

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

**NEWS OF THE NATIONAL ACADEMY
OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF
GEOLOGY AND TECHNICAL SCIENCES**

**№4
2025**

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)



N E W S
OF THE NATIONAL ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN,
SERIES OF GEOLOGY AND TECHNICAL
SCIENCES

4 (472)
JULY – AUGUST 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2025

«Central Asian Academic Research Center» LLP is pleased to announce that “News of NAS RK. Series of Geology and Technical sciences” scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of Geology and Technical Sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

«Орталық Азия академиялық гылыми орталығы» ЖШС «ҚР ҰҒА Хабарлары. Геология және техникалық гылымдар сериясы» гылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруды. Web of Science зерттеушілер, авторлар, баспашилар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық гылымдар сериясы Emerging Sources Citation Index-ке енүі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық гылымдар бойынша контентке адалдығымызды білдіреді.

ТОО «Центрально-азиатский академический научный центр» сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

EDITOR-IN-CHIEF

ZHURINOV Murat Zhurinovich, Doctor of Chemical Sciences, Professor, Academician of NAS RK, President of National Academy of Sciences of the Republic of Kazakhstan, RPA, General Director of JSC "D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry" (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

DEPUTY EDITOR-IN-CHIEF

ABSADYKOV Bakhyt Narikbayevich, Doctor of Technical Sciences, Professor, Academician of NAS RK, Satbayev University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6504694468>, <https://www.webofscience.com/wos/author/record/2411827>

EDITORIAL BOARD:

ABSAMETOV Malis Kudysovich, (Deputy Editor-in-Chief), Doctor of Geological and Mineralogical Sciences, Professor, Academician of NAS RK, Director of the Akhmedsafin Institute of Hydrogeology and Geocology (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=56955769200>, <https://www.webofscience.com/wos/author/record/1937883>

ZHOLTAEV Geroy Zholtayevich, Doctor of Geological and Mineralogical Sciences, Professor, Honorary Academician of NAS RK (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=57112610200>, <https://www.webofscience.com/wos/author/record/1939201>

SNOW Daniel, PhD, Associate Professor, Director, Aquatic Sciences Laboratory, University of Nebraska (Nebraska, USA), <https://www.scopus.com/authid/detail.uri?authorId=7103259215>, <https://www.webofscience.com/wos/author/record/1429613>

SELMANN Reimar, PhD, Head of Petrology and Mineral Deposits Research in the Earth Sciences Department, Natural History Museum (London, England), <https://www.scopus.com/authid/detail.uri?authorId=55883084800>, <https://www.webofscience.com/wos/author/record/1048681>

PANFILOV Mikhail Borisovich, Doctor of Technical Sciences, Professor at the University of Nancy (Nancy, France), <https://www.scopus.com/authid/detail.uri?authorId=7003436752>, <https://www.webofscience.com/wos/author/record/1230499>

SHEN Ping, PhD, Deputy Director of the Mining Geology Committee of the Chinese Geological Society, Member of the American Association of Economic Geologists (Beijing, China), <https://www.scopus.com/authid/detail.uri?authorId=57202873965>, <https://www.webofscience.com/wos/author/record/1753209>

FISCHER Axel, PhD, Associate Professor, Technical University of Dresden (Dresden, Berlin), <https://www.scopus.com/authid/detail.uri?authorId=35738572100>, <https://www.webofscience.com/wos/author/record/2085986>

AGABEKOV Vladimir Enokovich, Doctor of Chemical Sciences, Academician of NAS of Belarus, Honorary Director of the Institute of Chemistry of New Materials (Minsk, Belarus), <https://www.scopus.com/authid/detail.uri?authorId=7004624845>

CATALIN Stefan, PhD, Associate Professor, Technical University of Dresden, Germany, <https://www.scopus.com/authid/detail.uri?authorId=35203904500>, <https://www.webofscience.com/wos/author/record/1309251>

Jay Sagin, PhD, Associate Professor, Nazarbayev University (Astana, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=57204467637>, <https://www.webofscience.com/wos/author/record/907886>

FRATTINI Paolo, PhD, Associate Professor, University of Milano - Bicocca (Milan, Italy), <https://www.scopus.com/authid/detail.uri?authorId=56538922400>

NURPEISOVA Marzhan Baysanova – Doctor of Technical Sciences, Professor of Satbayev University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=57202218883>, <https://www.webofscience.com/wos/author/record/AAD-1173-2019>

RATOV Boranbay Tovbasarovich, Doctor of Technical Sciences, Professor, Head of the Department of Geophysics and Seismology, Satbayev University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=55927684100>, <https://www.webofscience.com/wos/author/record/1993614>

RONNY Berndtsson, Professor at the Center of Promising Middle Eastern Research, Lund University (Sweden), <https://www.scopus.com/authid/detail.uri?authorId=7005388716>, <https://www.webofscience.com/wos/author/record/1324908>

MIRLAS Vladimir, Faculty chemical engineering and Oriental research center, Ariel University, (Israel), <https://www.scopus.com/authid/detail.uri?authorId=8610969300>, <https://www.webofscience.com/wos/author/record/53680261>

N E W S O F T H E N A T I O N A L A C A D E M Y O F S C I E N C E S O F T H E R E P U B L I C O F K A Z A K H S T A N , S E R I E S O F G E O L O G Y A N D T E C H N I C A L S C I E N C E S

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Owner: «Central Asian Academic research center» LLP (Almaty).

