accounts for 70% of the energy used in wastewater treatment [4].

The municipal wastewater treatment sector is one of the most energy-intensive industries, with most of this energy being used to supply oxygen from the atmosphere to biological reactors to oxidize the organic matter of the effluent. Wastewater treatment accounts for about 3% of the U.S. electrical load, which is approximately 110 terawatt-hours per year, or the equivalent of 9.6 million electricity consumers annually [5]. At the same time, water aeration makes up 45-75% of the cost of electricity consumption by water treatment facilities, and the purification itself and waste disposal can be up to 60% of the total operating cost. Their biological tertiary treatment is used to increase the degree of purification and reduce energy losses. The simplest and most effective way is soil cleaning using the technology of irrigation and filtration fields, as well as «wetlands».

Biological treatment methods also include plant-microbial fuel cells (PMFC), which allow minimizing energy losses by turning wastewater treatment from an energy-intensive process into a method of generating electricity. Currently, the application of spread to environmentally friendly engineering systems [6], to generate bioelectricity from rice fields [7], wetlands [8], green roofs [9] and floating ponds [10]. In addition, there is potential for PMFC to be incorporated into agricultural land without any impact on food production [11]. Indoor plants, green roofs, and rooftop gardens can also be used in PMFC to generate bioelectricity, maintain air quality, and provide ecosystem services [12].

Among plant-microbial fuel cells, fuel cells based on "Constructed Wetlands" of sedimentary type, which have been widely used for wastewater treatment since the 70 years of the last century, have become widely used.

Constructed Wetlands (CW) imitate a swamp with aquatic plants, soil, and associated microorganisms, with a controlled environment for wastewater treatment in an aesthetic, sustainable, and economical way [13]. The ability of natural wetlands to treat wastewater was discovered as early as the 1950s [14]. The first constructed wetlands for municipal wastewater treatment were established in 1974 in Germany [5] thanks to the work of K. Seidel from the Max Planck Institute, which showed the possibility of using reeds for wastewater treatment. After that, C.W.'s popularity grew in Europe and North America. CW has traditionally been used for wastewater treatment. However, since the late 1980s, it has become more widely used to treat various types of industrial, domestic, and agricultural wastewater [15].

In wetland treatment systems, aquatic plants are the primary tool for removing heavy metals and bioremediation [16]. The first CW- MFC was constructed by A.K. Yadav [17]. Since then, several more systems have been developed and tested, such as the vertical flow system [18], horizontal subsurface flow system [19], and surface flow system with floating macrophytes [20]. They have been used in the treatment of various types of wastewaters, and some of the declared maximum power density of CW- MFC was 80 mW/m^2 [20], 35 mW/m^2 [18], 43 mW/m^2 [20] and 184.75 ± 7.50 mW/m^2 respectively [21].

One of the design options for the CW is shown in Figure 1. This shows the design with a horizontal wastewater supply.

CW designs are diverse, and attempts are being made to create combined CW, which includes plant-microbial fuel cells based on CW- MFC

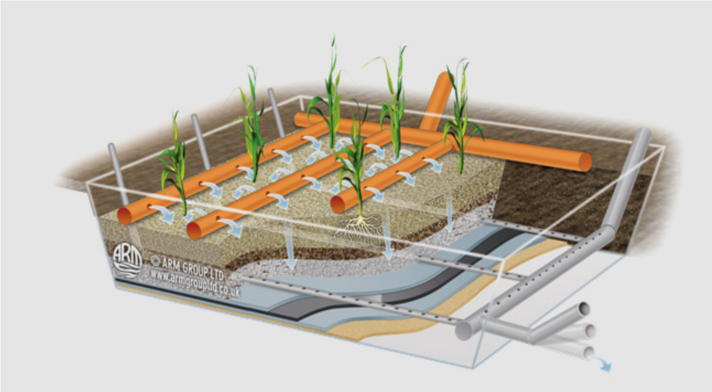


Figure 1. Diagram of a CW device.

Technology CW- PMFC allows you to generate energy continuously without causing competition for power and can work anywhere. Mild operating conditions make CW - PMFC more attractive than traditional alternative energy sources.

A typical microbial fuel cell consists of anode and cathode chambers. In the anode compartment, microorganisms oxidize organics, generating electrons and protons. Electrons flow through the electrical circuit doing work, and protons are transferred through the separator to the cathode chamber. Electrons and protons are consumed in the cathode compartment and combined with oxygen to form water.

$2\ C_6H_{12}O_6 + 6\ O_2 \rightarrow 12\ CO_2 + 24H^+ + 24e^-$ - (anode compartment)

$6O_2 + 24H^+ + 24e^- \rightarrow 12\ H_2O$ - (cathode compartment)

Chemical reactions occurring in a fuel cell are generally simple and have the following form:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 24e^-$$

Microorganisms that consume a substrate such as sugar under aerobic conditions produce carbon dioxide and water. Thus, the chemistry of the reaction is like the combustion process, where the released energy is converted directly into electrical energy.

The standard redox potential of the glucose/CO_2 pair is - 0.41 V. At the cathode side, the standard redox potential of the O_2/H_2O pair is + 0.82 V. Thus, the maximum potential difference that can be obtained between the anode and cathode in PMFC is equal to 1.23 V.

The advantages of fuel cells over other types of devices that produce energy are:

- higher efficiency;
- no moving parts and as a result, no sound pollution;
- no emissions of environmentally polluting gases such as SO_x, NO_x, CO, etc.

In contrast to the advantages, a significant disadvantage of microbial fuel cells is the low current strength, which leads to the need to connect numerous MFC into batteries, the need to use current amplifiers and converters, which ultimately increases the cost of the MFC themselves and the cost of the generated current. One of the solutions to this problem can be a combination of MFC with plants, i.e., plant-microbial fuel cells) or rhizome-microbial fuel cells within sedimentary systems [22].

According to [23] the current strength of such PMFC can reach values of 3.2 W/m^2 plant growth area. Dutch start-up Plant-e uses PMFC to generate electricity from rice fields. They promise to increase the capacity of their 100 m^2 of fuel cells to 2,800 kilowatt-hours per year [24]. MFC systems can be applied to generate electricity at the water/sediment interface in environments such as bay areas, wetlands, and rice fields. Using these systems, power generation in rice fields has been demonstrated up to ~80 mW/m^2 [25].

The ability of PMFC based on CW to produce electricity with the simultaneous processing of wastewater from livestock farms is shown. The removal efficiency was 93±1.7% chemical oxygen demand (COD); 85±5.2% for total nitrogen; 90±5.4% ammonium; 98±5.3% for total phosphorus and 99±2.9% for exchangeable phosphorus, respectively [26]. According to Zhao (2013), MFC integrated with wetlands is the most economical way to achieve both wastewater treatment and power generation goals [27].

Plants play a large role in PMFC, they provide filtration effects, nutrient absorption, and oxygen release from the roots, increasing the surface area for microorganism growth [28].

Many plant species have been researched for bioelectricity production and wastewater treatment in PMFC: this includes different types of rice [29], seaside marsh plants cordgrass and arundo cane (*Spartina anglica* and *Arundo donax*), freshwater plants evasive reed (*Arundinella anomola*), barnyard grass (*Echinochloa glabrescens*), *Pennisetum setaceum*, sucrose (*Cyprus involucratus*), ryegrass (*Lolium perenne*) [30-34], wetland plants - water hyacinth (*Echinorriea crassipes*), water morning glory (*Ipomoea aquatic*), broadleaf cattail (*Typha latifolia*), marsh calamus (*Acorus calamus*), small duckweed (*Lemna minuta*) and Indian canna (*Canna indica*) [21, 35-39].

Spartina anglica has been recognized as an ideal plant for large-scale implementation in wetland bioelectric production in the future. It provides maximum current generation and a high degree of wastewater treatment from contaminants [40]. Among floating plants, the water hyacinth (*E. crassipes*) is preferred, which is well known for its great ability to remove biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, phosphorus, organic carbon, suspended solids, phenols, pesticides, heavy metals, etc. from wastewater, also provides satisfactory current generation [41, 42].

In the CW- MFC system, the potential at the cathode is 299 mV, at the anode -341 mV. In the presence of a plant, the current generation increases up to 142% [35]. Studies have shown that the presence or absence of a plant in the field between the MFC- CW poles reduce internal resistance. Thus, the internal resistance in the presence and absence of plant root systems was 217.7 Ohm and 272.9 Ohm, respectively [43].

Due to the root secretions of different plants, a different microbial community is maintained in PMFC [44, 45]. Electrogenic microorganisms play an important role in the generation of electric current. Beneficial species of bacteria that produce electricity in PMFC have been identified and include *Geobacter spp., Ruminococcaceae spp., Desulfobulbus spp., Desulfovibrio, Bacillus, Geothrix, Pseudomonas, Shewanella, Acidobacteria* [46, 47].

Among the representatives of *Bacillus*, the main electrogenerating bacteria is *Bacillus subtilis* [48]. These bacteria are classified as electrogenic, anodophilic, and exoelectrogenic based on their ability to transfer electrons to electrodes without exogenous mediators [49]. Electrogenic bacteria (EGB) can be both gram-negative and gram-positive, they have been identified as electron donors in PMFC [50]. These microbes are grouped according to their location (on the anode or cathode) or their role in electron transport. In addition, EGB and anaerobic bacteria in sediments and surface waters oxidize available organic matter and directly transfer electrons to the anode [51].

Extracellular transfer of electrons by microorganisms to the anode is carried out in three ways:

1) mediated electron transfer, for example, *Shewanella* and *Pseudomonas* release mediators (flavins) that can transfer electrons from bacteria to the anode surface [52];

2) direct electron transfer by biofilm-forming bacteria, for example, *Shewanella* and *Geobacter* species transfer electrons through cytochromes or pili [53];

3) electron transfer through nanowires, for example, *Geobacter* and *Shewanella* use conductive processes to transfer electrons to the anode [54].

Recent studies aim to enhance electricity production by PMFC and wastewater treatment from various types of pollutants. Bulgarian researchers have shown the ability of PMFC to purify wastewater from oil products. The best results were achieved with a bottom feed of water, a 3:1 mixture of sludge and peat, the use of stainless-steel electrodes, and no separator between the aerobic and anaerobic zones. The plant was cordgrass. The oil supply was 100 mg/l crude oil (total oil content 1 mg/l, COD 4690 mg/l), the system was inoculated with highly active oil-oxidizing bacteria (*Pseudomonas veronii, Azoarcus communis, Pseudomonas chlororaphis, Pseudomonas putida, Pseudomonas libanensis*), the hydraulic retention time was 14 days. With this design and mode of operation, a maximum specific power of 10.40 mW/m^2 was achieved and the degree of purification of water and oil products was more than 99% in CW with an integrated PMFC [55].

Treatment of gray wastewater with the following composition: turbidity 15.4 NTU; COD_{total} - 477.8 mg O/l, COD_r - 380.4 mg O/l, suspended solids - 95.9 mg/l, nitrates - 7.1 mg/l and phosphates - 19.9 mg/l in the CW-MFC system with the common reed plant showed its effectiveness in 152 days for the purification of COD 91.7%, for phosphates 56.3%. The nitrate removal efficiency was above 86.5% with a current density of 33.52 achieved mW/m^2 [56].

Spanish researchers showed that CW-MFC was more effective with open circuits than with closed circuits in wastewater treatment. In the first case, cleaning was more efficient by 18%, 15%, 31% and 25% in terms of COD, HDTV, phosphates and ammonium, respectively. The optimal external resistance turned out to be 220 Ohm from the investigated resistance range from 50 to 1000 Ohm [57].

On the other hand, experiments, conducted by Indian scientists, in open-circuit and closed-circuit modes have shown that in a closed circuit the current generated is 12-20% more than in open-circuit operation and 27-49% better in removing COD [58]. The maximum power density of 320.8 mW/m^3 and current density of 422.2 mA/m^3 were achieved with a granular graphite anode and a Pt-coated carbon cloth cathode. The plant in the system was represented by the Indian shot

When adding 1/2 of the modified Hoagland's solution to the anolyte solution and potassium ferricyanide as an interelectronic transfer mediator the maximum power of 100 W/m^2 was achieved at the cathode in PMFC with the plant *S. anglica* [59]. Adding graphene oxide to anolyte PMFC gave a maximum power of 17 - 49 mW/m^2, which was higher than the control (7.7-20 mW/m^2) [60].

The addition of compost to the PMFC substrate with rice increased the maximum power density to 23 mW/m^2 [61]. Inoculation of CW-MFC with Ipomoea water plant (*I. aquatica*) with anaerobic sludge and phosphate buffer provided a maximum specific power of 12.42 mW/m^2, which was 142% higher than that of the control CW-MFC (5.13 mW/m^2) [61]. Based on results using different levels of dissolved oxygen among CW-MFC, the Chinese authors concluded that a distance of 20 cm between the anode and cathode provides an optimal COD elimination of 94.90% at a power density of 0.15 W/m^3, 339.80 W internal resistance and Coulomb efficiency of 0.31%. In addition, COD at 200mg O/L provided greater power generation (open circuit voltage 741mV, power density 0.20 W/m^3, internal resistance 339.80W and current 0.49mA) and cleaning capacity (removal 90, 45% COD) than at higher COD values. By adding 50 mM phosphate buffer solution to synthetic wastewater, relatively high conductivity and buffering capacity were achieved, resulting in improved power generation [62].

Enrichment of PMFC with raigras (*Lolium perenne*) electrogenic bacteria from another laboratory MFC allowed to remove 99% of Cr (VI) and obtain a current in the range of 30–70 mA/m^2 using half Hoagland's solution and sodium acetate [63].

The use of an aero cathode in the system under discussion made it possible to obtain a current amplification from 0.07 V to 0.52 V and a current density of 0.005 mV/m^2 and 4.21 mV/m^2, respectively, in 75 days of CW-MFC operation [64]. The use of a system of capacitors to collect electricity has increased the performance of the CW-MFC system by almost 20% [65].

Thus, the selection of plants and their cultivation conditions, plant substrate, nutrient solutions, electrogenic microflora, electrode design and material make it possible to regulate the production and degradation processes of wastewater organic substances in promising CW-MFC systems.

Experimental part

Representatives of aquatic phytophthores in water bodies and wetlands were selected as plants for plant and microbial fuel cells. Sediment type PMFC system for plants was used (Tab.1).

Table 1. Plants grown in laboratory and their characteristics in the experimental PMFC installation: a) Pistia, b) Eichhornia, c) Reeds, d) Seeded Rice

<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>a</td><td>b</td><td>c</td><td>d</td></tr>
<tr><td colspan="4">a) Pistia (lat. Pistia stratiotes) is a monotypic genus of the Aroid family (Araceae), including the only perennial herbaceous floating plant species. Small, evergreen, free-floating herbs with spreading roots. The roots are numerous, pinnate, and floating, and the stem is shortened. The leaves form a rosette, floating on the surface of the water, have intercellular spaces filled with air, gray-green, sessile, obtusely wedge-shaped, with the greatest width at the end and somewhat narrowed towards the base, with a rounded anterior margin, 15-25 cm long, 8-10 cm wide.</td></tr>
<tr><td colspan="4">b) Eichhornia thick-legged (lat. Eichhornia crassipes) - water hyacinth, aquatic plant; species of the genus Eichornia of the family Pontederiaceae. An annual floating aquatic plant shoots up to 2 m in length (Figure 3). Leaves are collected in the socket. At the base of the leaf is a swelling, inside which is a porous tissue, thanks to which the plant is kept afloat. The roots are long (up to 0.5 m), and completely submerged in water. The flower is shaped like a hyacinth, it can be pink, blue or purple.</td></tr>
<tr><td colspan="4">c) Reed (lat. Scirpus) is a genus of perennial and annual coastal aquatic plants of the sedge family (Figure 4). Reeds grown in the laboratory. It grows up to 4 meters and, in rare cases up to 6. Tall perennial plant. The stem is cylindrical or trihedral, up to 3.5 m high. The flowers are bisexual, in spikelets collected in an umbellate, paniculate or capitate inflorescence. Grows in swampy areas.</td></tr>
<tr><td colspan="4">d) Seeded Rice (lat. Oryza sativa) is a genus of annuals and perennial herbaceous plants in cereal families. Rice stalks reach up to one and a half meters in height, its leaves are quite broad, dark green and rough along the edge. One-year rice is grown as an agricultural crop in the tropics, subtropics, and warm temperate zones. Rice is one of the oldest food crops.</td></tr>
</table>

The PMFC system of sedimentary type for plants was used. The scheme is shown in Figure 2.

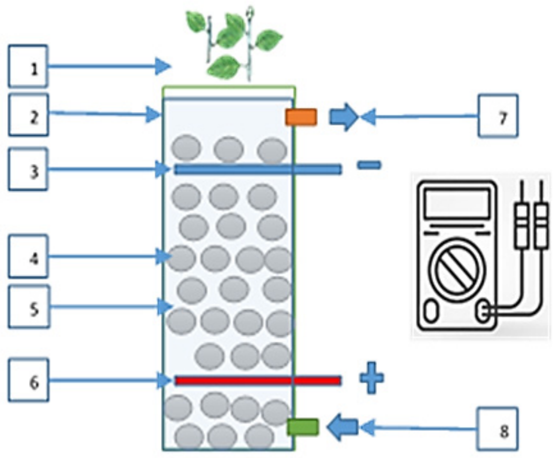


Figure 2. Scheme of the design of a sedimentary fuel cell: 1 - plants, 2 - plastic cylinder, 3 - cathode, 4 - gravel, 5 - substrate, 6 - anode, 7 - substrate output, 8 - substrate input

Membrane-free design. The electrodes included in the system close the electrical circuit. The following served as electrodes: an aluminum mesh 23.2 mm × 13.4 mm × 2.4 mm PVA (TU U00236010.001-97), carbon (graphite) electrodes with a diameter of 8.0 mm (GOST 10720-75), a graphite electrode, and a stainless steel sheet 2.0 mm, the anode is also made of the same materials.

The distance between the electrodes was 5, 10, 20 cm. Two electrodes were connected to a portable digital multimeter of the UT33C+ type (included in the State Register of Measuring Instruments of the Republic of Kazakhstan) using copper wires or through a 1000 Ohm resistance. System performance is determined by measuring open circuit voltage and short circuit current.

The plant system was installed on the Technopark NURIS Nazarbayev University premises, where the temperature fluctuated between 20-25°C and humidity was not controlled. Illumination with light from linear phytolamp of a full spectrum of 60 cm with a power of 12 W.

The imitation of the following composition (g/l) with pure substances was used as wastewater: CH_3COONa - 256.41 mg/l; NH_4Cl - 76.43 mg/l; $NaNO_3$ - 30.36; KH_2PO_4 - 14.24 mg/l; $CaCl_2$ - 14.7 mg/l; $MgCl_2$ - 20.3 mg/l and solution of microelements containing *Fe, B, Zn, Cu, Mn, Mo* in optimal quantities for the universal cultivation of almost any plants by hydroponics - 10 ml/l [21]. Synthetic wastewater was applied to the surface of each CW-MFC.

All systems were operated under laboratory conditions at room temperature of 20°C. Daily water loss due to evapotranspiration and sampling in the CW-MFC ranged from 1 to 5%. The evaporated water was replenished daily with fresh synthetic wastewater. As a filler, gravel from dense rocks with a fraction of 20-40 mm was used according to GOST 8267-93.

COD measurement was carried out according to GOST 31859-2012 *"Water. Method for determining the chemical oxygen demand»* on the device *Expert 003* (Spectrophotometer with a thermoreactor). The apparatus was calibrated with solutions of a standard sample of chemical oxygen demand GSO 7552-99. The device has the function of built-in construction of a calibration curve and automatic determination of the COD value.

The current voltage characteristics were measured using a *Fluke 8808A* multimeter. Standard sample of chemical oxygen demand GSO 7552-99). The Devard method calculates ammonium and nitrate nitrogen according to GOST 30181.4-94. Determination of phosphates according to GOST 18309-2014 '*Water. Methods for the determination of phosphorus-containing substances".*

Statistical results were processed using the software package «*Statistica 6.0*» with standard deviation ±1 for voltage (in mV) and *Microsoft Excel 97*. Measurements were made in three parallel.

As part of the creation of model PMFCs in CW, a series of experiments were carried out to generate electricity using various installations containing the following plant species: pistia *(Pistia stratiote)*, eichhornia *(Eichhornia crassipes)*, reed *(Scirpus)*, seed *(Oryza sativa)*.

For the production of plants, planting material has been purchased and in laboratory conditions a hydroponic plant for 150 litres of water, with a constant flow of water and illumination with full spectrum LED phytolamps has been created (Figure 3).

Figure 3. Hydroponic installation for growing aquatic plants

Cultivated crops were established in experimental PMTE. Experimental PMFC was based on a PVC pipe (polyvinyl chloride) with a diameter of 150.0 mm and a thickness of 2.0 mm (GOST 32413-2013), and the installation height is 37 cm. The working volume of PMFC was 6 liters (Figure 4).

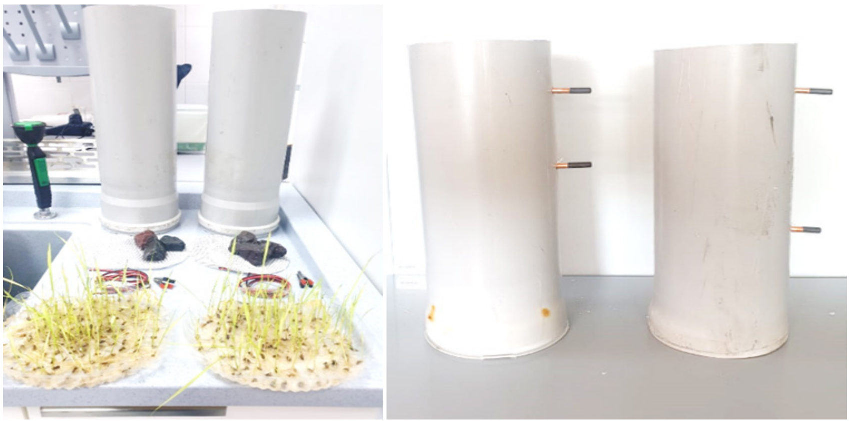


Figure 4. Experimental PMFC

When cultivating plants on experimental setups, the roots and the oxidized substrate are under aerobic conditions, aerated with air or pure oxygen in the PMFC cathode chamber. In turn, the lower compartment of the PMFC contains an anode, where anaerobic conditions are created (Figure 4).

The proposed PMFC does not have a proton-selective membrane in its design. At the anode, microorganisms assimilate organic substances from water, while free protons diffuse to the cathode, where they were oxidized by oxygen to water. A solution of synthetic wastewater was used as a substrate [21]. The wastewater solution was supplied from the bottom valve at a rate of 6 l/day, so the volume is updated in 24 hours.

The initial analysis of the chemical composition of synthetic wastewater showed: COD 210.4 ± 60.9 mg O_2/l, NH_4^+ - (N) = 19.7 ± 1.6 mg/l and NO_3^-- (N) = 4.78 ± 1.5 mg/l, while 70% to 82% TN is NH_4^+- N.

Indicators of voltage, current strength and potential difference were determined daily using a multimeter. Positive indicators of electrogenic activity were obtained during cultivation for 50-100 hours, the maximum indicators were achieved on days 10-15 (Figure 5).

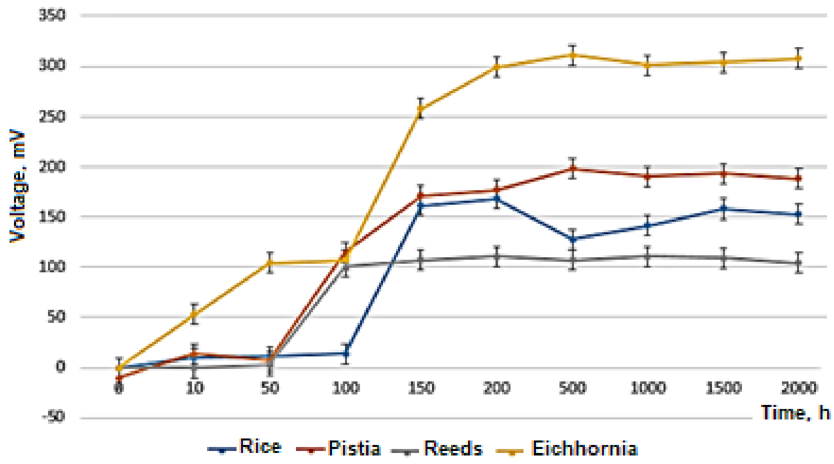


Figure 5. Dynamics of electrogenic activity of PMFC with various plants

As part of the study, high electrogenic activity was shown by installations with a graphite electrode, where the maximum voltage indicator was reached at the level of 512 mV, with a cultivation duration of 74 days using *Pistia stratiote* with a current strength of 1.61 mA (Table 2).

Table 2. Indicators of electrogenic activity of experimental models of PMFC

Plants	Model PMFC	Number of days	Max mV	Max mA
Pistia	graphite rod, 10 cm	74	512±1	1.61
Eichhornia	graphite rod, 10 cm	74	198±1	0.14
Rice	graphite rod, 10 cm	74	168±1	0.15±1
Reed	graphite rod, 10 cm	74	111±1	0.8

The electrical parameters of PMFC were studied depending on the design and material of the electrodes. The design parameters of the studied PMFC included various distances between the electrodes (100-200 mm), various plants (*Pistia, Eichhornia, Scirpus, Oryza sativa*), various shapes and sizes of electrodes (classic graphite electrode, graphite rod electrode 8 mm), as well as an aluminium mesh.

On average, between different electrode designs, no significant differences were observed between the specific power and strength of the studied PMFC experimental setups (Table 3).

Table 3. Indicators of electrogenic activity of experimental PMFC

No. p / p	Plants	PMFC design	Number of days	Voltage, mV	Current strength, mA
1	Rice	Sample 1, stainless steel metal, 10 cm.	74	405±1	0.15
2	Rice	Sample 2, stainless steel metal, 20 cm.	74	220±1	0.15
3	Rice	Sample 3, alum. grid, 10 cm.	83	443±1	1.38
4	Rice	Sample 4, alum. mesh, 20 cm.	83	222±1	1.10
5	Rice	Sample 5, graphite rod, 10 cm.	61	468±1	1.11
6	Rice	Sample 6, graphite rod, 20 cm.	61	222±1	1.17
7	Rice	Sample 7, graphite rod, 5 cm.	15	228±1	1.56
8	Pistia	Sample 8, stainless steel metal, 20 cm.	74	431±1	1.00
9	Pistia	Sample 9, alum. grid, 10 cm.	83	478±1	1.11
10	Pistia	Sample 10, alum. mesh, 20 cm.	83	408.4±1	1.05
11	Pistia	Sample 11, graphite rod, 10 cm.	61	447±1	1.27
12	Pistia	Sample 12, graphite rod, 20 cm.	61	88±1	0.58
13	Pistia	Sample 13, graphite rod, 20 cm.	15	180±1	1.58
14	Reed	Sample 14, stainless steel metal, 10 cm.	74	311±1	0.88
15	Reed	Sample 15, stainless steel metal, 20 cm.	74	180±1	0.58
16	Reed	Sample 16, alum. grid, 10 cm.	83	444±1	0.53
17	Reed	Sample 17, alum. mesh, 20 cm.	83	428±1	0.71
18	Reed	Sample 18, graphite rod, 10 cm.	61	401±1	0.25
19	Reed	Sample 19, graphite rod, 20 cm.	61	103±1	0.21
20	Eichhornia	Sample 20, stainless steel metal, 10 cm.	74	358±1	1.41
21	Eichhornia	Sample 21, stainless steel metal, 20 cm.	74	301±1	1.15
22	Eichhornia	Sample 22, aluminium grid, 10 cm.	83	468±1	0.75
23	Eichhornia	Sample 23, aluminium mesh, 20 cm.	83	388±1	0.38
24	Eichhornia	Sample 24, graphite rod, 10 cm.	61	408±1	0.97
25	Eichhornia	Sample 25, graphite rod, 20 cm.	61	255±1	0.57
26	Eichhornia	Sample 26, graphite rod, 5 cm.	15	270±1	0.44

However, it is important to note that PMFC. containing stainless steel electrodes achieved the highest voltage values of 607 mV. At the same time, graphite installations started up most quickly and produced current, in turn, aluminium mesh electrodes also showed a high potential with a maximum of 468 mV.

Of the presented in Table 3 indicators of electrogenic activity, the optimal distance between the electrodes in the setup was determined, which was 10 cm. The highest potential was developed by electrodes made of stainless steel and graphite. Of the plants, pistia plants show the greatest efficiency, then seed and eichhornia, the lowest indicators of the current generation were in reed.

Table 4. Power indicators of experimental PMFC

No. p / p	Experience variant	Open loop measurements		Measurements through resistance, 989 Ohm		Power, Wt
		Voltage, mV	Current strength, mA	Voltage, mV	Current strength, mA	
1	Sample 1	405	0.15	180	0.18	32.4
2	Sample 2	220	0.15	87	0.08	6.96
3	Sample 3	443	1.38	258	0.2	51.6
4	Sample 4	222	1.1	98	0.09	8.82
5	**Sample 5**	**468**	**1.11**	**314**	**0.35**	**109.9**
6	Sample 6	222	1.17	100	0.1	10
7	Sample 7	228	1.56	147	0.14	20.58
8	**Sample 8**	**431**	**1**	**305**	**0.3**	**91.5**
9	**Sample 9**	**478**	**1.11**	**323**	**0.35**	**113.05**
10	Sample 10	408.4	1.05	178	0.18	32.04
11	Sample 11	447	1.27	205	0.2	41
12	Sample 12	88	0.58	14	0.01	0.14
13	Sample 13	180	1.58	120	0.12	14.4
14	Sample 14	311	0.88	179	0.18	32.22
15	Sample 15	180	0.58	77	0.08	6.16
16	Sample 16	444	0.53	286	0.29	82.94
17	Sample 17	428	0.71	270	0.27	72.9
18	Sample 18	401	0.25	174	0.17	29.58
19	Sample 19	103	0.21	68	0.06	4.08
20	Sample 20	358	1.41	220	0.22	48.4
21	Sample 21	301	1.15	208	0.21	43.68
22	Sample 22	468	0.75	300	0.3	90
23	Sample 23	388	0.38	217	0.21	45.57
24	Sample 24	408	0.97	304	0.3	91.2
25	Sample 25	255	0.57	186	0.18	33.48
26	Sample 26	270	0.44	113	0.11	12.43

According to Table 4, sample No. 9 has the highest power, which consists of stainless steel electrodes located at a distance of 10 cm using pistia (*Pistia stratiote)* as a plant element.

Samples No. 5 seed *(Oryza sativa)*, graphite rod 10 cm), and No. 8 pistia (*Pistia stratiote)*, stainless steel, 20 cm) also showed high power.

The effectiveness of PMFC in the process of purification of polluted water with organo-mineral pollutants was carried out on experimental sedimentary-type PMFC installations with these planted plants and with the addition of the drug «*KazBioRem-EM*» at a dose of 109 CFU/cm^3. Synthetic wastewater was used as dirty water. The results of the experiment were presented in Table 5.

Table 5. Results of measurements of current-voltage characteristics and chemical composition of solutions

No.	Experience Variant	Voltage, mV	Current strength, μA	COD, mgO/dm^3	NO^{3-}, mg/dm^3	NH$_4^+$, mg/dm^3	PO$_4^{3-}$, mg/dm^3	NO$_2^-$, mg/dm^3
1	Initial	8.0	0	210.4	4.78	19.7	3.69	1.51
2	Sample 1	405±1	0.15	18.1	0.87	0.85	0.98	0.17
3	Sample 2	220±1	0.15	22.4	0.79	1.26	1.67	0.32
4	Sample 3	443±1	1.38	15.0	0.98	1.01	1.50	0.21
5	Sample 4	222±1	1.10	19.0	0.59	0.82	1.55	0.47
6	Sample 5	468±1	1.11	12.5	0.88	1.94	0.89	0.28
7	Sample 6	222±1	1.17	18.6	0.95	1.33	0.53	0.40
8	Sample 7	228±1	1.56	17.9	0.42	0.99	0.24	0.26
9	Sample 8	431±1	1.00	17.2	0.84	1.28	0.12	0.22
10	Sample 9	478±1	1.11	19.3	0.55	1.08	0.25	0.31
11	Sample 10	408.4±1	1.05	20.4	0.57	1.36	0.58	0.48
12	Sample 11	447±1	1.27	25.6	0.86	2.01	0.75	0.12
13	Sample 12	88±1	0.58	43.9	1.02	5.22	0.36	0.35
14	Sample 13	180±1	1.58	39.5	0.73	2.36	0.51	0.14
15	Sample 14	311±1	0.88	27.3	0.48	1.56	0.89	0.24
16	Sample 15	180±1	0.58	48.1	0.72	1.88	0.82	0.29
17	Sample 16	444±1	0.53	12.7	0.85	3.05	1.08	0.52
18	Sample 17	428±1	0.71	11.0	0.28	1.56	1.68	0.39
19	Sample 18	401±1	0.25	13.8	0.86	1.22	1.05	0.70
20	Sample 19	103±1	0.21	32.0	0.49	1.63	1.56	0.62
21	Sample 20	358±1	1.41	19.2	0.96	1.58	0.78	0.28
22	Sample 21	301±1	1.15	23.2	0.78	1.99	0.36	0.14
23	Sample 22	468±1	0.75	15.4	0.52	1.24	1.52	0.19
24	Sample 23	388±1	0.38	28.0	0.63	2.08	0.48	0.74
25	Sample 24	408±1	0.97	15.2	0.48	1.89	0.75	0.85
26	Sample 25	255±1	0.57	29.4	0.85	1.75	0.58	0.28
27	Sample 26	270±1	0.44	29.7	0.76	2.33	0.74	0.26

As can be seen from Table 5, almost all experiments show a significant decrease of 5 times or more in nitrate, nitrite and ion phosphate. Residual ion concentrations (5-0.1 mg/l) appear to be due to the inability of plants to absorb them due to the low ion force of the solution. It should be noted that ammonium, nitrite, and nitrate ions were interconnected because *Nitrosomonas*, *Nitrosococcus* and *Nitrosospira* oxidize ammonium to nitrite ions. Nitrite oxidation to nitrate is produced by nitrate bacteria of the soil genus *Nitrobacter* and aqueous genera *Nitrospira*, *Nitrococcus*, *Nitrospina*. Nitrate ions and phosphate ions were absorbed by plants.

The organic compound content in water is characterized by the COD parameter. It should be taken into account that organic compounds in water were breeding ground for microorganisms, due to their activity organic matter is reduced in water, and at the same time bacteria are organic compounds that are fixed when determining COD In the original solution, the COD was 210 mg/l after testing, dropping to 29-10 mg/l (almost 7-10 times). The decrease of carbon in water is due to its removal in the form of carbon dioxide, formed by the «breathing» of microorganisms.

Thus, as a result of water purification by PMFC systems, plants such as rice, pistia, and eihornia showed good results, due to the well-developed root system of these plants. It should be noted that these plants in nature live in symbiosis with microorganisms living on the surface of the roots

Conclusion

A review of the current literature suggests that the concepts of waste-to-energy conversion and the development of less energy-intensive wastewater management technologies have been developed and extensively researched worldwide. The development of economical and energy-neutral technologies is currently the most demanded approach. One such technology is the use of systems Constructed Wetlands, which generate electricity from certain plants and microorganisms along with wastewater treatment. The selection of plants and their cultivation conditions, plant substrate, nutrient solutions, electrogenic microflora, electrode design and material make it possible to regulate wastewater organic matter's production and degradation processes in advanced CW-MFC systems.

The conducted research on plant-microbial fuel cell systems resulted in the selection of electrodes made of stainless steel and graphite, which exhibited the highest potential, the determination of the optimal distance between the electrodes in the setup (10 cm), and it was established that among the investigated plants the Pistia (*Pistia stratiote)* proved to be the most efficient in generating electricity.

References

1. Jingyu H., Miwornunyuie N., Ewusi-Mensah, D., Koomson, D.A. Assessing the factors influencing the performance of constructed wetland–microbial fuel cell integration // Water Science Technology. – 2020. – Vol. 81. – P. 631-643.

2. Yang Z., Pei H., Hou Q., Jiang L., Zhang L., Nie C. Algal biofilm-assisted microbial fuel cell to enhance domestic wastewater treatment: nutrient, organics removal and bioenergy production // Chemical Engineering Journal. – 2018. – Vol.332. – P.277-285.

3. PandeyP., Shinde V.N., Deopurkar R.L., Kale S.P., Patil S.A., Pant D. Recent advances in the use of different substrates in microbial fuel cells toward wastewater treatment and simultaneous energy recovery // Applied Energy. – 2016. – Vol.168. – P.706-723.

4. Reddy C.N., Nguyen H.T., Noori M.T., Min B. Potential applications of algae in the cathode of microbial fuel cells for enhanced electricity generation with simultaneous nutrient removal and algae biorefinery: Current status and future perspectives // Bioresour Technology. – 2019. – Vol. 292. - P. 122010.

5. Logan B.E. Generating Electricity from Wastewater Treatment Plants // Editorial, Water Environment Research. –2005. – Vol. 77. – P. 209.

6. McCarty P.L., Bae J., Kim J. Domestic wastewater treatment as a net energy producer-can this be achieved? // Environ Science and Technology. – 2011. – Vol. 45. – P. 7100-7106.

7. Helder M., Strik D., Hamelers H., Kuhn A., Blok C., Buisman C. Concurrent bio-electricity and biomass production in three Plant-Microbial Fuel Cells using Spartina anglica, Arundinella anomala and Arundo donax // Bioresource Technology. – 2010. –Vol. 101. – P. 3541-3547.

8. Takanezawa K., Nishio K., Kato S., Hashimoto K., Watanabe K. Factors Affecting Electric Output from Rice-Paddy Microbial Fuel Cells // Bioscience, Biotechnology, and Biochemistry. – 2010. – Vol. 74. - P. 1271–1273.

9. Sudirjo E., Buisman C., Strik D. Electricity generation from wetlands with activated carbon bioanode // International Conference on Green Agro-industry and Bioeconomy IOP Publishing IOP Conf. Series: Earth and Environmental Science. – 2018. Vol. 131. – P. 012-046.

10. Helder M., Chen W.S., Van Der Harst E.J., Strik D., Hamelers H.B.V., Buisman C.J., Potting J. Electricity production with living plants on a green roof: environmental performance of the plant-microbial fuel cell // Biofuels Bioproducts and Biorefining. – 2013. – Vol. 7. -P. 52–64.

11. Wetser K., Liu J., Buisman C., Strik D. Plant microbial fuel cell applied in wetlands: spatial, temporal and potential electricity generation of Spartina anglica salt marshes and Phragmites australis peat soils // Biomass Bioenergy. - 2015. – Vol. 83. – P. 543–50.

12. Wetser K., Sudirjo E., Buisman C.J., Strik D. Electricity generation by a plant microbial fuel cell with an integrated oxygen reducing biocathode // Applied Energy. – 2015. Vol. 137 – P. 151–7.

13. Tapia N.F., Rojas C., Bonilla C.A., Vargas I.T. Evaluation of sedum as driver for plant microbial fuel cells in a semi-arid green roof ecosystem // Ecological Engineering. – 2017. – Vol. 108.- P. 203–10.

14. Kivaisi A. K. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review // Ecological Engineering. - 2001. – Vol.16. – P. 545–560.

15. Kadlec H., Wallace S. Treatment Wetlands. - Boca Raton, Florida: CRC Press. – 2009. – 1000p.

16. Verhoeven J., Beltman B., Bobbink R., Whigham D.F. Wetlands and natural resource management. - New York: Springer. – 2006. – 292p.

17. Yadav A.K. Design and development of novel constructed wetland cum microbial fuel cell for electricity production and wastewater treatment // In: Cerioni AM, Motta R, editors. Proceedings of 12th international conference on wetland systems for water pollution control (IWA). – 2010. - 321p.

18. Kadlec R., Wallace S. Treatment wetlands. second ed. - Boca Raton, Florida: CRC Press. - 2008. – 1046p.

19. Yadav A., Dash P., Mohanty A., Abbassi R., Mishra B.. Performance assessment of innovative constructed wetland-microbial fuel cell for electricity production and dye removal // Ecological Engineering. - 2012. – Vol. 47. – P. 126–31.

20. Villasenor J., Capilla P., Rodrigo M., Canizares P., Fernandez F.J. Operation of a horizontal subsurface flow constructed wetland-microbial fuel cell treating wastewater under different organic loading rates // Water Research. – 2013. Vol. – P. 6731–8.

21. Mohan S., Mohanakrishna G., Chiranjeevi P. Sustainable power generation from floating macrophytes based ecological microenvironment through embedded fuel cells along with simultaneous wastewater treatment // Bioresource Technology. – 2011. – Vol. 102. – P. 7036–42.

22. Oon Y., Ong S.A., Ho L., Wong Y., Dahalan F., Oon Y.. Role of macrophyte and effect of supplementary aeration in up-flow constructed wetland-microbial fuel cell for simultaneous wastewater treatment and energy recovery // Bioresource Technology. – 2017. – Vol. 224. - P. 265–75.

23. Bennetto H. Electricity Generation by Microorganisms // Biotechnology Education. – 1990. - Vol. 1. – P.163-168.

24. Kaku N., Yonezawa N., Kodama Y., Watanabe K. Plant/microbe cooperation for electricity generation in a rice paddy field // Applied Microbiology and Biotechnology. – 2008. – Vol. 79. – P. 43-49.

25. Strik D., Timmers R., Helder M., Steinbusch K., Hamelers H., Buisman C.. Microbial solar cells: applying photosynthetic and electrochemically active organisms // Trends in Biotechnology. – 2011. – Vol. 29. – P. 41-49.

26. Gollandskij-startap-nauchilsya-dobyvat-ehlektrichestvo-na-risovykh-polyakh-dostupno-na-. (https://nplus1.ru/news/2015/06/04/plant-is-plant) ot 04.06.15.

27. Zhao Y., Collum S., Phelan M., Goodbody T., Doherty L., Hu Y. Preliminary investigation of constructed wetland incorporating microbial fuel cell: batch and continuous flow trials. // Chemical Engineering Journal. – 2013. – Vol. 229. – P.364-370.

28. Doherty L., Zhao Ya. Operating a two-stage microbial fuel cell-constructed wetland for fuller wasterwater treatment and more efficient electricity generation // Water Science and Technology. – 2015. – P. 421-428.

29. Brix H. Do macrophytes play a role in constructed treatment wetlands? // Water Science and Technology. – 1997. – Vol. 35. – P.11–17.

30. Chiranjeevi P., Mohanakrishna G., Mohan S. Rhizosphere mediated electrogenesis with the function of anode placement for harnessing bioenergy through CO2 sequestration // Bioresource Technology. – 2012. – Vol. 124. - P. 364–70.

31. Klaisongkram N., Holasut K. Electricity generation of plant microbial fuel cell (PMFC) using Cyperus involucratus // KKU Engineering Journal – 2014. – Vol. 42. - P. 117–24.

32. Helder M., Strik D., Hamelers H., Kuhn A., Blok C., Buisman C. Concurrent bio-electricity and biomass production in three Plant-Microbial Fuel Cells using Spartina anglica, Arundinella anomala and Arundo donax // Bioresource Technology. – 2010. – Vol. 101. - P. 3541–7.

33. Bombelli P., Iyer D., Covshoff S., McCormick AJ., Yunus K., Hibberd JM., Fisher AC., Howe CJ. Comparison of power output by rice (Oryza sativa) and an associated weed (Echinochloa glabrescens) in vascular plant bio-photovoltaic (VP-BPV) systems // Applied Microbiology and Biotechnology. – 2013. – Vol. 97. - P. 429–38.

34. Habibul N., Hu Y., Wang YK., Chen W., Yu HQ., Sheng GP. Bioelectrochemical chromium (VI) removal in plant-microbial fuel cells // Environmental Science & Technology. – 2016. Vol. 50. - P. 3882–3889

35. Liu S., Song H., Li X., Yang F. Power generation enhancement by utilizing plant photosynthate in microbial fuel cell coupled constructed wetland system // International Journal of Photoenergy. – 2013.

36. Yan Z., Jiang H., Cai H., Zhou Y., Krumholz LR. Complex interactions between the macrophyte Acorus calamus and microbial fuel cells during pyrene and benzo [a] pyrene degradation in sediments // Scientific Reports. – 2015. – Vol. 5. - P. 10709.

37. Hubenova Y., Mitov M. Conversion of solar energy into electricity by using duckweed in direct photosynthetic plant fuel cell // Bioelectrochemistry. – 2012. – Vol. 87. -P. 185–91.

38. Lu L., Xing D., Ren ZJ. Microbial community structure accompanied with electricity production in a constructed wetland plant microbial fuel cell // Bioresource Technology. – 2015. – Vol. 195. - P. 115–21.

39. Oon Y.L., Ong S.An., Ho L.N., Wong Y.S., Oon Y.S., Lehl H. K., Thung W.E. Hybrid system up-flow constructed wetland integrated with microbial fuel cell for simultaneous wastewater treatment and electricity generation //Bioresource technology. – 2015. – Vol. 186. – C. 270-275.

40. Sarma P., Mohanty K. An Insight into Plant Microbial Fuel Cells // Bioelectrochemical Interface Engineering, First Edition. Edited by R. Navanietha Krishnaraj and Rajesh K. Sani. – 2020. - John Wiley & Sons, Inc. – P.137-148.

41. Dhote S., Dixit S. Water quality improvement through macrophytes: a case study // Asian Journal of Experimental Sciences. – 2007. – Vol. 21. – P.427–430.

42. Teoh T.P., Ong S.A., Ho L.N., Wong Y.S., Oon Y.L., Oon Y.S, Tan S.M., Thung W.E. Up-flow constructed wetland-microbial fuel cell: Influence of floating plant, aeration and circuit connection on wastewater treatment performance and bioelectricity generation // Journal of Water Process Engineering. – 2020. – Vol.36. – P. 101371.

43. Fang Z., Song H-L., Cang N., Li X-N. Electricity production from Azo dye wastewater using a microbial fuel cell coupled constructed wetland operating under different operating conditions //Biosensors & Bioelectronics. - 2015. – Vol. 68. - P. 135-141.

44. Nitisoravut R., Regmi R. Plant microbial fuel cells: a promising Biosystems engineering // Renew Sustainable Energy Reviews. – 2017. - Vol. 76. - P. 81–9.

45. Cabezas da Rosa A. Diversity and function of the microbial community on anodes of sediment microbial fuel cells fueled by root exudates [dissertaion]. - Marburg: Philipps-Universität. -2010.

46. Timmers RA., Rothballer M., Strik DP., Engel M, Schulz S, Schloter M. Microbial community structure elucidates performance of Glyceria maxima plant microbial fuel cell // Applied Microbiology and Biotechnology – 2012. Vol. 94. - P. 537–48.

47. Xu F., Cao F., Kong Q., Zhou L., Yuan Q., Zhu Y., Wang Q., Du Y., Wang Z. Electricity production and evolution of microbial community in the constructed wetland-microbial fuel cell // Chemical Engineering Journal. – 2018. – Vol.339. –P.479–486.

48. Nimje, V. R., Chen, C. Y., Chen, C. C., Jean, J. S., Reddy, A. S., Fan, C. W., ... & Chen, J. L. Stable and high energy generation by a strain of Bacillus subtilis in a microbial fuel cell. // Journal of Power Sources. – 2009. – Vol. 190. – P.258-263.

49. Logan B.E, Regan J.M. Electricity-producing bacterial communities in microbial fuel cells // Trends in Microbiology. – 2006. – Vol. 14. - P. 512–8.

50. Logan BE. Exoelectrogenic bacteria that power microbial fuel cells // Nature Reviews Microbiology. – 2009. – Vol. 7. – P. 375

51. Abbas S.Z., Rafatullah M., Ismail N., Syakir M.I. A review on sediment microbial fuel cells as a new source of sustainable energy and heavy metal remediation: mechanisms and future prospective // International Journal of Energy Research. – 2017. – Vol. 41. – P. 1242–64.

52. Raghavulu S.V., Babu P.S., Goud R.K., Subhash G.V., Srikanth S., Mohan S.V. Bioaugmentation of an electrochemically active strain to enhance the electron discharge of mixed culture: process evaluation through electro-kinetic analysis // RSC Advances. – 2012. – Vol. 2. – P. 677–88.

53. Gorby YA., Yanina S., McLean JS., Rosso KM., Moyles D., Dohnalkova A. Electrically conductive bacterial nanowires produced by Shewanella oneidensis strain MR-1 and other microorganisms // Proceeding of National Academy Science of U.S.A. – 2006. – Vol. 103. – P. 11358–63

54. El-Naggar MY., Wanger G, Leung K.M., Yuzvinsky T.D., Southam G., Yang J. Electrical transport along bacterial nanowires from Shewanella oneidensis MR-1 // Proceeding of National Academy Science of U.S.A. – 2010. – Vol. 107. – P. 18127–31.

55. Ivanov R., Nikolova K., Genova P. Investigation of the design of plant sediment microbial fuel cell on the electrical parameters and the water treatment effect from petroleum products // International Scientific Journal "Machines. Technologies. Materials." – 2019. – Vol. XIII. – P. 550-553.

56. Araneda I., Tapia N.F., Allende K.L., Vargas I.T. Constructed Wetland-Microbial Fuel Cells for Sustainable Greywater Treatment // Water. - 2018, V.10, - 940.

57. Corbella C., Puigagut J. Improving domestic wastewater treatment efficiency with Constructed Wetland-Microbial Fuel Cells: Influence anode material and external resistance // Science of total Environment. – 2018. – Vol. 631-632. – P.1406-1414.

58. Srivastava P., Yadav A.K., Mishra B.K. The effects of microbial fuel cell integration into constructed wetland on the performance of constructed wetland // Bioresource Technology. - 2015. V.195. – P.223-230.

59. Timmers R.A., Strik D., Hamelers H.V.M. et al. Long-term performance of a plant microbial fuel cell with Spartina anglica. // Applied Microbiology and Biotechnology – 2010. – Vol. 86. – P.973–981.

60. Goto Y., Yoshida N., Yamada T., Tero R., Hirachi A. Enhancement of electricity production by graphene oxide in soil microbial fuel cells and plant microbial fuel cells //Frontiers in Bioengineering and Biotechnology. – 2015. – Vol. 3. – P42.

61. Moqsud M.A., Yoshitake A.J., Bushra Q.S., Hyodo M., Omine K., Strik D. Compost in plant microbial fuel cell for bioelectricity generation // Waste Management. – 2014. – Vol. 36. – P. 63-69.

62. Song, H., Zhang, S., Long, X., Yang, X., Li, H., & Xiang, W. (2017). Optimization of bioelectricity generation in constructed wetland-coupled microbial fuel cell systems. Water, 9(3), 185. Optimization of Bioelectricity Generation in Constructed Wetland-Coupled Microbial Fuel Cell Systems // Water. – 2017. – V. 9. - P. 185.

63. Yan D., Song X., Weng B., Yu Z., Bi W., Wang J. Bioelectric generation from microbial fuel cell connected to constructed wetland // Water Science & Technology – 2018. – V.78.- P.1990-1996.

64. Xu L., Wang B., Liu X., Yu W., Zhao Y. Maximizing the energy harvest from a microbial fuel cell embedded in a constructed wetland // Applied Energy. – 2018. – Vol.214. – P.8-91.

65. Yang Y., Zhao Y., Tang C., Xu L., Morgan D., Liu R. Role of macrophyte species in constructed wetland-microbial fuel cell for simultaneous wastewater treatment and bioenergy generation // Chemical Engineering Journal. - 2019. - V.11. – P.16-21

Е.Е. Жатқанбаев[1,2], Қ.А. Куртибай[1], Ж.Қ. Жатқанбаева[2], А.М. Каюбалиева[1], А.Ә. Үсенова, Ә[1]. Қаппасұлы[1], Ш.М. Тұрарбек[1], Д.Ж. Сембаева[1], Э.Б. Молдагулова[1]

[1]«Экологиялық және өнеркәсіптік биотехнология ғылыми-өндірістік орталығы» ЖШС, Астана, Қазақстан

[2]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан

Өсімдік-микробтық отын элементтеріне негізделген ағынды суларды тазарту жүйелері

Аңдатпа. Мақалада біріктірілген жасанды сулы-батпақты жерлер және микробтық отын элементтерін пайдалану мәселесінің ағымдағы жағдайы және ағынды суларды тазарту мен электр энергиясын өндіруді қамтамасыз ететін факторлар туралы деректер келтірілген. Ағынды суларды тазарту көп энергияны қажет ететін салалардың бірі болып табылады, бұл энергияның көп бөлігі ағынды сулардағы органикалық заттарды тотықтыруға қажет оттекті биологиялық реакторларға атмосферадан беру үшін пайдаланылады. Суды тазартудың классикалық және заманауи әдістері қарастырылады, оның ішінде тазарту дәрежесін арттыру және энергия шығынын азайту үшін қолданылатын, биологиялық қайта тазарту. Ең қарапайым және тиімді әдіс – сүзу және егістерді суару технологиясын, сондай-ақ сулы-батпақты алқаптарды (ветландтарды) қолдану арқылы топырақты тазалау.

Шөгінді типтегі «Constructed Wetlands» негізінде жасалған өсімдікті-микробтық отын элементтері туралы деректер соңғы жылдары кеңінен қолданылуда. «Ветландтар» өткен ғасырдың 70-жылдарынан бастап ағынды суларды тазарту үшін кеңінен пайдаланылғанына қарамастан, қазіргі уақытта су өсімдіктері, топырақ және олармен байланысты микроорганизмдері бар сулы-батпақты жерді имитациялау болып табылатын «Constructed Wetlands» жүйелерін олардың электр энергиясын өндіру мүмкіндігімен ерекшеленеді.

Ұсынылған зерттеу нәтижелері эксперименттік өсімдік-микробтық отын элеметтерін құрастыруда табиғаты әртүрлі өсімдіктерді пайдалануға негізделген. Зерттеулер нәтижесінде шөгінді типті ӨМОЭ құрастыруда ең жоғары потенциалды көрсететін тот баспайтын болаттан және графиттен жасалған электродтар таңдалды, қондырғыдағы электродтар арасындағы оңтайлы қашықтық 10 см болатыны анықталды және өсімдіктер арасында тамыр жүйесі жақсы дамыған пистия, күріш және эйхнория өсімдіктерінің тиімдірек екендігі нақтыланды. Ең төменгі тоқты генерациялау көрсеткіштері қамыста болды.

Түйін сөздер: өсімдік-микробтық отын элементі, сулы-батпақты жерлер, тазарту, ағынды сулар, электр энергиясын өндіру, микроағзалар, электрод.

Е.Е. Жатканбаев[1,2], К.А. Куртибай[1], Ж.К. Жатканбаева[2], А.М. Каюбалиева[1], А.А. Усенова, А. Каппасулы[1], Ш. Турарбек[1], Д.Ж. Сембаева[1], Э.Б. Молдагулова[1]

[1]*ТОО «Научно-производственный центр экологической и промышленной биотехнологии», Астана, Казахстан*

[2]*НАО «Евразийский национальный университет имени Л.Н. Гумилева», Астана, Казахстан*

Системы очистки сточных вод на основе растительно-микробных топливных элементов

Аннотация. В статье приведены данные по современному состоянию вопроса использования комбинированных конструированных болотных угодий и микробных топливных элементов и о факторах, обеспечивающих очистку сточных вод и генерацию тока. Очистка сточных вод является одним из энергоемких производств, и большая часть этой энергии используется для подачи кислорода из атмосферы в биологические реакторы для окисления органических веществ в сточных водах.

Рассмотрены как классические, так и новые методы очистки воды, в том числе биологическая доочистка, которая используется для повышения степени очистки и снижения потерь энергии. Наиболее простым и эффективным способом служит почвенная очистка по технологии полей орошения и фильтрации, а также ветланды. Представлены данные о растительно-микробных топливных элементах, которые совершают очистку сточных вод и представляют собой способ получения электроэнергии за счет микробиологического окисления органических веществ кислородом.

Охарактеризованы топливные элементы на основе «Constructed Wetlands» осадочного типа, которые получили широкое применение в последнее время. Несмотря на то, что «Ветланды» широко используются для очистки сточных вод с 70-х годов прошлого столетия, современное использование Constructed Wetlands (CW) – это имитация болота с водными растениями, почвой и связанными с ними микроорганизмами, обусловлено возможностью генерации электроэнергии в таких системах.

Представлены результаты исследования экспериментальных растительно-микробных топливных элементов из растений различной природы. В результате проведенных исследований экспериментальных систем с РМТЭ были подобраны электроды из нержавеющей стали и графита, развивающие наиболее высокий потенциал, определено оптимальное расстояние между электродами в установке, которое составило 10 см и установлено, что из растений более эффективными являются растения пистия, затем рис и эйхорния, которые обладают хорошо развитой корневой системой, наименьшие показатели генерации тока были у камыша

Ключевые слова: растительно-микробный топливный элемент, болотные угодья, очистка, сточные воды, генерация электроэнергии, микроорганизмы, электрод.

Information about authors:

Zhatkanbayev Yerlan – Doctor of Technical Sciences, Associate Professor, Department of Chemistry, L.N. Gumilyov Eurasian National University, 2 Satpayev str., Astana, Kazakhstan. Leading Researcher, LLP «Research and Production Center for Ecological and Industrial Biotechnology», 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Kurtibay Kuanysh – Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Zhatkanbayeva Zhanna – Candidate of Chemical Sciences, Associate Professor, Department of Chemistry, L.N. Gumilyov Eurasian National University, 2 Satpayev str., Astana, Kazakhstan.

Kayubaliyeva Anel – Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Ussenova Alina – Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Kappasuly Alisher – Master, Researcher, Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Turarbek Shynar – Junior Researcher, Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Sembayeva Dinara – Researcher, Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Moldagulova Elmira – Junior Researcher, Junior Researcher, Research and Production Center for Ecological and Industrial Biotechnology LLP, 13/5, Kurgalzhynskoye road, Astana, Kazakhstan.

Ерлан Жатқанбаев – техника ғылымдарының докторы, химия кафедрасының доценті, Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Сәтбаев көшесі, 2 Астана, Қазақстан. «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС жетекші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Қуаныш Күртібай – «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС кіші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Жанна Жатқанбаева – химия ғылымдарының кандидаты, химия кафедрасының доценті, Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Сәтбаев көшесі, 2 Астана, Қазақстан.

Анель Каюбалиева – «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС кіші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Алина Үсенова – «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС кіші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Әлішер Қаппасұлы – магистр, ғылыми қызметкер, «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Шынар Тұрарбек – «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС кіші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Динара Сембаева – ғылыми қызметкер, «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС, 13/5, Қорғалжын жолы, Астана, Қазақстан.

Эльмира Молдағұлова – «Экологиялық және өндірістік биотехнологиялар ғылыми-өндірістік орталығы» ЖШС кіші ғылыми қызметкері, 13/5, Қорғалжын жолы, Астана, Қазақстан.

МРНТИ 67.09.91

А. Майконов[1], А.М. Абдыров[2], Л.С. Шаншарова[3*], Р.К. Ниязбекова[3],С.С. Алдабергенова[2], Р. Тлегенов[2]

[1]Казахстанско-Британский технический университет, Алматы, Казахстан
[2]Казахский агротехнический исследовательский университет им. С. Сейфуллина, Астана, Казахстан
[3]РГП «Казахстанский институт стандартизации и метрологии», Астана, Казахстан
(E-mail [1]amaykonov@gmail.com, [3]rimma.n60@mail.ru, [2]tlegenovrassul@gmail.com)
Автор для корреспонденции: [3]lyazzat_240488@mail.ru*

Исследование химического состава «летучей» золы и ее влияние на прочность цементного камня

Аннотация. *Статья посвящена проблемам, связанным со снижением негативного воздействия золошлаковых отходов ТЭЦ Казахстана на окружающую среду. Вырабатываемая в больших количествах летучая зола как продукт сгорания топлива на энергостанциях отрицательно влияет на внешнюю среду, загрязняя воздух, почвы, сточные воды и т.п.*
В статье приведены результаты химического состава золошлаковых отходов. Рассмотрены возможные пути использования золы. Также изучен фазовый состав цементного камня с добавлением летучей золы с помощью современных методов анализа: рентгенофазовый и рентгенофлуоресцентный. Было выявлено, что к основным макроэлементам золы относятся Si, Al, Fe, O, Ca, Ti, Mg, S, K, Na.
Помимо изучения размеров и форм микросфер в работе ставились задачи определения видов термоактивных фаз, составляющих цементного камня при термообработке; изучение структурных изменений при термообработке. Рентгенофазовый анализ по исследованию зольных микросфер показал следующие фазы: муллита $Al_6Si_2O_{13}$, кварца SiO_2 и аморфной стеклофазы.
Применение золы как источника оксидов алюминия и кремния не только позволит снизить использование невозобновляемых ресурсов, но и получить материалы с улучшенными теплофизическими характеристиками (прочность, термостойкость и теплопроводность). Выбор оптимального количества золы уноса взамен части цемента способствует образованию желательной структуры цементного камня.
Ключевые слова: *летучая зола, золоотвал, отходы производства, элементный анализ, рентгенофазовый метод, цемент.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-42-50

Введение

Актуальность. С каждым годом увеличивается большое количество выбросов золошлаковых отходов (летучая зола), образующихся на ТЭЦ. В настоящее время мировое ежегодное производство ЗШО (золошлаковых отходов) составляет примерно 750 миллионов тонн, и ожидается, что в ближайшем будущем это количество отходов будет расти. Данный факт является одной из серьезных экологических проблем, связанных с угрозой здоровью населения и экологической безопасности (нанесение ущерба почве, растениям, атмосфере). Летучая зола может даже попасть в почву и загрязнить грунтовые воды тяжелыми металлами [1-2]. Из золошлаковых отходов из угля, вырабатываемых ТЭЦ, в Казахстане перерабатывается около 8 % золы (менее 1,9 млн тонн).

Республика Казахстан занимает 8-е место в мире по разведанным запасам угля, содержит 3,4 % мировых запасов в недрах и входит в десятку крупнейших производителей угля на мировом рынке. Использование многотоннажной золы из месторождений является неотложной проблемой. Одним из способов решения является ее применение при производстве бетона. Повышение экологической безопасности предполагает снижение расхода природного сырья при производстве бетона и сокращение промышленных отходов.

Целью данного исследования является изучение химического состава летучей золы из золоотвалов тепловых электростанций, а также влияния в качестве добавки на структуру и свойства цементного камня.

Материалы и методы

Для изучения потенциального использования золы, отобранной из золоотвалов и золоуловителей, элементный состав определяли с помощью рентгенофлуоресцентного рентгенофлуоресцентного спектрометра Epsilon 1 (Malvern Panalytical, Малверн, Великобритания). В качестве источника рентгеновского излучения в спектрометре использовалась рентгеновская трубка с набором первичных фильтров (U = 50 хВ, I'' = 0,5 мА; максимальная мощность 5 ВА; материал анода — серебро).

Химический и фазовый состав используемых материалов осуществлялся с применением современных методов анализа: рентгенофазовый и рентгенофлуоресцентный. Рентгенофазовый анализ осуществлялся с помощью рентгеновского дифрактометра общего назначения, который предназначен для измерения интенсивности и углов дифракции рентгеновского излучения, дифрагированного на кристаллическом объекте, для решения задач рентгенодифракционного и рентгеноструктурного анализа материалов.

Была использована летучая зола из золоотвала Петропавловского ТЭЦ.

Результаты и обсуждения

Для полезного использования золы-уноса и зольного остатка в качестве сырья, для безопасного хранения и использования золошлаковых отходов (ЗШО) необходимо располагать информацией об их свойствах и характеристиках [3].

Золошлаковые отходы (ЗШО) энергетической промышленности относятся к числу многотоннажных промышленных отходов. Состав ЗШО определяется минеральным составом углей, который зависит от месторождения, глубины залегания пластов, методов добычи и обогащения.

Химические свойства ЗШО сильно варьируются в зависимости от типа угля, температуры горения, технологии сжигания, соотношения воздух / топливо и размера частиц угля. К основным макроэлементам золы относятся Si, Al, Fe, O, Ca, Ti, Mg, S, K, Na, которые составляют до 98-99 % золошлаковых отходов. Также в золе содержатся микроэлементы в концентрации 0,1 % и менее. Часть микроэлементов, таких, как Sr, Ba, Sc, Y, La, Ti, Zr и др. при сгорании угля концентрируется в шлаке. При температурах выше 1000˚С некоторые элементы улетучиваются из зоны высоких температур и оседают в электрофильтрах, циклонах (при 110–120 ˚С) [4].

Химический состав золы приведен в таблице 1. Химический состав исходных материалов определялся по [5].

Таблица 1 – Химический состав летучей золы из золоотвала Петропавловского ТЭЦ

Элемент %	Образец №1	Образец №2
Al	10,377	10,763
Si	18,798	17,240
P	0,868	0,720
S	0,019	0,063
Cl	0,099	0,014
K	0,491	0,188
Ca	3,400	4,560
Ti	1,003	0,255
V	0,029	0,008
Cr	0,039	0,001
Mn	1,107	1,250
Fe	62,617	40,633
Cu	0,043	0,032
Zn	0,021	0,007
Ga	0,011	0,012
As	0,010	0,004
Rb	0,004	0,006
Sr	0,140	0,143
Y	0,022	0,003
Zr	0,104	0,014
Nb	0,003	
Sn	0,036	0,016
Te	0,024	0,011
Ba	0,265	0,045
Eu	0,433	0,015
Yb	0,036	0,002

Как видно из результатов анализа, образцы летучей золы содержат макроэлементы Al, Si, S, K, Ca, Fe и микроэлементы P, Cl, Ti, V, Cr, Mn, Cu, Zn, Ga, As, Rb, Sr. Особенностью летучей золы является повышенное содержание.

Результаты, полученные с помощью энергодисперсионного рентгенофлуоресцентного анализа с радиоизотопным возбуждением K-линий, подтвердили, что данный метод адекватен для анализа твердых образцов в широком диапазоне концентраций. В данной работе установлено, что в исследуемых золах Sr присутствует относительно высокая концентрация, в то время как концентрация La чрезвычайно низкая.

Средние значения концентраций в исходных пробах Ba (барий), Sr (стронций), Zr (цирконий) было обнаружено составляют менее 1%. Как правило, такие элементы и их соединения могут быть токсичными. Известно, что особенно летучая зола размером менее 1 мкм также оказывает вредное воздействие на здоровье человека. Представленные результаты могут быть полезными для экологических, химических, геохимических, промышленных и других исследований.

Показатели качества материала (летучей золы) в значительной степени определяются их элементным составом. Макроэлементы (Al, Si, K, Ca, Fe) влияют на качество конечной продукции, а микроэлементы (Ti, V, Cr, Mn, Ni, Cu, Zn, As, Br, Rb, Ba, Pb, РЗЭ) определяют экологические аспекты утилизации золошлаков.

Основной состав летучей золы качественно близок к природным материалам, таким, как почва, глина, сланцы. Окислы (окисленные соединения) Si, Al, Fe и Ca составляют почти 90% состава летучей золы. Другие элементы, такие, как Mg, K,Na, Ti и S встречаются в качестве второстепенных компонентов и составляют небольшой процент суммарного объемного состава. Как правило, все остальные элементы встречаются в диапазоне частей на миллион и в совокупности редко превышают 1% от общего состава. Летучая зола связана с различными полезными составляющими, такими, как Ca, Mg, Mn, Fe, Cu, Zn, B, S и P, а также со значительными количествами токсичных элементов, таких, как Cr, Pb, Hg, Ni, V, As и Ba. Концентрация микроэлементов в золе чрезвычайно изменчива и зависит от состава исходного угля, условия при сжигании угля, полноты сгорания и прочее [6-7].

Сущность рентгеновского метода анализа заключается в изучении дифракционной картины, получаемой при отражении рентгеновских лучей атомными плоскостями в структуре кристаллов. Так как интенсивность дифракционного отражения определенной фазы является прямой пропорциональной в зависимости от объемной доли конкретной фазы в исследуемом многофазном материале, можно сделать вывод о количественном значении искомой фазы в композите. Рентгено-диффракционный анализ заключается в проведении количественного сопоставления эталонных линий известной интенсивности, полученных в определенных условиях, с линейной интенсивностью для исследуемых фаз, полученных в подобных условиях.

Результаты химического фазового состава летучей золы был определен с помощью рентгено-флуоресцентной спектрометрии (XRF) (рисунок 1).

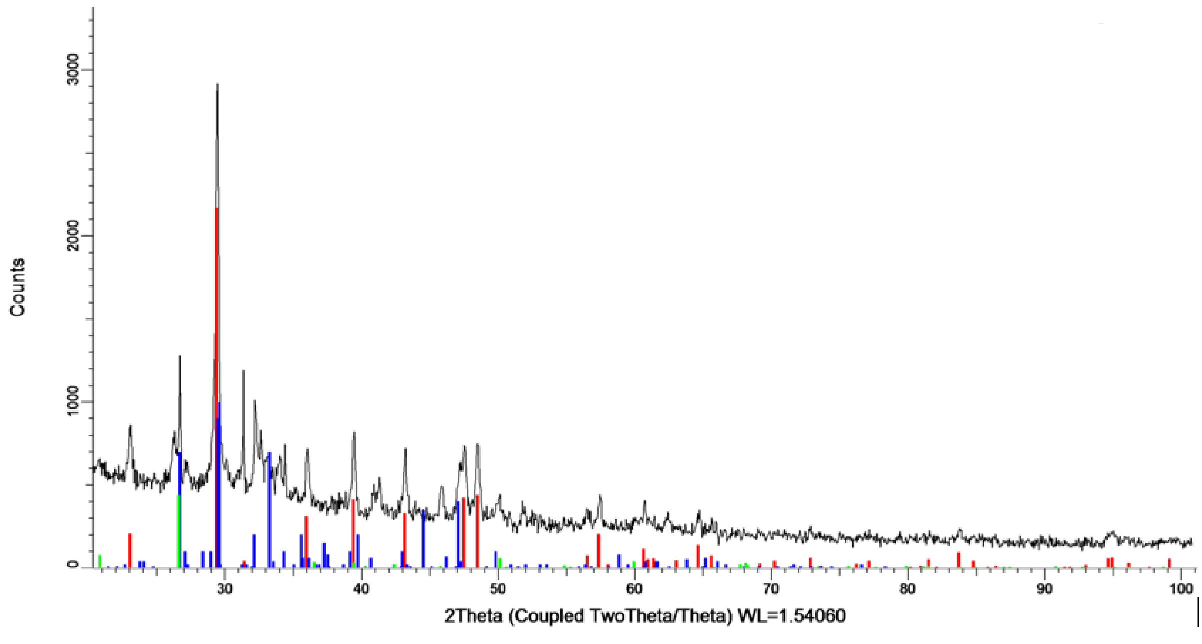


Рисунок 1 - Рентгеновская дифракция образца

Как видно на рисунке 1, CaO, SiO_2, Al_2O_3 и Fe_2O_3 составляют большую часть летучей золы. По мере увеличения CaO содержание SiO_2, Al_2O_3 и Fe_2O_3 уменьшается. Однако, когда увеличивается CaO, содержание щелочей, включая Na_2O и K_2O, а также $SO_{3,}$ увеличивается.

Из рисунка 1 можно сделать вывод, что в процессе сжигания угля все органоминеральные компоненты разрушаются и на первой стадии образуются кислородсодержащие соединения - чаще всего оксиды. Оксиды вступают в химическое взаимодействие друг с другом и материалом котла. Более важные термические изменения происходят с неорганическими соединениями как основных золообразующих элементов, так и микроэлементов [6-7].

На основании анализа фаз были определены вклады каждой фазы на прочность цемента. Результаты анализа представлены на рисунке 2.

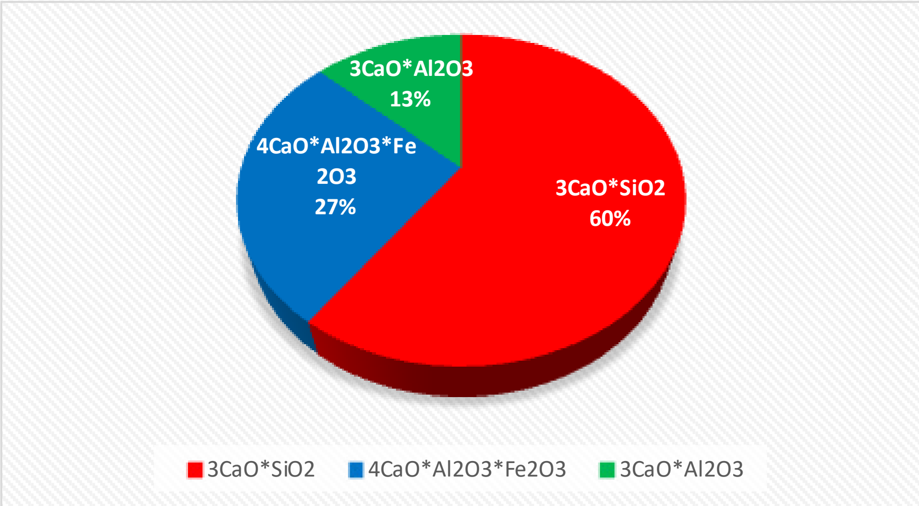


Рисунок 2 - Фазовый состав цементного камня с добавлением летучей золы

Как показано на рисунке 2, фазовый состав цементного камня с добавлением летучей золы разнообразен. Исследования структуры рентгенофазовым методом показали, что в образцах присутствуют следующие фазы: трехкальциевый силикат $3CaO*SiO_2$, двухкальциевый силикат $2CaO*SiO_2$, четырехкальциевый алюмоферрит $4CaO*Al_2O_3*Fe_2O_3$, трехкальциевый алюминат $3CaO*Al_2O_3$. Это дает возможность использования данных материалов в качестве вторичного сырья взамен силикатной и кальциевой составляющей в производстве цемента, силикатного кирпича, бетона и композиционных материалов.

В таблице 2 представлены данные структурных параметров, установленных в ходе анализа основных фаз.

Таблица 2 – Структурные параметры основных фаз

№	Наименование фазы	Тип структуры	Параметры кристаллической решетки, Å
1	$3CaO*SiO_2$	Rhombo.H.axes	a=4.97436, c=17.09880, V=366.41 Å^3
2	$4CaO*Al_2O_3*Fe_2O_3$	Orthorhombic	a=12.59110, b=15.70192, c=7.70441, V=1523.20 Å^3
3	$3CaO*Al_2O_3$	Hexagonal	a=4.92518, c=5.39059, V=113.24 Å^3

Весьма значительно изменяется в углях содержание железа, основными соединениями которого являются сидерит и пирит, которые иногда образуют довольно крупные конкреции. На рисунке 3 приведена микрофотография частиц летучей золы.

ISSN: 2616-6771, eISSN: 2617-9962

Рисунок 3 – Микрофотография летучей золы

На рисунке 3 видно, что частицы летучей золы представляют собой сферы и агрегаты компактной формы, размер частиц которых колеблется от 10 до 100 микрон. Из приведенных данных можно сделать вывод, что данный образец очень мелкодисперсный.

Летучая зола содержит диоксид кремния (SiO), оксид кальция (CaO), оксид алюминия (AlO) и оксид железа (FeO). Компоненты варьируются в зависимости от типа сжигаемого угля. Как показано на рисунке 3, летучая зола образуется в результате быстрого охлаждения расплавленной золы. Следовательно, большинство частиц летучей золы находятся в аморфном состоянии. Частицы летучей золы обычно имеют сферическую форму с диаметром от менее 1 мкм до 150 мкм, в то время как частицы цемента имеют размер менее 45 мкм. Такая сферическая форма и размер частиц повышают текучесть бетонной смеси и снижают водопотребность.

Заключение

Исследования показали, что минеральная часть зол ТЭС на 90-92% состоит из стекловидной фазы. Основным компонентом этой фазы является кремнезем, который в значительной степени формирует физические и химические свойства золы. Он участвует в процессах гидратационного твердения вяжущего, а также в процессах синтеза, образуя различные гидросиликаты.

Вопросы утилизации золы ТЭЦ во всех регионах Казахстана актуальны, если принять во внимание следующие факторы: близость золоотвалов к городской застройке; ограниченные площади для расширения золоотвалов; ущерб, наносимый окружающей среде. Как видно из элементного анализа состава золы, все образцы золы содержали кальциевые и силикатные компоненты и могли быть использованы в промышленности строительных материалов.

Список литературы

1. Hemmings R.T., Berry E.E. On the Glass in Coal Fly Ashes: Recent Advances//Mater. Res. Soc. Symp. Proc. – 1988. - Vol. 113. – P.3-38. https://doi.org/10.1557/PROC-113-3.

2. Reis J., Freire F., de Brito J. The effect of fly ash on the carbonation resistance of Portland cement-based materials//Mag. Concr. Res. – 2021. - Vol. 73, – P.61–72.

3. Durdziński P.T., Dunant C.F., Haha M.B., Scrivener K.L. A New Quantification Method Based on SEM-EDS to Assess Fly Ash Composition and Study the Reaction of Its Individual Components in Hydrating Cement Paste//Cem. Concr. Res. – 2015, - Vol. 73, – P.111–122. https://doi.org/10.1016/j.cemconres.2015.02.008.

4. Golewski G.L. Combined Effect of Coal Fly Ash (CFA) and Nanosilica (nS) on the Strength Parameters and Microstructural Properties of Eco-Friendly Concrete// Energies. – 2023. - Vol. 452. https://doi.org/10.3390/en16010452.

5. ГОСТ 5382-91 «Цементы и материалы цементного производства. Методы химического анализа».

6. Dvorkin L., Zhitkovsky V., Sitarz M., Hager I. Cement with Fly Ash and Metakaolin Blend-Drive towards a More Sustainable Construction// Energies. – 2022. - Vol. 15, – P.3556. https://doi.org/10.3390/en15103556.

7. Szostak B., Golewski G.L. Improvement of Strength Parameters of Cement Matrix with the Addition of Siliceous Fly Ash by Using Nanometric C-S-H Seeds// Energies. – 2020, - Vol. 13, – P.6734. https://doi.org/10.3390/en13246734.

A. Maykonov[1], A.M. Abdyrov[2], L.S. Shansharova[3], R.K. Niyazbekova[3], S.S. Aldabergenova[2], R.Tlegenov[2]

[1] Kazakh-British Technical University, Almaty, Kazakhstan
[2] S. Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan
[3] RSE «Kazakhstan Institute of Standardization and Metrology», Astana, Kazakhstan

Investigation of the chemical composition of «fly» ash and its effect on the strength of cement stone

Abstract. The article is devoted to the problems associated with reducing the negative impact of ash and slag waste from the CHP of Kazakhstan on the environment. The fly ash produced in large quantities, as a product of fuel combustion at power plants, negatively affects the external environment, polluting air, soil, sewage, etc.

The article presents the results of the chemical composition of ash and slag waste. Possible ways of using ash are considered. The phase composition of cement stone with the addition of fly ash was also studied using modern methods of analysis: X-ray phase and X-ray fluorescence. It was found that the main macroelements of ash include Si, Al, Fe, O, Ca, Ti, Mg, S, K, Na.

In addition to studying the sizes and shapes of microspheres, the work set the tasks of determining the types of thermoactive phases that make up cement stone during heat treatment; studying structural changes during heat treatment. X-ray phase analysis of ash microspheres showed the following phases: $Al_6Si_2O_{13}$ mullite, SiO_2 quartz and amorphous glass phase.

The use of ash as a source of aluminum and silicon oxides will not only reduce the use of non-renewable resources, but also obtain materials with improved thermophysical characteristics (strength, heat resistance and thermal conductivity). Choosing the optimal amount of fly ash instead of a part of cement contributes to the formation of the desired structure of cement stone.

Keywords: fly ash, ash dump, production waste, elemental analysis, X-ray phase method, cement.

А. Майконов[1], А.М. Абдыров[2], Л.С. Шаншарова[3], Р.К. Ниязбекова[3], С.С. Алдабергенова[2], Р. Тлегенов[2]

[1] Қазақстан-Британ техникалық университеті, Алматы, Қазақстан

[2] С. Сейфуллин ат. Қазақ агротехникалық зерттеу университеті, Астана, Қазақстан

[3] «Қазақстан стандарттау және метрология институты» РМК, Астана, Қазақстан

«Ұнтақ» күлдің химиялық құрамын және оның цемент беріктігіне әсерін зерттеу

Аңдатпа. Мақала Қазақстанның ЖЭО күл-қож қалдықтарының қоршаған ортаға теріс әсерін төмендетуге байланысты мәселелерге арналған. Энергетикалық станциялардағы отынның жану өнімі ретінде көп мөлшерде өндірілетін күл сыртқы ортаға теріс әсер етеді, ауаны, топырақты, ағынды суларды және т.б. ластайды.

Мақалада күл-қож қалдықтарының химиялық құрамының нәтижелері келтірілген. Күлді қолданудың мүмкін жолдары қарастырылған. Сондай-ақ, қазіргі заманғы талдау әдістерін қолдана отырып, күл қосылған цемент тасының фазалық құрамы зерттелді: рентгендік және флуоресцентті. Күлдің негізгі макронутриенттеріне Si, Al, Fe, O, Ca, Ti, Mg, S, K, Na элементтері кіретіні анықталды.

Микросфералардың өлшемдері мен формаларын зерттеумен қатар, жұмыста термиялық өңдеу кезінде цемент қоспасын құрайтын термоактивті фазалардың түрлерін анықтау; термиялық өңдеу кезіндегі құрылымдық өзгерістерді зерттеу міндеттері қойылды. Күл микросфераларын зерттеуге арналған рентгендік фазалық талдау келесі фазаларды көрсетті: $Al_6Si_2O_{13}$ муллиті, SiO_2 кварцы және аморфты шыны фазасы.

Күлді алюминий және кремний оксидтерінің көзі ретінде пайдалану қалпына келмейтін ресурстарды пайдалануды азайтып қана қоймай, сонымен қатар жақсартылған жылу-физикалық сипаттамалардан тұратын материалдарды (беріктік, ыстыққа төзімділік және жылу өткізгіштік) алуға мүмкіндік береді. Цементтің бір бөлігінің орнына күлдің оңтайлы мөлшерін таңдау цемент қоспасының қажетті құрылымын қалыптастыруға ықпал етеді.