The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420**, issued 29.07.2020.

Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*

Periodicity: 6 times a year.

<http://www.geolog-technical.kz/index.php/en/>

БАС РЕДАКТОР

ЖУРЫНОВ Мұрат Жұрынұлы, химия ғылымдарының докторы, профессор, КР ҰҒА академигі, РКБ «Қазақстан Республикасы Ұлттық Ғылым академиясының» президенті, АҚ «Д.В. Сокольский атындағы отын, катализ және электрохимия институтының» бас директоры (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

БАС РЕДАКТОРДЫҢ ОРЫНБАСАРЫ:

АБСАДЫҚОВ Бақыт Нарікбайұлы, техника ғылымдарының докторы, профессор, КР ҰҒА академигі, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6504694468>, <https://www.webofscience.com/wos/author/record/2411827>

РЕДАКЦИЯ АЛҚАСЫ:

ӘБСӘМЕТОВ Мәліс Құдысұлы (бас редактордың орынбасары), геология-минералогия ғылымдарының докторы, профессор, КР ҰҒА академигі, У.М. Ахмедсағин атындағы Гидрогеология және геоэкология институтының директоры, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=56955769200>, <https://www.webofscience.com/wos/author/record/1937883>

ЖОЛАТАЕВ Герой Жолтайұлы, геология-минералогия ғылымдарының докторы, профессор, КР ҰҒА құрметті академигі, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57112610200>, <https://www.webofscience.com/wos/author/record/1939201>

СНОУ Дэниел, PhD, қауымдастырылған профессор, Небраска университетінің Су ғылымдары зертханасының директоры, (Небраска штаты, АҚШ), <https://www.scopus.com/authid/detail.uri?authorId=7103259215>, <https://www.webofscience.com/wos/author/record/1429613>

ЗЕЛЬТМАНН Раймар, PhD, Жер туралы ғылымдар бөлімінің петрология және пайдалы қазбалар кен орындары саласындағы зерттеулерінің жетекшісі, Табиги тарих мұражайы, (Лондон, Ұлыбритания), <https://www.scopus.com/authid/detail.uri?authorId=55883084800>, <https://www.webofscience.com/wos/author/record/1048681>

ПАНФИЛОВ Михаил Борисович, техника ғылымдарының докторы, Нанси университетінің профессоры, (Нанси, Франция), <https://www.scopus.com/authid/detail.uri?authorId=7003436752>, <https://www.webofscience.com/wos/author/record/1230499>

ШЕН Пин, PhD, Қытай геологиялық қоғамының Тау-кен геологиясы комитеті директорының орынбасары, Американдық экономикалық геологтар қауымдастырының мүшесі, (Бейзін, Қытай), <https://www.scopus.com/authid/detail.uri?authorId=57202873965>, <https://www.webofscience.com/wos/author/record/1753209>

ФИШЕР Аксель, қауымдастырылған профессор, PhD, Дрезден техникалық университеті, (Дрезден, Берлин), <https://www.scopus.com/authid/detail.uri?authorId=35738572100>, <https://www.webofscience.com/wos/author/record/2085986>

АГАБЕКОВ Владимир Енокович, химия ғылымдарының докторы, Беларусь ҰҒА академигі, Жана материдар химиясы институтының құрметті директоры, (Минск, Беларусь), <https://www.scopus.com/authid/detail.uri?authorId=7004624845>

КАТАЛИН Стефан, PhD, қауымдастырылған профессор, Техникалық университеті (Дрезден, Германия), <https://www.scopus.com/authid/detail.uri?authorId=35203904500>, <https://www.webofscience.com/wos/author/record/1309251>

САҒЫНТАЕВ Жанай, PhD, қауымдастырылған профессор, Назарбаев университеті (Астана, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57204467637>, <https://www.webofscience.com/wos/author/record/907886>

ФРАТТИНИ Паоло, PhD, қауымдастырылған профессор, Бикокк Милан университеті, (Милан, Италия), <https://www.scopus.com/authid/detail.uri?authorId=56538922400>

НҮРПЕСІСОВ Маржан Байсансызы – Техника ғылымдарының докторы, Қ.И. Сәтбаев атындағы Қазақ ұлттық зерттеу техникалық университетінің профессоры, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57202218883>, <https://www.webofscience.com/wos/author/record/AAD-1173-2019>