Түйін сөздер: күл, күл үйіндісі, өндіріс қалдықтары, элементтік талдау, рентген-фазалық әдіс, цемент.

References

1. Hemmings R.T., Berry E.E. On the Glass in Coal Fly Ashes: Recent Advances//Mater. Res. Soc. Symp. Proc. 113. 3-38(1988). https://doi.org/10.1557/PROC-113-3.

2. Reis J., Freire F., de Brito J. The effect of fly ash on the carbonation resistance of Portland cement-based materials//Mag. Concr. Res. 73. 61–72(2021).

3. Durdziński P.T., Dunant C.F., Haha M.B., Scrivener K.L. A New Quantification Method Based on SEM-EDS to Assess Fly Ash Composition and Study the Reaction of Its Individual Components in Hydrating Cement Paste//Cem. Concr. Res. 73. 111–122(2015). https://doi.org/10.1016/j.cemconres.2015.02.008.

4. Golewski G.L. Combined Effect of Coal Fly Ash (CFA) and Nanosilica (nS) on the Strength Parameters and Microstructural Properties of Eco-Friendly Concrete// Energies. 452(2023). https://doi.org/10.3390/en16010452.

5. GOST 5382-91 «Cementy i materialy cementnogo proizvodstva. Metody himicheskogo analiza» [Cements and materials for cement production. Chemical analysis methods].

6. Dvorkin L., Zhitkovsky V., Sitarz M., Hager I. Cement with Fly Ash and Metakaolin Blend-Drive towards a More Sustainable Construction// Energies. 15. 3556(2022). https://doi.org/10.3390/en15103556.

7. Szostak B., Golewski G.L. Improvement of Strength Parameters of Cement Matrix with the Addition of Siliceous Fly Ash by Using Nanometric C-S-H Seeds// Energies. 13. 6734(2020). https://doi.org/10.3390/en13246734.

Сведения об авторах:

Майконов Аслан – магистр технических наук, докторант Казахстанско-Британского технического университета, ул. Толе би, 59, Алматы, Казахстан.

Абдыров Айтжан Мухамеджанович – д.п.н., профессор, НАО «Казахский агротехнический исследовательский университет им. С. Сейфуллина», пр. Женис, 62, Астана, Казахстан.

Шаншарова Лаззат Сарсенбаевна – магистр технических наук, научный сотрудник, РГП «Казахстанский институт стандартизации и метрологии», проспект Мәңгілік Ел, 11, Астана, Казахстан.

Ниязбекова Римма Калманбаевна – д.т.н., профессор кафедры «Стандартизация, метрология и сертификация», НАО «Казахский агротехнический исследовательский университет им. С.Сейфуллина», пр. Женис, 62, Астана, Казахстан.

Алдабергенова Сауле Салимжановна – PhD, заведующий кафедрой «Стандартизация, метрология и сертификация», НАО «Казахский агротехнический исследовательский университет им. С. Сейфуллина», пр. Женис, 62, Астана, Казахстан.

Тлегенов Расул – магистр технических наук, докторант кафедры «Стандартизация, метрология и сертификация», НАО «Казахский агротехнический исследовательский университет им. С. Сейфуллина», пр. Женис, 62, Астана, Казахстан.

Maikonov A. – Master of Technical Sciences, doctoral student of the Kazakh-British Technical University, Tolebi 59, Almaty, Kazakhstan.

Abdyrov A.M. – d.p.s, Professor, Member of the Board, First Vice-Rector of S. Seifullin Kazakh Agrotechnical Research University, Zhenis avenue, 62, Astana, Kazakhstan.

Shansharova L.S. – Master of Technical Sciences, Researcher, RSE "Kazakhstan Institute of Standardization and Metrology", 11 Mangilik El Avenue, "Standard Center" Building, Astana, Kazakhstan.

Niyazbekova R.K. – Doctor of Technical Sciences, Professor, Department of Standardization, Metrology and Certification, S. Seifullin Kazakh Agro Technical Research University, 62 Zhenis avenue, Astana, Kazakhstan.

Aldabergenova S.S. – PhD, Head of the Department of Standardization, Metrology and Certification, S. Seifullin Kazakh Agrotechnical Research University, 62 Zhenis avenue, Astana, Kazakhstan.

Tlegenov R. – Master of Technical Sciences, PhD student, Standardization, Metrology and Certification Department, S. Seifullin Kazakh Agro Technical Research University, 62 Zhenis avenue, Astana, Kazakhstan.

МРНТИ 31.15.25

Е.А. Покинтелица, Н.В. Щебетовская*

ФГБОУ ВО «Донбасская национальная академия строительства и архитектуры», Макеевка, Россия
(*автор для корреспонденции:*lnk0013@gmail.com*)

Особенности кристаллизации эвтектического сплава 20.5 вес.% нафталина-79.5 вес.% о-терфенила

Аннотация. *Терфенильные смеси в кристаллическом состоянии применяются как сцинтилляторы, люминофоры, фоторезисторы, сенсибилизаторы и др. Их структура и свойства во многом зависят от условий кристаллизации. Методом циклического термического анализа изучены особенности кристаллизации эвтектического сплава углеводородов о-терфенила (79.5 вес.%) и нафталина (20.5 вес.%). В результате проведенных экспериментов на эвтектическом сплаве было установлено, что горизонтальные плато, фиксируемые при нагревании, соответствуют температуре плавления (304 K) эвтектического сплава. Установлено, что слабо прогретые расплавы кристаллизуются изотермически при температуре* T_S*=298 K, лежащей ниже температуры плавления эвтектики* T_L*=304 K. На кривых охлаждения расплавов, ранее прогретых выше «критической» температуры* T_c*=314 K, не наблюдаются экзотермические эффекты, которые свидетельствовали бы об их кристаллизации. С увеличением времени изотермической выдержки метастабильного расплава либо времени пребывания расплава (без выдержки) в переохлажденном состоянии увеличивается длина плато плавления в последующем цикле, что свидетельствует об увеличении степени кристалличности образца. Предложена методика определения степени кристалличности* η *по продолжительности* t_e *изотермической выдержки переохлажденного расплава и длительности* τ_L *плавления. По этой методике вычислены константа скорости валовой кристаллизации Z и параметр Аврами n.*

Ключевые слова: *термический анализ, о-терфенил, нафталин, терфенильная смесь, плавление, перегрев, переохлаждение, изотермическая выдержка, кристаллизация, степень кристалличности.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-51-62

Введение. Терфенильные смеси в кристаллическом состоянии находят применение в качестве сцинтилляторов, люминофоров, фоторезисторов, сенсибилизаторов и др. [1]. Их структура и свойства во многом зависят от условий кристаллизации. Кроме того, эти углеводороды могут выступать в качестве модельных при изучении кинетики кристаллизации из расплава, поскольку они практически не подвержены окислению и деструкции вблизи температуры плавления. Особый интерес представляют подобные исследования на терфенильных смесях эвтектического типа, в частности, в системе о-терфенил-нафталин.

Ранее методами термического анализа нами были исследованы процессы плавления и кристаллизации различных углеводородов и их смесей [2-5]. Было обнаружено, что в зависимости от термической предыстории расплава происходит резкий переход от квазиравновесной кристаллизации (КРК) без переохлаждения к неравновесно-взрывной (НРВК) со значительными переохлаждениями. Кроме того, в бинарных смесях эвтектического типа было установлено, что по мере приближения состава к эвтектическому предкристаллизационные переохлаждения закономерным образом уменьшаются для одних систем и увеличиваются для других. Данная работа посвящена особенностям кристаллизации смеси нафталина (Н) и о-терфенила (о-Т) эвтектического состава 20.5 вес.% Н-79.5 вес.% о-Т (ЕС).

Методика экспериментов. Эксперименты проводили методами циклического термического анализа – ЦТА и ДТА путем последовательного термоциклирования [6]. Сплавы готовили путем смешения нафталина марки ЧДА и о-терфенила (Merck KGaA). Массы отдельных компонентов взвешивали на аналитических весах Waga torsyjna-wt (typ prlt T5) с точностью до 2 мг. Масса каждого сплава одинакового состава во всех экспериментах составляла 0.15 г. Образцы помещали в герметически закрытые стеклянные пробирки. Термоциклирование проводили в специально изготовленных печах сопротивления со скоростями нагревания и охлаждения в пределах 0.08 -0.12 K/c. Температуру измеряли с помощью ХА термопары диаметром 0.2 мм, спай которой был помещен в образец и не касался стенок пробирок. Запись кривых нагревания и охлаждения вели с помощью двухканального термоизмерителя Unit 325 через интерфейс на ПК. Систематическая погрешность измерения температуры составляла 0.1 K. Образцы термоциклировали в непрерывном режиме на одном и том же образце. Затем повторяли опыты в том же режиме на других образцах того же состава. На каждом образце записывали не менее 10 термоциклов нагревания и охлаждения. Достоверность эффектов подтверждалась на основании их воспроизводимости при достаточно большом количестве термоциклов. Реперными точками являлись температуры плавления чистых компонентов, которые сопоставлялись со справочными данными. В зависимости от конкретных задач границы нагревания и охлаждения варьировали в пределах 50 градусов выше и ниже эвтектической температуры.

Результаты экспериментов. Приведем результаты исследования процессов фазовых превращений, полученных методом ЦТА в координатах температура – время. На первом этапе изучали влияние перегрева ΔT^{+} жидкой фазы относительно температуры плавления T_L=31˚C (304 K) эвтектического сплава ЕС на характер кристаллизации при охлаждении. Для этого термографирование проводили в пределах ± 20 K выше и ниже температуры плавления. Нижнюю границу 21˚C (294 K) поддерживали неизменной, а верхнюю границу повышали на 2-3 градуса относительно предыдущего цикла.

На рис. 1 показана схематическая картина изменения вида кривых нагревания и охлаждения от цикла к циклу. Установлено, что после относительно слабых прогревов расплава до ~10 K выше T_L и охлаждении на термограмме наблюдается горизонтальное плато (*cd*) кристаллизации при T_S=298-299 K, т.е. при разнице $\Delta T_{LS}= T_L - T_S \approx$ 5-6 K. Это свидетельствует о том, что кристаллизация при T_S носит изотермический равновесный характер, несмотря на неравновесное переохлажденное состояние жидкой фазы. Если совместить линии нагревания и охлаждения (термограмма 1 на рис. 1), записанные соответственно в прямом (сплошная линия) и обратном (пунктирная линия) направлениях, получим температурный гистерезис первого рода [7] в виде фигуры *abc'd'a*.

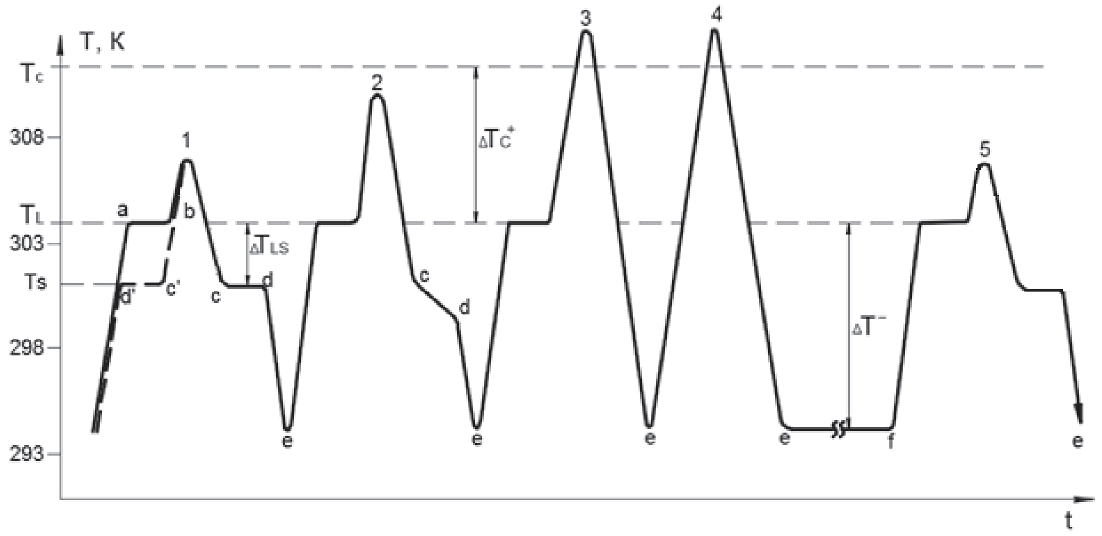


Рис. 1. Схематические термограммы, характеризующие влияние прогревов жидкой фазы на тип кристаллизации эвтектики 20.5 % Н-79.5 % о-Т

Подобный гистерезис ранее был обнаружен и на чистом о-терфениле с ΔT_{LS}=8 K [8]. На нафталине подобный гистерезис не наблюдается (ΔT_{LS}=0 K) [9].

При увеличении температуры прогрева расплава до определенного «критического» значения (ΔT_c^+~10-11 K) и его охлаждении линия *cd* на термограмме разворачивалась из горизонтального положения к направлению линии охлаждения *de* (термограмма 2, рис.1). При перегреве расплава выше ΔT_c^+ и охлаждении на кривых не фиксируются экзоэффекты ни в каком виде, а линия «плато» *cd* сливается с линией охлаждения (термограмма 3, рис. 1). Это означает, что в данном случае за время охлаждения кристаллизация не должна происходить. Об этом свидетельствует также следующая термограмма 4 на рис. 1, на восходящей части которой (при нагревании) не фиксируется плато плавления. Плато появляется лишь в случае изотермической выдержки переохлажденной жидкости в течение определенного промежутка времени от точки *e* до точки *f* (термограмма 5, рис. 1). Таким образом, можно обозначить определенное переохлаждение ΔT^- относительно T_L, при котором кристаллизация может происходить в результате изотермической выдержки метастабильной фазы, в то время как при переохлаждении ΔT_{LS} кристаллизация происходит без подобной термической обработки расплава (термограмма 1, рис. 1).

На следующем этапе изучали влияние продолжительности t_e изотермической выдержки переохлажденного расплава ЕС при разных температурах на время τ_L кристаллизации. Для этого расплав прогревали выше установленной ранее «критической» температуры на 10 градусов, затем охлаждали ниже температуры плавления и выдерживали в течение определенных промежутков времени t_e при фиксированных переохлаждениях ΔT^-=6, 10, 13, 20, 24, 47 K. В качестве примера на рис. 2 приведены схематические термограммы, отражающие влияние продолжительности t_e выдержки расплава эвтектического состава при ΔT^-=6 K на длительность τ_L плавления. Видно, что с увеличением времени выдержки расплава в переохлажденной области поэтапно увеличивается и время плавления. Причем после выдержки в течение 40 минут время плавления для образцов массой 0.15 г становится максимальным τ_{max}=140 с (рис. 2, термограмма 5) и равным времени плавления на термограмме 0 (рис. 2).

Аналогичную закономерность наблюдали и с помощью метода ДТА. На том же рисунке приведены для сравнения ЦТА- и ДТА-граммы. Видно, что площади S_i пиков ДТА, соответствующие теплотам Q_i плавления, имеют такую же последовательность увеличения, как и длины l_i плато на ЦТА-граммах в зависимости от продолжительности изотермических выдержек переохлажденных расплавов. Следует отметить, что на ДТА, как и на ЦТА-граммах, экзотермические эффекты кристаллизации не фиксировались.

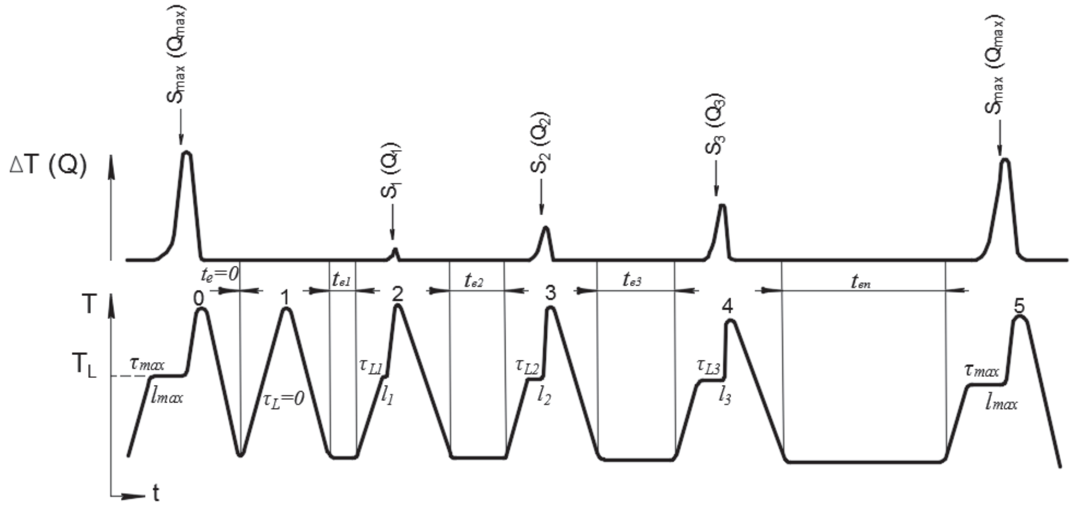


Рис. 2. Схематические ЦТА- и ДТА-термограммы, отражающие влияние продолжительности изотермических выдержек расплава эвтектического состава 20.5 % Н-79.5 % о-Т на длительность плавления от цикла к циклу

Влияние переохлаждения (без изотермических выдержек) на длительность последующего плавления демонстрируют схематические термограммы на рис. 3, полученные методом ЦТА. Видна та же закономерность, что и в случае с изотермическими выдержками: чем больше переохлаждение, тем дольше пребывание расплава в метастабильном состоянии. Соответственно, при нагревании растет время плавления. Это говорит о том, что пока расплав находится в переохлажденном состоянии, в нем происходит медленная кристаллизация.

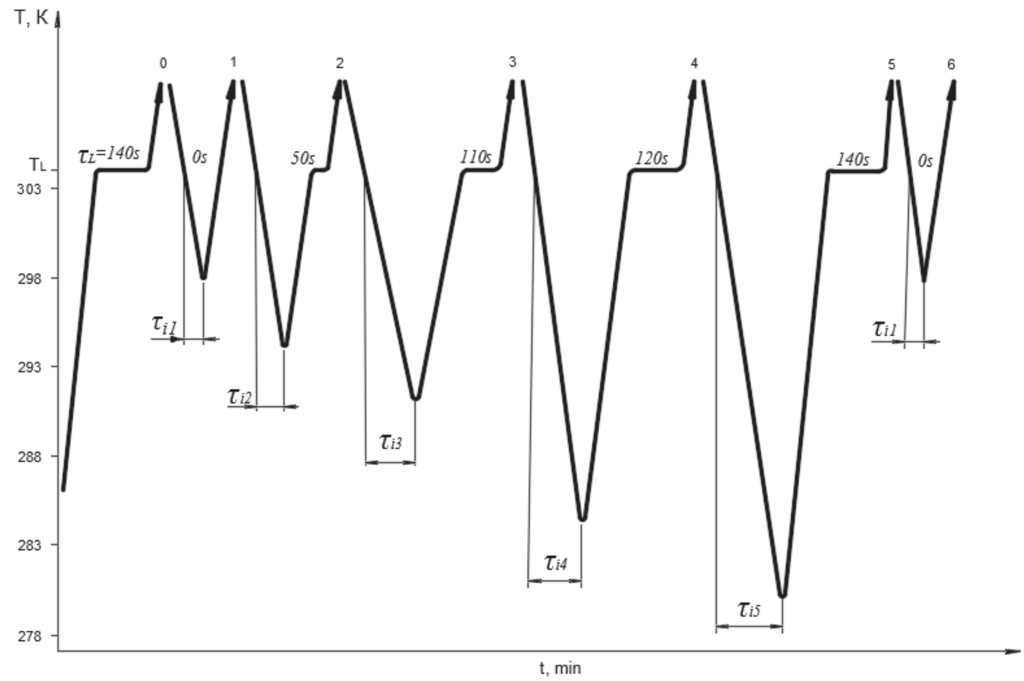


Рис. 3. Термограммы, отражающие влияние переохлаждения расплава ЕС на продолжительность дальнейшего плавления при последующем нагревании. Стрелками показаны времена t_{ei} изотермических выдержек при ΔT^{-}=6 K (термоцикл 1), 10 K (2), 13 K (3), 20 K (4), 24 K (5)

Результаты найденных параметров плавления и кристаллизации ЕС, полученных методами ЦТА и ДТА в различных условиях термообработки в переохлажденном состоянии, приведены в табл. 1. В ней показаны температуры выдержек T_e, переохлаждения ΔT^-, времена изотермических выдержек t_e расплава, длительности плавления τ_L, теплоты плавления Q_i, степени кристалличности η и η', инкубационные периоды t_i при разных переохлаждениях, общее время нахождения расплава в переохлажденном состоянии с учетом инкубационного периода t_e+t_i.

На основании данных, приведенных в табл. 1, строились графики зависимостей степени кристалличности $\eta=\tau_L/\tau_{max}$ от времени выдержек t_e при разных фиксированных переохлаждениях (рис. 4). Эти графики имеют S-образный вид. Видно, что с увеличением переохлаждения растет быстрота полного затвердевания.

В результате проведенных экспериментов на эвтектическом сплаве ЕС были установлены следующие закономерности:

- горизонтальные плато, фиксируемые при нагревании, соответствуют температуре плавления (304 K) эвтектического сплава;
- слабо прогретые расплавы кристаллизуются изотермически при температуре T_S=298 K, лежащей ниже температуры плавления T_L=304 K;
- на кривых охлаждения расплавов, ранее прогретых выше «критической» температуры T_c=314 K, не наблюдаются экзотермические эффекты, которые свидетельствовали бы об их кристаллизации;
- после изотермических выдержек переохлажденных расплавов и дальнейшем их нагревании фиксируются плато плавления при температуре T_L=304 K, свидетельствующие о том, что в процессе выдержки (рис. 2) расплав кристаллизуется;
- с увеличением времени изотермической выдержки метастабильного расплава либо времени пребывания расплава (без выдержки) в переохлажденном состоянии увеличивается длина плато плавления в последующем цикле, что свидетельствует об увеличении степени кристалличности образца.

Таблица 1. Экспериментальные и расчетные параметры плавления и кристаллизации эвтектического сплава 20.5 вес.% Н-79.5 вес.% о-Т

№ п/п	T_e, K	ΔT^-, K	t_e, c	τ_L, c	Q_i, Дж	η	η'	n	Z	t_i, c	t_e+t_i	n′	Z′
1	298	6	0	15	1.21	0.11	0.09	-	-	15	15	-	-
			600*	39	4.03	0.28	0.30	2.36	$0.66\cdot10^{-8}$		615	2.08	$4.0\cdot10^{-7}$
			1200	88	8.06	0.63	0.60	-	-		1215	-	-
			1800	120	11.68	0.86	0.87				1815		
			2400	140	13.43	1.00	1.00				2415		
			3000	140	13.43	1.00	1.00				3015		
2	294	10	0	20	1.61	0.14	0.12	-	-	175	175	-	-
			600*	60	5.37	0.43	0.40	1.80	$5.60\cdot10^{-6}$		775	2.25	$1.8\cdot10^{-7}$
			1200	120	10.74	0.86	0.80	-	-		1375	-	-
			1800	140	13.43	1.00	1.00				1975		
			2400	140	13.43	1.00	1.00				2575		

3	291	13	0	50	4.30	0.36	0.32	-	-	200	200	-	-
			600*	70	6.85	0.50	0.51	1.20	3.20·10^{-4}		800	1.43	5.0·10^{-5}
			1200	110	10.07	0.79	0.75	-	-		1400	-	-
			1800	140	13.43	1.00	1.00				2000		
4	284	20	0	85	7.79	0.61	0.58	-	-	325	325	-	-
			600*	135	12.62	0.96	0.94	0.22	0.78		925	1.23	7.6·10^{-4}
			1200	140	13.43	1.00	1.00	-	-		1525	-	-
5	280	24	0	100	9.80	0.71	0.73	-	-	375	375	-	-
			600*	140	13.43	1.00	1.00	0.15	1.15		975	1.48	1.4·10^{-2}
6	257	47	0	140	13.43	1.00	1.00	-	-	675	675	-	-

Экзотермический эффект кристаллизации расплава в нашем случае не фиксируется аппаратурой из-за чрезвычайно малых скоростей образования зародышей и их роста в переохлажденном расплаве, в результате чего скорость выделения теплоты фазового перехода на несколько порядков меньше скорости теплоотвода в окружающую среду. Скорость же плавления значительно выше скорости кристаллизации, поэтому подводимое тепло легко поглощается образцом и фиксируется термопарой.

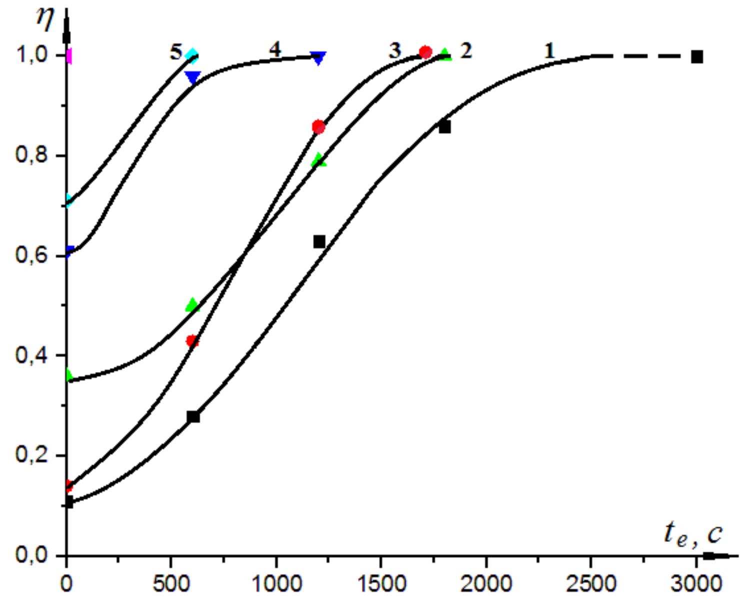


Рис. 4. Графики зависимостей η от температур выдержек t_e расплава ЕС при фиксированных переохлаждениях 6 (кривая 1), 10 (2), 13 (3), 20 (4), 24 (5) и 47 K

Покажем, что по длительности плавления можно судить о степени кристалличности вещества как методом ЦТА, так и методом ДТА (рис. 2). Количество теплоты, затрачиваемое на плавление Q_L, равно теплоте кристаллизации Q_S

$$Q_L = Q_S = \Delta H \cdot m, \qquad (1)$$

где m – масса, ΔH –энтальпия фазового перехода.

Выразив величины Q_L и Q_S через массовые скорости плавления $\upsilon_L^m = m/\tau$ и кристаллизации $\upsilon_S^m = m/t$ и подставив их в равенство (1), получим

$$\upsilon_L^m \tau = \upsilon_S^m t, \qquad (2)$$

где τ и t – соответственно времена плавления и кристаллизации.

Степень кристалличности *i*-го образца $\eta_i = m_i / m_{\max}$, где $m_i = \upsilon_s^m t_i$ – масса частично закристаллизованного расплава за время t_i, а $m_{\max} = \upsilon_s^m t_{\max}$ – масса максимально закристаллизованного вещества за время $t_{\max}$. Считая, что $\upsilon_S^m = const$, получим

$$\eta_i = \upsilon_s^m t_i / \upsilon_s^m t_{\max} = t_i / t_{\max} . \quad (3)$$

Запишем выражение (2) для частично и максимально закристаллизованных расплавов: $\upsilon_t^m \tau_i = \upsilon_s^m t_i$ и $\upsilon_L^m \tau_{\max} = \upsilon_S^m t_{\max}$. Разделив последние равенства друг на друга, получим при $\upsilon_L^m = const$

$$t_i / t_{\max} = \tau_i / \tau_{\max} . \quad (4)$$

Тогда степень кристалличности η из формулы (3) с учетом выражения (4) можно записать в виде

$$\eta_i = \tau_i / \tau_{\max} . \quad (5)$$

Степень кристалличности можно рассчитать и по отношению длин плато плавления методом ЦТА: l_i – для частично и $l_{\max}$ – для максимально закристаллизованных образцов.

$$\eta_i = l_i / l_{\max} . \quad (6)$$

Длина плато плавления пропорциональна количеству теплоты [10], затраченной на плавление образца, а выражение (6) эквивалентно соотношению

$$\eta_i' = Q_i / Q_{\max} , \quad (7)$$

где Q_i и $Q_{\max}$ – количества теплот, необходимые для полного плавления частично (i) и максимально ($\max$) закристаллизованных образцов.

Степень кристалличности η_i', определяемая по формуле (7) методом ДТА (рис. 2), рассчитывается из сравнения площадей под кривыми, фиксирующими эндотермические эффекты плавления ($\eta_i' = S_i / S_{\max}$).

По формулам (6) и (7), основываясь на результатах (табл. 1), полученных методами ЦТА и ДТА соответственно, рассчитывались степени кристалличности η и η'. Из этой таблицы видно, что значения η и η' достаточно близки друг к другу, а их небольшое отличие связано с особенностями измерений методами ЦТА и ДТА.

По данным, приведенным в таблице 1, и с помощью уравнений Аврами–Колмогорова [11] $\eta = 1 - \exp\left(-Z^{\,n}\right)$ и $\eta = 1 - \exp\left(-Z' t^{n'}\right)$ находились значения «валовых» скоростей кристаллизации *Z*, *Z′*, а также параметры Аврами *n*, *n′*. Параметры *Z* и *n* относились к случаям изотермических выдержек переохлажденных расплавов за время t_e (без учета инкубационного периода), а *Z′*, *n′* за время t_e+t_i (с учетом инкубационного периода).

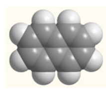
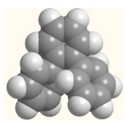
Для конкретных расчетов указанных параметров были отобраны результаты опытов с одинаковым интервалом продолжительности изотермических выдержек (по 600 с) при разных фиксированных переохлаждениях. Эти значения в табл. 1 обозначены «звездочками» (*). Следует отметить, что параметры *n*, *n′*, *Z*, *Z′* достаточно близки к их значениям для высокомолекулярных соединений [12].

На основании уравнения Аррениуса $\eta = \eta_0 \exp\left(-\frac{W}{RT}\right)$ [13] и по данным таблицы 1 было было найдено значение энергии активации кристаллизации *W*=49*кДж/моль*. Эта энергия примерно в 3 раза превышает значение энтальпии плавления сплава ЕС ΔH=17.55 *кДж/моль.*

Трактовка результатов. При исследовании нафталина и о-терфенила ранее был установлен определенный интервал температур ΔT_c^+ выше температуры плавления, характерный тем, что при охлаждении слабо прогретого расплава из этого интервала наблюдалась кристаллизация типа КРК, а после перегревов выше ΔT_c^+ и охлаждении – кристаллизация типа НРВК. При этом переход от КРК к НРВК (и наоборот) проходил скачкообразно. Следует подчеркнуть, что при НРВК температура резко поднималась на величину ΔT^- до температуры плавления со скоростями ~ 30-40 К/с. Такое явление трактовалось на основании т.н. кластерно-коагуляционной модели кристаллизации [3], согласно которой в слабо прогретой жидкости сохраняются кристаллоподобные кластеры и при ее охлаждении кристаллизация происходила как бы на собственных затравках. После перегрева расплава выше ΔT_c^+ кристаллоподобные кластеры разрушаются, а при последующем охлаждении молекулам необходим инкубационный период для образования кластеров и зародышей. Достигнув в переохлажденном состоянии определенной концентрации этих частиц, они коагулируют между собой. За счет излишней межфазной поверхностной энергии весь расплав прогревается на величину ΔT^-. При малых объемах вещества на этом кристаллизация и заканчивается. Для более массивных образцов наступает третий этап – стадия изотермического дозатвердевания оставшейся части расплава.

По-видимому, подобный механизм имеет место и при кристаллизации сплавов. Сплавы нафталина и о-терфенила образуют механические смеси ромбических и моноклинных кристаллов, а в сплаве эвтектического состава выпадают мелкие кристаллики того и другого компонентов (табл. 2).

Таблица 2. Кристаллохимические параметры нафталина, о-терфенила и эвтектического сплава [14-17].

Вещество	Модели молекул	Кристаллическая решетка	Параметры решеток, Å	T_L, *K*	ΔH, $\frac{кДж}{моль}$	ΔT^-, *K*	ν, *сПз*	W, $\frac{кДж}{моль}$
Нафталин $C_{10}H_8$		Моноклинная (М)	*a* = 8.23; *b* = 6.00; *c* = 8.66; *β*=122°55'	353	18.80	10	0.9	-
О-терфенил $C_{18}H_{14}$-1,2		Ромбическая (Р)	*a* =18.64 *b* = 6.04 *c* = 11.80	329	17.19	32	13.5	-
20.5 вес.% Н-79.5 вес.% о-Т (эвтектика)	-	М+Р	-	304	17.55	-	-	49.0

При исследовании кристаллизации смесей углеводородов [2, 18-19] было установлено, что по мере приближения состава к эвтектическому со стороны обоих компонентов переохлаждения закономерно уменьшались, а для эвтектического сплава они доходили до минимума. В нашем случае (с эвтектическим сплавом 20.5 вес.% Н- 79.5 вес.% о-Т), наоборот, имеет место резкое увеличеное переохлаждения с отсутствием взрывной кристаллизации. Подобное явление, по-видимому, связано с увеличением вязкости жидкого сплава. В этом случае должна уменьшаться подвижность хаотически разбросанных молекул нафталина и о-терфенила. Уменьшается также вероятность объединения однотипных молекул для их встраивания в кристалл. Эта вероятность должна иметь, в первую очередь, временной характер: чем дольше расплав находится в метастабильном состоянии, тем больше возможность столкновения собственных молекул друг с другом. Об обоснованности подобного тезиса свидетельствуют данные по вязкости расплавов нафталина и о-терфенила вблизи температур плавления и увеличению вязкости при их смешивании, согласно уравнению зависимости ν от концентрации c компонентов $\nu = \nu_0 e^{ac}$, где a, ν_0 – *const*. Применяя это уравнение для смесей как со стороны о-терфенила, так и со стороны нафталина, получим пунктирные кривые, изображенные на рис. 5. Видно, что при приближении к эвтектике вязкость сплава *ЕС* должна увеличиваться. Увеличение вязкости жидких сплавов может быть связано с ассоциацией разнородных молекул в крупные некристаллоподобные кластеры, создающие стерические помехи, мешающие перемещению «свободных» молекул и их встраиванию в упорядоченные структуры.

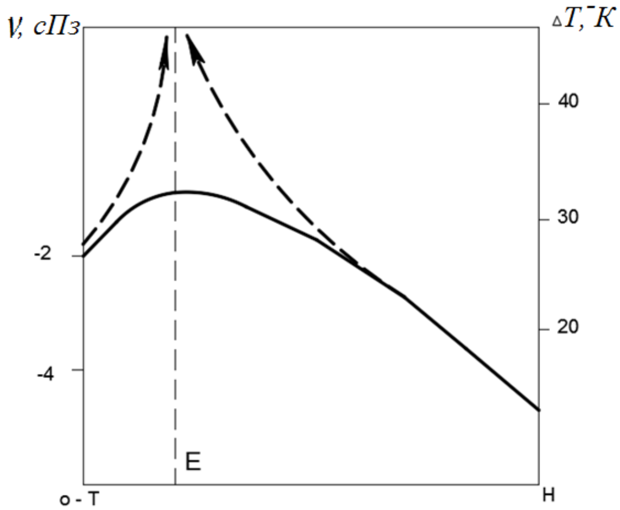


Рис. 5. Зависимость логарифма вязкости (пунктирные линии) и переохлаждения (сплошная кривая) сплавов от концентрации в системе о-терфенил-нафталин

Из рис. 5 видна определенная связь между вязкостью и степенью переохлаждения. Так, вязкость жидкого о-терфенила (~13.5 сПз) вблизи температуры плавления примерно в 15 раз выше вязкости нафталина (0.9 сПз) [15]. Соответственно и переохлаждения выше ~32 К у о-терфенила и ~10 К у нафталина. Аналогичная картина, по-видимому, наблюдается и для эвтектического сплава.

Список литературы

Budakovsky S.V., Galunov N.Z., Kim J.K., Kim Y.K., Tarasenko O.A., Martynenko E.V. New effective organic scintillators for fast neutron and short-range radiation detection // IEEE Trans. Nucl. Sci. – 2007. – V. 54. № 6. – P. 2734–2740. –

2. Aleksandrov V.D., Pokyntelytsia O.A., Shchebetovskaya N.V. Nonequilibrium Crystallization of Alloys in the Naphthalene–Dibenzyl System // Russian Journal of Physical Chemistry A. – 2014. – Vol. 88, № 8. – P. 1307–1311. –

3. Александров В.Д. Кластерно-коагуляционная кристаллизация переохлажденных жидкостей. Теория кристаллизации расплавов / В.Д. Александров, Е.А. Покинтелица. - Palmarium Academic Publishing, 2015. -176 с.

4. Александров В.Д., Покинтелица Е.А. Особенности кристаллизации дифенила, дифенилметана, дифенилэтана в зависимости от термической предыстории жидкой фазы // Вестник ДонНТУ. – Донецк. – 2016. – № 2(2). – С. 18-23.

5. Александров В.Д., Покинтелица Е.А. Особенности кристаллизации о-, m-, р- терфенилов из расплава // Материаловедение. – 2016. - № 6. - С. 23-27.

6. Александров В.Д., Фролова С.А., Прокоф'єв С. В. Спосіб сумістного циклічного та диференційного термічного аналізу / Патент на винахід 2008 - №83721. - Бюл. № 15 від 11.08.2008.

7. Александров В.Д., Покинтелица Е.А., Соболев А.Ю. Термический гистерезис при плавлении и кристаллизации макрообъектов // Журнал технической физики. 2017. – Т. 87. – В. 5. – С. 722-725.

8. Александров В.Д., Покинтелица Е.А., Щебетовская Н.В. Особенности кристаллизации о-терфенила при охлаждении жидкой фазы // Наукові праці Донецького національного технічного університету. Сер.: Хімія і хімічна технологія. – 2014. – В.1. – С. 54-62.

9. Александров В.Д., Покинтелица Е.А. Влияние перегрева расплавов нафталина, дифенила, дибензила на их кристаллизацию // Межвузовский сборник научных трудов «Физико-химические аспекты изучения кластеров наноструктур и наноматериалов». Тверь. - 2014. - В. 6. - С. 4-14.

10. Merzhanov A.G. et al. Methodological principles in studying chemical reaction kinetics under conditions of programmed heating // Thermochim. Acta. - 1977. – V.21. – P. 301-322.

11. Колмогоров А.Н. О статистике процесса кристаллизации в металлах // Изв. АН ОССР. Сер. мат. – 1937. – № 3. – С. 335-359.

12. Вундерлих Б. Физика макромолекул. Т. 2. / Б. Вундерлих – М.: Химия, 1979. – 335 с.

13. Китайгородский А.И. Органическая кристаллохимия / А.И. Китайгородский. – М.: АН СССР, 1955. – 364 с.

14. Бабиков Ю.М. Органические и кремнийорганические теплоносители / Ю.М. Бабиков, Д.С. Рассказов. - М. Энергия,1975. -271 с.

15. Greet R.J. Solidification kinetics of 1,2-diphenylbenzene // J. Cryst. Growth. – 1967. – V. 1, № 4. – P.195-203.

16. Chang S.S., Bestul A.B. Heat capacity and thermodynamic properties of o-terphenyl crystal, glass, and liquid // Journal of chemical physics. - 1972. – V.56. – P. 503-516.

17. Александров В.Д., Покинтелица Е.А. Построение и анализ неравновесной диаграммы состояния в системе дифенил-дибензил // Пятая международная научная конференция «Химическая термодинамика и кинетика». - Великий Новгород, 25-29 мая 2015 г. - С. 8-9.

18. Щебетовская Н.В. Неравновесная кристаллизация бинарных систем ароматических соединений: дисс. кандидата химических наук: 02.00.04 / ДонНАСА. – Макеевка, 2011. – 163 с.

Е.А. Покинтелица, Н.В. Щебетовская

«Донбасс ұлттық құрылыс және сәулет академиясы» Федералдық мемлекеттік бюджеттік жоғары оқу орны, Макеевка, Ресей

Эвтектикалық қорытпаның кристалдану ерекшеліктері 20,5 масс.% нафталин-79,5 масс.% о-терфенил

Аңдатпа. Кристалл күйіндегі терфенил қоспалары сцинтилляторлар, фосфорлар, фоторезисторлар, сенсибилизаторлар және т.б. ретінде пайдаланылады. Олардың құрылымы мен қасиеттері көбінесе кристалдану жағдайларына байланысты. Циклдік термиялық талдау әдісін қолдана отырып, көмірсутектердің эвтектикалық қорытпасының кристалдану ерекшеліктері о-терфенил (мас. 79,5%) және нафталин (мас. 20,5%) зерттелді. Эвтектикалық қорытпасында жүргізілген тәжірибелер нәтижесінде қыздыру кезінде тіркелген көлденең үстірттердің эвтектикалық қорытпаның балқу температурасына (304 К) сәйкес келетіні анықталды. Әлсіз қыздырылған балқымалар эвтектиканың балқу температурасынан төмен T_S=298 К температурада изотермиялық кристалданатыны анықталды T_L=304 К. Бұрын «критикалық» температурадан жоғары қыздырылған балқымалардың салқындату қисықтарында T_c=314 К., экзотермиялық әсерлер байқалмайды, бұл олардың кристалдануын көрсетеді. Метатұрақты балқыманың изотермиялық ұсталу уақытының жоғарылауымен немесе балқыманың өте салқындатылған күйде қалуының (ұстаусыз) уақытының

артуымен келесі циклдегі балқу платосының ұзындығы артады. Бұл кристалдық дәрежесінің жоғарылауын көрсетеді. Өте салқындатылған балқыманың изотермиялық әсер ету ұзақтығы мен балқудың τL ұзақтығынан η кристалдылық дәрежесін анықтау әдісі ұсынылды. Бұл әдісті пайдаланып көлемді кристалдану жылдамдығының тұрақтысы Z және Аврами параметрі n есептелді.