РАТОВ Боранбай Товбасарович, техника ғылымдарының докторы, профессор, «Геофизика және сейсмология» кафедрасының мөнгерушісі, Қ.И. Сәтбаев атындағы Қазақ ұлттық зерттеу техникалық университеті, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=55927684100>, <https://www.webofscience.com/wos/author/record/1993614>

РОННИ Бернітссон, Лунд университетінің Тау Шығысты перспективалы зерттеу орталығының профессоры, Лунд университетінің толық курсты профессоры, (Швеция), <https://www.scopus.com/authid/detail.uri?authorId=7005388716>, <https://www.webofscience.com/wos/author/record/1324908>

МИРЛАС Владимир, Ариэль университетінің Химиялық инженерия факультеті және Шығыс ғылыми зерттеу орталығы, (Израиль), <https://www.scopus.com/authid/detail.uri?authorId=8610969300>, <https://www.webofscience.com/wos/author/record/53680261>

**NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN,
SERIES OF GEOLOGY AND TECHNICAL SCIENCES**

**ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)**

Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).

Казахстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген № KZ39VPY00025420 мерзімдік басылым тіркеуіне койылу туралы қуалік.

Такырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылдан 6 рет.

<http://www.geolog-technical.kz/index.php/en/>

© «Орталық Азия академиялық ғылыми орталығы» ЖШС, 2025

ГЛАВНЫЙ РЕДАКТОР

ЖУРИНОВ Мурат Журинович, доктор химических наук, профессор, академик НАН РК, президент РОО Национальной академии наук Республики Казахстан, генеральный директор АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского» (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

ЗАМЕСТИТЕЛЬ ГЛАВНОГО РЕДАКТОРА

АБСАДЫКОВ Бахыт Нарикбаевич, доктор технических наук, профессор, академик НАН РК, Казахский национальный исследовательский технический университет им. К.И. Сатпаева (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6504694468>, <https://www.webofscience.com/wos/author/record/2411827>

РЕДАКЦИОННАЯ КОЛЛЕГИЯ:

АБСАМЕТОВ Малис Кудысович, (заместитель главного редактора), доктор геолого-минералогических наук, профессор, академик НАН РК, директор Института гидрогеологии и геоэкологии им. У.М. Ахмедсафина (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=56955769200>, <https://www.webofscience.com/wos/author/record/1937883>

ЖОЛТАЕВ Герой Жолтаевич, доктор геологоминералогических наук, профессор, почетный академик НАН РК (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57112610200>, <https://www.webofscience.com/wos/author/record/1939201>

СНОУ Дэнниел, PhD, ассоциированный профессор, директор Лаборатории водных наук Университета Небраски (штат Небраска, США), <https://www.scopus.com/authid/detail.uri?authorId=7103259215>, <https://www.webofscience.com/wos/author/record/1429613>

ЗЕЛЬТМАНН Раймар, PhD, руководитель исследований в области петрологии и месторождений полезных ископаемых в Отделе наук о Земле Музея естественной истории (Лондон, Англия), <https://www.scopus.com/authid/detail.uri?authorId=55883084800>, <https://www.webofscience.com/wos/author/record/1048681>

ПАНФИЛОВ Михаил Борисович, доктор технических наук, профессор Университета Нанси (Нанси, Франция), <https://www.scopus.com/authid/detail.uri?authorId=7003436752>, <https://www.webofscience.com/wos/author/record/1230499>

ШЕН Пин, PhD, заместитель директора Комитета по горной геологии Китайского геологического общества, член Американской ассоциации экономических геологов (Пекин, Китай), <https://www.scopus.com/authid/detail.uri?authorId=57202873965>, <https://www.webofscience.com/wos/author/record/1753209>

ФИШЕР Аксель, ассоциированный профессор, PhD, технический университет Дрезден (Дрезден, Берлин), <https://www.scopus.com/authid/detail.uri?authorId=35738572100>, <https://www.webofscience.com/wos/author/record/2085986>

АГАБЕКОВ Владимир Енокович, доктор химических наук, академик НАН Беларуси, почетный директор Института химии новых материалов (Минск, Беларусь), <https://www.scopus.com/authid/detail.uri?authorId=7004624845>

КАТАЛИН Стефан, PhD, ассоциированный профессор, Технический университет (Дрезден, Германия), <https://www.scopus.com/authid/detail.uri?authorId=35203904500>, <https://www.webofscience.com/wos/author/record/1309251>

САГИНТАЕВ Жанай, PhD, ассоциированный профессор, Назарбаев университет (Астана, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57204467637>, <https://www.webofscience.com/wos/author/record/907886>

ФРАТТИНИ Паоло, PhD, ассоциированный профессор, Миланский университет Бикокк (Милан, Италия), <https://www.scopus.com/authid/detail.uri?authorId=56538922400>

НУРПЕИСОВА Маржан Байсанова – доктор технических наук, профессор Казахского Национального исследовательского технического университета им. К.И. Сатпаева, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57202218883>, <https://www.webofscience.com/wos/author/record/AAD-1173-2019>

ПАТОВ Боранбай Товбасарович, доктор технических наук, профессор, заведующий кафедрой «Геофизика и сейсмология», Казахский Национальный исследовательский технический университет им. К.И. Сатпаева, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=55927684100>, <https://www.webofscience.com/wos/author/record/1993614>

РОННИ Бернхтссон, Профессор Центра перспективных ближневосточных исследований Лундского университета, профессор (полный курс) Лундского университета, (Швеция), <https://www.scopus.com/authid/detail.uri?authorId=70053887116>, <https://www.webofscience.com/wos/author/record/1324908>

МИРЛАС Владимир, Факультет химической инженерии и Восточный научно-исследовательский центр, Университет Ариэля, (Израиль), <https://www.scopus.com/authid/detail.uri?authorId=8610969300>, <https://www.webofscience.com/wos/author/record/53680261>

**NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN,
SERIES OF GEOLOGY AND TECHNICAL SCIENCES**

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан № KZ39VPY00025420, выданное 29.07.2020 г.

Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*

Периодичность: 6 раз в год.

<http://www.geolog-technical.kz/index.php/en/>

©ТОО «Центрально-азиатский академический научный центр», 2025

CONTENTS

Sh.K. Aitkazinova, B.B. Imansakipova, O.O. Sdvizhkova, D.M. Kirgizbaeva, A.B. Imansakipova	
Localization of the sinkhole hazard of the earth's surface during underground mining.....	8
T.M. Almenov, R.K. Zhanakova, G.E. Askarova, M.R. Shautenov, K. Amantayuly	
Comprehensive assessment of ore losses and dilution impacting Vasilkovsky gold deposit profitability.....	27
K.A. Bashmur, V.V. Bukhtoyerov, N.N. Bryukhanova, R.V. Kononenko, V.V. Kondratyev	
Intelligent diagnostics and prediction of wear of drilling equipment elements using LSTM and GRU models.....	46
A.Z. Bukayeva, V.V. Povetkin	
Development of thermal jet tool for preparation and combustion of pulverized coal fuel.....	59
A.Z. Darkhan, A.A. Anarbayev	
Study of the process of producing ceramic granite based on mineral raw materials and silica production waste.....	74
G.K. Dzhangulova, T.V. Dedova, O.P. Kuznetsova, N.Z. Bashirova, A.A. Kalybekova	
Dam break flooding simulation using a dem constructed from lidar data.....	92
B.T. Zhumabayev, A.A. Altaibek, A.T. Sarsembayeva, M. Nurtas	
Space weather influence on seismic activity: analyzing the May 1, 2011, MW 5.1 earthquake in Kazakhstan.....	109
S. Zhussupbekov, L. Abzhanova, Y. Orakbaev, S. Sagyndykova, A. Kuanyshbayeva	
Network hydrodynamic model of underground uranium leaching.....	125
G.I. Issayev, I.G. Ikramov, N.A. Akhmetov, G.Zh. Turmetova, R. Izimova	
The impact of lead production on the nature of the distribution of slag waste in the environment.....	137
B. Isakulov, D. Zhumamuratov, H. Abdullaev, Z. Tukashev, A. Issakulov	
Increasing the durability of deep impregnation arbolite with gray petrochemical wastes.....	153

Israa J. Alhani, Wael M. AlbadriDeveloping prediction equation for the swelling and swelling pressure
of swellable clay based on experimental data.....169**A.G. Kassanova, G.M. Efendihev, I.A. Piriverdiyev, M.K. Karazhanova,
N.M. Akhmetov**Assessment of the characteristics of the geological section of wells based
on complex geophysical and technological information.....184**S.Zh. Kassymkhanov, K.K. Tolubayeva**

Rheological model of molding mixtures in foundry machines.....199

A. Kuttybayev, O. Khayitov, L. Saidova, A. Umirzokov, Y. MakhatThe influence of chloride ions on uranium sorption from productive solutions
of sulfuric acid leaching of ores.....211**A.N. Munaitpassova, A.K. Zheksenbaeva, A. Zhadi, A. Zhanat**

Regional climate changes in Almaty region under global climate change.....222

**M.N. Mussabayeva, T.K. Salikhov, Sh.K. Musabayeva, Y.K. Shulghaubayev,
G.K. Baimukasheva**

Natural resource potential of the lake geosystem of Akmola region.....242

A. Mustafina, Zh. Inkarova, G. Baimukasheva, M. Jexenov, Zh. TukhfatovImpact of oil and gas fields on atmospheric air and public health in Atyrau
region (a case study of Zhylyoi district).....260**K.G. Satenov, Ye.M. Suleimen, G.K. Mamytbekova, A.S. Kalauova**Development and modeling of a resource-saving process for methanol
extraction by the example of X oilfield.....280**D.Kh. Sunakbaeva, D.Kh. Yuldashbek, K. Aitekova, S.M. Nurmakova,
M. Waris**Assessment of the effectiveness of biostabilization in improving the geotechnical
properties of degraded soils in the arid regions of Kazakhstan.....295**E.V. Khudyakova, V.V. Kukartsev, A.A. Stupina, S.V. Pchelintseva,
K.S. Muzalev**Machine learning for modelling the impact of geo-environmental factors
on natural resource allocation.....312

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 4. Number 472 (2025), 125–136

<https://doi.org/10.32014/2025.2518-170X.534>

UDC 681.51:622.234.42(043)

© S. Zhussupbekov*, L. Abzhanova, Y. Orakbaev, S. Sagyndykova,
A. Kuanyshbayeva, 2025.