Түйін сөздер: термиялық талдау, о-терфенил, нафталин, терфенил қоспасы, балқу, қызып кету, төмен салқындату, изотермиялық әсер ету, кристалдану, кристалдық дәрежесі.

O.A. Pokyntelytsia, N.V. Shchebetovskaya

Donbass National Academy of Civil Engineering and Architecture, Makeevka, Russia

Features of crystallization of the eutectic composition 20.5 wt.% naphthalene-79.5 wt.% o-terphenyl

Abstract. Terphenyl mixtures in the crystalline state are used as scintillators, phosphors, photoresistors, sensitizers, etc. Their structure and properties largely depend on crystallization conditions. The features of crystallization of the eutectic composition of hydrocarbons o-terphenyl (79.5 wt.%) and naphthalene (20.5 wt.%) were studied by the method of cyclic thermal analysis. As a result of experiments carried out on the eutectic alloy, it was found that the horizontal plateaus recorded during heating correspond to the melting temperature (304 K) of the eutectic alloy. It has been established that weakly heated melts crystallize isothermally at a temperature T_S=298 K, which lies below the melting temperature of the eutectic T_L=304 K. about their crystallization. With an increase in the time of isothermal holding of a metastable melt, or the time the melt stays (without holding) in a overcooled state, the length of the melting plateau in the subsequent cycle increases, which indicates an increase in the degree of crystallinity of the sample. A method is proposed for determining the degree of crystallinity η from the duration t_e of isothermal holding of the overcooled melt and the duration τ_L of melting. By this method, the bulk crystallization rate constant Z and the Avrami parameter n were calculated.

Key words: thermal analysis, o-terphenyl, naphthalene, terphenyl mixture, melting, overheating, overcooling, isothermal exposure, crystallization, degree of crystallinity.

References

1. Budakovsky S.V., Galunov N.Z., Kim J.K., Kim Y.K., Tarasenko O.A., Martynenko E.V. New effective organic scintillators for fast neutron and short-range radiation detection [IEEE Trans. Nucl. sci.] 2007, V. 54, №6, P. 2734-2740

2. Aleksandrov V.D., Pokyntelytsia O.A., Shchebetovskaya N.V. Nonequilibrium Crystallization of Alloys in the Naphthalene–Dibenzyl System [Russian Journal of Physical Chemistry A] 2014, Vol. 88, №8, P. 1307-1311

3. Aleksandrov V.D. Cluster-coagulation crystallization of overcooled liquids. Theory of crystallization of melts (Palmarium Academic Publishing, 2015, 176 p.) [in Russian]

4. Aleksandrov V.D., Pokintelitsa E.A. Peculiarities of crystallization of diphenyl, diphenylmethane, diphenylethane depending on the thermal history of the liquid phase [Bulletin of DonNTU] 2016, №2(2), P. 18-23 [in Russian].

5. Alexandrov V.D., Pokyntelytsia O.A. Peculiarities of crystallization of o-, m-, p-terphenyls from melt [Materials Science] 2016, №6, P. 23-27 [in Russian]

6. Aleksandrov V.D., Frolova S.A., Prokofiev S.V. Method of summative cyclic and differential thermal analysis (Patent for winemaking 2008, № 83721, Bull. №15 dated 11.08.2008) [in Ukrainian]

7. Aleksandrov V.D., Pokyntelytsia O.A., Sobolev A.Yu. Thermal hysteresis during melting and crystallization of macroobjects [Journal of technical physics] 2017, T. 87, Ed. 5, P. 722-725 [in Russian]

8. Aleksandrov V.D., Pokyntelytsia O.A., Shchebetovskaya N.V. Peculiarities of crystallization of o-terphenyl during liquid phase cooling [Scientific works of the Donetsk National Technical University. Ser.: Chemistry and chemical technology] 2014, Ed.1, P. 54-62 [in Russian]

9. Aleksandrov V.D., Pokyntelytsia O.A. Influence of overheating of melts of naphthalene, diphenyl, dibenzyl on their crystallization [Interuniversity collection of scientific papers «Physical and chemical aspects of the study of clusters of nanostructures and nanomaterials», Tver] 2014, V.6, P. 4-14 [in Russian]

10. Merzhanov A.G. et al. Methodological principles in studying chemical reaction kinetics under conditions of programmed heating [Thermochim. Acta] 1977, V.21, P. 301-322

11. Kolmogorov A.N. On the statistics of the crystallization process in metals [Izv. an OSSR. Ser. mat.] 1937, №3, P. 335-359 [in Russian]

12. Wunderlich B. Physics of macromolecules. T. 2. (M.: Chemistry, 1979, 335 p.) [in Russian]

13. Kitaygorodsky A.I. Organic crystal chemistry (M.: An SSSR, 1955, 364 p.) [in Russian]

14. Babikov Yu.M. Organic and organosilicon coolants (M. Energy, 1975, 271 p.) [in Russian]

15 Greet R.J. Solidification kinetics of 1,2-diphenylbenzene [J. Cryst. Growth] 1967, V. 1, №4, P. 195-203

16. Chang S.S., Bestul A.B. Heat capacity and thermodynamic properties of o-terphenyl crystal, glass, and liquid [Journal of chemical physics] 1972, V.56, P. 503-516

17. Aleksandrov V.D., Pokyntelytsia O.A. Construction and analysis of a non-equilibrium state diagram in the diphenyl-dibenzyl system [Fifth International Scientific Conference Chemical Thermodynamics and Kinetics, Great Novgorod] 2015, P. 8-9 [in Russian]

18. Shchebetovskaya N.V. Non-equilibrium crystallization of binary systems of aromatic compounds: diss. candidate of chemical sciences: 02.00.04. DNSACEA, Makeevka, 2011, 163 p [in Russian]

Сведения об авторах:

Покинтелица Елена Анатольевна – кандидат технических наук, доцент кафедры физики и прикладной химии ФГБОУ ВО «Донбасская национальная академия строительства и архитектуры», ул. Державина, д. 2, Макеевка, Россия.

Щебетовская Наталья Витальевна – кандидат химических наук, доцент кафедры физики и прикладной химии ФГБОУ ВО «Донбасская национальная академия строительства и архитектуры», ул. Державина, д. 2, Макеевка, Россия.

Pokyntelytsia Olena Anatoliyivna – Candidate of Technical Sciences, Associate Professor, Department of Physics and Applied Chemistry, Federal State Budgetary Educational Institution of Higher Education «Donbass National Academy of Civil Engineering and Architecture», 2 Derzhavin Str., Makeevka, Russia.

Shchebetovskaya Nataly Vitalievna – Candidate of Chemical Sciences, Associate Professor, Department of Physics and Applied Chemistry, Federal State Budgetary Educational Institution of Higher Education «Donbass National Academy of Civil Engineering and Architecture», 2 Derzhavin Str., Makeevka, Russia.

IRSTI 39.19.31

A.Ye. Yeginbayeva[1], E. Atasoy[2], E.K. Keikin[*]

*[*1]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan*
[2]Uludag University, Bursa, Turkey
(E-mail:aeginbaeva@mail.ru, geograf1969@gmail.com)
Corresponding author: [*]erk-09@mail.ru

Geographical bases of the formation of toponyms of Saryarka

Abstract. *The article discusses physical and geographical conditions (relief, climate, hydrography, soils), flora and fauna of Saryarka, and geographical basis of the features of their display in local toponyms. Saryarka is one of the largest physical-geographical and natural-historical regions in Kazakhstan. Saryarka borders on Western Siberia in the north, reaches Lake Balkhash in the south, the Kalbinsky Ridge and Tarbagatai in the east, and the Torgai Plateau in the west.*
The territory of Saryarka is characterized by the complexity of the relief in Central Kazakhstan. The features of the relief are influenced by its geological structure and relief-forming factors. Due to the geographical location of the territory, there is a sharply continental climate, a shortage of water resources and their uneven distribution, arid landscapes. These natural features are reflected in the toponyms of the territory. During the work on the classification of geographical names and the grouping of types of toponyms, the dominant names associated with the physical and geographical conditions of the region were determined.
Keywords: *Saryarka, toponyms, relief, climate, hydronyms, vegetation.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-63-76

Introduction. The science of toponymy, which studies the reflection of historical and geographical phenomena in space, has become one of the most important directions in geography in the last decade. The history and settlement, the traditional economy of the Saks, Huns, Turks (Oguz, Kipchak, Nogai) and other tribes that have inhabited the territory of Saryarka since ancient times have contributed to the formation of toponyms indicating social changes, historical-geographical and physical-geographical features of the region. The proof of this can be the manuscripts of Herodotus, written monuments of the ancient Turks, records of Arab travelers, where there are such toponyms as Ulytau, Kishitau (Bertagi, Kertagi), Arganats, Bulants, Bileuti, Sarlyk, Sorkudyk, Milykudyk, Taldysay, Balkhash (Koksheteniz), Yesil (Asus), Sarysu (Sokuk), Torgai, Bayanaula, etc. Numerous ethnic groups that inhabited the spaces between the ancient Bertagi (Ulytau) to the modern name Belgi tas (the name associated with the stone), gave names to geographical objects in these spaces [1].

The ancient history of the studied territory has been preserved in geographical names, i.e. toponyms. The impact on the natural environment of intensive economic activity during the development of human society can be clearly traced through toponyms.

The famous scientist G.Y. Rylyuk wrote about the connection of toponymy with geography as follows: «Toponyms refer to geographical objects, often contain their clear characteristics, reflecting the natural features of the area, therefore they are of interest to geography. Hence, toponymy is a geographical science»[2].

E.M. Murzaev, B.A. Budagov, H.L. Khanmogamedov, Kazakh scientists K.D.Kaimuldinova, K.T.Saparov, S.Omarbekova, A.E.Ayapbekova, A.U.Makanova, Z.A.Myrzalieva, K.T.Mambetaliev, O.Zh.Sagymbai, A.Ye.Yeginbayeva, A.G.Abdullina and others wrote about the connections of toponyms with the environment in their works.

In their scientific works, they considered the issues of the connection of toponyms with physical and geographical locations. E.M. Murzaev in the work *Essays of Toponymy* notes that «with the help of toponymy, it is possible to determine the physical and geographical features of the territory, the location and formation of some settlements» [3].

Research methods and research materials. ***Saryarka, Arka*** is a plateau region covering the entire central part of Kazakhstan. Saryarka is a folk name. Since ancient times, the local population has called this area of the steppe «*Saryarka*», «*Arka*». The name Saryarka means «*a large, vast hill with burnt-out, and yellowed vegetation, a flat plateau, a ridge of numerous hills*.» It is located between the North Kazakh Plain in the north, Betpakdala and Lake Balkhash in the south. In the west it rests on the Torgai plateau. In the east, the border reaches the foothills of Tarbagatai, capturing the northeastern outskirts of Lake Balkhash, then along the Zaisan basin reaches the Kalba ridge [4, p. 231]. Saryarka is located between 54°-46° s.w. and 66°-80° v.d., in accordance with the above, in plan it has the shape of an irregular trapezoid, more elongated in the eastern part. The length from west to east is 1200 km. The width in the west is 900 km, in the east 400 km. The area is about 1 million km^2. Administratively, it completely covers the territories of Karaganda, Ulutau, Akmola regions, a significant part of the Abai region, partly Pavlodar, Kostanay, North Kazakhstan, Zhambyl regions [5].

Results and discussion. *Relief features.* Saryarka consists of separate low mountains, hills and ridges scattered over a high denudation plain. The relief gradually decreases to the outskirts, passing into the territory of the surrounding lowlands. It descends steeply along the northern rocky coast of Lake Balkhash. According to the features of the relief, Saryarka is divided into western and eastern parts. The western part is more flat, low-mountainous and poorly dissected (the average absolute height is 300-350 m). In this part, high plains and extensive depressions, hollows dominate, residual mountain ranges (isolated mountains) and hills are not widespread. The central part is occupied by the *Teniz-Kurgaldzhin basin*. Together with the adjacent plains, the western part of Saryarka is divided into *northern and southern halves*. The northern regions cover the low-mountain, shallow *Kokshetau upland* (Kokshe mountain, 947 m). The relief of the southern part mainly has the character of a high hilly plain. In the western part, a large mountain range – *Ulytau* (1134 m) stretches between high plains and hills from north to south. The relief of its southeastern part, stretching from west to east in the eastern part of the Sarysu River valley, is more elevated (the average absolute height is 500-1000 m) and dissected. The north, northeast of Saryarka consists of numerous mountain elevations and isolated mountain ranges that make up the central part of the watershed of river valleys flowing in a southerly direction. The largest are: *Kyzylarai* (the highest peaks are located (1565 m), *Karkaraly* (1377 m), Kent (1361 m), in the extreme east the *Shyngystau* massif rises in isolation (Kosoba mountain, 1305 m). Along with this, the list of mountain ranges also includes the mountains of *Bayanaul* (1026 m), *Koyandy* (922 m), *Zheltau* (909 m), *Ereimentau* (892 m), *Niyaz* (830 m), which are spread out in different places, etc. These mountain nodes are surrounded on all sides by high plains. There are hills and hills on them, forming a small-mound. In the north, the high plains are part of the basins of the *Sileti, Olenti, Shiderti* and *Ashysu* rivers, in the south the Okhrat and the Balkhash region, in the west Ulytau and the adjacent areas of the Teniz depression [6].

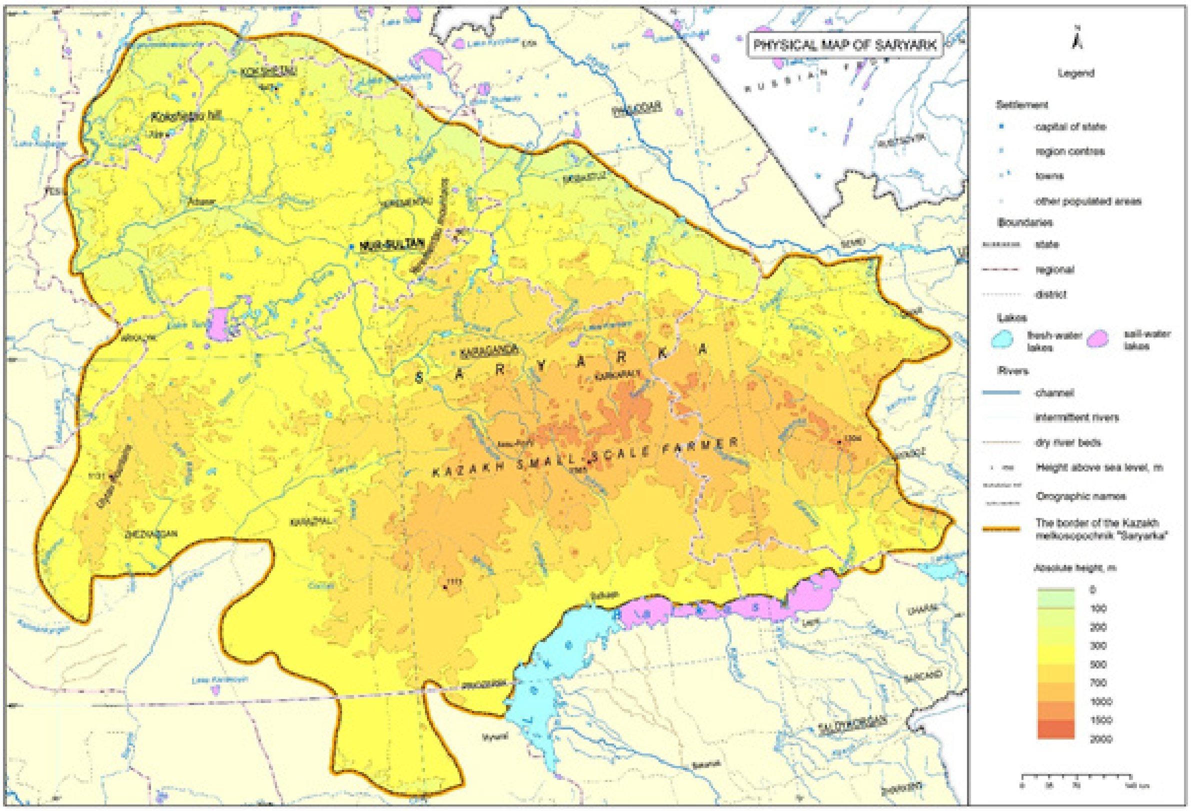


Figure 1 – Physical map of Saryarka

Small hills and individual mountain ranges, manes and raised flat relief became the basis for the formation of various orographic terms. On the territory of Kazakhstan, a specific feature can be traced in the names of orographic objects. For example, in Saryarka, characterized by a shallow relief, high mountains are distinguished by comparative terms biik - high (*Abiik, Kyzylbiik*), Uly – great (*Ulytau*), soran - peak (*Aқsoran, Kyzylsoran, Soran*), karқara. The names located in the steppe zone of the Arch are associated with the shapes and colors of *Karatau, Konyrtau, Sarytau, Ulytau, Aktau, Akdin, Akbet, Kyzyltau*, associated with the lithological basis of *Kokshetau, Borlytau, Altintau* and other toponyms. The low-mountain belt is characterized by the dominance of isolated mountains with a height of 1000-2000 meters, dome-shaped, ridge, ridged, hillside relief. Features of the relief depend on the geological structure and history of development, relief-forming factors [7] (Figure 1).

If we talk about the lands of Saryarka, the naked flat steppe, hills, low mountains of Ulytau, Karkaraly, Kyzylarai, the nature of Kokshetau, Ereimentau, Bayanaul, Kyzyltau, Shyngystau and others, glorified in songs, appears before our eyes [8]. The highest mountains are Saryarka Kyzylarai, the highest point is *Aksoran* (1565 m). Further to the north are the *Karkaraly* mountains (1403 m), *Kent* (1460 m), then *Bayanaul* (1026 m), *Kyzyltau* (1055 m), in the east of the *Shyngystau* mountains (1304 m). This mountain system is mainly composed of granites. Pine forests grow on the northern slopes, the southern slopes are bare and steep. Placer gritty rocks are widespread at the foot of the mountains.

The formation of the relief of the Kokshetau Territory, along with prolonged weathering processes, was significantly influenced by the deposition of the Cretaceous and Neogene periods. There is a large trough, the Teniz-Kurgaldzhin depression, which divides the western part of the Saryarka into two parts. The Kokshetau mountains (about 947 m) are located in the northwest of it. They are composed of Paleozoic limestones, quartzites and porphyrites. Dissected by watercourses. The mountains are of an intermediate nature; in the modern period, as a result of tectonic movements, they are at the stage of leveling. Absolute heights in the range of 300-400 m, heights of more than 500 m are observed in the area of the Kokshetau Upland. The highest points of the Kokshetau Upland are *Kokshe peak (947 m), Zhalgyztau (730 m), Zhylandy (665 m), Dombyrali (471 m), Imantau (661 m), Sandyktau (626 m), Zerendi (587 m), Muzbel (501 m).* There are picturesque lakes in the intermontane depressions. Pine forests grow on the shores of lakes and mountain slopes [9]. "The word "Kok" corresponds to the meaning "very high" or even "heavenly", writes E. Koishybaev. According to T. Zhanuzak, the meaning of the name Kokshe (an adjective) is associated with «the bluish appearance of the area or with the blue, visible from afar» [10].

In the southeast of the Kokshetau mountains, the Ereimentau mountains are located. The highest point is *Akdin* (901 m). Since its time, the name has undergone distortion, the name of the hill Aқdin (Akdym) was formed on the basis of the ancient Turkic term "din". In the north-east of Saryarka there is the Siletinskaya plain, in the north-west there is a plain along the Esil River, the Atbasar plain, and the Teniz-Kurgaldzhin depression. To the west of Saryarka up to the Esil River, the Turgai plateau enters its eastern part. The right bank of the Esil River joins the Atbasar, the left bank with the Teniz plain, in the central part of the plain there are lakes Teniz and Kurgaldzhin (Figure 1).

Ulytau is a remnant of a large anticlinorium, composed mainly of granites and stretching in the meridional direction. The mountain slopes are composed of crystalline schists, sandstones, mixed rocks (conglomerate). The region is a convex plain composed of various clay rocks, the peripheral territories of which were formed in the Lower Cenozoic. The most important watershed of the Saryarka latitudinal direction starts from Ulytau. It separates the river valleys of the Aral and Balkhash from the river basins of Lake Teniz and the Ertis River. The watershed in the east runs along a mountain ridge, then abuts against the Tarbagatai mountains [11]. Names in the Ulytau region - *Ulytau, Kishitau (Bertagy, Kertagy) Arganaty, Bulanty, Bileuti, Sarlyk, Edigenin maily zhurt, Kengir*, etc. carry our thoughts into the abyss of ancient times. The highest point of Ulytau is the *Ulytau hill* (1133 m), you can also name the Edige mountains (1064 m), Zhaksy Arganaty (757 m), which witnessed historical events [12]. As if protecting the mountains of the *Shyngystau* (Naimantau) ridge from loneliness, located on the «most honorable place» of Saryarka (1304 m), Mother Nature spreads in the north-west of the mountains Hanshyngys (1152 m), Kosbastau (1077 m), and in the south- in the east, the highest point of the Akshatau mountains is *Kosoba peak* (1304 m). The mountains Saryshoky (1076 m), Bugyly (1061 m), Zhumak (1149 m), Konyr-Sandyktas (1102 m) are located between these mountain ranges (Figure 2).

The *Akshatau* ridge, dissected by river valleys, gradually descending to the southwest of Saryarka, borders the Bolshoy Kuykentai (836 m), Karaungir (865 m) mountains in the north, Kotanemil (1089 m) in the southwest, and the Zhorga Mountains (1084 m) in the west. The plain-landscape relief attracts the eye with its uniqueness. As a result of the influence of external and internal forces, amazing rock formations, combed stones, caves «Konyr Aulie, Ungirtas» appeared. In the north-west of the Kaskabulak ridge in the direction of the peaks of Sholtan, Shyngys, the Yeraly plain stretches. The second edge of the plain of Yeraly rests on the hills of Malaya and Bolshaya Akshoky. To the east of the Kaskabulak ridge are the Baigabyl, Araltobe, Borli ridges, and the Arkat Mountains are visible in the southeast. In the east, dissected by the Shet River, in the west by the Shagan River, the slopes and foothills of Shyngystau are crossed by such small rivers as Kos, Buzau, Kundyzdy, Mukyr, Takyr, Karauyl, Bokenshi, Koldenen, Karazhartas, etc., drying up in vast meadows [13]. The eastern and southern parts of the Abraly mountains (1299 m) are framed by a chain of mountains Shyngystau, Kalmak Emel, Ogiztau, Zhorga, Temirshi, Karkaraly, the north covers the mountains of Bayanaula (Kyzyltau), Myrzyk, Zhalgyztau, Dogalan, Degelen, as well as various high hills, hills, plains. Located in the east of the Zhaks mountains, the Abrals are more elevated than the Zhaman Abrals, which, due to their natural features, are distinguished by adjectives (the word «Zhaman» is in the context of «small») [14].

The main ridges of the Bayanaula mountains consist of three parts *Akbettau, Zhaksaula, Zhamanaula*. The mountain region consists of ridges rising by a ridge, separated by river valleys of mountain blocks, separate hills. The highest points of the mountains: Mount Akbet (1026 m), Mount Ogelen (969 m), Shibet (728 m), Zhasybai (804 m), Sarytau (747 m), belong to the district of Zhaksaula. Sh. Ualikhanov considers the etymology of the toponym Bayanauyl as - «Bayan» - bai, «Ola» (a distorted name, a more accurate historical name - Bayanaula; Mong. Bayan-ola) is a beautiful, fertile mountainous country. Zhamanaula, on the contrary, corresponds to the meaning of a bare hill mountain. The highest point of Kyzyltau, located in the south-east of the Bayanaul mountains, is Aulie Peak (1055 m) [15].

Kokshetau mountains

Zerenda mountains in Kokshe region

Ermentau mountains

Bayanaul mountains, near Lake Zhasybay

Mount Naizatas

Mount Saken in Toraigyr

Kempirtas Bayanaul

Cave of Brown Aulie in Bayanaul

Mount Chingistau

Konyr Aulie cave in Chingistau

Karkaraly mountains

Mount Aksoran

Mount Kyzylaray

Ulytau mountains

Akshatau mountain

Figure 2 – Small hills and isolated mountain massifs in Saryarka

Geological structure and minerals. The long and heterogeneous history of the development of each part of Saryarka led to the formation of a complex geological structure. The folded structures in the west and north of Saryarka are composed of Caledonian, and the central and eastern parts of Hercynian folding. Folding took place accompanied by deep faults of the Earth's crust, shear-thrust tectonic movements, significant elevation of intrusives and powerful metamorphism. In this regard, rich and valuable ore deposits are common here.

The western folding includes the blocks of *Kokshetau, the Teniz trough, the Ulytau anticlinorium, the Sarysu-Teniz uplift, the Zhezkazgan mulda*. Two structural layers are distinguished here. The lower layer is formed by volcanic formations and strongly metamorphosed, compressed deposits of the Early Paleozoic with intrusions of granites, gneisses, glassy rocks of the anticline core. The upper layer is dominated by large-block and carbonate tiers of the Middle and Upper Paleozoic. They are little pressed, the degree of metamorphism is weakly manifested. They are characterized by rupture-block tectonics.

In the eastern part, the profile of Paleozoic deposits has a completely different picture. There is no division into structural layers and the profile consists entirely of geosynclinal deposits interrupted by numerous intrusions of granitoids. Paleozoic effusive-sedimentary rocks consist of folds of the north-western direction. Among the largest structures of the Hercynian folding are the Shyngys, Balkhash and Tekturma anticlinories, forming complex tectonic nodes at the intersections, as well as the North Balkhash synclinorium [16].

The Mesozoic deposits of Saryarka are concentrated in tectonic mulds and grabens that overlap the area of the Paleozoic basement. They consist of loose, clastic, in most industrial-coal deposits (Karaganda, Maykubensky basins, etc.), clay formations of the Mesozoic weathering crust are widespread in the plains. Cenozoic Paleogene-Neogene sandy-clay deposits are common in large depressions (Teniz) and valleys of the ancient water systems of Saryarka. Almost ubiquitous quaternary sediments have a low-power layer and consist of sandy-clay alluvium of modern river valleys, large-block slope formations and eluvium of various origins.

Ores of chromite nickel, titanium, magnetite, cobalt ores are concentrated in the Caledonian magma, and ores of copper, lead, gold, silver, iron, manganese, and tin are concentrated in the Hercynian intrusions. At the end of the Paleozoic, Saryarka completely moved to the continental stage of development, having been subjected to prolonged denudation. At the end of the Mesozoic, the region turned into a peneplain with the spread of residual uplands. In the Cenozoic, as a result of repeated tectonic movements, denudation plains were replaced by accumulative ones. The main low-mountain and hilly watersheds Balkhash-Ertis (1000-1559 m), Sarysu-Teniz (1134 m) and Yesil-Ertis (600-1358 m) underwent uplift. Saryarka is mainly composed of Precambrian and Paleozoic metamorphic shales, quartzite, sandstone and limestone. Granite, diorite, intrusions and effusions of gabbro are widespread among them. Deposits of ferrous and non-ferrous metals are associated with granite intrusions. In the sandy-clay formations of the Carboniferous period, layers of high-quality coal were formed. Rich reserves of brown coal are concentrated in the Jurassic sediments lying on Paleozoic rocks (Ekibastuz brown coal basin). Various denudation forms of relief are associated with the nature of rocks and the peculiarities of their occurrence.

Rock granites, hump-shaped, spherical and chest-shaped forms are common. The extended layers of sandstones and limestones are characterized by ridges and manes, for quartzites – hills. Suffusion depressions and deflationary basins are often found in accumulative rocks [6].

The complexity of the geological structure of the territory of Saryarka, the spread of rocks of various origin (igneous, metamorphic and sedimentary) affected the species composition and mineral reserves. To date, about 150 deposits of coal and drilling coal have been discovered in the carboniferous and Jurassic deposits in the region. More precisely, the Karaganda, Ekibastuz, Maykubenskoye and Teniz-Kurgaldzhinskoye deposits [17]. There are many copper deposits concentrated, mostly they are complex, which contain reserves of gold, molybdenum, silver, zinc, lead, nickel, etc. components. Copper and nickel deposits *Bozshakol, Samar, Sokyrkai, Konyrat, Kenkudyk-Kaskyrkazgan, Karatas, Bozshoky, Sayak, Tastau, Moldybai, Zhalbas, Berikkara, Umit, Eshki-Olmes, Tesiktas, Uspen, Altyntobe*, etc. It can be said that some deposits, the so-called «chud», «places of copper», where stone and bronze tools are found, are widespread in Saryarka. The gold-bearing areas of Maykayyn and Northern Balkhash, the gold-producing region of Stepnyak are distinguished. You can name *Alpys, Souvenir, Zhosaly, Shoptikol, Abyz, Meyzek, Akbastau, Kosmuryn*, gold-silver-containing *Taskar, Muzbel, Sayak, Dominnye, Ayli, Nauryzbai, Sulu shoki, Eshkiolmes*, etc., lead-zinc deposits (*Karagaily, Akzhol, Uzynzhol, Atabai-Dogaly, Ushtobe, Kayrakty, Berikkara, Akshagyl, Uytas, Kyzylespe, Mynshunkyr, Tumiot, Abyz, Akbastau, Kosmuryn*), deposits of rare metals: *Verkhne Kayrakty, Koktin koli, Baynazar, Soran, Tastau, Ontustik Zhauyr, Koytas, Aksorly, Kyzylarai, Shygys Konyrat*, etc. We also found such names that were based on the names of minerals and geological structure, for example, on the basis of iron and manganese deposits, the names *Sarybulak, Akbuyrat, Kotyrtas, Batyrtas, Kenkazgan, Keregetas, Myrzyk, Aigyrzhal, Shoytas, Katpar*, etc. In general, a group of specific names characterizing the features of the territorial distribution of geological rocks and minerals was studied [18].

Climate. Due to the inland location, the climate of Saryarka largely depends on radiation factors. The climate is sharply continental, humidity is insufficient, increasing aridity is characteristic in the south at all. The northern part is occupied by forest-steppes and arid steppe with islands of forest, the southern part corresponds to semi-deserts of the temperate zone. The border of the desert zone runs along the latitude of the Northern Balkhash region. The average annual temperature in January is 14-18°C. The absolute minimum is 46-52 °C. The average annual temperature in July is 19-24°C, the absolute maximum is above 40°C. The average annual amplitude of air temperature exceeds 35 °C. The thickness of the soil layer in the north reaches 90-140 cm, in the south 50-60 cm. Snow cover in the north is 20-25 cm, in the south 15 cm. Frosty weather is observed even before snowfall. Sometimes, due to the impact of a cyclone from the southwest, during a thaw, the air temperature rises to +5-70, then there is a sharp cooling and, as a result, ice. The surface layer of air heats up strongly, the air temperature rises rapidly. The average annual precipitation in the north reaches 300 mm, in the south 150 mm. The low-mountain band holds part of the wet winds and therefore the average annual precipitation in the mountains of Kokshetau and Karkaraly, according to long-term calculations, exceeds 400 mm, in Ulytau 350 mm. Most of the precipitation in the north and in the center falls during the warm period, and in the south, usually in December. Evaporation degree everywhere is 2-4 times higher than the amount of precipitation. In summer, there is a frequent recurring drought. In the north, the winds of the south-west direction prevail, in the south of the north-east. The average annual wind speed is 4-6 m/sec. Days with strong winds (more than 15 m/sec) in Kokshetau 60 m/sec, on Balkhash 20 m/sec are not often observed [19].

Toponyms expressing the degree of climate and weather favorability: *Akkar, Karlykol, Dauyldy, Zheltau, Zheldiadyr, Zhelbuzyl, Zhylysay, Zhylytobe, Mezgilsor, Muzbel, Muzdybulak, Salkyntau, Taigakkol, Shantobe* are based on physical and geographical information formed as a result of the identification of nomads features of natural phenomena.

Internal waters. The *hydrographic network* of Saryarka is mainly seasonal in nature, the main source of food is snow (more than 80% of the annual runoff is meltwater). Unlike the northern rivers, the water availability of the southern rivers is low, the area of the Northern Balkhash region belongs to the local runoff. The largest river is *Yesil*. Its waters are used for water supply of industrial enterprises and settlements. Starting from the watershed elevation, 70-90% of the annual runoff passes on the rivers flowing from north to south (*Nura, Sarysu, Sileti, Shiderti, Tokyrauyn, Ayakoz,* etc.) during the spring flood (2-3 weeks). The rest of the time, their waters become much shallower or they break up into old trees. In winter, rivers freeze, small ones freeze to the bottom. Only in the Yesil River there is a constant water flow. For the purpose of water supply of settlements and industrial enterprises of Central Kazakhstan and irrigation of lands, the Ertis-Karaganda canal named after K.I. Satpayev was carried out. Numerous depressions in the relief of Saryarka became the basis for the formation of seasonal and permanent lakes. There are many lakes in Saryarka, the water in many lakes is salty. They all have common features: isolation, shallow water, rapid variability of the level and amount of water throughout the year. The largest lake is *Lake Teniz* in the Kurgaldzhin depression, the water of which has a bitter-sour taste. Freshwater, tectonic lakes (*Burabai, Shortandy, Bolshoe Chebachye, Maloe Chebachye*) are common in the Kokshetau upland. There are also deflationary and suffusion lakes [4].

The names of the rivers *Yesil, Nura, Sarysu, Sileti, Shiderti, Tokyrauyn, Ayagoz, Kulanotpes, Terisakkan, Karakengir, Sherubai-Nura, Shagalaly, Kalkutan, Kusak, Tundik, Itchysu, lakes, Karagenuka, Karaysor Meshkeisor, Shoshkakol, Kozhakol, Sholak, Burabay, Shortandy, Bolshoye Chebachye, Maloye Chebachye*, microhydronyms (names of springs, wells) of water sources of the economy also found special reflection in local toponyms.

Soil and vegetation cover. The soil and vegetation cover of Saryarka consists of the main zones: arid forb-feather grass steppes of the temperate zone on ordinary chernozems; arid herb-feather-grass steppes on southern chernozems; arid feather-grass-fescue steppes on dark chestnut soils and xerophytic-forb fescue-feather grass steppes on chestnut soils; cereal-wormwood semi-deserts on brown and light brown soils; wormwood-saline deserts on light brown saline soils.

Three natural zones pass along the territory of Saryarka in the latitudinal direction. These are: steppe, semi-desert and desert zones. In the northern part and on the chernozems of the southern territory (the vicinity of Kokshetau, Atbasar, along the Esil River), various herbs of wormwood-feather grass steppes grow. These lands are used as cultivated areas. Vegetation rarely grows on gravelly soils of hills. In the valleys between the hills, birch and aspen grow, and there are bushes. Birch and pine grow on the northern slopes of low-mountain massifs. Kokshetau, Niyaz, Ereimentau and other low mountains folded by granite are covered with a belt of birch-pine forests. On the plains and hummocks of the Saryarka, starting from the Teniz-Kurgaldzhin depression and further east to the valley of the Tundik river, sour-carbonate red earth soils have formed. They are covered with fescue-feather grass steppes. The Teniz and Sarysu plains, together with the southern part of the steppe zone, Ulytau, Karkaraly, the foot of Shyngystau belong to the semi-desert zone. The climate of this zone is arid, on dark brown, red-brown soils, wormwood, fescue-feather grass vegetation, feather grass-hairy are widespread. Hay meadows, poplar, birch, pine, juniper, willow grow along the rivers. The desert area is favorable for grazing land. Birch and pine groves grow on the low-mountain slopes of Bayanaul, Karkaraly. In the west, east of the Sarysu valley to the Ayagoz river valley, there is a real gravelly semi-desert. Grass-wormwood vegetation dominates on the red-brown soils of the plains. On the northern slopes of the hills, feather-grass-fescue steppes have formed, in the south there are rare wormwood steppes, and in the gorges there are bushes. In mountain gorges, birch, wild rose, bird cherry, hawthorn, meadowsweet grow. Pine and juniper (juniper) are found on the tops of the mountains. The desert zone covers the southern part of Ulytau and the vicinity of Zhezkazgan, the North Balkhash coast. Here, on brown gray-brown soils of deserts, desert plants grow - meadowsweet, karagannik, feather grass, fescue, white feather grass, biyurgun, light brown wormwood, gray wormwood, white quinoa, bayalych [20].

Place names associated with the vegetation cover help to restore the former and modern names of plant species and the appearance of landscapes of the historical past. The features of the zonal distribution of vegetation cover form the seasonal nature of their use. Toponymic studies in relation to changes in the landscape are reflected in the problems of studying the areas of distribution of phytoonyms. This is due to the fact that the vegetation cover as an active component can be a specific orienting object in paleoclimatic and paleogeographic studies. The first studies (on the basis of maps, tables) of the reflection of the vegetation cover in toponyms, the relationship with natural conditions, the territory of distribution were carried out in the studies of D. Kaimuldinova, A.S. Omarbekova, A.U. Makanova, K.T. Saparov [21].

Animal world. The fauna of Saryarka is distinguished by a rich species composition of animals that live in the steppes and low-mountain regions, as well as in permanent and temporary water bodies - rivers and lakes. The fauna was formed in connection with the peculiarities of the steppe, semi-desert and desert zones. In the forest-steppe regions, various types of rodents are widespread, from predators lynx, fox, wolf; white hare and gray hare; from ungulates roe deer, elk. Among the birds of hunting and commercial importance are often hazel grouse, partridge, chicken species, hawks and golden eagles from birds of prey.

In the steppe belt of Saryarka, rodents are found: hamsters, ground squirrels, marmots, jerboas, chipmunks, steppe whistlers; from predators wolves, foxes, steppe foxes, ferrets. Among the birds are several species of larks (steppe, crested, white-winged, black), from large birds - crane, heron, bittern; among the waterfowl are ducks, gray geese, several species of swans. Pikes, ides, bream and many other types of fish are found in rivers and lakes. There are many birds on the lakes. A specially protected bird is the pink flamingo, the number of which has recently been decreasing. In the south of Saryarka, sand mice and jerboas, a semi-desert wolf and a semi-desert ermine are widespread, especially a lot of reptiles - the gray gecko, steppe agama, fast lizard and other species of semi-desert and desert representatives of the animal world. In the pine and birch-pine groves of low-mountain areas, there are forest species of animals: elk, roe deer and many species of birds. In the mountains Ereimentau, Karkaraly, Kyzylarai, Ulytau, argali survived [22].

In the restoration of the landscapes of the past and the formation of modern landscapes, the names of animals found in the names of rivers, lakes, tracts, orographic objects on the geographical maps of Kazakhstan play an important role. *Kulanotpes, Kulanshat, Shoshkaly, Shortandy, Maitaban, Shabakty, Kargaly, Sonaly* and other similar names of rivers and lakes, names of animals and birds in the names of orographic objects, such as *Ayuly, Bugyly, Kiikti, Sarykulzha, Arkarly, Kulantobe, Borioynak, Tulkili, Kundyzdy, Koyandy, Zhylandy, Burkitti* and others complement the characteristics of geographic objects. The influence of climatic conditions and vegetation cover on the territorial distribution of fauna is traced. In the process of collecting material, toponyms were determined, formed with the participation of the names *ayu, kulan, bugy, maral, boken, kiik, kulzha, shoshka, kundyz, arhar*. The toponyms formed using the names of these animals provide information about their distribution in this area earlier and great opportunities for paleoecological research by providing information about the geoecological conditions of their habitat. The variety of natural conditions of the study area has influenced their development since ancient times, and the degree of development has formed a very complex system of geographical names [23].

As a result of the analysis of toponyms based on physical and geographical conditions (oronyms, hydronyms, oikonyms, phytonyms, zoonyms, ethnonyms and genonyms, comonyms, necronyms, etc.), a regularity of their concentration in the conditions of certain landscapes was revealed (Figure 3). As can be seen from the figure, more than half of the geographical names of the territory were nominated by landscape features.