Almaty University of Power Engineering and Communications,
Almaty, Kazakhstan.

E-mail: l.abzhanova@aues.kz

NETWORK HYDRODYNAMIC MODEL OF UNDERGROUND URANIUM LEACHING

Zhussupbekov Sarsenbek Seitbekovich — Candidate of technical sciences, professor department of «Automation and control», Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev, Almaty, Kazakhstan,

E-mail: s.zhussupbekov@aues.kz, <https://orcid.org/0000-0003-3220-713X>;

Abzhanova Laulassyn Kossylganovna — PhD, associate professor, head of the department of «Automation and control» Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev, Almaty, Kazakhstan,

E-mail: l.abzhanova@aues.kz, <https://orcid.org/0000-0003-1781-269X>;

Orakbaev Yerbol Zhumageldievich — PhD, associate professor, department of «Automation and control», Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev, Almaty, Kazakhstan,

E-mail: e.orakbaev@aues.kz, <https://orcid.org/0000-0003-3100-7419>;

Sagyndykova Sholpan Nazarovna — Candidate of technical sciences, associate professor department of «Automation and control», Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev, Almaty, Kazakhstan,

E-mail: sh.sagyndykova@aues.kz, <https://orcid.org/0000-0001-5909-584X>.

A. Kuanyshbayeva — Master of engineering sciences, senior lecturer, department of «Automation and control», Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev, Almaty, Kazakhstan,

E-mail: a.kuanyshbayeva@aues.kz, <https://orcid.org/0009-0002-3701-7108>

Abstract. Uranium is a strategic raw material widely used in nuclear energy. Among the existing methods of uranium mining, open and underground mining, as well as in-situ leaching (ISL), are widely applied. ISL is recognized as the most environmentally friendly and cost-effective method for developing hydrogenous uranium deposits. In Kazakhstan, all hydrogenous uranium deposits are developed using the ISL method. The efficiency of the process significantly depends on timely control of parameters, which emphasizes the need for mathematical modeling. This paper presents modern approaches to managing the ISL process based on

mathematical models. Particular attention is paid to the network hydrodynamic model, which, using data on uranium concentration, environmental permeability, and other geotechnological parameters, increases the profitability of deposit development. Measuring flow rates and nodal pressures in a well network allows calculation of the pressure drop in the ore body between injection and production wells, as well as hydraulic resistance. Determining these parameters is important for increasing production efficiency, reducing energy costs, and minimizing reagent consumption. The obtained results create a scientific basis for developing innovative solutions in the field of ISL process automation. These solutions can be used to design optimal well placement schemes and determine the most effective cell radius. In the future, this study will contribute to the creation of an intelligent control system for the uranium leaching process. The use of neural networks for modeling and analyzing the ISL process is of particular interest and is a promising direction for further development.

Keywords: underground leaching, uranium mining, control system, network model, intelligent control systems, network graph, operational field

© С. Жусупбеков*, Л. Абжанова, Е. Оракбаев, Ш. Сагындыкова,
Ә. Қуанышбаева, 2025.

Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс
университеті. Алматы, Қазақстан.

E-mail: l.abzhanova@aues.kz

УРАНДЫ ЖЕРАСТЫ ШАЙМАЛАУДЫҢ ЖЕЛІЛІК ГИДРОДИНАМИКАЛЫҚ МОДЕЛІ

Жусупбек Сарсенбек Сейтбекович — техника ғылымдарының кандидаты, «Автоматтандыру және басқару» кафедрасының профессоры, Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс университеті, Алматы, Қазақстан,
E-mail: s.zhussupbekov@aues.kz, <https://orcid.org/0000-0003-3220-713X>;

Абжанова Лауласын Қосылғановна — PhD, «Автоматтандыру және басқару» кафедрасының менгерушісі, доцент, Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс университеті, Алматы, Қазақстан,

E-mail: l.abzhanova@aues.kz, <https://orcid.org/0000-0003-1781-269X>;

Оракбаев Ербол Жұмагельдиевич — PhD, «Автоматтандыру және басқару» кафедрасының доценті, Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс университеті, Алматы, Қазақстан,

E-mail: e.orakbaev@aues.kz, <https://orcid.org/0000-0003-3100-7419>;

Сагындыкова Шолпан Назаровна — техника ғылымдарының кандидаты, «Автоматтандыру және басқару» кафедрасының доценті, Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс университеті, Алматы, Қазақстан,

E-mail: sh.sagyndykova@aues.kz, <https://orcid.org/0000-0001-5909-584X>;

Қуанышбаева Әсемай Тынышбайқызы — техника ғылымдарының магистрі, «Автоматтандыру және басқару» кафедрасының аға оқытушысы, Ғұмарбек Дәүкес атындағы Алматы энергетика және байланыс университеті, Алматы, Қазақстан,

E-mail: a.kuanyshbayeva@aues.kz, <https://orcid.org/0009-0002-3701-7108>.