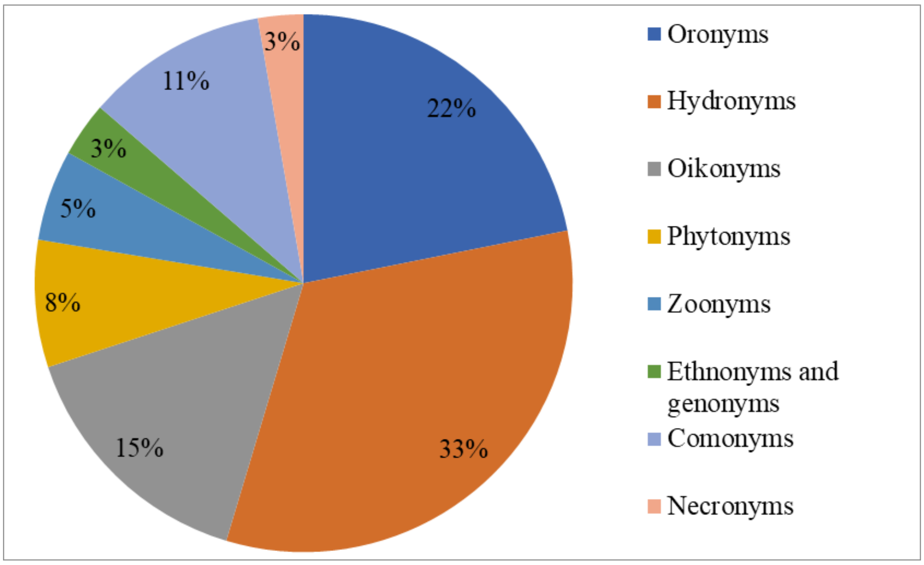


Figure 3 – Toponymic system of Saryarka

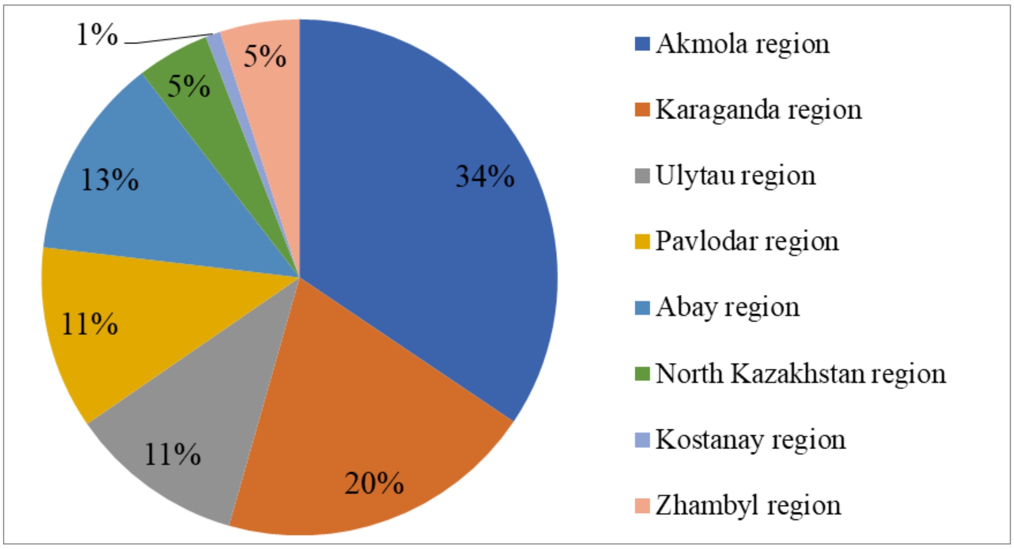


Figure 4 – Space of the toponymic system of regions on the territory of Saryarka

In the course of our research, systems of more than 9000 toponyms were identified, formed in connection with physical and geographical features, based on the State catalog of geographical names of the Republic of Kazakhstan (Akmola, Karaganda, Ulytau, Pavlodar, Kostanay, Zhambyl, Abay, North Kazakhstan region, 2004-2010) [24], and are depicted in the form of diagrams (Figure 4). In the future, it is planned to continue work on geographical, etymological studies in the system of landscape toponyms.

Conclusion. During the analysis of the system of toponyms of Saryarka, it was found that almost half of the names are named depending on the physical and geographical features of the region, among the names of the territory there are toponyms characterizing climatic, hydrographic, geological features, soil cover, flora and fauna. Toponyms can be called the language of the landscape, that is, its oral representation. Thus, through toponyms, you can get information about the landscape, its history, dynamics and features. Geographical names and terms make it possible to identify and explore the components of the natural landscape and are used in the restoration of geographical conditions of the past. Therefore, the definition of geographical factors in the nominations of toponyms is important.

Currently, geographical names, their meaning, origin, and history are of great interest. The proof of this is the published toponymic dictionaries and works of fundamental and applied research. Also, elective disciplines on toponymy are being introduced into geographical specialties at universities. Recently, the relevance of the study of toponyms by territory and region has been increasing. However, such studies have a historical and linguistic direction. Studies of the toponymy of Saryarka in the geographical aspect are insufficient. It can also be noted that today there are few real studies in the areas of hydronymy, oronymy.

Список литературы

1. Saparov K.T, Yeginbayeva A.Ye. and others. The question of Kazakh national and geographical toponymic as a potential factor of tourism development. GeoJournal of Tourism and Geosites. ISSN 2065-0817, E-ISSN 2065-1198. Year X, no. 1, vol. 19, May 2017, p.115-125. https://www.scopus.com/record/display.uri?eid=2-s2.0-85020118546&origin=resultslist&sort=plf-

2. Рылюк Г.Я. Истоки географических названий Беларуси. Минск: «Вегас», 1997.

3. Мурзаев Е.М. Очерки топонимики. Москва «Мысль», 1974.

4. Бейсенова Ә.С. Қазақстанның физикалық географиясы: оқулық. – Алматы, 2014. – 540 б.

5. Қазақстан Республикасының физикалық картасы (Масштабы 1:1500000) Алматы: «Қазақ энциклопедиясы» - 2012. - Том. 4. - Б. 304.

6. Қазақстан табиғаты: энциклопедия / ред. Б.Ө.Жақып. Алматы: «Қазақ энциклопедиясы» ЖШС. - 2012. - Том. 4. - Б. 304.

7. Сапаров К.Т., Егинбаева А.Е. Сарыарқаның географиялық нысандарын атаудың табиғи негіздері. әл-Фараби атындағы Қазақ ұлттық университетінің хабаршысы. География сериясы. - Алматы, 2016. – № 2(43). - 28-35 б.

8. Тілеке Ж. Шежіре: Ертіс-Баянауыл өңірі. Павлодар.: Қазақстан, 1995. – Том.1.-368 б.

9. Сапаров К.Т., Егинбаева А.Е. және т.б. Көкшетау өңірінің оронимдерінің табиғат жағдайларында бейнелену заңдылықтары. «Ғылым және білім – 2016» студенттер мен жас ғалымдардың XI Халықаралық ғылыми конференциясының материалдар жинағы. - Астана: Л. Н. Гумилев атындағы ЕҰУ, 2016. - 1091-1096 б.

10. Saparov K, Chlachula J, Yeginbayeva A.Ye. Toponymy of the ancient Sary-Arka (North-Eastern Kazakhstan). Quaestiones Geographicae. ISSN 0137-477X, eISSN 2081-6383. 37 (3), 2018. – P. 35-52. DOI 10.2478/quageo-2018-0024.

11. Айқынбай Б.Ә., Ештанаев Ғ.Е.Ұлытау-Жезқазған өңірінің жер-су аттары. Ө.А. Байқоңыров атындағы Жезқазған университеті. - Алматы: «Эверо», 2007. – 220 б.

12. Сапаров К.Т., Егинбаева А.Е. Ұлытау өңірінің тарихи және мәдени нысандарының топонимикалық көрінісі. Д. Серікбаев атындағы ШҚМТУ хабаршысы. - Өскемен, 2016. - № 2. - 61-66 б.

13. Сапаров Қ.Т., Мекишева Б.М., Егинбаева А.Е. Абыралы –Шыңғыстаудың ланшафт ерекшеліктерін анықтайтын топонимдер бірлестігі. // «XVII Сәтбаев оқулары»: Жас ғалымдардың, магистранттардың, студенттер мен оқушылардың халықаралық ғылыми конференциясының материалдары. - Павлодар: С. Торайғыров атындағы ПМУ, 2017. - 87-92 б.

14. Насенов Б. Абыралы-Сарыарқаның кіндігі. - Новосибирск, 2002. - Том. 1. 488 б.

15. Уалиханов Ш. Таңдамалы шығармалар. Алматы, 1985. – Бас. 2. - 560 б.

16. Шығыс Сарыарқа. Қарқаралы өңірінің өткені мен бүгіні: монография / ред. Қ.С. Алдажұманова., А.З.Бейсенова. Алматы: Эверо, 2004. - 703 б.

17. Богданов А.А. Основные черты палеозойской структуры Центрального Казахстана // Бюлл. ОИП., отд. геол. – 1959. - №1. – С.35-46.

18. Сапаров К.Т., Егинбаева А.Е. Сарыарқаның пайдалы қазбаларын анықтаудағы қолданбалы топонимиканың рөлі // Қ.И. Сәтбаев атынд. ҚазҰТУ Хабаршысы.-2015. - №5(111). - 397-403 б.

19. Физическая география Республики Казахстан: учебное пособие / под ред. К.М. Джаналеевой. Астана: ЕНУ им. Л.Н.Гумилева «Аркас», 2010. - 592 с.

20. Карамышева З.В., Рачковская Е.И. Ботаническая география степной части Центрального Казахстана. – Л., 1973. – 160 с.
21. Егинбаева А.Е. Сарыарқа топонимикасы. Монография. - Алматы: ССК, 2019. - 224 с.
22. Атамекен: географиялық энциклопедия / ред. Б.Ө.Жақып. - Алматы: «Қазақ энциклопедиясы», 2011. - 648 б.
23. Yeginbayeva A.Ye., Saparov K., Rakisheva A., Atasoy E. Toponymy of flatlands of Kazakhstan. EBSCO. Marmara Coğrafya Dergisi. İstanbul – ISSN:1303-2429 E-ISSN 2147-7825. Sayi: 33, Ocak - 2016, S.641-655.
24. Ахметов Қ., Байтелиева Ж. Жерінің аты – Елімнің хаты: энциклопедиялық анықтамалық. – Алматы: Аруана Ltd ЖШС, 2006. - 808 б.

А.Е. Егинбаева[1], Е. Атасой[2], Е. Кейкин[1]
[1]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан
[2]Улудаг университеті, Бурса, Түркия

Сарыарқа топонимдері қалыптасуының географиялық негіздері

Аңдатпа. Мақалада Сарыарқаның физикалық-географиялық жағдайы (жер бедері, климат, гидрография, топырақ), флорасы мен фаунасы және олардың жергілікті жер атауларында бейнелену ерекшеліктерінің географиялық негіздері қарастырылады. Сарыарқа – Қазақстанның ірі физикалық-географиялық және табиғи-тарихи аймақтарының бірі. Солтүстігінде Батыс Сібір жазығымен ұштасып, оңтүстігінде Балқаш көліне дейін, шығысында Қалба және Тарбағатай жоталарымен шектесіп, батысында Торғай қолатына дейін созылған.

Сарыарқа аумағы Орталық Қазақстандағы жер бедерінің күрделілігімен сипатталады. Жер бедерінің ерекшеліктеріне оның геологиялық құрылымы мен жер бедерін құраушы факторлары әсер етеді. Аумақтың географиялық орналасуына байланысты күрт континентальды климат, су ресурстарының жетіспеушілігі және олардың біркелкі таралмауы, аридті ландшафт түрлері байқалады. Бұл табиғи ерекшеліктер аумақтың топонимдерінде көрініс тапқан. Географиялық атауларды жіктеу және топонимдердің түрлерін топтастыру жұмыстары кезінде аймақтың физикалық-географиялық жағдайларына байланысты басым атаулар анықталды.

Түйін сөздер: Сарыарқа, топонимдер, жер бедері, климат, гидронимдер, өсімдіктер.

А.Е. Егинбаева[1], Е. Атасой[2], Е. К.Кейкин[1]
[1]Евразийский национальный университет имени Л.Н. Гумилева, Астана, Казахстан
[2]Университет Улудаг, Бурса, Турция

Географические основы формирования топонимов Сарыарки

Аннотация. В статье рассматриваются физико-географические условия (рельеф, климат, гидрография, почвы), флора и фауна Сарыарки и географические основы особенностей отображения их в местных топонимах. Сарыарка - один из крупных физико-географических и природно-исторических регинов Казахстана. Сарыарка граничит на севере с Западной Сибирью, на юге достигает озера Балхаш, на востоке Калбинского хребта и Тарбагатая, на западе Торгайского плато.

Территория Сарыарки характеризуется сложностью рельефа в Центральном Казахстане. На особенности рельефа влияют его геологическое строение и рельефообразующие факторы. Из-за географического расположения территории наблюдается резкоконтинентальный климат, нехватка водных ресурсов и их неравномерное распределение, засушливые ландшафты. Эти природные особенности отражены в топонимах территории. Во время работы по классификации географических названий и группировки видов топонимов были определены доминирующие названия, связанные с физико-географическими условиями региона.

Ключевые слова: Сарыарка, топонимы, рельеф, климат, гидронимы, растительность.

References

1. Saparov K.T., Yeginbayeva A.Ye. and others. The question of Kazakh national and geographical toponymic as a potential factor of tourism development. GeoJournal of Tourism and Geosites. ISSN 2065-0817, E-ISSN 2065-1198. Year X, no. 1, vol. 19, May 2017, p.115-125. https://www.scopus.com/record/display.uri?eid=2-s2.0-85020118546&origin=resultslist&sort=plf- f&featureToggles=FEATURE_NEW_DOC_DETAILS_EXPORT:1

2. Rylyuk G.Ya. Istoki geograficheskih nazvanij Belarusi (s osnovami obshej toponimiki) [The origins of geographical names of Belarus (with the basics of general toponymy)] (Minsk: «Vedas», 1997.) [in Russian]

3. Murzaev E.M. Ocherki toponimiki [Essays on toponymy.] (Moscow: «Mysl», 1974.) [in Russian]

4. Beisenova A.S. Kazakstannyn fizikalyk geografiyasy [Physical geography of Kazakhstan] (textbook. - Almaty, 2014. - 540 p.) [in Kazakh]

5. Kazakstan Respublikasynyn fizikalyk kartasy (Masshtaby 1:1500000). [Physical map of the Republic of Kazakhstan (scale 1: 1 500 000).] (Almaty: RSE «National Cartographic and Geodetic Fund», -2014.-1 p.) [in Kazakh]

6. Kazakstan tabigaty: enciklopediya / red. B.O. Zhakyp [Nature of Kazakhstan: Encyclopedia / edited by B. O. Iakov] (Almaty: Kazakh Encyclopedia LLP. - 2012. - Vol. 4. - P. 304.) [in Kazakh]

7. Saparov K.T., Yeginbayeva A.Ye. Saryarkanyn geografiyalyk nysandaryn ataudyn tabigi negizderi [and others. Natural bases of naming geographical objects of Saryarka] (Bulletin of Al-Farabi Kazakh National University. Geography series. – Almaty, 2016. – No. 2(43). - p. 28-35.) [in Kazakh]

8. Tleke J. Shezhire: Ertis Bayanaula onir [Shezhire: Irtysh region of Bayanaul]. (Pavlodar.: Kazakhstan, 1995. - Vol. 1. - 368 p.) [in Kazakh]

9. Saparov K.T., Yeginbayeva A.Ye. and others. Kokshetau onirinin oronimderinin tabigat zhagdajlarynda bejnelenu zandylyktary [Patterns of reflection of the oronyms of the Kokshetau region in natural conditions] (Collection of materials of the XI International Scientific Conference of Students and young scientists «Science and Education - 2016». – Astana: L.N. Gumilev ENU, 2016. - P. 1091-1096.) [in Kazakh]

10. Saparov K., Chlachula J., Yeginbayeva A.Ye. Toponymy of the ancient Sary-Arka (North-Eastern Kazakhstan). Quaestiones Geographicae. ISSN 0137-477X, eISSN 2081-6383. 37 (3), 2018. – P. 35-52. DOI 10.2478/quageo-2018-0024.

11. Aikynbai B.A., Yeshtanaev G.E. Ulytau-Zhezkazgan onirinin zher-su attary [Toponyms of Ulytau-Zhezkazgan region] (U.A. Baikonurov. Zhezkazgan University. – Almaty: «Evero», 2007. – 220p.) [in Kazakh]

12. Saparov K.T., Yeginbayeva A.Ye. Ulytau onirinin tarihi zhane madeni nysandarynyn toponimderdegi korinisi [Reflection of historical and cultural objects of the Ulytau region in toponyms] (Bulletin of EKSTU D. Serikbayev. - Ust-Kamenogorsk, 2016. - No. 2. - P. 61-66.) [in Kazakh]

13. Saparov K.T., Mekisheva B.M., Yeginbayeva A.Ye. Abyraly – Shyngystaudyn landshaft erekshelikterin anyktajtyn toponimder birlestigi [Unification of toponyms defining the features of the landscape of Abraly-Chingistau] (Materials of the international scientific conference of young scientists, undergraduates, students and schoolchildren «XVII Satpayev readings». - Pavlodar: S. Toraighyrov PSU, 2017. - P. 87-92.) [in Kazakh]

14. Nasenov B. Abyraly-Saryarkanyn kindigi [Abraly-navel of Saryarka.] (Novosibirsk, 2002. – Vol. 1. 488 p.) [in Kazakh]

15. Ualikhanov Sh. Tandamaly shygarmalar [Selected works.] (Almaty, 1985. - Chapter 2. – 560 p.) [in Kazakh]

16. Shygys Saryarka. Karkaraly onirinin otkeni men bugini: monografiya / red. K.S. Aldazhumanova, A.Z. Bejsenova [Eastern Saryarka. Past and present of the Karkaraly region: monography / Ed. Aldazhumanova K.S., Beisenova A.Z.] (Almaty: Evero, 2004. - 703 p.) [in Kazakh]

17. Bogdanov A.A. Osnovnye cherty paleozojskoj struktury Centralnogo Kazahstana [The main features of the Paleozoic structure of Central Kazakhstan] (Byull. OIP., Department of Geology, 1959. – No. 1. – p. 35-46.) [in Russian]

18. Saparov K.T., Yeginbayeva A.Ye. Saryarkanyn pajdaly kazbalaryn anyktaudagy koldanbaly toponimikanyn roli [The role of applied toponymy in determining the minerals of Saryarka] (Bulletin of KazNTU. – 2015. – №5(111). - P. 397-403.) [in Kazakh]

19. Fizicheskaya geografiya Respubliki Kazahstan: uchebnoe posobie / pod. red. K.M. Dzhanaleevoj [Physical geography of the Republic of Kazakhstan: textbook / edited by K.M. Dzhanaleeva.] (Astana: «Arkas», 2010. - 592 p.) [in Russian]
20. Karamysheva Z.V., Rachkovskaya E.I. Botanicheskaya geografiya stepnoj chasti Centralnogo Kazahstana [Botanical geography of the steppe part of Central Kazakhstan.] (L., 1973. - 160 p.) [in Russian]
21. Yeginbayeva A.Ye. Saryarka toponimikasy [Toponymy of Saryarka.] (Monography. - Almaty: SSK, 2019. - 224 p.) [in Kazakh]
22. Atameken: geografiyalyk enciklopediya / red. B.O. Zhakyp [Atameken: Geographical Encyclopedia] (Edited by B.O. Iakov. – Almaty: «Kazakh encyclopedia», 2011. - 648 p.) [in Kazakh]
23. Yeginbayeva A.Ye., Saparov K., Rakisheva A., Atasoy E. Toponymy of flatlands of Kazakhstan. EBSCO. Marmara Coğrafya Dergisi. İstanbul – ISSN:1303-2429 E-ISSN 2147-7825. Sayi: 33, Ocak - 2016, S.641-655.
24. Akhmetov K., Baytelieva Zh. Zherinin aty – Elimnin haty: enciklopediyalyk anyktamalyk [The name of the place is the letter of the country: an encyclopedic reference.] (Almaty: Aruana Ltd LLP, 2006. - 808 p.) [in Kazakh]

Information about the authors:

Yeginbayeva Aigul Yessengaliyevna – PhD, Associate Professor, L. N. Gumilyov Eurasian National University, Department of Physical and Economical Geography, 2 Satpayev str., Astana, Kazakhstan.

Emin Atasoy – Prof. Dr., Uludag University, 16059 Görükle, Bursa, Turkey.

Keikin Yernar Kuatovich – PhD student, L.N. Gumilyov Eurasian National University, Department of Physical and Economical Geography, 2 Satpayev str., Astana, Kazakhstan.

Егінбаева Айгүл Есенғалиқызы – PhD докторы, доцент, Л.Н.Гумилев атындағы Еуразия ұлттық университеті, Физикалық-экономикалық география кафедрасы, Сәтбаев көш. 2, Астана, Қазақстан

Емин Атасой – профессор, география ғылымдарының докторы, Улудаг университеті, 16059 Görükle, Бурса, Түркия

Кейкин Ернар Куатович–PhD докторанты, Л.Н.Гумилев атындағы Еуразия ұлттық университеті, Физикалық-экономикалық география кафедрасы, Сәтбаев көш. 2, Астана, Қазақстан.

IRSTI 39.29

A.A. Tursynbayeva

Al Farabi Kazakh National University, Almaty, Kazakhstan
(E-mail: ai.aizhan95@mail.ru)

Analysis of the assessment of the salinity degree of irrigated lands in Karmakshy District of Kyzylorda region

Abstract. *The article examined a comprehensive analysis of the modern reclamation state of irrigated lands of Karmakshy District of Kyzylorda region, located in the lower reaches of the Syrdarya River, studied the causes and degree of salinization of soil cover. The territory of Kyzylorda region is located in the Turan lowland. Over the past half century, large changes have taken place in the entire natural complex due to the decrease in the flow of the Syrdarya River in the Aral Sea region. As a result of the drying up of the Aral Sea, a desert with an area of 21.4 thousand km2 was formed in its Kazakh Part. The work was carried out to compile a soil map of Kyzylorda region. When creating a map, we used GIS technologies. By compiling a soil map, we conducted a survey of the soil of Karmakshinsky district. In addition, the soil cover of irrigated lands of Karmakshy District in Kyzylorda region is grouped by types of salinization, the features of their development and distribution are described, and ways to improve the soil-salt regime of irrigated lands are considered.*
Key words: *irrigated lands, analysis, soil, mapping, salinization, GIS, soil-salt regime.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-77-87

Introduction. The development of environmental processes in an unfavorable direction for wildlife did not bypass the Aral Region. The territory of Kyzylorda region is located in the Turan lowland. Over the past half century, large changes have taken place in the entire natural complex due to the decrease in the flow of the Syrdarya River in the Aral Sea region. As a result of the drying up of the Aral Sea, a desert with an area of 21.4 thousand km2 was formed in its Kazakh Part. In the lower reaches of the Syrdarya river, adjacent to the Aral Sea, 2582 large and small lakes remain 155. In the agricultural part of the river delta, the incoming items of the groundwater balance were reduced, which led to an increase in their mineralization from 1 to 10 g/l and a 3-fold increase in land area with groundwater mineralization to 10-25 G/L.

In this regard, in order to further develop irrigated agriculture in this region, the problem arose of a detailed study of the history and modern halogenesis of the soils of the Kyzylorda region. In this case, there is a need to study the qualitative and quantitative characteristics of the salinity of the soils of this region and map their areas.

Karmakshinsky District of Kyzylorda region is an administrative-territorial division located in the central part of Kyzylorda region. Founded in 1928. The land area is 31.0 thousand km^2. The district center is the village of Zhosaly [4].The territory of the district is completely occupied by the Turan lowland. From the far north are the hilly Sandy basins of the Aral Karakum Yızıshkekum and Kolkudykkum, in the center-the Aktogay and Zhosaly steppes of the Alakay, in the south-the hilly sands of the Kyzylkum. The highest point of the district is in the North (Mount Targul, 160 m). Construction materials were explored from the bowels of the Earth. The Syrdarya river flows through the middle part of the district. From it are the Karmakshy and Shieli canals. In the South pass the ancient channels of the Syr Darya — Zhanadarya, Inkar Darya, etc.[1].

The climate is very continental, winters are quite cold, summers are hot and dry, and legend has it. The average annual air temperature in January is 9-13°C, in July — 27-29°C. The average annual precipitation is 100-150 mm. The soil in the North is gray, Sandy-Gray, barren and barren, in the central part-Sandy-gray, pale gray, in the Syr Darya Valley and floodplain-Meadow and Meadow-swampy soils. They grow gray Wormwood, yerkeshop, bayalysh, buygun, tasbuyyrgun, kokpek, Shi, Kara saksaul, sarsazan, reeds, reeds, karatal, Zhide, zhingyl, shengel, etc. From animals live wolves, foxes, badgers, sand rabbits, from birds-geese, ducks, pheasants, Bluebirds, etc. The Syrdarya River is rich in fish.

The climate of karmakshy district is sharply continental. The flat area of the district is open for cold air masses from the North, dry dry winds from the South. The remoteness of the area from the World Ocean also plays an important role. The average annual temperature is 8°, the average January temperature is 26.1°. In winter, when arctic air masses invade, the temperature drops to -34°. The highest temperature reaches in June (+42°). In summer, there is dryness of the air and cloudlessness. The average annual rainfall is 118 mm, with the greatest amount (61 mm) falling in March, April and may. In winter, precipitation decreases to 57 mm and falls in November, December and January. Annual rainfall is insufficient for the development of crops, so irrigated agriculture is developed in the area.

The soil and vegetation cover of karmakshinsky district is a typical semi-desert zone.

The soil of Karakhov and Zhuankum sands near the island is characterized by a low content of nutrients: nitrogen, phosphorus, potassium and humus (less than 1%). In some places, saline-salt and thakyr-like soils are found. For farming, they are less suitable and are used as spring-summer pastures.

The soil cover of the district is divided into groups: moist soils of the agricultural belt and complex soils.

Agricultural land is represented by the following types of soils (%): Sands – 45.6; Brown – 24.4; desert – like thakyr-11.1; swampy and Meadow – swampy-11.0; gray – brown-2.9; floodplain-Meadow 3.6.

In terms of mechanical composition, sandy loam (46.6%) and medium loam (33.1%), sandy loam (18.1%), heavy and medium loam (1.8%), heavy loam (0.2%), light loam (0.1%) predominate among them.

The main backgrounds of the area are sands and brown soils, then Desert thakyr-like, swampy and Meadow-swampy, floodplain-Meadow, gray-brown, salt marshes are reduced.

In the delta areas, Meadow intrasonal soils (Meadow-swampy, floodplain-meadow) with different complexities were formed, which are 8.4% of the territory where most of the irrigated arable land and hayfields are located.

Under the pasture is the widest set of soil groups, from sands to salt marshes and salt marshes.

All soils of the studied territory have some common features: low reserves and content of humus, weak anti-erosion and deflation resistance, a sharp impact on salinization and salinization processes, low supply of nitrogen and phosphorus compounds available to plants, sufficient reserves of potassium, predominance of an alkaline reaction and high carbonate content.

The surface water resources of the karmakshinsky district are represented by the lower reaches of the Syrdarya River, which has the character of a flat river, strongly meandered, divided into branches and channels. The river bed passes in its accumulative sediments and rises in relation to it and the surrounding surface. The nutrition of the Mixed River is snow and Glacier, rain and soil. Flat lake-full of elders. The average annual water loss is 444 m3/sec, the maximum annual loss during the flood period is 1070 m3/sec, and the minimum is 1.68 m3/sec. The river water reaches 560.6 million tons per season. the volume of M3 is used for regular irrigation, including 362 million for rice production. M3[2].

Research methods: expert decryption, standard statistical methods of correlation analysis of remote recordable parameters (NDVI, LST, etc.) and Terrestrial information. Methods for clustering and classifying satellite data.

Scope of application and implementation of results: salinization of irrigated fields and degradation of agricultural land in the south of Kazakhstan.

Current results: 2002-2022 historical data of the period (based on the materials of hydrogeological and reclamation expeditions of the Ministry of Agriculture of the Republic of Kazakhstan, relevant regions and other sources).

At the main sites, a kind of surface study of the salinization of irrigated fields of the project territories was carried out, which included the selection of soil samples, analysis of the composition of salts and, as part of Route Studies, an expert, rank description of the state of agricultural land by FAO salinization classes.

The available open archive data were analyzed, it was obtained that various cartographic materials have been stored in the system of the state institution «Department of land relations» at the regional level since the Times of the former USSR (since 1972). Archives are stored in non-digitized and paper form.

Mapping the salinity of irrigated fields faces significant technical challenges. A review of the scientific literature showed the presence of only individual works related to this task. Salinization of irrigated fields has significant variability throughout the season. The cards of spring and autumn salting are practically of interest. To solve the task of mapping the salinity of irrigated fields in the south of Kazakhstan, the following satellite products were used:

NDVI vegetation index. The format of individual scenes is Sentinel — 2, with a resolution of 10m. monitoring data for the period from 2003 to the present (source-fews NET), decade update, resolution up to 250m, on scales: absolute values of NDVI; deviation from the average; assessment of the depth of deviation, on the scale of historically recorded variations (perennial minimum-maximum) at this time here.

Salinity indices (the selection of indices continues). The format for individual scenes of Sentinel-2 and (or) Landsat -8 Is resolution (10-30 m) during the spring period (March-April).

Sentinel-2, Landsat-8 images with resolution (10-30 m) optical channels. The format of individual scenes for assessing the spectral characteristics of the bottom surface, detecting flooding and waterlogging of irrigated fields throughout the year, restoring rice crop rotation and assessing the autumn-winter washing of fields, monitoring the area of water mirrors of the main reservoirs of the region (assessment of the current fullness of reservoirs and operating modes for diagnosing the wateriness of the season).

Surface temperature (Land Surface Temperature). In the format of monitoring the period from 2003 to the present (source — FEWS NET), ten-day update, 5 km resolution; on the scale: absolute values; deviation from the average; quantitative assessment of the amount of cooling due to irrigation of the field (Irrigation Cooling Effect).

Height of snow cover (Snow Depth). In the format of monitoring the period from 2001 to the present (source — FEWS NET), ten-day Update, 1 km resolution.

The practical significance of the described phenomenon is associated with the demand for a long-term forecast of the water of the rivers of Central Asia. The forecast of the volume of river flow affects the planning of acreage under various crops. «Long memory in the mountain snowy perennial mode on the Tien Shan justifies the use of a simple inertial» forecast. At the same time, it is assumed that the snowfall next year will be close to the level of the current year.

In the process of conducting research activities of this stage of the project, documentation was developed on geoparal, a web Geoinformation service of operational monitoring, which includes recommendations and software solutions on architecture for the development of a Geoinformation system for quantitative assessment of soil salinity[3].

The work was carried out with the support of the grant BR10965172 of the Ministry of education and science of the Republic of Kazakhstan, implemented at the Institute of information and computing technologies of the Ministry of education and science of the Republic of Kazakhstan under the agreement No. 362 of September 07, 2022.

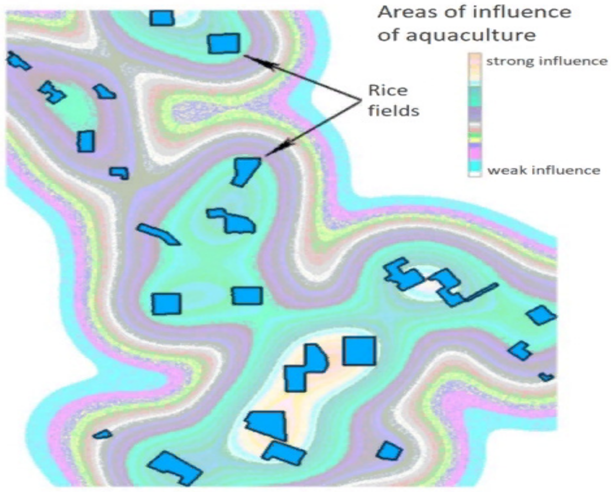


Fig.1. Reconstruction of rice crop rotation in the massif

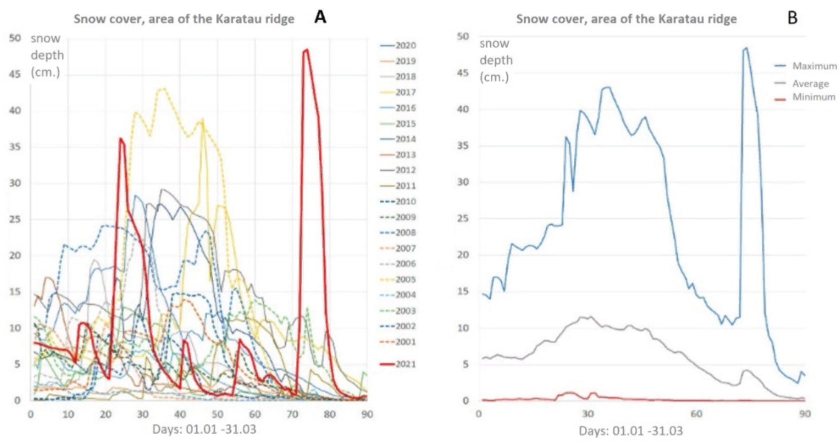


Fig.2. Satellite monitoring SD FEWS NET

Research methods and discussion of the results obtained. In other equal conditions, the predominance of the salinity factor mainly depends on the type and intensity of soil use and taking into account the complexity of the soil-reclamation and environmental conditions of the kazaly-Aral irrigation Massif, as well as in accordance with the objectives of scientific research and to determine the degree of salinity of the soil, a field study was conducted.

In order to solve the tasks set, the calculation sites for sampling Salt soils of the Karmakshy district with an area of 95.25 km2 were selected, in particular, the territory of the Abay settlement, 5 km from the Karmakshy station, the basykara settlement, 10 km from the Kazaly station and the Orkandeu settlement, located 30 km away. The following soil sampling points were distinguished: 1-3 sampling points – 1, 3.5 km and 6 km southeast of the settlement of orkandeu, 4 points 5 km south of the Abay settlement irrigated lands, 5-7 points 2-6 km southeast of the Abay settlement, 8 points 1 km north-east of the basykara settlement, 9 points 1.5 km south of the Aiteke bi settlement and 10 points 1.5 km northeast of the Altai settlement were selected.

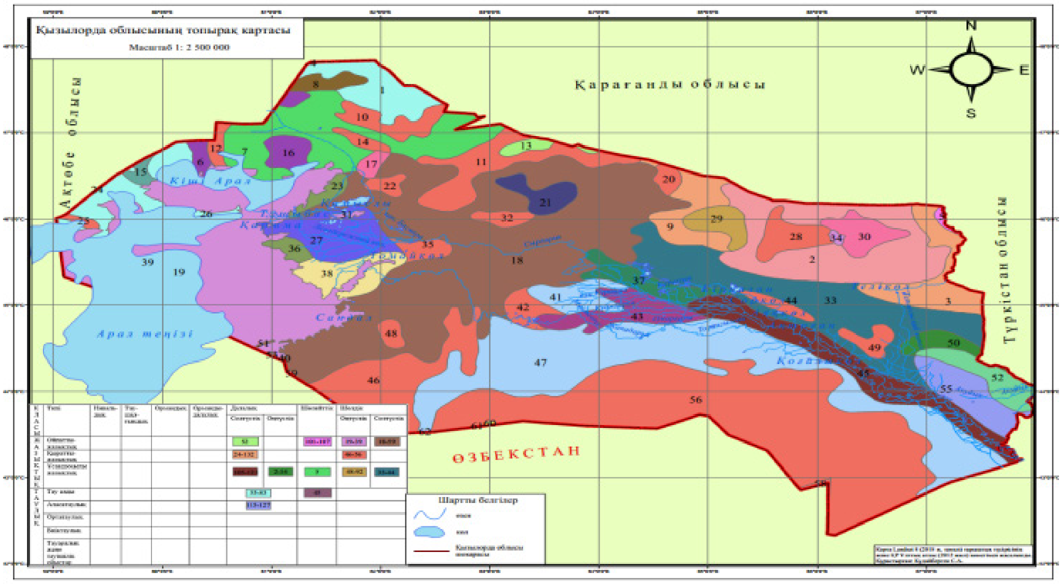
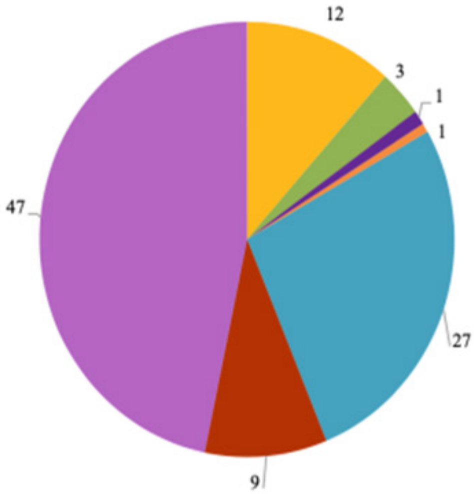


Fig.3. Soil map of Kyzylorda region

Assessment of saline soils according to the methodology of V. A. kovdu and V. V. Egorov according to 3 main criteria: chemistry, degree of salinity and depth of the Salt horizon. The chemistry of saline soils was determined by the content of anions and cations. Especially the anions, the magnitude of their relationship in the water pumps of the soil were taken into account[4].

In Kyzylorda region in 2022, 24,099. 2 thousand hectares were used (including the territory of Kyzylorda region – 22,601. 9 thousand hectares, leased land of Ulytau District of Karaganda region – 2,210. 8 thousand hectares), including:

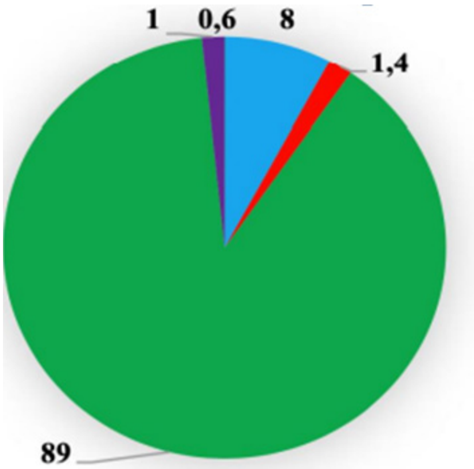
- agricultural land – 2,788. 2 thousand hectares (2022 – 2,701. 6 thousand hectares, increase 86.6);
- land of settlements (cities and rural settlements) -838.3 thousand hectares 2022 – 838.3 thousand hectares);
- industrial, communications, defense and other non – agricultural land – 254.6 thousand hectares (2022-256 thousand hectares, decreased by 1.4 thousand hectares);
- lands of specially protected natural areas – 161.2 thousand hectares (2021 – 161.2 thousand hectares);
- lands of the Forest Fund – 6 510.3 thousand hectares (2021 – 6 510.3 thousand hectares);
- lands of the Water Fund – 2 288.1 thousand hectares (2022 – 2 287.2 thousand hectares), an increase of 0.9
- lands of the fund-11 258.5 thousand hectares (2022 - 11,289. 8 thousand hectares), decreased by 31.3 thousand hectares in 2022, the largest share of the land fund of the Kyzylorda region is occupied by the lands in the fund and the lands of the Forest Fund (figure 4).



agricultural land
lands of settlements
lands of industry, etc.
lands of specially protected natural territories
lands of the forest fund
lands of the water fund
lands of the reserve

Fig.4. Distribution of the Land Fund of Kyzylorda region by Category, %

In 2022, the area of reclaimed land in the Kyzylorda region amounted to 0.711 thousand hectares.the largest share of agricultural land is pastures – 1,997.6 thousand hectares or 89%, the smallest share or 0.6% is perennial plantings.



Arable land
Deposits
Pastures
Haymaking
Perennial plantings

Fig.5. Distribution of the Land Fund of Kyzylorda region by Category, %

Unlike water and atmospheric air, which are only migration environments, soil is the most objective and stable indicator of man-made pollution. It clearly reflects the emission of pollutants and their actual distribution sources of soil pollution

- emissions of harmful substances into the atmospheric air from permanent
and mobile sources of pollution
- landfills of industrial and household waste;
- unauthorized landfills of industrial and household waste;
- chemical plant protection products and mineral fertilizers[5]. The growth of oil

and gas production, the high aggressiveness of the extracted raw materials affect the processes of intensive pollution of the atmosphere, surface and groundwater, and through them the soil and vegetation cover, where heavy metals, petroleum products, polychlorinated diphenyls and dioxins accumulate. In 2022, RSE «Kazhydromet» monitored soil contamination with heavy metals in the spring and autumn periods in the cities of Zhosaly, Toretam and the villages of Akai, Akzhar (table 1).

Table 1 – soil pollution by heavy metals in Kyzylorda region, mg / kg

Sampling points	chrome	lead	zinc	cadmium	copper
spring period					
Zhosaly c.	0,43-0,6	12,6-25,5	5,7-18,6	0,1-0,2	0,6-1,03
Toretam c.	0,46-3,4	15,9-26,1	5,7-6,1	0,13-0,17	0,65-2,33
Akai v.	0,19	3,4	1,5	0,08	0,25
Akzhar v.	0,16	2,1	1,6	0,04	0,32
autumn period					
Zhosaly c.	0,07-0,18	7,1-16,4	2,3-7,8	11-0,22	0,3-3,8
Toretam c.	0,04-0,13	10,7-16,3	5,9-10,9	0,08-0,19	0,46-1,2
Akai v.	0,02	2,4	2,5	0,005	0,11
Akzhar v.	0,03	3,3	2,6	0,04	0,8

In addition, a number of studies were carried out on the territory of the region on soil salinization (chlorides, sulfates), soil pollution with persistent organic pollutants (PPE) and pesticides.

According to natural and climatic conditions, almost the entire territory of the Kyzylorda region belongs to an extremely unfavorable arid zone. The region is characterized by increased solar radiation, low precipitation, strong winds and dust storms that move tons of sand for several kilometers.

The main environmental problems associated with land pollution (oil spills) by oil producing companies, as well as soil degradation and salinization.

Studies on the chemical composition of salt soils of the karmakshinsky district are conducted on calcium, magnesium, sodium, potassium and chlorine anions, sulfate anions, bicarbonates (tab. 2).

Table 2 – Studies on the chemical composition of salt soils of the karmakshinsky district

Place of soil sampling	Depth, m	Designations	Cations			Anions			Dry residue at 105 C	The degree of salinity of soils	Type of soil salinization
			Ca++	Mg++	Na+K	HCO3	C1	SO4			
1	0.5	%	0.096	0.036	0.384	0.018	0.518	0.46	1.129	medium saline	Sulfate-chloride
	1.0	%	0.092	0.031	0.359	0.012	0.44	0.499			
2	0.5	%	0.055	0.157	0.671	0.054	0.072	1.897	3.206	highly saline	Sulfate
	1.0	%	0.063	0.165	0.738	0.036	0.1	1.957			
3	0.5	%	0.109	0.029	0.064	0.012	0.142	0.317	0.642	slightly saline	Sulfate-chloride
	1.0	%	0.07	0.029	0.191	0.018	0.163	0.422			
4	0.5	%	0.15	0.08	0.102	0.016	0.334	0.374	1.053	medium saline	Chloride-sulfate
	1.0	%	0.142	0.076	0.240	0.074	0.326	0.643			
5	0.5	%	0.062	0.158	0.671	0.053	0.08	2.497	4.107	slightly saline	Sulfate
	1.0	%	0.073	0.165	0.738	0.012	0.14	2.557			
6	0.5	%	0.12	0.05	0.584	0.006	0.951	0.422	0.938	slightly saline	Chloride
	1.0	%	0.06	0.032	0.324	0.024	0.341	0.49			
7	0.5	%	0.026	0.058	0.246	0.030	0.029	0.68	1.062	slightly saline	Sulfate
	1.0	%	0.032	0.064	0.252	0.036	0.035	0.128			
8	0.5	%	0.036	0.104	0.451	0.024	0.049	1.267	2.057	medium saline	Sulfate
	1.0	%	0.042	0.110	0.492	0.096	0.067	1.334			
9	0.5	%	0.096	0.164	0.511	0.102	0.059	1.327	2.253	medium saline	Sulfate
	1.0	%	0.102	0.170	0.517	0.018	0.065	1.333			
10	0.5	%	0.048	0.054	0.221	0.012	0.023	0.63	0.962	slightly saline	Sulfate-soda
	1.0	%	0.051	0.057	0.247	0.018	0.033	0.69			

The results of the study showed that all soils of the studied territory have a certain degree of salinity. According to chemism, soils in the form of sulfate-chloride, sulfate-soda and chloride of salinity predominate. A large area of karmakshy district (64.3%) is occupied by saline Medium-Salt soils. Further, in descending order, weak (22.6%) and heavily salted (13.1%) soil. A small area of the studied area is occupied by saline and deep saline soils. Most of the areas are salted from the surface of the Earth, which is currently the result of irreversible secondary salinization of this soil[6].

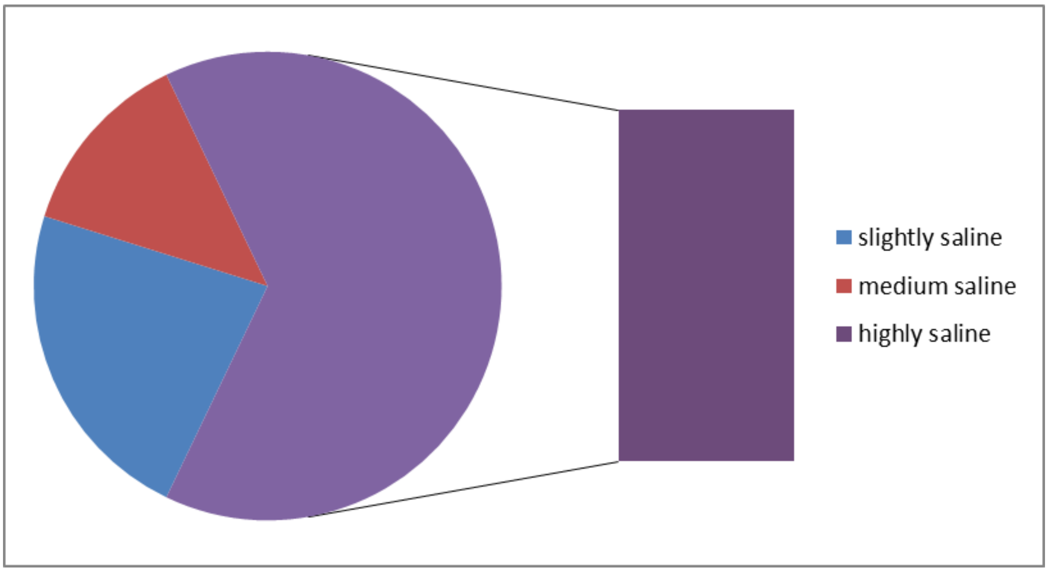


Figure 6 – distribution of soils of varying degrees of salinity at accounting sites of Karmakshinsky District of Kyzylorda region(slightly saline-22.6%; medium saline -64.3%; highly saline – 13.1%)

Conclusions:

1. Drawing up a soil map of Kyzylorda region;
2. Conducting research by drawing up a map, it is possible to solve the following problems.
3. The studied areas of irrigated saline soils of Karmakshinsky District of Kyzylorda region showed the intensification of secondary salinization processes due to an increase in the level of mineralized groundwater;
4. Sulfate-chloride, sulfate, chloride and chloride-sulfate salinization of soils occurs in irrigated areas;
5. Anionic salinization of the soil is represented by chloride ions, bicarbonates and sulfate anions;
6. In order to maintain the design level of soil fertility in these conditions, it is necessary to use more intensive technologies for its support, including biological reclamation on the basis of proper crop rotation and the use of crops adapted to these natural conditions.

References

1. Система сельскохозяйственного производства Кызылординской области/ Под ред. С.У. Нургисаева. - Алматы: Bastau, 2002. - 346 с.
2. Султангазин У.И., Мукитанов Н.К., Гелдиева Г.В., Малковский И.М. Концепция сохранения и восстановления Аральского моря и нормализация экологической и социально-экономической ситуации в Приаралье// Проблемы освоения пустынь. - 1991. №3-4. - С. 97-107.
3. Нургизарынов А. Экологическое дыхание Арала. - Алматы: Гылым, 2006. – 223 с.
4. Документация землеустройства Кармакшинского района Кызылординской области / Под ред. Т.Г. Бледных. - Алматы, 1991. - С. 157.
5. Гелдиева Г.В., Будниова Т.И., Скоринцева И.В. Ландшафтное обеспечение схемы борьбы с опустыниванием долины реки Сырдарья. -Алматы: Аркас, 2004. - 235 с.
6. Кауричев И.С., Панов Н.П., Розов Н.Н. Почвоведение. - Москва: ВО Агропромиздат, 1989. - С.706.

А.А. Тұрсынбаева
Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан

Қызылорда облысы Қармақшы ауданындағы суармалы жерлердің сортаңдану дәрежесін бағалауды талдау

Аңдатпа. Мақалада Қызылорда облысы Қармақшы ауданының Сырдария өзенінің төменгі ағысында орналасқан суармалы жерлерінің қазіргі заманғы мелиорациялық жай-күйіне кешенді талдау жүргізіліп, топырақ жамылғысының тұздану себептері мен дәрежесі зерделенді. Қызылорда облысының аумағы Тұран ойпатында орналасқан. Соңғы жарты ғасырда бүкіл табиғи кешенде Арал теңізі аймағында Сырдария өзені ағынының азаюына байланысты үлкен өзгерістер болды. Арал теңізінің құрғауы нәтижесінде оның қазақстандық бөлігінде ауданы 21,4 мың км^2 шөл пайда болды. Осыған байланысты, осы өңірде суармалы егіншілікті одан әрі дамыту мақсатында Қызылорда облысының топырақтарының тарихы мен қазіргі заманғы сортаңдануын егжей-тегжейлі зерттеу мәселесі туындады. Қызылорда облысы Қармақшы ауданының бұл жағдайда топырақтың тұздануының сапалық және сандық сипаттамаларын зерттеу қажет Қызылорда облысының топырақ картасын жасау жұмыстары жүргізілді. Картаны жасау кезінде ГАЖ-технологиялар пайдаланылды. Топырақ картасын жасау мен картографиялау кезінде Қармақшы ауданының топырағына тексеру жүргізілді. Бұдан басқа, Қызылорда облысы Қармақшы ауданының суармалы жерлерінің топырақ жамылғысы сортаңдану түрлері бойынша топтастырылды міндетті түрде, олардың даму және таралу ерекшеліктері сипатталды, сондай-ақ суармалы жерлердің топырақ-тұздық режимін жақсарту жолдары қаралды.

Түйін сөздер: суармалы жерлер, талдау, топырақ, картаға түсіру, тұздану, ГАЖ, топырақ-тұз режимі.

А.А. Турсынбаева
Казахский национальный университет имени аль-Фараби, Алматы, Казахстан

Анализ оценки степени засоления орошаемых земель Кармакшинского района Кызылординской области

Аннотация. В статье проведен комплексный анализ современного мелиоративного состояния орошаемых земель Кармакшинского района Кызылординской области, расположенных в нижнем течении реки Сырдарьи, изучены причины и степень засоления почвенного покрова. Территория Кызылординской области расположена на Туранской низменности. За последние полвека во всем природном комплексе произошли большие изменения в связи с уменьшением стока реки Сырдарья в регионе Аральского моря. В результате осушения Аральского моря в его Казахстанской части образовалась пустыня площадью 21,4 тыс. км^2. В связи с этим, в целях дальнейшего развития орошаемого земледелия в этом регионе, возникла проблема детального изучения истории и современного засоления почв Кызылординской области. В этом случае возникает необходимость изучить качественные и количественные характеристики засоления почв.

Была проведена работа по составлению почвенной карты Кызылординской области. При создании карты использовались ГИС-технологии. При составлении почвенной карты проведено обследование почв Кармакшинского района. Кроме того, почвенный покров орошаемых земель Кармакшинского района Кызылординской области сгруппирован по типам засоления, описаны особенности их развития и распространения, а также рассмотрены пути улучшения почвенно-солевого режима орошаемых земель.

Ключевые слова: орошаемые земли, анализ, почва, картографирование, засоление, ГИС, почвенно-солевой режим.

References

1. Systema selskochozyaistvenogo proizbodstba Kyzylordinskoy oblasty [System of agricultural production of Kyzylorda oblast]. Pod.red. S.U. Nurgysaeva. –Almaty: Bastau, 2002. -346s. [in Russian]

2. Sultangazin U.I., Mukitanov N.K., Geldieva G.B., Malkovsky I.M. Konsepsia sochranenia ii vostanovlenia Aralskogo moria ii normalizasia ecologisheskoi ii sosialno-ekonomisheskoi situasyi b

Priarale [The concept of preservation and restoration of the Aral Sea and normalization of ecological and socio-economic situation in the Aral Sea region] // Problemi osvoenie pustin. - 1991. №3-4. -S. 97-107. [in Russian]

3. Nurgizarinov A. Ecologicheskoe dihanie Arala [Ecological breath of the Aral Sea]. –Almaty: Gilim, 2006. – 223s. [in Russian]

4. Dokumentasia zemleustroystva Karmakshinskogo raiona Kyzylordinskoy oblasty [Documentation of land management of Kazaly district of Kyzylorda region] / pod.red. T.G. Blednih. –Alma-Ata, 1991. – S.157. [in Russian]

5. Geldieva G.B., Budnikova T.I., Skorinseva I.B. i dr. Landshaptnoe obespeshenie schemi borbe s opustinibaniem dolini reki Syrdary [Landscape provision of the scheme to combat desertification of the Syrdarya river valley]. -Almaty: Arkas, 2004. – 235s. [in Russian]

6. Kaurichev I.S., Panov N.P., Rozov N.N., dr. Poshvovedenie [Soil science]. –Moskva: BO Agropromizdat. 1989. –S.706. [in Russian]

Information about author:

***Tursynbayeva Aizhan Almatkyzy* –** PhD student, Department of Cartography and Geoinformatics**.** Faculty of Geography and Nature Management, Al Farabi Kazakh National University, 050038, 71 al-Farabi Avenue, Almaty, Kazakhstan.

Турсынбаева Айжан Алматқызы – докторант кафедры картографии и геоинформатики, факультет географии и природопользования, Казахский национальный университет имени аль-Фараби, 050038, пр. аль-Фараби, 71, Алматы, Казахстан.

IRSTI 39.23.15

N.V. Hahina, E.I. Galai*, A.E. Yarotau

Belarusian State University, Minsk, Belarus
Corresponding author: galaygeo@mail.ru*

The main features of ski tourism development in the territory of the Republic of Belarus

Abstract. *Ski tourism is a common form of tourism worldwide, generally associated with rural areas and activities in the snow. However, it is also offered as a tourist product in urban destinations in indoor and outdoor areas associated with sports. The conducted research considered the main features of ski tourism development on the territory of the Republic of Belarus, a country with a flat terrain character. The landscape-climatic and socio-economic conditions in eight ski tourism centers of the country are analyzed, and their specialization in the presentation of tourist products and the development of basic and specialized infrastructure are discussed. It is noted that the development of ski centers is associated with the popularization of active recreation, and amateur skiing. In the research, it has been determined that it is much more appropriate to examine ski tourism separately in mountainous and flat areas without making comparisons in terms of both landscape and orographic conditions. When the research findings are evaluated in general, it shows that the ski tourism in the Belarus destination is unevenly distributed, and the highest density is in the influence area of the capital Minsk.*
Keywords: *ski tourism, the Republic of Belarus, winter recreation.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-88-104

Introduction

Tourist destinations are one of the central factors of the tourism sector. With their rich content and complex structure, tourist destinations are studied holistically as they are of interest to various disciplines such as geography, ecology, economics, marketing, spatial planning, management, etc. The attractiveness of destinations paves the way for different types of tourism, which are becoming places of experience. One of them is ski tourism.

Ski tourism is one of the most popular and profitable types of tourism, the development of which requires specific conditions in terms of natural resources, the creation of ski infrastructures, and the production of suitable equipment. In the tourism market, there is an increase in the number of ski destinations that are becoming points of attraction through investments in ski slopes, mechanical facilities, and accommodation developed in relation to climatic and geographical conditions.

Ski tourism is created by a large number of tourist flows, the target audience, and special marketing techniques to promote tourist products. Currently, there is globalization in the development of this segment of the tourism sector. According to the 14th Edition of the 2019 International Report on Snow & Mountain Tourism, in the 2017-2018 winter season, there were 2084 ski resorts worldwide, including snowmaking and equipped resorts in 67 countries around the world (Vanat, 2020). This «pre-Covid» period can be considered favorable for the development of the ski tourism industry. The researcher Laurent Vanat has ranked the main ski resorts in the world according to their most objective evaluation indicator – the number of average annual visits. The most visited ski resort in the world with more than 2.5 million tourists is La Plagne (France). More than 2.0 million visits are in the resorts of SkiWelt Wilder Kaiser-Brixental (Austria), Les Arcs (France), Saalbach hinterglemm leogang fieberbrun (Austria), Ischgl and Samnaun Silvretta Arena (Austria, Switzerland), Whistler Blackcomb (Canada), Madonna di Campinglio (Italy), Gardena / Alpe di siusi (Italy), Val Thorens/ Orelle (France) (Vanat, 2020).

The geography of the largest ski resorts shows that the landscape-orographic factor has the greatest importance for their development. Of the largest ski resorts in the world (51 ski resorts), 80% are located in the Alpine region of Europe, 14% in the ski resorts of America, and only 6% in the non-Alpine ski resorts of Western Europe (Vanat, 2020).

From the methodological point of view, it seems to us important to consider ski tourism in mountainous and apartment areas as two different classes of objects, which are not comparable in terms of landscape and orographic conditions and, consequently, in terms of the capacity of ski centers, but the centers of each class can be very attractive for domestic and international tourism. In this research, the historical development and basic characteristics of ski tourism in the Republic of Belarus were discussed, and an attempt was made to show the current situation by presenting the current potential and supply data related to winter tourism. In this context, the landscape-climatic and socio-economic conditions of the country's eight ski tourism centers were analyzed, and their competencies in providing tourist products and developing basic and specialized infrastructure were discussed.

1. **Relevant Literature**

Ski tourism is one of the types of tourism in which interest is increasing worldwide. It includes activities in the snow and various tourist services, usually in rural and mountainous areas. In addition, it can be offered to the tourism market as a stand-alone tourism product by adding sports activities that are carried out both indoors and outdoors in urban destinations (Mursalov, 2009). They are usually practiced on snow or ice and require freezing temperatures, such as skiing, skating, and sledding.

Ski destinations are very sensitive to the continuous development of destination plans, branding, and the level of competitiveness. It is a prerequisite for success to manage ski resorts with good planning that takes into account both the landscape and climate that make the destination attractive and the socio-economic conditions (Cihangir Çamur et al., 2021). In the context of ski tourism, investments are made in cable cars, chairlifts, and snowmaking equipment in the destinations, which enable tourism development on the one hand and access to inaccessible mountain slopes on the other. It is well known that modern ski resorts allocate a high level of capital (e.g., 2.79 billion euros in Tyrol, Austria) for investments in technical infrastructure (Bausch & Gartner, 2020). Within the tourism industry, skiing is a vulnerable market segment with a high level of competitiveness that is exposed to numerous threats, particularly global warming, which could hinder long-term growth (Vanat, 2020).

A review of the tourism literature reveals that there are studies that focus on the image of ski destinations (Hallmann et al., 2015), factors that influence the choice of ski destinations (Klenosky et al., 1993; Sun et al., 2022), motivations of ski tourists (Matzler and Siller, 2003; Dickson and Faulks, 2007; Mlađenović and Jovanović, 2019; Bichler and Pikkemaat, 2021), perceptions of ski tourists (Haugom and Malasevska, 2019), satisfaction of skiers (Miragaia and Martins, 2015; Manap Davras, 2021), and loyalty and repeat visits of ski tourists (Alexandris et al., 2006; Faullant et al., 2008, He and Luo, 2020). In addition, the problem of the potential of natural resources in terms of their use by skiers is discussed in detail in the scientific literature in the work of A.I. Zyryanov (2021), A.I. Zyryanov and D. I. Shilov (2020), Chun-Hung (Hugo) Tang and Soo Cheong (Shawn) Jang (2011), M. Falk and E. Hagsten (2016). In ski tourism centers, care is also taken to minimize the negative impact of recreation and tourism on natural complexes through the implementation of an environmental certification system (Weib and Bentlage, 2006).

The development of ski tourism is based on the cluster model considered in the works of H. Konu et al. (2011), E. G. Kropinova and A. V. Mitrofanov (2011), P. V. Panchenko (2011), E.V. Seredina (2016). According to A. H. Shidov et al. (2019), the main criteria for evaluating a ski resort as a cluster project should include its specialization in the tourism industry and the production of a tourism product, the geographic location of the cluster, the demand/expenditure ratio, and the capacity of the cluster. The effectiveness of the cluster approach in the organization of ski tourism is determined by the natural geographical location of ski centers, their main specialization in tourism services compared to other types of tourism, the need to create infrastructure, including ski slopes, snowboard parks, lifts, equipment rental, the hotel sector.

For the development of ski tourism, various factors should be considered that are important for the destination preferences of ski tourists. Unbehaun et al. (2008) lists these factors from the most important to the least important as follows: “snow secure destination”, “winter experience”, “size of skiing area”, “waiting time at lifts”, “high quality of accommodation”, “price of accommodation”, “the opportunity to ski down to the bottom of the valley”, “artificial snow”, “restaurants”, “outdoor activities”, “après-ski”, and “shopping facilities”. Miragaia and Martins (2015) list the top five factors which tourists look for when choosing a ski resort: “Accommodation”, “restaurants and social life”, “holiday facilities/services”, “quantitative and qualitative characteristics of the slopes”, and “distance/access/price”.

Haugom and Malasevska (2019) examined how skiers perceive different ski resorts and their weather-related characteristics using data from 400 skiers at a Norwegian inland destination. The researchers found that “daily weather at the time of skiing” and “the price of a lift ticket” were the most important attributes for skiers, followed by “chairlift wait time” and the “percentage of open slopes”. Unbehaun et al. (2008), who examined the effects of climate change on skiers’ preferences and their tourism activities, concluded that climate change is an issue on winter sports tourists’ agendas, that destinations with sufficient/natural snow are strongly preferred, and that loyalty to destinations with low snowfall is declining.

Bausch and Gartner (2020) emphasize that the focus in the Alps is on skiing and the associated winter sports market, and that other important market segments of winter tourism are overlooked. Bausch at al. (2019) note that some tourists (e.g., those who prefer pure winter nature - natural attractions not modified for winter sport - sightseeing itineraries, mountain tours, or a sense of peace and solitude) give up after a trip to the Alps because too little attention is paid to them. In other words, tourists’ intention and behavior to revisit the destination will be negatively affected if their expectations are not met.

Bichler and Pikkemaat (2021) sought to uncover the motivational factors that influence skiers’ visitation to urban destinations with winter sports infrastructure. In their study, they found that there were five push (“exciting”, “knowledge”, “relaxation”, “achievement”, and “family”) and six pull factors (“basic assets”, “urban assets”, “natural scenery”, “social events”, “economic aspects”, and “winter sports activities”). In addition, they typologically categorized ski tourists in urban destinations as «moderate skiers,» «urban recreational skiers,» and «focused skiers,» and pointed out the market potential of combining urban tourism and winter sports.

The study conducted by Tikunova and Krapivina (2014) on the attractiveness of ski resorts in Europe, based on the calculation of the attractiveness index according to the method of evaluation classification (Tikunov, 1985), has shown that the most attractive ski resorts in terms of the main indicators (“duration of the season”, “total length of ski slopes”, “capacity of lifts”) are cross-border ski resorts oriented towards international tourism. This theory is confirmed by the leading position of the countries of the Alpine region – France, Austria, Switzerland, Italy - in the ski tourism sector (Tikunova and Krapivina, 2014). Taking into account additional indicators reflecting the specialization of ski resorts, the variety of services, and the price offer (cost of a subscription, availability of snowboard parks, freeride zones, artificial lighting of ski slopes, and artificial snow on ski slopes), the authors have arrived at a different grouping of ski resorts, which seems questionable. The result of the research is that the countries with several conditions for ski tourists are as follow: the most attractive conditions, Austria, Serbia, Andorra; highly attractive conditions, Switzerland, Italy, Finland, Bosnia and Herzegovina, Germany; attractive ones, France, and Czech Republic; insufficiently attractive ones, Poland, Norway, Sweden, Romania, Croatia, and Russian Federation; few attractive ones, Montenegro, Greece, Slovenia, Slovakia, Bulgaria, Ukraine, Spain, Belarus, Liechtenstein, and Latvia (Tikunova and Krapivina, 2014).

Countries with flat terrain in Europe are Denmark, Lithuania, Latvia, the Netherlands, the Republic of Belarus, and Estonia. The natural conditions of these countries allow the development of ski tourism in the conditions of low absolute and relative heights of undulating land, temperate continental climate with constant snow cover, transitional climate from temperate continental climate to marine climate with unstable snow cover, and marine climate without snow cover in winter. As a result, the ski centers of these countries have a length of equipped slopes of varying complexity of no more than a few kilometers. In countries with no or unstable snow cover, artificial conditions for skiing in the mountains have been created – nylon coating of slopes in Denmark, indoor complexes in the Netherlands, Lithuania. Their advantage is the possibility to use these slopes all year round. A distinctive feature of the ski centers in the lowlands is the extensive development of winter recreation, the creation of slopes for cross-country skiing and ice rinks. As indicated on the websites of these ski resorts, their capacity is designed for several thousand visitors. For example, Snow Arena-Drusininkaj is designed for 1000 visitors, and the centers Otepa, Silichi and Logoisk – for several thousand people. On weekends and during competitions and mass events, up to 10 thousand visitors can come. The largest ski centers in the flat countries of Europe are listed in Table 1.

Table 1. Large ski centers of the flat countries of European region

Country	The highest point of the country (m)	The largest ski centers	Special infrastructure
Denmark	170.86	Silkeborg, DanParcs Rønbjerg, Gjern glegene DanParcs Søhøjlandet Center	Nylon slope, all year-round artificial slopes
		Hedelands Ski Centre	All year-round artificial slopes, ice ring
The Netherlands	322.00	SnowWorld Landgraaf	2 indoor ski slopes, 1040 m, snowpark
		Snowworld Zoetermeer	2 indoor ski slopes, 420 m, snowpark
Lithuania	293.84	Snow Arena-Drusininkaj	2 indoor ski slopes, 600 m, 1 open ski slope 640 m.
		Liepkalnis - Vilnus	10 open slopes, 2600 m, snowboarding
		Mortos Kalns	1 open ski slope 500 m, snowboarding, cross-country ski trails
Latvia	311.94	Ozolkans	5 open slopes, 2500 m
		Riektsu Kalns	16 open slopes, 4900 m, snowboarding, cross-country ski trails
		Milnzkalns	11 open slopes, 1600 m snowpark
The Republic of Belarus	345.00	Logoisk	5 open slopes, 5000 m snowboarding, cross-country ski trail
		Silichi	10 open slopes, 4090 m snowpark, cross-country ski trail
Estonia	318.00	Kuutsemäe	7 open slopes, 200-500 m each, snowboarding
		Kivioli	4 open slopes, 2000 m springboard, snowboarding
		Otepaa	Snowboarding, cross-country ski trails, ice ring

Resource: tripmydream.com, 2023; ski-atlas.ru, 2023; logoisk.by, 2021; silichy.by, 2023; http://skistop.ru/resorts/indoor/netherlands/snow_world_netherlands; https://touristam.com/gornolyzhnye-kurorty-estonii.html

Despite the flat terrain of the Republic of Belarus, a number of ski centers have emerged that cater to both domestic and international tourism. The scientific rationale for the development of ski centers as a new direction of nature management is considered in a number of works by Belarusian scientists (Pirozhnik, 2009; Zaitsev and Petrusevich, 2011). However, the problem of the creation and development of ski centers in Belarus has not received much attention in the scientific literature. In this regard, the aim of the work to conduct a comparative analysis of the development of ski centers in Belarus seems relevant and practically significant for the development of the tourism sector.

2. **Materials and Methods of Research**

In this qualitative study, data were collected through document research. An attempt was made to identify the main features of the development of ski tourism in the Republic of Belarus based on the available documents and records. The documentary survey method uses all kinds of scientific studies, reports, and websites as documents (Karasar, 2008). In this study, about eighty documents consisting of websites, articles, and tourism reports were used using the documentary survey method. In addition, the methodological basis of the study is comparative geographical and cartographic methods. The subject of the study is the ski parks and ski resorts of the Republic of Belarus, the location of which is shown in Figure 1.

The peculiarities of ski tourism development on the territory of Belarus are determined by the flat terrain with elevations, a temperate continental climate with a stable snow cover in winter. Winter sports are very popular in the country, so the various types of ski tourism and recreation are aimed at meeting the demand of domestic mass tourism. At the same time, the visa-free regimes for many countries, the developed hotel sector in major cities, and favorable transport infrastructure create conditions for the development of international ski tourism in Belarus.

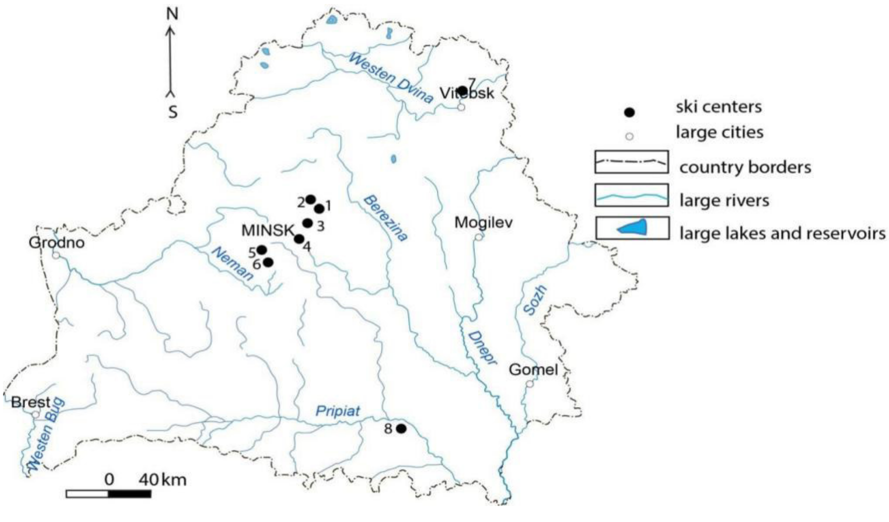


Figure 1. Ski centers of Belarus

1-ski center «Silichi», 2-ski sport and recreation complex «Logoisk», 3-Olympic training center for winter sports «Raubichi», 4-educational and entertainment ski center Solnechnaya Dolina (Sunny Valley), 5-ski complex «Westa», 6-active corporate recreation park «Yakutskie mountains», 7-ski center «Ruba», 8-sport and recreation ski complex «Mozyr».

In order to analyze the ski centers of the country, the following criteria were selected for their evaluation:

- prerequisites for the development of a ski center, which were evaluated by indicators of the favorability of the landscape-climatic and socio-economic characteristics of the site;
- the specialization of the center in the tourism industry and the production of tourist products;
- the development of infrastructure and a wide range of services.

The evaluation of the favorable landscape and climatic conditions includes the absolute height and vertical separation of the natural relief in the area of the ski center; the height of the artificial relief and the created height differences on the ski slopes; the average daily air temperature in winter; the height of the snow cover; the amount of precipitation in the cold season; days with snowstorms. The favorability of socio-economic conditions is evaluated by the indicator of the accessibility radius of the ski center for large cities that generate tourist demand.

Specialization in the production of a tourist product is determined by the characteristics of the main specialized services of the ski center, analyzed by the indicators of the length and types of ski slopes, as well as additional specialized winter recreation services, including snow parks, ice rinks, springboards, tobogganing, and biathlon tracks, etc.

The capacity of each center is determined by the indicators of the development of basic recreational infrastructure, including hotels, restaurants, and a variety of services, which also includes the total number of lifts, ski equipment rental points, the availability of lighting on the slopes, the seasonality of the ski center. Infrastructure for additional services is considered the presence of wellness centers, bathing complexes, and other infrastructure for recreation outside the ski season. Reference books, thematic maps of the national atlas of Belarus, cartographic and reference sources on the official websites of the state institution «Republican center for hydrometeorology, control of radioactive contamination and environmental monitoring» (rad.org.by, 2023), as well as ski centers and resorts (logoisk.by, 2021; silichy.by, 2023; rau.by, 2023; westa.by, 2023; sdolina.by, 2023; yago.by, 2023; www.ski.ru, 2023), have been used during conducting the research.

3. **Results and Discussion**

The pronounced geographical unevenness in the placement of ski tourism facilities on the territory of the Republic of Belarus is due to a combination of landscape-orographic and socio-economic factors. All ski resorts are located in the hills. The concentration of ski centers is in the central part of the Minsk Highlands, where Silichi, Logoisk, Raubichi, Solnechnaya Dolina, Yakutskie Mountains, and Westa are located. Hilly-Moraine erosional and Kame-Moraine landscapes with large-hill relief are widespread in this area, with the exception of the «Sunny Valley», which is located within the boundaries of small-hilly relief. The absolute marks are from 250 to 345 m, the vertical dismemberment of the natural relief in the area of the centers «Logoisk», «Raubichi», «Silichi», «Solnechnaya Dolina» is 30-20 m / km2, and in the area of the centers «Yakutsk mountains», "Westa" decreases to 20-15 m/km2 (National Atlas of the Republic of Belarus, 2002). Taking into account the artificially created relief, the largest differences in altitude indicated on the official websites of the centers are 100 m in Silichi Center, 80 m in Logoisk Center, 60 m in the Yakut Mountains, and 60 m in Solnechnaya Dolina and «Westa» - about 40 m.

The Mozyr ski center is located in the southeast of the country and is characterized by the fact that in terms of physical and geographical conditions, it is located within the borders of Belarusian Polesia, a region characterized by flat marshy lowlands. However, the center itself was created within the boundaries of the Mozyr Plateau with a medium-hilly relief of a hilly, morainic and erosive landscape. Despite the low absolute values of - 220 m, the vertical dismemberment here reaches 20 m / km2, the height difference on the tracks is 35 m.

In the north-eastern part of the Republic of Belarus, within the borders of the Surazh Plain, there is the ski center «Ruba». The landscape and orographic conditions for the development of ski tourism are given here by the considerable local roughness on the high bank of the western

Dvina valley, the vertical dismemberment is about 10 m/km^2, the height difference on the slopes is 40 m (National Atlas of the Republic of Belarus; http://hotel- pripyat.by).

The climatic conditions throughout the country, characterized by a temperate continental climate with mild and humid winters, are quite favorable for the development of winter recreation. The meteorological elements were analyzed on the basis of the weather stations located near the ski tourism centers in Vitebsk, Minsk, and Mozyr (Table 2). The snow cover forms in November and the stable snow cover lasts for at least one month in December. The duration of the season for all ski centers covers the period December-March, in some years the season can be extended to the first decade of April. Climatic resources for ski tourism on the territory of the Republic of Belarus in winter show territorial differences. The height of snow cover depends on the amount of solid precipitation and air temperature during the period of snow accumulation. The average snow depth in the Vitebsk region is 18.9 cm, in the Minsk Upland region - 13.3 cm, and in Mozyr it drops to 11.3 cm. From north to south the amount of winter precipitation decreases, and winter air temperatures in February change from -0.6 ^{0}C in Vitebsk and -0.2^{0}C in Minsk to +0.7^{0}C in Mozyr. The unfavorable meteorological conditions for the activity of ski centers include the days with snowstorms, the number of which naturally decreases from north to south.

Table 2. Climatic indicators in the areas where the ski centers of Belarus are located

Indicators	Weather stations (^{0}C)		
	Vitebsk	Minsk	Mozyr
Average air temperature ^{0}C January February	-6.0 -0.6	-5.1 -0.2	-4.6 +0.7
Precipitation for November-February, mm medium maximum	58.0 73.5	40.9 47.5	38.3 64.7
Snow cover height for November-February, cm medium maximum	18.9 32.0	13.3 26.0	11.1 22.0
The number of days with snowstorms	>25	20	<15

(according to the State Institution «Republican enter for hydrometeorology, control of radioactive contamination and environmental monitoring»)

Depending on the local landscape and climatic conditions, the activity of ski centers is most favorable in the central part of Belarus on the territory of the Minsk Highlands, where the main ski centers are located. In the areas of Ruba and Mozyr objects the natural conditions are less favorable for the formation of large ski centers. Taking into account the orientation of the country's ski centers towards domestic tourism, the main socio-economic indicator that determines the advantageousness of their territorial location is the distance to major cities. The optimal distance from the city is no more than 30 minutes, taking into account the type of road and speed limits. From this point of view, ski centers are divided into those located within the city limits - «Solnechnaya Dolina» (within the city of Minsk), «Mozyr» (within the city of Mozyr). These centers fully rely on the city infrastructure, but their capacity is limited by the size of the place.

Large ski centers are located mainly within 30-40 minutes from Minsk along the highways of national and international importance. They are the centers «Raubichi» (travel time 34 minutes, distance from Minsk 26 km), «Silichi» (respectively 36 minutes and 38 km), «Logoisk» (respectively 41 minutes and 39 km) located to the north of Minsk, in the southern direction from Minsk there is a center «Westa» (respectively 37 minutes and 39 km). The location of the Yakutskie mountains center is less favorable (respectively 54 minutes and 48 km). The location of the ski center «Ruba» is also favorable (20 minutes and 17.4 km to Vitebsk). A winter sports cluster has formed north of Minsk, based on two of the country's leading ski centers - Silichi and Logoisk, where national skiing competitions are held, and the Raubichi biathlon center, which is known as a center for Olympic training in winter sports and hosts international competitions in biathlon and freestyle. As can be seen from the data in Table 3, the most comfortable conditions for active mass ski tourism have been created in the centers «Silichi» and «Logoisk». The slopes here are the longest (4000-5000 m) and are characterized by the presence of slopes of difficulty «green», «blue» and «red» according to the international classification, snow parks, and springboards of increased complexity, whose characteristics meet international standards.

Table 3. Special services of the ski centers of Belarus

Ski center official website	Ski tracks				Additional services of winter activities
	Number	Total length of tracks (m)	Level of tracks complexity	Additional tracks	
«Silichi» https://silichy.by	10	4090	for beginners, easy, medium	extreme park (snowpark, springboards, half-pipe)	skating ring, snow tubing, sledging
«Logoisk» https://logoisk.by	5	5000	for beginners, easy, medium	snowboarding	roller ski track, snow tubing
«Raubichi» http://rau.by	-	-	-	springboards, freestyle zones	biathlon tracks, cross-country ski trail, ice ring
«Solnechnaya dolina» http://sdolina.by	2	350	for beginners, easy	extreme park (snowpark, snowboard park)	attraction of sledge-rail track, snow tubing
«Westa» https://westa.by	3	749	for beginners, easy		cross-country ski trail, snow tubing
«Yakutskie mountains» https://yago.by	1	480	easy	snowboarding	cross-country ski trail, snow tubing
«Ruba» https://probelarus.by/catalog/recreational/gornolyzhnye-kurorty/gornolyzhnyy-centr-ruba.html	4	900	for beginners, easy	snowboarding	snow tubing
«Mozyr» https://www.ski.ru/az/resort/395	2	420	for beginners, easy	snowboarding	sledge track toboggan, ice ring

(compiled by the authors according to the data of the official websites of the ski centers)

The centers Silichi, Logoisk, Raubichi, which are national ski and biathlon centers, are characterized by a good supply of specialized and basic infrastructure and a range of additional services. In terms of development and quality of services offered, these centers meet international standards and are oriented not only to domestic but also to international tourism (Figure 2).

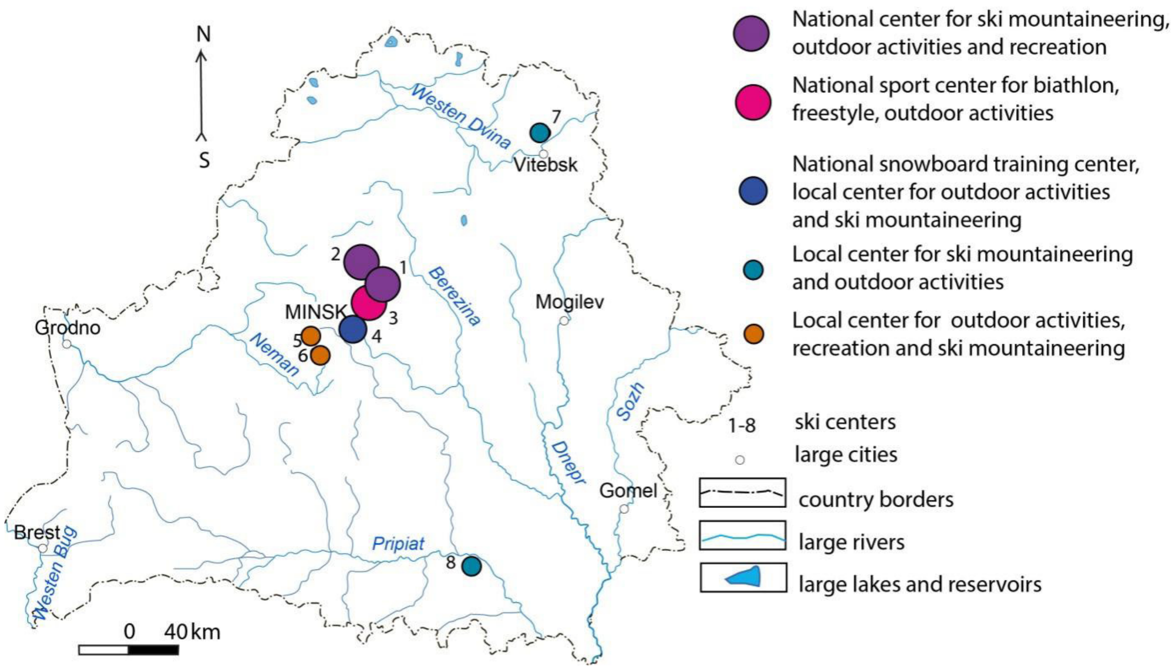


Figure 2. Specialization of ski centers in Belarus
1-8 the numbers of ski centers corresponding Figure 1

The sport and training concept is an important part of most ski centers. The centers «Ruba», «Mozyr» and «Solnechnaya Dolina» offer training groups for ski mountaineering, freestyle, and snowboarding. The ski centers «Solnechnaya Dolina», «Ruba», «Mozyr» are focused on active recreation of the local population due to their location in the cities or in their immediate vicinity. At the same time, the center «Solnechnaya Dolina» is intended for the mass recreation of Minsk residents and has a unique simulator for training of the national snowboard team.