Аннотация. Уран – ядролық энергетикада кеңінен қолданылатын стратегиялық шикізат. Уранды өндірудің қолданыстағы әдістерінің ішінде карьерлік, шахталық және жерасты сілтісіздендіру әдістерін атауға болады. Соңғы әдіс гидрогендік уран кен орындары үшін экологиялық және экономикалық жағынан ең тиімді әдіс ретінде танылады және қазіргі таңда кеңінен қолданылады. Қазақстан Республикасында барлық гидрогендік уран кен орындары жерасты сілтісіздендіру әдісімен игерілуде. Бұл процестің тиімділігі оның параметрлерін үақтылы басқаруға тікелей байланысты болғандықтан, осы процестің нақты математикалық моделін жасау қажеттілігін көрсетеді. Бұл мақалада процестің математикалық моделіне негізделген жерасты шаймалау процесін басқарудың заманауи тәсілдері жанжақты талқыланады. Әсіресе, уранның концентрациясы, орта өткізгіштігінің көрсеткіштері және басқа да геотехнологиялық сипаттамалар негізінде кен орнын игерудің тиімділігін арттыратын желілік гидродинамикалық модельге ерекше назар аударылады. Ағын шығыны мен тораптық қысымдар бойынша жүргізілетін өлшеулер айдау және сорғы ұнғымалары арасындағы кен орнында қысым айырмасын және гидравликалық кедергілерді нақты анықтауға мүмкіндік береді. Бұл параметрлерді дәл анықтау өндірістік тиімділікі арттыруға, энергия шығынын төмендетуге және реагенттерді үнемдеуге мүмкіндік береді. Алынған нәтижелер жерасты сілтісіздендіру процесін автоматтандыруды инновациялық шешімдерді әзірлеуге қажетті ғылыми негіз бола алады. Бұл шешімдер ұнғымаларды орналастырудың технологиялық схемасын жобалауға, ұяшықтың тиімді радиусын дәл анықтауға қолданыла алады. Зерттеу нәтижелері болашакта уран сілтісіздендіру процесін интеллектуалды басқару жүйесін құруда кеңінен пайдаланылатын болады. Жерасты сілтісіздендіру процесін зерттеуде нейрондық желілерді қолдану – ерекше ғылыми қызығушылық тудырады.

Түйін сөздер: жерасты шаймалау, уран өндіру, басқару жүйесі, желілік модель, интеллектуалды басқару жүйелері, желілік график, пайдалану өрісі

**© С. Жусупбеков*, Л. Абжанова, Е. Оракбаев, Ш. Сагындыкова,
А. Куанышбаева, 2025.**

Алматинский университет энергетики и связи имени Гумарбека Даукеева,
Алматы, Казахстан.

E-mail: l.abzhanova@aues.kz

СЕТЕВАЯ ГИДРОДИНАМИЧЕСКАЯ МОДЕЛЬ ПОДЗЕМНОГО ВЫЩЕЛАЧИВАНИЯ УРАНА

Жусупбеков Сарсенбек Сейтбекович — кандидат технических наук, профессор кафедры «Автоматизация и управление», Алматинский университет энергетики и связи имени Гумарбека Даукеева, Алматы, Казахстан,
E-mail: s.zhussupbekov@aues.kz, <https://orcid.org/0000-0003-3220-713X>;

Абжанова Лауласын Косылгановна — PhD, ассоциированный профессор, заведующая кафедрой «Автоматизация и управление», Алматинский университет энергетики и связи имени Гумарбека Даукеева, Алматы, Казахстан,

E-mail: l.abzhanova@aues.kz, <https://orcid.org/0000-0003-1781-269X>;

Оракбаев Ербол Жумагелдиевич — PhD, ассоциированный профессор, кафедры «Автоматизация и управление», Алматинский университет энергетики и связи имени Гумарбека Даукеева, Алматы, Казахстан,

E-mail: e.orakbaev@aues.kz, <https://orcid.org/0000-0003-3100-7419>;

Сагындыкова Шолпан Назаровна — кандидат технических наук, ассоциированный профессор кафедры «Автоматизация и управление», Алматинский университет энергетики и связи имени Гумарбека Даукеева, Алматы, Казахстан,

E-mail: sh.sagyndykova@aues.kz, <https://orcid.org/0000-0001-5909-584X>;

Куанышбаева Асемай Тынышбайкызы — магистр техн. наук, старший преподаватель кафедры «Автоматизация и управление», Алматинский университет энергетики и связи имени Гумарбека Даукеева, Алматы, Казахстан,

E-mail: a.kuanyshbayeva@aues.kz, <https://orcid.org/0009-0002-3701-7108>.

Аннотация. Уран является стратегическим сырьём, широко применяемым в ядерной энергетике. Среди существующих методов добычи урана можно выделить методы: карьерный, шахтный и подземного выщелачивания. Последний метод признан наиболее экологичным и экономически эффективным для гидрогенных урановых месторождений. В Республике Казахстан методом подземного выщелачивания разрабатываются все гидрогенные урановые месторождения. Эффективность данного процесса в значительной степени зависит от своевременного управления его параметрами, что подчёркивает необходимость разработки математической модели процесса. В данной статье рассматриваются современные подходы к управлению процессом подземного выщелачивания на основе математической модели процесса. Особое внимание уделено сетевой гидродинамической модели процесса, которая позволяет на основе данных о концентрациях урана, показателях проницаемости среды и других геотехнологических характеристиках повысить рентабельность разработки месторождений. Измерения расходов потоков и узловых напоров в сети позволяют определять перепад давлений на рудном теле между закачкой и откачкой скважиной и гидросопротивление рудного тела. Определение этих параметров направлено на повышение производственной эффективности, сокращение энергозатрат и расхода реагентов. Полученные результаты создают научную основу для разработки инновационных решений в области автоматизации процесса подземного выщелачивания урана. Эти решения могут быть применены для проектирования технологической схемы расположения скважин и определения оптимального радиуса ячейки. В дальнейшем результаты данного исследования будут применяться для создания интеллектуальной системы управления процессом выщелачивания урана. Особый интерес представляет применение нейронных сетей для исследования процесса подземного выщелачивания урана.

Ключевые слова: подземное выщелачивание, добыча урана, система

управления, сетевая модель, интеллектуальные системы управления, граф сети, эксплуатационное поле

Introduction.

The development of a hydrogenous uranium deposit is carried out by the simplest, highly effective method of in-situ leaching (ISL) (Laverov et al., 1998). Uranium is extracted from the ore body through a system of process wells. A working solution, usually consisting of a sulfuric acid solution capable of dissolving uranium-containing minerals, is fed into the productive horizon through injection wells. As a result of the physicochemical interaction of the leaching solutions with the ore-forming minerals in the productive horizon, a productive solution is formed containing useful components, which is then extracted to the surface using a system of pumping wells (Beletsky et al., 1997). The main objectives of managing the geotechnological process of in-situ leaching are to increase the profitability of deposit development, increase the share of uranium extracted from the productive horizon, and reduce groundwater pollution (Zhiganov et al., 2001). To solve these problems, information is needed on the hydrogeological state of the productive horizon and groundwater, as well as methods of deposit development (Muzaparov, 2011). Hydrogeological initial data include information on the permeability of ores and host rocks, the position of the piezometric level of groundwater, the pressure of various aquifers found in the deposit section and the nature of their connections with each other, the temperature and composition of groundwater (Ravshanov et al, 2025). These data are needed to determine the isolation zones in wells, select the number of columns when designing wells, determine the type of well pump for pumping out productive solutions and select the design of the receiving part of the wells (Istomin et al., 2013).

In the Republic of Kazakhstan, the underground leaching method is used for all hydrogenic uranium deposits. The advantage of the method is the processing of large reserves of poor ores, as well as individual deposits with small reserves of the useful component. Despite this, the efficiency of this process largely depends on the timely management of its parameters, which emphasizes the need to develop a mathematical model of the process. The existing practice of managing the technological process of underground leaching is aimed at maintaining the balance flow characteristics of leaching and productive solutions. In this case, the tasks for flow characteristics are determined empirically. Thus, the process is controlled under conditions of insufficient information on the current characteristics of the ore body.

This paper proposes the development of a network hydrodynamic model of the in-situ leaching process, designed to optimize uranium mining by the in-situ leaching method, allowing the selection of the optimal method for developing a deposit.

In practice, depending on the location of injection and extraction wells, the

scheme for opening the production field of a hydrogenous uranium deposit is determined (Altayev et al., 2003).

Materials and methods

The objective of ISL process management is to increase the efficiency of uranium extraction from the subsoil and reduce the cost of uranium mining. This can be achieved by creating optimal physical and chemical conditions for the transition of uranium from ore to process solutions and optimal hydrodynamic conditions for uranium extraction to the surface with the productive solution through pumping wells. Factors that negatively affect the efficiency of ISL are incorrect layout of process wells, dilution of the productive solution with formation waters, the release of process solutions beyond the ore deposits, uneven leaching of uranium in the block and the formation of pillars, and low intensity of uranium extraction (Bugenov et al., 2006). These phenomena lead to an increase in the terms of block development, an increase in the specific consumption of acid and the L:S ratio, a decrease in the concentration of uranium in the productive solution, and, as a consequence, an increase in material and financial costs per unit of output (Dzhakupov, 2019).