The recreational orientation is typical for the Yakutskie mountains and the centers of Westa, where the ski slopes can be considered as an additional offer for active recreation (Table 4).

Table 4. Infrastructure of the ski centers in Belarus

Ski center	Specialized infrastructure			Basic infrastructure		Additional services
	lifts, units	inventory rental	track lighting	catering	living	
«Silichi»	4	+	+	restaurant, cafes	hotel, guest houses	bath complex, health complex
«Logoisk»	2	+	+	restaurant, bar	hotel, guest houses	bath complex, gym
«Raubichi»	2	+	+	restaurant, cafes	hotel, guest houses	bath complex, gym

«Solnechnaya Dolina»	1	+	+	restaurant, cafes	-	gym, snowboard trainer
«Westa»	2	+	+	restaurant, cafes, bar	hotel, sanatorium	SPA center
«Yakutskie mountains»	1	+	+	cafe	-	corporate entertainment events
«Ruba»	2	+	+	-	-	-
«Mozyr»	1	+	+	cafe	-	-

(compiled by the authors according to the data of the official websites of the ski centers)

As shown in Table 4, the basic infrastructure in the country's ski centers shows considerable differences. Standard living conditions in hotels and guesthouses are typical for the centers «Logoisk», «Silichi», «Raubichi». Hotel rooms are equipped with a bathroom, shower, TV, air conditioning, refrigerator, and free Wi-Fi access. The hotels have restaurants, cafes, and saunas. The guest houses are also equipped with bathrooms, refrigerators, TVs, showers, and Wi-Fi, which meets international requirements for centers of this level. The Raubichi complex has the largest number of rooms - 3 hotels with 283 beds and 15 guest houses with 10 beds each (Table 5).

Table 5. Means of accommodation and catering in the ski centers of Belarus

Ski center	Hotels, guest houses		Restaurants, cafes, bars	
	number, units	capacit, beds	number, units	capacity, person
«Silichi»	Hotel - 1 Guest houses - 12	90 28	Restaurants- 3, cafes - 2	300
«Logoisk»	Hotel - 1 Guest houses - 1	50 48	Restaurant- 1, outdoor terrace - 1	350 200
«Raubichi»	Hotels - 3 Guest houses - 15	283 150	Restaurants- 2, cafes - 3	300
«Westa»	Hotel - 1 Sanatorium- 1	188 375	Restaurants, cafes, bars, verandas	850
«Yakutskie mountains»	-	-	cafe, open terrace, gazebos	80 500
«Solnechnaya Dolina»	-	-	cafe, open terrace, gazebos	120 135
«Mozyr»	Hotel «Pripyat» of the town	246	Restaurants, cafe, bars	350
«Ruba»	-	-	-	-

(compiled by the authors according to the data of the official websites of the ski centers)

There are most differences in post-skiing services, reflecting each center's individual approach to attracting tourists. In Silichi there is a wellness center with health-promoting phyto-procedures, breathing exercises, urethral gymnastics, Nordic walking, halotherapy and amber therapy, and a steam bath with peeling. Sports activities include cycling, cable car, trolley track, tennis, volleyball, basketball, and mini soccer.

In the centers «Logoisk» and «Raubichi» such services are less varied, are less advertised on the market, and are mainly associated with the possibility of visiting saunas or bathing complexes. On the territory of the Raubichi sports complex, there is a medical and rehabilitative center.

Solnechnaya Dolina does not have its own accommodation facilities, as the center is oriented to the accommodation infrastructure of the city of Minsk. Catering is provided by a café in alpine chalet style with wooden and wrought iron elements in the interior. Guests have at their disposal 3 floors, a fireplace hall (with a capacity of 45 people) and a hunting hall (75 people). In the center of Mozyr, which is also located within the city, tourists are accommodated in the city hotel Pripyat, which has 194 rooms with 246 beds (http://hotel-pripyat.by). Ruba center does not provide accommodation and catering during the winter season but is aimed at local lovers of skiing vacations in Vitebsk. In the center of the Yakutian Mountains there is only one cafe with 80 seats, which operates all year round, while the main services are focused on corporate recreation in the summer season upon prior request. Thus, skiing here is not a specialized direction.

The center «Westa» is characterized by a unique location and positions itself as a multifunctional complex for a variety of recreational activities. The ski slopes are a small part of the promoted sports orientation and active recreation. In addition, Westa offers the rental of bicycles, roller skates, boats, and catamarans, there are gymnasiums and sports halls, tennis courts, volleyball and soccer fields, a barbecue area, and the aqua zone of the center consists of three swimming pools. The wellness center, located in Westa, offers more than 100 wellness treatments, including spa treatments, massages, saunas, stone therapy, and body wraps. Accommodation facilities include a 188-bed hotel and a 375-bed sanatorium, and the entire complex receives more than 5.000 guests per year.

The geographical location of ski centers in the Republic of Belarus is inconsistent. Most of them are located within the sphere of influence of the city of Minsk, only the ski resort «Ruba» is located near the city of Vitebsk. The conducted analysis has shown that Silichi, Logoisk, and Solnechnaya Dolina are developing steadily among the ski centers. It is promising to create ski centers in each regional city of the Republic of Belarus. Taking into account the modern technologies of artificial covering, ski centers can be opened in the cities of Gomel and Brest. The cities of Grodno and Mogilev have favorable scenic-orographic and climatic conditions for opening ski centers with open slopes. The population in the regional centers, which is 340-500 thousand people each, creates favorable conditions for the formation of a sustainable tourist demand for skiing vacations.

4. **Conclusion**

The analysis of literary sources has shown that it is useful to study ski tourism in mountainous and flat areas as two different classes of objects, which are not comparable in terms of landscape and orographic conditions. Ski resorts with developed infrastructure are located in the mountains, especially in the Alpine region. The Alpine mountains and the surrounding regions with their unique "ecosystem", "climate", "topography", "landscape", and "seasonal cycle" determine the ski tourism potential and the activities to be realized. Among the most important factors influencing the success of mountain destinations in developing their capacity for ski tourism are the amount of snow, the suitability of the terrain for sports activities, and architecturally attractive infrastructure (Undzhieva, 2020). Of the 1945 ski resorts worldwide, 39% are located in Central Europe (Switzerland, northern Italy, southeastern France, Austria, and southern Germany), where the Alps are located. On the European continent, there are only two countries with more than 200 ski resorts and more than 4 ski lifts: France and Italy. Although there are many ski resorts in Germany, most of them are small ski resorts (Vanat, 2022). Overall, it can be said that the developed destinations in the Alps and its sub-regions are characterized by a high level of equipment.

The peculiarity of the ski centers in the lowland countries lies in the overall development of winter recreation. Some of the prominent features of Denmark, Lithuania, Latvia, the Netherlands and Estonia, the countries among the lowland states within Europe, for ski tourism and the recreational activities they offer are as follows:

Denmark, one of the flattest countries in the world, which includes Greenland, the largest island in the world, has a total of 5 ski resorts. These are Hedeland, Kolding, Bornholm, and Nuuk and Angmassalik in Greenland. These ski resorts have limited (few) covered ski facilities, T-bar lifts, chair lifts and limited vertical downhill skiing. In addition, in Greenland, where snow is plentiful, skiers have the option of heliskiing, i.e., being dropped into the mountains by helicopter and skiing 2000 meters vertically down to sea level (Vanat, 2022).

The highest point in Lithuania is only 294 meters above sea level. Snowfall usually occurs between September and February. The country has 11 ski resorts with 5 or more lifts. The Liepkalnis ski resort in the capital city of Vilnius has a total of 10 slopes 2.6 km long, 10 lifts and an artificial snowmaking system. It is planned to build a symbolic building complex in this area to make it a center for recreational activities. For several years, Lithuanians have been practicing cross-country and night skiing in hilly areas several hundred meters high, about 80 kilometers from the capital, with 4 or fewer lifts and several lifts (Vanat, 2022).

The highest point in Latvia, another Baltic republic, is 311 meters above sea level. An average of 800,000 skiers ski or snowboard at 12 resorts with 5 or more lifts. The ski resorts include Riekstukalns (8 slopes), Milzkalns (8 lifts), Zviedru Cepure (summer toboggan run), Ventspils-Lemberga Huts amusement park (3 lifts, Snowmaking and adventure park in summer), as well as Sigulda and its surroundings (6 ski resorts, entertainment centers), Zagarkalns and Ozonlkalns near Cesis (chairlift, snowmaking, snowpark, beginner and children's area, ski schools and cafes). In these areas it is possible to practice alpine skiing, cross-country skiing and/or night skiing (Vanat, 2022).

The Netherlands is one of the countries with many ski halls, but no ski resorts, only ski domes. It is known that the country has a ski culture and about 1 million people travel internationally to participate in ski tourism (Vanat, 2022). Estonia offers a wide range of opportunities for winter sports enthusiasts due to its climatic conditions. With 9 ski resorts with 5 or more lifts, cross-country skiing and snowshoeing are much more popular than alpine skiing. Downhill skiing, snowboarding and night skiing are available at the resorts. Otepää, where the World Cup stage in Cross-Country skiing events is held, is called the «winter capital» of Estonia. To sum up, the Baltic republics and Belarus have many similarities in terms of geography and natural features, as well as winter tourism and skiing.

The Republic of Belarus differs from other European lowland countries in landscape and climatic characteristics (the maximum absolute altitude is 345 m, the average air temperature in January varies from -4.60 °C in Mozyr to -6.00 °C in Vitebsk, the average snow depth varies from 11.3 cm in Mozyr to 18.9 cm in the Vitebsk region), which favors the development of ski tourism in the country. The analysis of the conditions for the development of this type of tourism has shown that they are unevenly distributed over the territory of Belarus, with the highest concentration in the zone of influence of the capital Minsk. The city has a professionally organized transport network that ensures accessibility. Minsk is a thriving tourist destination with a growing number of international airlines, newly established routes, and direct flights from all over Europe.

Of national importance is the ski resort «Silichi-Logoisk», which is characterized by the largest number of slopes (10 and 5) and their length (4090 and 5000 m), including three levels of difficulty. Tourists are accommodated in hotels and guest houses (the total capacity for two centers is 261 beds), and they are provided with a varied menu in four restaurants and two cafes (for 650 people). The wellness center is used to attract tourists to Silichi. In terms of the development and quality of services offered, the Raubichi center stands out, with a developed basic infrastructure (three hotels with 283 beds and 15 guest houses with 10 beds each) and the presence of a medical rehabilitation center.

The conducted comparative analysis has shown that the development of ski centers in Belarus combines sports orientation with the popularization of amateur skiing, snowboarding, and tubing. Ski and snowboard slopes develop most actively in ski centers. The ski centers also organize cross-country ski trails, ice skating rinks, and toboggan runs. All centers have training slopes, and the development of infrastructure corresponds to the capacity of the centers. The conducted analysis has shown that Silichi and Logoisk are experiencing a steady development among ski centers. The development of ski tourism in the center «Yakutskie Mountains» is problematic due to the lack of winter accommodation, and in the center «Westa» ski tourism is considered only one of the many types of outdoor activities, while the ski slopes are not open every season. The development of Ruba and Mozyr ski centers into commercially successful projects requires investment in their infrastructure and the obligatory opening of a café for visitors. The positive experience of developing ski centers in flat areas can be useful for other countries with similar landscapes and climate conditions.

References

1. Alexandris K., Kouthouris C., Meligdis A. Increasing customer' loyalty in a ski resort: The contribution of place attachment and service quality // International Journal of Contemporary Hospitality Management. – 2006. – Vol. 18. – P. 414-425. https://doi.org/10.1108/ 09596110610673547

2. Bausch T., Gartner W. Winter tourism in the European Alps: Is a new paradigm needed? // Journal of Outdoor Recreation and Tourism. – 2020. – Vol. 31.https://doi.org/10.1016/j.jort.2020.100297

3. Bausch T., Humpe A., & Gossling S. Does climate change influence guest loyalty at alpine winter destinations? // Sustainability. – 2019. – Vol. 11. https://doi.org/10.3390/su11154233.

4. Bichler B., Pikkemaat B. Winter sports tourism to urban destinations: Identifying potential and comparing motivational differences across skier groups. // Journal of Outdoor Recreation and Tourism. – 2021. – Vol. 36. https://doi.org/10.1016/j.jort.2021.100420

5. Cihangir Çamur K., Şeremet M., Cihangir E., Özer B. Kış Destinasyonlarında Başarı için Stratejik Planlama: Kayseri-Erciyes Kayak Merkezi Hikayesinden Çıkarımlar. In A. Ünal (Eds.) (2021) // Destinasyon Konulu Güncel Araştırmalar. – 2021. – Vol. 1. – P. 93-507.

6. Dickson T. J., Faulks P. Exploring overseas snowsports participation by Australian skiers and snowboaders // Tourism Review. – 2007. – Vol. 62. – P. 7-14. https://doi.org/10.1108/16605370780000315.

7. Falk M.,Hagsten, E. Importance of early snowfall for Swedish ski resorts: Evidence based on monthly data // Tourism Management. – 2016. – Vol. 53. – P. 61-73. https://doi.org/10.1016/j.tourman.2015.09.002

8. Faullant R., Matzler K., Füller J. The impact of satisfaction and image on loyalty: The case of Alphine ski resorts // Managing Service Quality: An International Journal. – 2008. – Vol. 18. – P. 163-178. https://doi.org/10.1108/09604520810859210

9. Hallmann K., Zehrer A., Müller S. Perceived destination image: An image model for a winter sports destination and its effect on intention to revisit // Journal of Travel Research. – 2015. – Vol. 54. – P. 94-106. https://psycnet.apa.org/doi/10.1177/0047287513513161

10. Haugom E., Malasevska I. The relative importance of ski resort- and weather- related characteristics when going alpine skiing // Cogent Social Sciences. – 2019. – Vol. 5. https://doi.org/10.1080/ 23311886.2019.1681246.

11. He X., Luo J. M. Relationship among travel motivation, satisfaction and revisit intention of skiers: A case study on the tourists of urumqi silk road ski resort // Administrative Sciences. – 2020. – Vol. 10. https://doi.org/10.3390/admsci10030056

12. Karasar N. Bilimselaraştırmayöntemi // Ankara: Nobel AkademikYayıncılık. – 2008.

13. Klenosky D.B., Gengler C.E., Mulvey M.S. Understanding the factors influencing ski destination choice: A means-end analytic approach // Journal of Leisure Research. – 1993. – Vol. 25. – P. 362-379. https://doi.org/10.1080/00222216.1993.11969934

14. KonuH., LaukkanenT., Komppula R. Using ski destination choice criteria to segment Finnish ski resort customers // Tourism Management. – 2011. – Vol.32. – P. 1096-1105. https://doi.org/10.1016/j.tourman.2010.09.010

15. Кропинова Е.Г., Митрофанова А.В. Региональный туристический кластер как туристско-рекреационная система регионального уровня // Региональные исследования. – 2011. – №1. – С. 40-46.

16. Manap Davras G. Classification of winter tourism destination attributes according to three factor theory of customer satisfaction // Journal of Quality Assurance in Hospitality & Tourism. – 2021. – Vol. 22. – P. 496-516. https://doi.org/10.1080/1528008X.2020.1810195

17. Matzler K., Siller H.J. Linking travel motivations with perception of destinations:The case youth travellers in Alphine summer and winter tourism // Tourism Review. – 2003. – Vol. 58. – P. 6-11. https://doi.org/10.1108/eb058418.

18. Miragaia D.A.M., Martins M.A.B. Mix between satisfaction and attributesdestination choice: A segmentation criterion to understand the ski resorts consumers // International Journal of Tourism Research. – 2015. – Vol. 17. – P. 313-324. https://doi.org/10.1002/ jtr.2009

19. Mladenovic D., Jovanovic S.V. The research of skier motivations and factors influencing the choice of a ski destination // Facta Universitatis-Series: Physical Education and Sport. – 2019. – Vol 43. https://doi.org/10.22190/FUPES180913007M

20. Mursalov M. Bir turistik ürün çeşitlendirmesi olarak kış turizmi ve kış turizmi açısından Azerbaycan'ın Guba-Haçmaz turizm bölgesinin arz potansiyeli // Unpublished Master's Thesis, Dokuz Eylül Üniversitesi, SBE. - 2019

21. Национальный атлас Республики Беларусь. Morphometric maps. Scale 1: 3,000,000. - Minsk, Belkartografiya. P. 64.

22. Панченко П.В. Пути совершенствования горнолыжных курортов юга России // Вестник Волгоградского государственного архитектурно-строительного университета. Серия: Строительство-архитектура. – 2011. – Т. 23. – С. 156-161.

23. Pirozhnik I.I. Tourist ski resorts of the Logoisk Upland - A new direction of nature management // Land of Belarus. – 2009. – Vol. 4. – P. 42-48.

24. Середина Е.В. Изменения концепции развития спортивного туризма на примере российских горнолыжных центров // Вестник Российской международной академии туризма. – 2016. – Vol. 3. – P. 122-127.

25. Shidov A.Kh., Efendiev G.A.,Gedgafova I.Y. Criteria for the formation of regional clusters on the example of the Kabardino-Balkarian Republic // Journal Economy and Business. – 2019. – Vol. 12. – P. 152-154. https://doi.org/10/24411|2411-0405-2019-11501

26. Sun H., Xie X., Gao J., Zhang L. Influencing factors of destination choice of ski tourism enthusiasts: A means-end chain analytical perspective // Front. Psychol. – 2022. – Vol.13. https://doi.org/10.3389/fpsyg.2022.1017961

27. Tang C.-H., Jang S. C. Weather risk management in ski resorts: Financial hedging and geographical diversification // International Journal of HospitalityManagement. – 2011. – Vol.30. – P. 301-311. https://doi.org/10.1016/j.ijhm.2010.09.012

28. Tikunov V. S. A method for classifying geographic complexes to create scorecards // Bulletin of Moscow University, GeographicalSeries. – 1985. – Vol. 4. – P. 28-36.

29. Крапивина М.Г., Тикунова И.Н. Классификация горнолыжных курортов Европы//Наука. Инновации. Технологии – 2014. – Т. 3. -С.162-173.

30. Unbehan W., Probstl U., Haider W. (2008). Trends in winter sport tourism: Challenges for the future // Tourism Review. – 2008. – Vol.63. – P. 36-47.https://doi.org/10.1108/16605370810861035

31. Undzhieva M. The specifics of the offer of a mountain destination for ski tourism. Paper presented at the Anniversary Scientific Conference with International Participation Tourism and Connectivity 2020, University publishing house «Science and Economics», University of Economics - Varna, 2020. – P. 632-640.

32. Vanat L. The 2019 InternationalReport on Mountain &Snow Tourism:Overview of the key industry figures for ski resorts, (12th edition), 2020. – P. 220.

33. Vanat L. International Report on Snow &Mountain tourism: Overview of the key industry figures for ski resorts (Report No. 10), 2022. – P. 241.

34. Weib P., Bentlage J. Environmental managementsystem and certification // Uppsala: The Baltic University Press. – 2006.

35. Зайцев В.М., Петрусивеч О.Н. Горнолыжный туризм как фактор повышения конкурентноспособности туристического комплекса Республики Беларусь// Беларусь в современном мире: материалы 10 международной научной конференции, посвященной 90-летию образования Белорусского государственного университета. – Минск, 2011. – С. 192-193.

36. Зырянов А.И. Теория и методология рекреационной географии. Перм.гос. нац. исслед. университет.– 2021.

37. Зырянов А.И., Шилова Д.И. Структура и размещение сети горнолыжных комплексов Большого Урала // Известия Российской Академии наук. Серия географическая.–2020.–Т.2.–С.272-281. https://doi.org/10.31857/S2587556620020181

Н.В. Гагина, Е.И. Галай, А.Е. Яротов
Белорусский государственный университет, Минск, Беларусь

Основные особенности развития горнолыжного туризма на территории Республики Беларусь

Абстракт. Лыжный туризм представляет собой широко распространенную форму туризма, связанную с активными занятиями на снегу, и пользуется популярностью во всем мире. Эта форма туризма обычно ассоциируется с сельской местностью, однако также предлагается и в городских районах, в помещениях и на открытом воздухе, связанных со спортом. В данном исследовании были изучены основные особенности развития горнолыжного туризма в Республике Беларусь, которая характеризуется равнинным рельефом. Были проанализированы ландшафтно-климатические и социально-экономические условия в восьми горнолыжных центрах страны, а также рассмотрена их специализация в предоставлении туристических продуктов и развитии инфраструктуры. Было отмечено, что развитие горнолыжных центров связано с ростом популярности активного отдыха и любительского катания на лыжах. В результате исследования было установлено, что горнолыжный туризм следует рассматривать отдельно в горных и равнинных районах, не проводя сравнений между ними по ландшафтным и орографическим условиям. В итоге исследования становится ясно, что горнолыжный туризм в Беларуси распределен неравномерно, с наибольшей концентрацией в зоне влияния столицы Минска.

Ключевые слова: горнолыжный туризм, Республика Беларусь, зимний отдых.

Н.В. Гагина, Е.И. Галай, А.Е. Яротов
Беларусь мемлекеттік университеті, Минск, Беларусь

Беларусь Республикасы аумағындағы тау шаңғы туризмінің дамуының негізгі ерекшеліктері

Аңдатпа. Шаңғы туризмі – қарлы туризмнің кең тараған және бүкіл әлемге танымал түрі. Туризмнің бұл түрі тек ауылдық жерлерде ғана емес, қалалық жерлерде, спортқа арналған жабық және ашық алаңдар да өткізіле береді. Осы зерттеу тегіс жер бедерімен сипатталатын Беларусь Республикасындағы тау-шаңғы туризмінің негізгі даму ерекшеліктерін қарастырады. Елдің сегіз түрлі шаңғы орталығының ландшафттық-климаттық және әлеуметтік-экономикалық жағдайлары сарапталып, олардың туристік өніммен қамтамасыз ете алуы және инфрақұрылымды дамытуға мамандануы зерттелді. Шаңғы орталықтарының дамуы әуесқой шаңғы спортының танымалдығы артуына байланысты боп шықты. Тау-шаңғы туризмін таулы және жазық аймақтарда зерттегенде осы аймақтардың ландшафттық және орографиялық жағдайларын салыстырмай, жеке-жеке қарастыру керектігі анықталды. Зерттеу нәтежиесінде Беларусьте тау шаңғы туризмі біркелкі тарамаған, ең көп шоғырланған орталығы халық тығыздығы жоғары Минск астанасының аумағы екені белгелі болды.

Түйін сөздер: шаңғы туризмі, Беларусь Республикасы, қысқы демалыстар.

References

1. Alexandris K., Kouthouris C., Meligdis A. Increasing customer' loyalty in a ski resort: The contribution of place attachment and service quality. International Journal of Contemporary Hospitality Management, 18, 414-425(2006). DOI:10.1108/ 09596110610673547
2. Bausch T., Gartner W. Winter tourism in the European Alps: Is a new paradigm needed? Journal of Outdoor Recreation and Tourism, 2020, Vol. 31. DOI: 10.1016/j.jort.2020.100297
3. Bausch, T., Humpe, A., & Gossling, S. Does climate change influence guest loyalty at alpine winter destinations? Sustainability, 2019, Vol. 11. DOI:10.3390/su11154233.
4. Bichler B., Pikkemaat B. Winter sports tourism to urban destinations: Identifying potential and comparing motivational differences across skier groups. Journal of Outdoor Recreation and Tourism, 2021, Vol. 36. DOI:10.1016/j.jort.2021.100420
5. Cihangir Çamur K., Şeremet M., Cihangir E., Özer, B. Kış Destinasyonlarında Başarı için Stratejik Planlama: Kayseri-Erciyes Kayak Merkezi Hikayesinden Çıkarımlar. In A. Ünal (Eds.) (2021), Destinasyon

Konulu Güncel Araştırmalar[Strategic Planning for Success in Winter Destinations: Inferences from the Kayseri-Erciyes Ski Resort Story. In A. Ünal (Eds.) (2021) // Current Research on Destination], 1, 93-507(2021).

6. Dickson T. J., Faulks P. Exploring overseas snowsports participation by Australian skiers and snowboaders, Tourism Review, 62, 7-14(2007). DOI:10.1108/16605370780000315

7. Falk M., Hagsten, E. Importance of early snowfall for Swedish ski resorts: Evidence based on monthly data. Tourism Management, 53, 61-73(2016). DOI:10.1016/j.tourman.2015.09.002

8. Faullant R., Matzler K., Füller J. The impact of satisfaction and image on loyalty: The case of Alphine ski resorts. Managing Service Quality: An International Journal, 18,163-178(2008). DOI:10.1108/09604520810859210

9. Hallmann K., Zehrer A., Muller S. Perceived destination image: An image model for a winter sports destination and its effect on intention to revisit. Journal of Travel Research, 54, 94-106(2015). DOI:10.1177/0047287513513161

10. Haugom E., Malasevska I. The relative importance of ski resort- and weather-related characteristics when going alpine skiing, Cogent Social Sciences, 2019, Vol. 5. DOI:10.1080/23311886.2019.1681246.

11. He X., Luo J. M. Relationship among travel motivation, satisfaction and revisit intention of skiers: A case study on the tourists of urumqi silk road ski resort. Administrative Sciences, 2020, Vol. 10. https://doi.org/10.3390/admsci10030056

12. Karasar N. Bilimselaraştırmayöntemi [Scientific Research Method] Ankara: Nobel AkademikYayıncılık, 2008.

13. Klenosky D.B., Gengler C. E., Mulvey M. S. Understanding the factors influencing ski destination choice: A means-end analytic approach. Journal of Leisure Research, 25, 362-379(1993). DOI:10.1080/00222216.1993.11969934

14. KonuH., LaukkanenT., Komppula R. Using ski destination choice criteria to segment Finnish ski resort customers. Tourism Management, 32,1096-1105(2011). DOI:10.1016/j.tourman.2010.09.010

15. Kropinova E.G., MitrofanovaA. V. Regional'nyj turisticheskij klaster kak turistsko-rekreacionnaya sistema regional'nogo urovnya [Regional tourist cluster as a tourist and recreational system of the regional level]. Regional'nye issledovaniya [Regional studies], 1(31), 40-46 (2011). [in Russian]

16. Manap Davras G. Classification of winter tourism destination attributes according to three factor theory of customer satisfaction. Journal of Quality Assurance in Hospitality & Tourism, 22,496-516(2021). DOI:10.1080/1528008X.2020.1810195

17. Matzler K., SillerH. J. Linking travel motivations with perception of destinations:The case youth travellers in Alphine summer and winter tourism, Tourism Review, 58, 6-11(2003). DOI:10.1108/eb058418.

18. Miragaia D.A.M., Martins M.A.B. Mix between satisfaction and attributesdestination choice: A segmentation criterion to understand the ski resorts consumers. International Journal of Tourism Research,17, 313-324(2015). DOI:10.1002/ jtr.2009

19. Mladenovic D., Jovanovic S.V. The research of skier motivations and factors influencing the choice of a ski destination. Facta Universitatis-Series: Physical Education and Sport, 2019, Vol 43. https://doi.org/10.22190/FUPES180913007M

20. Mursalov M. Bir turistik ürün çeşitlendirmesi olarak kış turizmi ve kış turizmi açısından Azerbaycan'ın Guba-Haçmaz turizm bölgesinin arz potansiyeli.[Winter tourism as a touristic product diversification and the supply potential of the Guba-Khachmaz tourism region of Azerbaijan in terms of winter tourism] Unpublished Master's Thesis, Dokuz Eylül Üniversitesi, SBE, 2019

21. Nacional'nyj atlas Respubliki Belarus' [National Atlas of the Republic of Belarus], Morphometric maps. Scale 1: 3,000,000. Minsk, Belkartografiya, 292(2002). [in Russian]

22. Panchenko P. V. Puti sovershenstvovaniya gornolyzhnyh kompleksov yuga Rossii [Ways to improve ski resorts in the South of Russia]. Vestnik Volgogr. gos. arhit.-stroit. un-ta. Ser.: Str-voiarhit [Bulletin of the Volgograd State University of Architecture and Civil Engineering Series: Construction and Architecture], 23(42), 156-161 (2011). [in Russian]

23. PirozhnikI.I. Turisticheskie gornolyzhnye kompleksy Logojskoj vozvyshennosti – novoe napravlenie prirodopol'zovaniya [Tourist ski resorts of the Logoisk Upland - A new direction of nature management]. Zemlya Belarusi [Land of Belarus], 4, 42-48 (2009).[in Russian]

24. SeredinaE.V. Izmenenie koncepcii razvitiya sportivnogo turizma na primere rossijskih gornolyzhnyh centrov [Changing the concept of sports tourism development on the example of Russian ski centers]. Vestnik Rossijskoj mezhdunarodnoj akademii turizma [Bulletin of the Russian International Academy of Tourism], 3, 122-127 (2016). [in Russian]

25. Shidov A.Kh., Efendiev G.A.,GedgafovaI.Y.Criteria for the formation of regional clusters on the example of the Kabardino-Balkarian Republic. Journal Economy and Business, 12, 152-154(2019). DOI:10/24411|2411-0405-2019-11501

26. Sun H., Xie X., Gao J., Zhang L. Influencing factors of destination choice of ski tourism enthusiasts: A means-end chain analytical perspective. Front. Psychol, 2022, Vol.13. DOI:10.3389/fpsyg.2022.1017961

27. Tang C.-H., Jang S.C. Weather risk management in ski resorts: Financial hedging and geographical diversification // International Journal of Hospitality Management, 30, 301-311(2011). DOI:10.1016/j.ijhm.2010.09.012

28. Tikunov V.S. A method for classifying geographic complexes to create scorecards. Bulletin of Moscow University. Geographical Series, 4,28-36(1985)

29. Krapivina M.G., Tikunova I.N. Klassifikaciya gornolyzhnyh kurortov Evropy [Classification of ski resorts in Europe]. Nauka. Innovacii. Tekhnologii [The science. Innovation. Technologies. EarthScience], 3, 162-173 (2014). [in Russian]

30. Unbehan W., Probstl U., Haider W. Trends in winter sport tourism: Challenges for the future. Tourism Review, 63, 36-47(2008).

31. Undzhieva M. The specifics of the offer of a mountain destination for ski tourism. Paper presented at the Anniversary Scientific Conference with International Participation Tourism and Connectivity 2020, University publishing house «Science and Economics», University of Economics - Varna, 2020, P. 632-640.

32. Vanat L. The 2019 InternationalReport on Mountain &Snow Tourism:Overview of the key industry figures for ski resorts, (12th edition), 2020, P. 220.

33. Vanat L. International Report on Snow & Mountain tourism: Overview of the key industry figures for ski resorts (Report No. 10), 2022, P. 241.

34. Weib P., Bentlage J. Environmental management system and certification. Uppsala: The Baltic University Press, 2006.

35. Zajcev V.M., Petrusevich O.N. Gornolyzhnyj turizm kak factor povysheniya konkurentnosposobnosti turisticheskogo kompleksa Respubliki Belarus' [Ski tourism as a factor of increasing the competitiveness of the tourist complex]. Belarus' v sovremennom mire: materialy X Mezhdunarodnoj nauchnoj konferencii, posvyashchennoj 90-letiyu obrazovaniya Belorusskogo gosudarstvennogo universiteta, Minsk [Paper presented at the X International Scientific Conference «Belarus in the Modern World». Minsk], 192-193(2011).[in Russian]

36. Zyryanov, A.I. Teoriyai metodologiya rekreacionnoj geografii [Theory and Methodology of RecreationalGeography]. Uchebnoe posobie [Textbook].Perm. gos. nac. issled. un-t. [Perm: Perm State National Research University]. 2021. [in Russian]

37. Zyryanov A.I., SHilova D.I. Struktura i razmeshchenie seti gornolyzhnyh kompleksov Bol'shogo Urala [Structure and location of the network of ski resorts in the Great Ural]. Izvestiya Rossijskoj akademii nauk. Seriya geograficheskaya [News of the Russian Academy of Sciences. Geographic Series], 2, 272-281 (2020). DOI:10.31857/S2587556620020181. [in Russian]

Information about authors:

Gagina N. – Candidate of Geography, Associate Professor, Head of the Department of Geographical Ecology, Belarusian State University, 4 Nezavisimost str., Minsk, Republic of Belarus.

Galai E. – Candidate of Geography, Associate Professor of the Department of Geographical Ecology, Belarusian State University, 4 Nezavisimost str., Minsk, Republic of Belarus.

Yarotov A. – Candidate of Geography, Associate Professor, Department of Physical Geography of the World and Educational Technologies, Belarusian State University, 4 Nezavisimost str., Minsk, Republic of Belarus.

Гагина Н. – география ғылымдарының кандидаты, доцент, Беларусь мемлекеттік университетінің географиялық экология кафедрасының меңгерушісі, Независимост к-сі, 4, Минск, Беларусь Республикасы.

Галай Е. – география ғылымдарының кандидаты, Беларусь мемлекеттік университетінің географиялық экология кафедрасының доценті, Независимост к-сі, 4, Минск, Беларусь Республикасы.

Яротов А. – география ғылымдарының кандидаты, доцент, Әлемнің физикалық географиясы және білім беру технологиялары кафедрасы, Беларусь мемлекеттік университеті, Независимост к-сі, 4, Минск, Беларусь Республикасы.

IRSTI 39.29

S.K. Kasimgaliev[1], R. ZH. Kelinbaeva, M.K Sultanov, N.KH. Yunisbekova

Al Farabi Kazakh National University, Almaty, Kazakhstan
(Corresponding author: [1]Symbat_1997.kz@mail.ru)

Geoinformation support, analysis, evaluation and forecasting of the use of land resources of Kyzylorda region

Abstract. *Currently, the agricultural activities of almost all developed, civilized countries in the world are carried out on the basis of the design of a system of Agriculture adapted to the landscape and are actively engaged in it. In order to comprehensively substantiate this branch of Industrial Science and identify the possibilities and features of its formation in Kazakhstan, it is necessary to carry out specific research work with a high degree of truth. Therefore, in the proposed work, the best ways to use the modern Geoinformation system in order to select, recognize and analyze the agro-landscapes of the Kyzylorda region and analyze them from the point of view of Geographical Sciences were sought. Kyzylorda region is an administrative region located in the southern part of the Republic of Kazakhstan. The region is distinguished by its agriculture. Agriculture has developed in the region since ancient times. In addition, every year farmers are intensively working in the direction of changing varieties, diversifying crops.*

We can solve the main problems of our country through preliminary design work using modern technologies.

Key words: *cartography, agriculture, research method, landscapes, agrolandscapes, GIS.*

DOI: https://doi.org/10.32523/2616-6771-2023-144-3-105-118

Introduction. The terrain is widely studied and discussed on maps that have special morphometric indicators. However, the method of collecting relief information and, based on it, capturing morphometric maps in the traditional «way» requires a lot of labor and effort to use for large-scale areas.

With the development of modern science and technology, the widespread development of geoinformation systems has made it much easier to obtain quantitative data on the studied area. Therefore, an electronic image of the relief is displayed on the basis of geographic information systems with digital samples of the relief. The main requirement in the process of obtaining this information and using GIS Technologies is the adequacy and high quality of samples.

Currently, in the vast majority of frequently used GIS technologies, although many methods and techniques have been created to create a digital pattern of relief, almost all of them have some limitations and errors. In this regard, the main goal is considered to be the compilation and use of methodologies that reduce the amount of errors. Since morphometry is a scientific area of geomorphology, in order to identify and describe relief, it studies detailed numerical data about it.

He determined the history of the formation and development of the relief through his methods and methods of research, formed the main patterns and morphological foundations that determine the formation of the terrain in the study of the relief in accordance with the research direction of Science. The most important one, including the main method, is morphometric analysis. After determining the quantitative indicators of the relief using special measurements, the set of their characteristics may differ. It also depends on the purpose of morphometric research and the regional units used. The history of morphometric analysis, in principle, can be divided into three stages. Each of them was widely discussed in the work of subsequent researchers. According to G.I. Yurenkov and I.S. Shchukin, the initial stage includes work related to the compilation of methods for determining Heights, lengths, areas, complex edematous areas of the terrain. It is worth noting that all this data was achieved on the basis of the appearance of various devices. For example, as a result of the initial stage, topographic characteristics of morphometric analysis were compiled. The second stage of development of morphometry was determined in the course of analyzing the obtained quantitative data on the relief.

Among the earliest works published at the beginning of the period, one can name the works of A. Humboldt, who conducted an orometric study in the Andes at the end of the 18th century. The features of morphometric studies of that time are the comparison of simple relief shapes and geometric shapes. At the same time, the first morphometric maps and the first coefficient indicators were compiled and determined. So, in 1826, Karl Ritter introduced the concept of «compactness» (compactness) of continents, that is, the ratio of area to perimeter. These were the first attempts to describe the relief. In addition, there were many researchers who suggested different coefficients in the description of the relief.

Karl Koritzka [1], for example, proposed a new method for determining the average height of a region in 1854. A. Penk defined gypsum curves for individual regions. Among those who contributed the most to morphometric research by the middle of the 19th century was A. Penk. Although there were many successes achieved in the second period, interest in this direction subsided by the middle of the twentieth century. Although the third stage continued in the development of morphometry, it received its full place only towards the end of the twentieth century. It is characterized by an increase in morphometric research; interrelation of morphometric analysis with cartography; mathematical models of relief formed based on the morphometric analysis.

On the basis of these, a mathematical direction was born in geomorphology and a system-structural approach to the study of relief was added to morphometry. The development of cartographic and mathematical modeling led to the development and creation of morphometric thoughts, as well as the emergence and development of new computing, processing and information storage devices. During this period, much attention was paid to morphometric research, and among the scientists, it is worth noting the proposals of K. Efremov and A. I. Spiridonov to «geometrize» simple relief. One of the most valuable offers after this was A.S.Appears in the works of Devdariani. He proved that it is necessary not only to consider the relief itself, but also to take into account its development.The main idea of the third stage is to consider the relief as a zone of heights. From the point of view of theory, it is the coordinate of a given area, the function of two variables.

Materials and methods. Considering a relief as an equation can help a lot in studying and determining its properties. The same xiak at the stage of its development in this direction set the following global goals:

1) description of the object;
2) explanation of its properties;
3) track changes;
4) monitoring the situation;
5) creation of an object, an object that has such properties. In this work, an attempt is made to solve geoecological problems using morphometric relief indicators, describing it, and based on the data obtained. In particular, by determining the slope of the relief, surface exposures, using the data obtained, determining the extent of water erosion of the soil in the studied area, analyzing it, rational use of land, non − destructive use, and increasing fertility were the main issues. In the description of the relief, there are two classes of work that are divided into two large groups: qualitative description of the relief and quantitative description[2].

The ArcGIS 10.4 program was used to compile a slope map of the terrain, which is represented primarily by Heights from a topographic map, obtaining various indicators, creating tables, etc. In particular, as part of this program, the main components of ArcGIS 3D Analyst, which is an additional module, are compiled maps of the terrain of the Kyzylorda region using 3D visualization, relief creation and analysis. In addition, the regional and volumetric characteristics of the relief, slope, surface exposures and the level of surface leaching were also determined [3]. The use of these maps in determining spatial bundles is very effective: using this model, it is very helpful in determining how these processes relate to mountains, valleys, high institutions, and other three-dimensional objects . The course of cartographic studies used to obtain information on any information provided on the maps consisted of 4 stages :

Stage 1 - promotion of issues to be solved with the participation of data available on the map;

Stage 2-the preparatory stage;

Stage 3-conducting the study;

Stage 4-examination, processing of the received data.

In comparison with the corresponding date of February 1, 2023, the number of horses in all categories of farms increased by 13.4 and 134.7 thousand heads; poultry increased by 13.0% and 126.4 thousand heads, respectively; camels – by 7.9%-A and 45.2 thousand heads; sheep-by 6.2% and 445.5 thousand heads; cattle – by 4.7% and 324.5 thousand heads; pigs-by 2.2% and 2.2 thousand heads. Goat heads-decreased by 0.1% and amounted to 155.6 thousand heads. As of February 1, 2023, 67.7% of cattle were counted in public farms;30.2% – in peasant or farm farms and individual entrepreneurs; 2.1% – in agricultural enterprises; sheep – 55.8%, 39.7% and 4.5%, respectively; goats – 87.0%, 12.9% and 0.1%; pigs – 87.9%, 12.1%; horses – 60.9%, 37.1% and 2.0%; camels – 61.9%, 34.7% and 3.4%; poultry – 74.8%, 5.6% and 19.6% [4].

Results. In January 2023, all types of livestock and poultry were slaughtered or slaughtered on the farm in live weight amounted to 2.9 thousand tons, which is 1.4% higher than in the corresponding period last year, cow's milk production increased by 1.7% and amounted to 5.4 [5] thousand tons, chicken egg production-by 65.2% and amounted to 0.6 thousand pieces. Statistical data of animal husbandry in the ArcGIS program are mapped as follows:

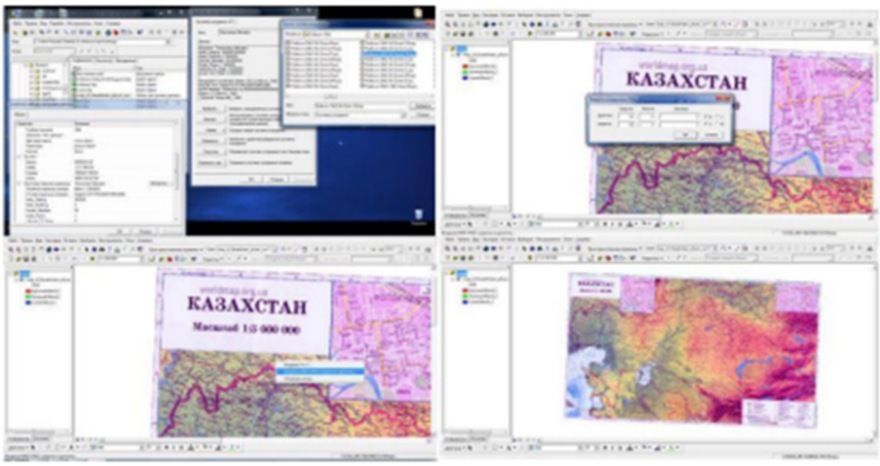


Fig.1. Works in the ArcGIS program

Figure 1 linking the map to the coordinate system - collecting, analyzing and evaluating information sources; - studying the phenomena of the mapped area included in the map content; includes the processes of compiling the first vector layers (shape file) and starting editing work. Shown in Figure 4.

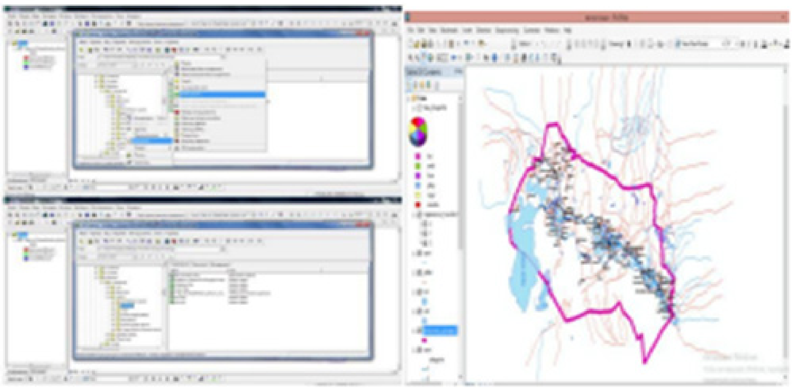


Fig.2. Editing vector layers

Figure 2 development of vector layers, editing process if the first version of the prepared map does not meet the requirements of the customer, an additional version is developed. At the stage of preparing the same card for printing, small printing works are introduced. All this work on the compilation of the map map

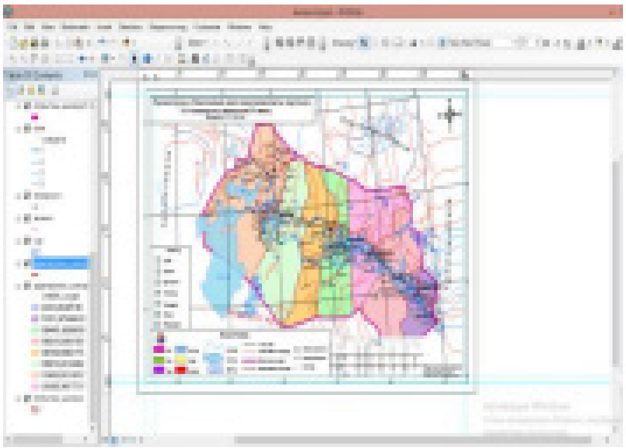


Fig.3. Preparing the card for printing

Figure 3 Preparation of the card for printing refers to the stage of preparation for printing. That is, it is the processing or reproduction of the finished card using a printing or other method. This stage includes the preparation of the printable version and the sections for printing cards. The result obtained during the implementation of these stages on the diploma topic is shown in Figure 3. In cartographic production, maps are developed by various teams of specialists, which is why this work requires scientific and technical guidance, which is called map editing. The process that checks the work at all stages is called proofreading.

In 2023, agricultural formations received a gross income of 2316299 tenge from the sale of crop production (the level of profitability was 11.5%), including wheat - 94074 thousand tenge (33.0%), forage crops-352941 thousand tenge (27.2%), vegetables-54083 thousand tenge (26.4%), potatoes-19836 thousand tenge (24.4%), barley-1444 from the sale of melons-205663 thousand tenge (28.5%), oilseeds-36949 thousand tenge (13.4%) and rice-1527994 thousand tenge (8.9%). Agricultural formations of all districts successfully sold crop production. In 2018, the largest income was accounted for by agricultural formations of Zhanakorgan district (736752 thousand tenge, 25.3%), Shieli district (376573 thousand tenge, 12.2%), Kyzylorda city (266656 thousand tenge, 20.1%), Zhalagash district (272946 thousand tenge, profitability level 5.7%).Agricultural enterprises received income from the sale of crop production in the amount of 476046 thousand Tenge (the level of profitability was 5.6%), peasant or farm farms-in the amount of 1840253 thousand tenge (15.8%).

Fig.5. Animal husbandry map of Kyzylorda region

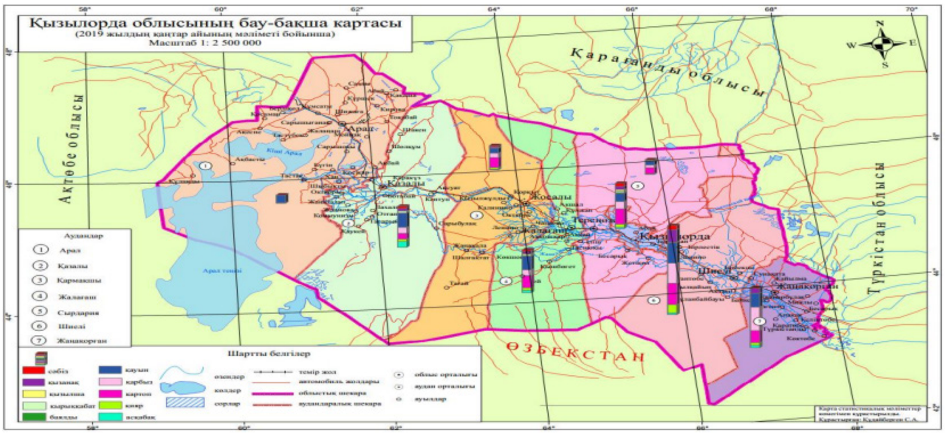


Fig.6. Garden map of Kyzylorda region

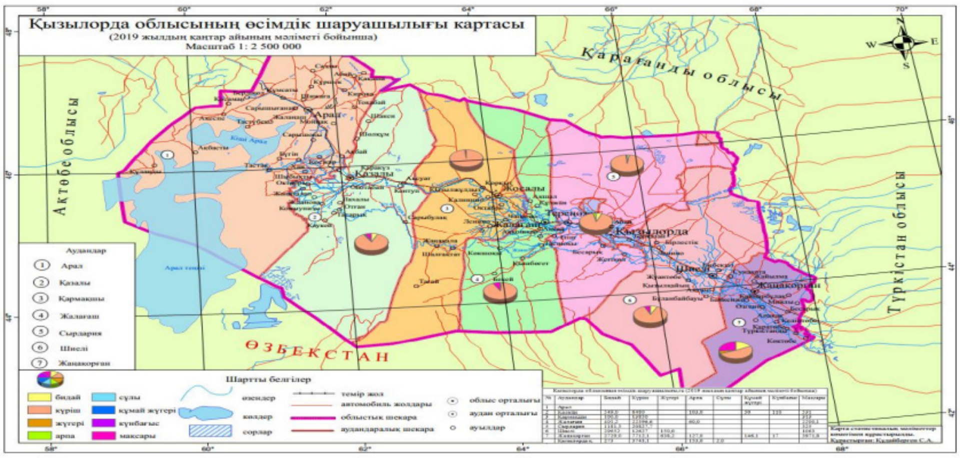


Fig.7. Map of crop production of Kyzylorda region

Kazakhstan has long been known all over the world as an agrarian country. The main task of agricultural production is to fully provide the population of the Republic with types of food that are adjusted to medical standards. For this purpose, 1.4 million tenge per year is allocated in the Republic. More than a ton of meat, about 7.0 million tons of milk and dairy products, 4 billion tons. It is necessary to produce eggs, 2.4 million tons of vegetables, 640 thousand tons of sugar and about 2.0 million tons of bread and bakery products [6]. However, at present, the main types of food, including animal products, are not produced in sufficient quantities. Meat, dairy products, vegetable oils, sugar up to 30-40% are imported from foreign countries. In order to eliminate such gaps, the intensive development of animal husbandry in the field of Agriculture is the responsibility of today.

To do this, first of all, it is necessary to fully provide animal husbandry with nutritious and high – quality feed with the harmonious use of our rich resources-natural Meadows and arable land. After a thorough analysis of the structure and tasks of the feed production industry, we will find out that its main sources are natural Meadows and arable land. In addition, waste from field fields (grain, industrial crops) is also used as animal feed.

The share of animal feed can also include products produced in the microbiology and chemical industries (vitamins, yeast, enzymes and other biologically active substances). However, 95% of the total volume of feed used in livestock and poultry farms is made up of plant-based feeds. Therefore, the development of feed production from natural Meadows and pastures and forage Fields plays a key role in creating a solid supply of animal feed for animal husbandry in the Republic. Natural pastures and Meadows occupy the vast expanses of the Republic.

The area of pastures is 182 million hectares, hayfields – 4.7 million hectares, or about 1 hectare of hayfields per 39 hectares. The main reason for this contradiction lies in the fact that fertile Meadows are plowed and turned into fields to increase the volume of grain production. In this regard, in most farms of the Republic, especially in grain-growing regions, there is a shortage of winter feed. For this, in the 70-80s of the last century, Hay began to be prepared from forced Natural Pastures. Such «mowed pastures» were included in the government's plan, the size of which reached 15-20 million hectares.

Of course, the yield of such» hayfields « was low, and the cost of hay increased, and the efficiency of animal husbandry in most areas decreased. In those days, a large number of forage crops began to be grown on the arable land. Its volume is up to 10 MLG hectares in the Republic, a third of the volume of hay, silage, succulent and fodder feeds were completely removed from the fields. However, the production of natural pastures and fodder forage and arable land still does not meet the current demand. Feed production is a large and complex branch of the agricultural economy. Its intensive development and prosperity in accordance with the requirements of today is due to the introduction into production of the humiliated scientific and technological achievements in this area. The main ones include the following areas:

1. Effective and rational use of the main sources of animal feed, natural grasslands and pastures and fodder fields, taking into account the bioclimatic capabilities of each region and the peculiarities of economic formation;

2. Collection of high-quality, nutritious feeds, increasing the yield of natural Meadows and pastures and forage fields with the introduction of achievements of Science and advanced production practices in farms (farms, Joint-Stock complexes, etc.);

3. Implementation in farms of advanced technologies for the preparation of animal feed and planning of daily, monthly and annual feed menus based on science for each type of animal, age and obtained animal products;

4. Reducing the cost of feed through the improvement, efficient use of fodder land on farms and the introduction of new equipment and machines for the production of feed [7]. Forage production as a branch of Agriculture and science is engaged in the cultivation of forage crops on arable land, cultivation and use of natural pastures and hayfields.

The goals set by this industry are the maximum intensification of animal feed production in the Republic. The main source of cheap and highly nutritious food is natural forage lands.

Such lands occupy 70% of the land area of the Republic, as mentioned above. However, the volume of feed from these natural pastures and hayfields accounts for only about 40% of the total volume of feed used in animal husbandry throughout the year. The main reason is the low yield of natural fodder lands. Irregular use and untimely maintenance of natural pastures leads to the degradation of Meadow soils, the disappearance of valuable plant species from the plant community,the replacement of other infertile grass species, arugula, the invasion of Meadows by bumps and shrubs, as a result of which the yield decreases.

To eliminate such shortcomings, it is important to properly use natural forage lands with improvement. As shown by the achievements of Science and advanced farms, it turned out that in all regions of the Republic, with the radical improvement of natural pastures and fly agarics (sowing perennial grasses instead of destroying natural grasses), the yield can be increased up to 3-5 times and higher. Methods of light improvement (removal of bumps, bushes, spraying of fertilizers, sowing of grass seeds, etc.) increased the yield of meadowsweet by 1.5-3.0 times. A progressive new method is widely introduced in the field of feed production in the summer season, creating irrigated pastures in each farm. It has been known from many experiments that on irrigated pastures , the milk yield of cows increases to 15-30%, and the meat content of cattle in Bordak increases to 25-35%.

It was found that the effective use of Natural Pastures in Steppe, semi-desert and desert zones can preserve valuable grass species and increase yields, as a result of which livestock products (meat, wool) from each hectare can be doubled. In many studies, it has been proven that the creation of grass-planted pastures in the southern and south-eastern regions of Kazakhstan is very effective both economically and ecologically. The cultivation of arable fodder has been carried out in the Republic for a long time. But his current position is not critical. The amount of feed per hectare of arable land where forage crops are grown is lower than the yield obtained from sown fields with grain crops. The main reason for this is the non-compliance with the technology of cultivation of feed crops, and the study of the technology of cultivation of some crops is not adapted to each region. In the future, the production of feed from arable land should be carried out in the following main areas: improving the structure of feed fields in each region; increase the yield of fodder crops; widespread introduction of intermediate, legendary and compacted fields in farms; widespread use of green conveyors; preparation of feed from the field according to new technologies; scientific establishment of feeding. For the intensive development of animal husbandry in the Republic, in the future, the volume of sowing of fodder crops in the field will be increased by at least 3 times and the yield per hectare to 2.0-2.5 tons of agricultural products. The cultivation of forage crops in intermediate and compacted fields should also be significantly introduced into production. It is established that by growing 2-3 crops per year from one arable land, the yield per hectare can be increased to 20-50%.

For example, experiments have shown that high-yielding feed grain crops are effective if they are sown with protein-rich legumes. In general, the science of animal feed production in the former Union dates back to the end of the 18th century. The first Russian scientists were I. I. Levshin, I. T. Bolotov, A.V. Sovetov, I. A. Stebut, P. A. Kostychev, etc. He studied the fodder land of different regions of Russia, studied ways to improve it, the quality of fodder plants, the possibilities of their acclimatization, cultivation in the field. However, the widespread, planned development of the feed production industry in 45 dates back to the beginning of the 20th century.

The famous Russian scientists V. R. Williams [8] and A.M. Dmitriev were in charge of these works. During these years, special expeditions were organized to Kazakhstan from the Center (Research Institute in Moscow, Leningrad) to study the state of natural pastures and meadows, their location in each region, groups, main plant communities, plant species, products and Feed values. Among the scientists who led such research and did a lot, one can single out academician I. V. Larin, professors L. G. Ramensky [9], I. A. Tsatsenkin, S. P. Smelov. Among the scientists of Kazakhstan of that time, one can name the works of D. A. Zykov, B. A. Bykov, K. K. Kurmanov, I. V. Matveev, K. D. Postoyalkov, P. A. Salyukov. In the 60s of the last century, at the Kazakh Scientific Research Institute of hayfields and pastures, which was opened again in the Republic, the problems of improving and efficient use of natural forage lands began to be studied in depth and comprehensively in all regions. The current conditions of natural pastures and hayfields located in each region of the Republic were identified, and ways to improve and effectively use dilapidated land were proposed. Among the scientists who led the scientific work and did a lot, one can name zh.a.Dzhambakin, S. N. Pryanishnikov, K. A. Asanov, E. Sh.Shakhanov, G.T. Meyrmanov, K. A. Aubakirov, I. I. Alimaev, K. A. Baitkanov [10], E. L. Bekmukhamedov, K.Sh.Smailov, U. H. Almishev. Among the scientists who scientifically investigated the problems of animal feed production in agriculture, we can mention Yu.d.Zykov, N. I. Mozhaev, V. A. Benz, a.m. Sveshnikov, G. M. Chasovitina, A. Akhmet.

It is known that relief is considered the determining factor in the development of various natural processes occurring on earth. Basically, it emits radiation from the sun and determines the features of the formation of all types of surface currents and surface processes on them. All this contributes to the definition of landscape classification in both local and regional areas. Digital data is essential to determine the extent to which relief in Geosystems takes place. The most effective way to solve this problem is the morphometric method.

Most often, this method is widely used in geomorphology and is widely used in determining the studied objects, their quantitative indicators using the basis of GIS technology. However, the scope of the morphometric method is not limited to this, but the scope of its research is very wide and is also used to solve other geoecological problems. At the same time, today, Fast and optimal solutions are solved through the digital features of GIS technology. The Earth is the most basic natural asset. He is the source of all life, the habitat. Now people get 88% of the nutrients they need from arable land, 10% from forests and pastures, and 2% from sea and ocean waters. Therefore, the protection and effective use of the Land Fund is the most basic and urgent issue that never ceases to be relevant.

The development of industry, the construction of cities, roads, hydraulic structures destroy the surface of the Earth and lead to a change in natural landscapes.

The changed lands are undervalued economically, polluting the environment with toxic substances, reducing the sanitary and hygienic conditions of human life. Considering the changes in the structural and qualitative state of the Land Fund, we can see that the direction of their development, especially agricultural land, is negative. Such negative processes lead to a reduction in the resource potential of the land, as a result of which agricultural production decreases and pose a threat to the national security of the state. The most basic way to stop this process quickly is to use the land efficiently. This is especially important in modern economic conditions, that is, at a time when there is a shortage of industrial resources and a decrease in soil productivity. The lack of an economic mechanism of economy and land use leads to a shortage and degradation of land resources. In this regard, the economic basis for the effective use of land resources by moving from a free form of land use to a paid one has been developed. The Land Fund is the most important national asset of our people, so its value is calculated in monetary terms as part of the national wealth. On the basis of determining the magnitude of all this, the value of land is an economic assessment. Like all natural riches, the economic valuation of land has three main different functions :

1. Calculation. Land is counted as a national wealth, as the production and material Fund of Regions, enterprises, individual landowners and land users. Land is also taken into account as a place of production, other structures, residential buildings, etc., as a place of economic activity.

2. For an economic incentive to effectively use the land fund, it must have a price and thereby be included in market relations.

3. Qualitative properties of land units — productivity, location efficiency are different. There are not enough fertile, efficient lands, so even those with low productivity and efficiency are used, and good (efficient) users, regardless of the Labor spent, earn additional profit. Depending on the efficiency, different land units are evaluated differently, creating more uniform conditions for land users. As a result, the population is encouraged to use less efficient, but economically necessary land. All services of economic assessment of the Land Fund are inextricably linked,

serve to protect, effectively use the land as a whole. In general, the Land Fund in the region can be divided into three natural and economic zones, depending on soil and climatic and other economic conditions. The first Zone (South) includes two administrative districts (Zhanakorgan and Shieli), the second (central) zone includes four administrative districts (Zhalagash, Karmakshy, Syrdarya and Kyzylorda), and the third zone (north) includes two administrative districts (Aral and Kazaly) . Due to the specialization of the region in rice farming, taking into account the peculiarities of the soil and climate and other conditions, natural irrigated arable land can be divided into three natural Spurs: Zhanakorgan-Shieli, Kyzylorda and Kazaly-Aral. In recent years, small rice fields have begun to form in agricultural areas of the Aral region.

The main cultivated plant in these ranges, rice, is sown in the former engineering — ready lands together with the cultivated plant corresponding to it. 9193.0 thousand hectares or 74.0% of the total land fund of the region is irrigated pasture land. At the same time, the area of vacant land increased by 129.8 thousand hectares.

This is mainly due to the deterioration of the financial situation of Agriculture, the lack of mineral and organic fertilizers, the lack of seeds, as well as the dilapidated material and technical base.

Due to the different natural and economic conditions on the territory of the region, specialization in the placement of agricultural production, a different type of agricultural development has developed near the island (a type of self-financing, specializing in various specialties and self-financing). In the northern zone, in recent years, due to a lack of irrigation water, the volume of fields growing rice and other cultivated plants has decreased.

However, the remoteness of the settlements from each other is conducive to the development of animal husbandry. It is especially convenient for the development of sheep, camel and horse breeding. In the southern zone, due to the favorable temperature conditions, it is convenient for farming, especially for growing vegetable and garden, fruit, oil and technical crops and grapes. Therefore, in recent years, the main cultivated plant has been cultivated here, along with rice, cotton, etc. in the development of cultivation. Due to the favorable economic development in the central zone, rice and other cultivated plants belonging to the rice family, grain, oilseed, horticultural, fruit crops are planted here. Any land fund is distinguished by fertility. The soil cover, formed on the basis of climate, flora, hydrology and hydrogeology characteristic of the Kyzylorda region, has a special impact on the qualitative state of land resources. Based on this, the soils on the territory of the region can be divided into two large groups:

- Atyrau moist soils with developed irrigated agriculture;
- in the semi-desert part there is a trace of irrigated agriculture from ancient times and dry soils used for grazing livestock. Changes in soil fertility are also influenced by human activity. If it acts scientifically, it increases soil fertility, and if it is treated irresponsibly, it reduces or destroys soil fertility. The main agronomic, agrotechnical, agromeliorative, organizational measures to improve soil fertility, land use efficiency are as follows:

1.protection of soil from erosion (fangs). There are three main types of erosion: wind, water and technical. In uneven, barren areas, precipitation washes away the fertile soil layer. Open areas without forests, especially those where productivity is deforested (plowed), are subject to wind erosion, the fertile soil layer is blown away by the wind. Tillage of land with heavy equipment, year-on-year sowing of one crop, the movement of equipment on off-road areas increases soil erosion. In desert and semi-desert regions, excessive grazing of livestock without compliance with the order of seasonal use, the movement of equipment leads to the destruction of vegetation, especially valuable ones. Exposed soil is subject to wind, sun, water erosion. The main way to protect against this threat is the cultivation, irrigation, regulatory use of Groves.

2. Protection of soil from salinization (salinization). Soil salinization occurred when the amount of precipitation was less than the amount of evaporating moisture. Many years of irrigation of crops cause salinization of the soil. The evaporation of rainwater from the surface of the earth is saline. The use of advanced effective methods of irrigation of fields and pastures protects the soil from salinization.

3. Ways to protect the soil from sandblasting — planting trees (saxaul, Genghis), shrubs, sowing perennial grasses.

4. Protecting the land from waterlogging, it will be necessary to carry out hydro-reclamation works, improve irrigation systems.

5. For the preservation of nutrients in the soil, reclamation works, treatment of salt marshes with lime, gypsum, plowing by special methods, fertilizing, re-grazing, etc. agronomic works are carried out.

6. Protection of soil from poisoning — regulation of the amount of use of pesticides, herbicides, fertilizers, protection from production, household waste, sanitary rehabilitation measures.

7. Restoration (reclamation) of lands damaged as a result of construction, road construction, subsoil exploration, mineral extraction, waste disposal will significantly improve the subsoil of the Republic.

8. Measures to prevent the exclusion of arable fertile land from agricultural circulation require legalization. In recent years, the distribution of fertile flat lands, forests, suitable for arable land for various construction, summer cottages, roads, retail outlets, has become widespread. It is also necessary to legalize it. These works are carried out based on achievements in the field of special Sciences. At the same time, these are economic measures. After all, it is necessary to determine the economic efficiency of measures, taking into account the financial, material costs spent. For the implementation of measures for the protection, effective use of land, economic calculations, assessments are carried out. Assessment of land fertility, determination of the costs of restoration, protection, improvement, inclusion of land in market relations, etc.require economic calculations, assessments. In short, land as a source of production reserves and a medium for placing production applies to all areas of production. As the rate of development of production increases, the amount of use of land wealth and Land Resources also increases. In this regard, the decline in the quality of effective reserves of land resources negatively affects the increase in the costs of society for production. The negative impact on production efficiency caused by a decrease in the quality of land resources is also not eliminated by the results of scientific and technical achievements. Therefore, the economical and efficient use of land resources is becoming an urgent problem that must be solved. To solve it, it is necessary to organize new economic conditions in accordance with the current economic mechanism of effective land use and choose from such complex ways the most effective, most suitable, specific.

The normalized vegetation index NDVI (NDVI) is a standardized index that reflects the existing and condition (relative biomass) of a plant. This index uses the contrast of two channel characteristics from a multispectral raster data set – absorption of chlorophyll pigment in the red channel and high reflectivity of plant raw materials in the infrared channel (NIR). NDVI is often used worldwide for drought monitoring, agricultural production monitoring and forecasting, assistance in predicting fire risk zones, and desert occurrence mapping. NDVI is suitable for global plant monitoring as it helps compensate for changes in lighting conditions, surface slope, exposure and other external factors.

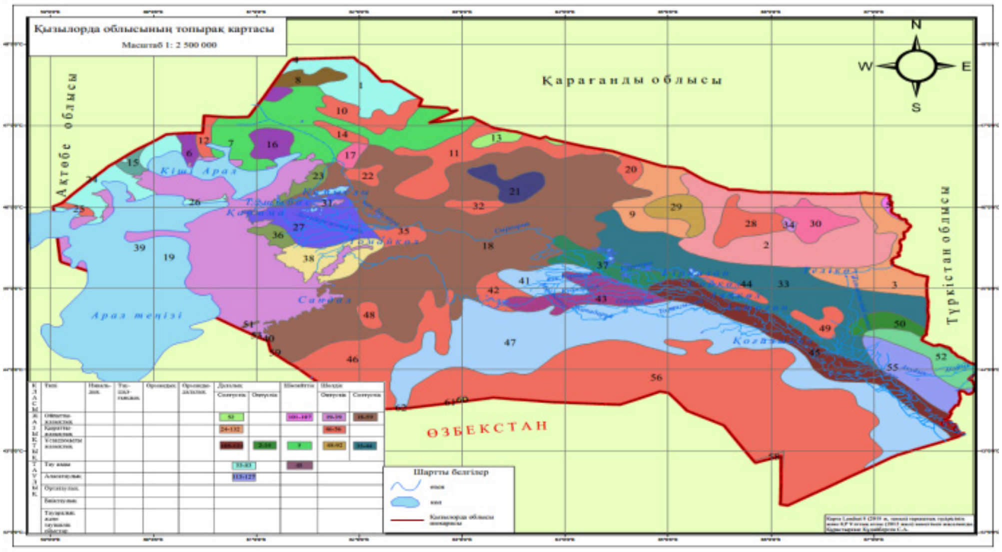


Fig.8. Soil map of Kyzylorda region [11]

NDVI is often used worldwide for drought monitoring, agricultural production monitoring and forecasting, assistance in predicting fire risk zones, and desert occurrence mapping. NDVI is suitable for global plant monitoring as it helps compensate for changes in lighting conditions, surface slope, exposure and other external factors. Different visibility in red and infrared (IR) channels allows you to monitor the growth density and intensity of green plants using spectral reflection of solar radiation. Green leaves usually show better visibility in the near range of infrared waves than at visible wavelengths. If the leaves are flooded or dead, they will be yellow and will be significantly less visible in the near infrared range. Clouds, water and snow provide better visibility in the visible range than in the near infrared range, and the difference is zero for rock and bare soil. NDVI processing creates a single-channel dataset that is mostly green. Negative values mean clouds, water and snow, and values close to zero mean rocks and bare soil. Default NDVI documented equation:

$$NDVI = ((IR-R) / (IR + R)) \quad (1)$$

IR = values of pixels from the infrared channel R = values of pixels from the red channel this index is formed mainly from clouds, water and snow, while values close to zero are formed mainly from rock and bare soil. Very small values (0.1 and less) the NDVI function corresponds to free areas of rock, sand or snow. Average values (from 0.2 to 0.3) indicate shrubs and meadows, and large values (from 0.6 to 0.8) indicate medium and tropical forests. ArcGIS equation used to generate output data:

$$NDVI = ((IR - R)/(IR + R)) * 100 + 100 \quad (2)$$

Discussion. This results in a range of 0-200 values and fits the 8-bit structure, allowing them to be displayed using a color scale or color map. If you need specific pixel values (-1.0-1.0), select the NDVI method using the channel arithmetic function (Band Arithmetic function) function. When you use the Add function button in the image Analysis window to use NDVI: you can open the image analysis Options dialog box, click the NDVI tab, and then select scientific output data. Also on this tab there is an option to use the wavelength, which will try to determine the correct channels if there is information about the wavelength (use Wavelength). If not, the number of channels is used. Below are examples of combinations of Landsat 7,4,3 channels (left) and NDVI channels that highlight the field of agricultural activity (right).

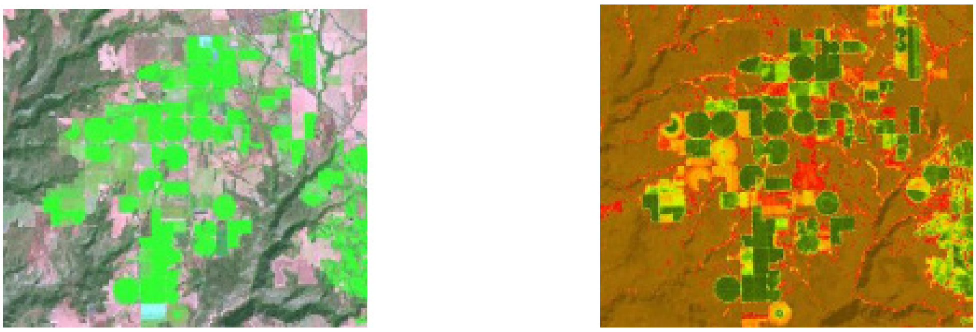


Fig. 9. NDVI indicator

Conclusion. The agricultural system of Kazakhstan developed on the basis of the long-term Agrarian Policy of the Soviet Union, which was formed in the 30s. It was subordinate to the goals of industrialization and urbanization of the state and considered agriculture only as sources of raw materials, labor, financial and other resources of the city. This intensive work was carried out in extensive ways under the strict supervision of the administrative system, and the achievements of scientific and technological development did not reach significant indicators in villages, farms. Such a system was the same for all regions of the USSR. As a result, the volumes of arable and pasture land were increased, fertilizing many lands and increasing the volume of irrigated land. Agriculture was not properly implemented, and plant protection measures were not satisfactory. This project» increasing arable land and providing the population with food in full « has many, if not many, controversial aspects. So, this new agrolandscape direction should also be in our state. To implement this system, a special order has now been placed by the state to compile a system for adapting agriculture to landscapes. To implement this, first of all, systematize them by analyzing the methodological foundations of compiling maps that determine the features and characteristics of landscapes in Kazakhstan. By classifying the territory into landscapes, brief descriptions of the terrain, climate, composition of the underlying rocks, vegetation, surface and underground are made. After they are identified, it is necessary to analyze them, using the optimal options for GIS technologies in accordance with the objects under study and the problems being solved, and then embed them into the computer. GIS technologies underlie Geoinformatics. It studies natural and socio-economic Geosystems at various hierarchical levels through computer processing of specially created databases. The object of my research was the Kyzylorda region. Kyzylorda region is one of the leading agricultural regions of the country. Changes occur in this region every year. For example, agricultural land replacement, sowing of another farm crop due to lack of water, breeding of another type of livestock in animal husbandry, hybridization work, etc. We need to intensively study all these situations and organize mapping measures. Monitoring of the terrain, as well as agriculture, will greatly contribute to the rapid development of land.

References

1. Agroecological assessment of the land, design of adaptive landscape systems of agriculture and agrotechnologies (Methodological guidance) under.Ed. Academicians RASKHN V.I. Kiryushin and A.L. Ivanov. FSUE «Rosinformagrotech» – Moscow, 2005. - 794 p.
2. Atlas of the Republic of Kazakhstan, 2010. – 163 p.
3. Armand A.D. Field theory and the problem of geosystems allocation // Questions of geography. - 1975. – No.98.- P.92-106.
4. Isachenko A.G. Landscape of the USSR. – L.: LSU, 1985. -320 p.

5. Milkov F.N. The doctrine of anthropogenic landscapes: history, current state and prospects of development // Anthropogenic landscapes and nature conservation issues. - 2003. –P.3-9.
6. Nikolaev V.A. Fundamentals of the doctrine of agricultural landscapes. // Agro-landscape research. – 2000. - P 4-57.
7. Perelman A.I. Geochemistry of landscape. – M.: Higher School, 1975. - 242 p.
8. Savin Yu. Geoinformation analysis of the resource potential of lands for agricultural purposes/ Modern problems of soil science: scientific tr. - M., 2000. –272-285 p.
9. Katorgin Yu. Structure of the GIS data bank»Agrolandscapes of the Stavropol Territory»/»Questions of physical geography», 47 scientific.- method. conf. «University Science-to the region». M. V. Lomonosov. - method. conf. «University Science-to the region». - Stavropol, 2003. – 119 p.

С.К. Қасымғалиев, Р.Ж. Келинбаева, М.К. Султанов, Н.Х. Жүнісбекова
Әл-Фараби атындағы Қазақ Ұлттық университеті, Алматы, Қазақстан

Қызылорда облысының жер ресурстарын пайдалануды геоақпараттық қамтамасыз ету, талдау, бағалау және болжам жасау

Аңдатпа. Қазіргі уақытта әлемнің дамыған, өркениетті елдерінің барлығында дерлік ауылшаруашылық қызметі ландшафттарға бейімделген ауыл шаруашылығы жүйесін (ASR) жобалау негізінде жүзеге асырылады. Өнеркәсіптік ғылымның бұл саласын жан-жақты негіздеу және оның Қазақстанда қалыптасу мүмкіндіктері мен ерекшеліктерін анықтау үшін жоғары сенімділікпен нақты ғылыми-зерттеу жұмыстарын жүргізу қажет. Сондықтан ұсынылып отырған жұмыста Қызылорда облысының ауылшаруашылық ландшафттары таңдалып, географиялық ғылымдар тұрғысынан зерттеліп, сарапталып, қазіргі заманғы географиялық ақпараттық жүйені бейімді пайдаланудың оңтайлы жолдарын іздеуге бағытталды. Сондықтан ұсынылып отырған жұмыста Қызылорда облысының ауылшаруашылық ландшафттары таңдалып, географиялық ғылымдар тұрғысынан зерттеліп, сарапталып, қазіргі заманғы географиялық ақпараттық жүйені бейімді пайдаланудың оңтайлы жолдарын іздеуге бағытталды. Қызылорда облысы — Қазақстан Республикасының оңтүстік бөлігінде орналасқан әкімшілік аймақ. Облыс өзінің ауыл шаруашылығымен ерекшеленеді. Өңірде егін шаруашылығы ерте заманнан дамыған. Сонымен қатар, шаруалар жыл сайын сорт ауыстырып, дақылдарды әртараптандыру бойынша қарқынды жұмыс істейді.

Карта жасау барысында Қызылорда облысының әкімдігінен негізгі мәліметтерді жинаймыз, картаны құрастыру үшін деректерді ArcGIS бағдарламасына енгіземіз. Заманауи технологияларды пайдалана отырып, біз алдын ала жобалау жұмыстары арқылы еліміздің негізгі мәселелерін шеше аламыз.

Түйін сөздер: картографиялау, ауылшаруашылық, зерттеу әдісі, ландшафттар, ауылшаруашылық ландшафттары, ГАЖ.

С.К. Касымгалиев, Р.Ж. Келинбаева, М.К. Султанов, Н.Х. Жунусбекова
Казахский национальный университет им. аль-Фараби, Алматы, Казахстан

Геоинформационное обеспечение, анализ, оценка и прогнозирование использования земельных ресурсов Кызылординской области

Аннотация. В настоящее время аграрная деятельность практически всех развитых, цивилизованных стран мира осуществляется на основе проектирования системы земледелия (ЛНР), адаптированной к ландшафтам. Для того, чтобы всесторонне обосновать эту область производственной науки и определить возможности и особенности ее формирования в Казахстане, необходимо выполнить реальные исследовательские работы с высокой степенью достоверности. Поэтому в предлагаемой работе были выбраны агроландшафты Кызылординской области, изучены и проанализированы с точки зрения географических наук, направлены на поиск оптимальных путей адаптивного использования современной геоинформационной системы. Кызылординская область - административная зона, расположенная в южной части Республики Казахстан. Область отличается своим сельским хозяйством. Сельское хозяйство в области развито с давних времен. В ходе данной статьи мы рассмотрим пути решения проблем и картографирования сельскохозяйственных земель

Кызылординской области. Кроме того, ежегодно аграрии интенсивно работают по направлению смены сортов, диверсификации культур.

В ходе картографирования мы собираем основные данные из акимата Кызылординской области, вводим данные с составлением карты в программе ArcGIS. Используя современные технологии, мы можем решить главные проблемы нашей страны с помощью предварительных проектных работ.

Ключевые слова: картографирование, сельское хозяйство, метод исследования, ландшафты, агроландшафты, ГИС.

References

1. Agroecological assessment of the land, design of adaptive landscape systems of agriculture and agrotechnologies (Methodological guidance) under.Ed. Academicians RASKHN V.I. Kiryushin and A.L. Ivanov. FSUE «Rosinformagrotech». (Moscow, 2005, 794 p.)
2. Atlas of the Republic of Kazakhstan, 2010. – 163 p.
3. Armand A.D. Field theory and the problem of geosystems allocation // Questions of geography. (M, 1975, 98, 92-106p.)
4. Isachenko A.G. Landscape of the USSR. (L.: LSU, 1985. 320 p.)
5. Milkov F. N. The doctrine of anthropogenic landscapes: history, current state and prospects of development // Anthropogenic landscapes and nature conservation issues. (Ufa, 2003, 3-9).
6. Nikolaev V. A. Fundamentals of the doctrine of agricultural landscapes. Agro-landscape research. – (M., 2000, 4-57p.)
7. Perelman A. I. Geochemistry of landscape. (M. Higher School, 1975. 242 p.)
8. Savin.Yu. Geoinformation analysis of the resource potential of lands for agricultural purposes. Modern problems of soil science: scientific tr. /V.V. Dokuchaev Soil Institute. (M., 2000, 272-285p.)
9. Katorgin.Yu. Structure of the GIS data bank»Agrolandscapes of the Stavropol Territory».»Questions of physical geography», 47 scientific.- method. conf. «University Science-to the region». M. V. Lomonosov.- method. conf. «University Science-to the region». - Stavropol, 2003. – 119 p.

Information about authors:

Kassymgaliev S.K. – PhD student, Department of Geography, Land Management and Cadaster, Faculty of Geography and Nature Management, Al Farabi Kazakh National University, 71 al-Farabi Ave., Almaty, Kazakhstan.

Kelinbaeva R.Zh. – Senior Lecturer, Department of Geography, Land Management and Cadaster, Faculty of Geography and Nature Management, Al Farabi Kazakh National University, 71 al-Farabi Ave., Almaty, Kazakhstan.

Sultanov M.K. – Master's degree student, Department of Geography, Land Management and Cadaster, Faculty of Geography and Nature Management, Al Farabi Kazakh National University, 71 al-Farabi Ave., Almaty, Kazakhstan.

Zhunisbekova N.Kh. – Master's degree student, Department of Geography, Land Management and Cadaster, Faculty of Geography and Nature Management, Al Farabi Kazakh National University, 71 al-Farabi Ave., Almaty, Kazakhstan.

Қасымғалиев С.Қ. – Докторант, География, жерге орналастыру және кадастр кафедрасы, География және табиғатты пайдалану факультеті, Әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби даңғылы, 71, Алматы, Қазақстан.

Келінбаева Р. Ж. – Аға оқытушы, География, жерге орналастыру және кадастр кафедрасы, География және табиғатты пайдалану факультеті, Әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби даңғылы, 71, Алматы, Қазақстан.

Сұлтанов М.К. – Магистрант, География, жерге орналастыру және кадастр кафедрасы, География және табиғатты пайдалану факультеті, Әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби даңғылы, 71, Алматы, Қазақстан.

Жүнісбекова Н.Х. – әл-Фараби атындағы Қазақ ұлттық университеті, география және табиғатты пайдалану факультеті география, жерге орналастыру және кадастр кафедрасының магистранты, әл-Фараби даңғылы, 71, Алматы, Қазақстан.

Бас редакторлары: **Э.Е. Копишев, Н.Е. Рамазанова, Ж.Г. Берденов**

Компьютерде беттеген: **Ж.Қ. Оспан**

Авторларға арналған нұсқаулықтар,
жарияланым этикасы журнал сайтында енгізілген: http://bulchmed.enu.kz

Л.Н. Гумилев атындағы Еуразия ұлттық университетінің Хабаршысы.
Химия. География. Экология сериясы.
– 3(144)/2023 – Астана: ЕҰУ. – 120 б.
Шартты б.т. – 7.5. Таралымы – 8 дана.
Басуға қол қойылды: 29.09.2023 ж.

Ашық қолданыстағы электронды нұсқа: http://bulchmed.enu.kz

Мазмұнына типография жауап бермейді

Редакция мекен-жайы:
010008, Қазақстан Республикасы Астана қ., Сәтбаев көшесі, 2.
Л.Н. Гумилев атындағы Еуразия ұлттық университеті
Тел.: +7(71-72) 70-95-00(ішкі 31-413)

Л.Н. Гумилев атындағы Еуразия ұлттық универститетінің баспасында басылды