Results. One of the main indicators of the underground leaching process is the pressure difference on the ore body between the injection and extraction wells, which is determined by Darcy's law (Mukhanov et al., 2016).

$$\Delta P_i = r_i Q_i \quad (1)$$

where r_i – is the hydraulic resistance of the ore body.

The value r – of hydraulic resistance to filtration of a liquid solution in a porous medium during plane-radial movement is determined by the expression (Rogov et al., 2000):

$$r = \frac{\ln \frac{R_o}{R_c} + C_k}{2,3 K_\Phi H} \quad (2)$$

The process of underground leaching includes the simultaneous operation of N process wells, consisting of N_{sc} injection wells and N_{oc} pumping wells.

$$N = N_{\text{sc}} + N_{\text{oc}} \quad (3)$$

In addition, depending on the location of the process wells, linear, hexagonal and square underground leaching schemes are distinguished (Tsoy et al., 2016).

Thus, the well network with the technological layout scheme and with the ore-bearing permeable layer, as well as with surface pipelines and pumps form a single network hydrodynamic structure. This network structure is a very complex artificial network system (wells, filters, pipelines, pumps), interacting with an even more complex natural system - a rock massif containing an ore-bearing layer (Ismanova et al., 2021).

Using the principle of superposition of the potential field ΔP of pressures on wells, taking into account the interaction of all N wells with each other for a

stationary steady flow, we obtain the following system of equations (Rogov et al., 2000).

$$\begin{cases} r_{11}Q_1 + r_{12}Q_2 + \dots + r_{1N}Q_N = \Delta P_1 \\ r_{21}Q_1 + r_{22}Q_2 + \dots + r_{2N}Q_N = \Delta P_2 \\ \dots \\ r_{N1}Q_1 + r_{N2}Q_2 + \dots + r_{NN}Q_N = \Delta P_N \end{cases} \quad (4)$$

where Q_i – is the productivity of the i -th well.

The productivity of a pumping well is determined by the expression (Yazikov, 2014).

$$Q_i = \frac{1,157 \cdot n \cdot 2\pi \cdot K_\phi \cdot M_s \cdot (S_h + S_o)}{100 \cdot (\ln \frac{R_o}{R_c} + S_k)} \quad (5)$$

We determine the productivity of the injection well, that is, the injection of the working reagent into the formation per unit of time:

$$Q_i = \frac{1,157 \cdot n \cdot 2\pi \cdot K_\phi \cdot M_s \cdot S_h}{100 \cdot (\ln \frac{R_o}{R_c} + S_k)} \quad (6)$$

Where,

R_o – optimal cell radius, m;

R_c – actual cell radius, m;

K_ϕ – filtration coefficient in the ore part of the horizon;

M_s – effective capacity of the productive horizon;

S_h – pressure at injection wells, m H₂O;

S_k – depression in pumping wells, m of water column;

n – the ratio of the number of injection wells to the number of pumping wells.

The optimal cell radius is determined from the following expression (Yazikov et al., 2005) for the hexagonal scheme:

$$R_o = \sqrt[4]{\frac{S \cdot (n+1) \cdot H \cdot C_{cck} \cdot K_\phi \cdot \beta \cdot (n \cdot S_h + S_o) \cdot \pi \cdot \ln(\ln \frac{R_L}{R_c})}{395 \cdot f \cdot \rho_n \cdot C_s}} \quad (7)$$

Where

$$\beta = \frac{4,23}{\left(\ln \frac{R_L}{R_c} + S_k \right) \cdot \ln \left(\ln \frac{R_L}{R_c} \right)} \quad (8)$$

Optimal radius of the linear process flow diagram:

$$R_o = \sqrt[4]{\frac{S \cdot (n+1) \cdot H \cdot C_{cck} \cdot K_\phi \cdot \beta \cdot (n \cdot S_h + S_o) \cdot \pi \cdot (\xi^2 + 0,25)^2 \cdot \ln \left(\ln \frac{R_L}{R_c} \right)}{160 \cdot f \cdot \rho_n \cdot C_s \cdot \xi (\xi + 1)^2}} \quad (9)$$

$$\beta = \frac{11,04}{\alpha \cdot \left(\ln \frac{R_I}{R_c} + S_k \right) \cdot \ln \left(\ln \frac{R_I}{R_c} \right)} \quad (10)$$

The optimal radius of a square cell is determined by the following expression:

$$R_o = \sqrt{\frac{S \cdot (n+1) \cdot H \cdot C_{ckk} \cdot K_\phi \cdot \beta \cdot (n \cdot S_n + S_o) \cdot \pi (\xi^2 + 0,25)^2 \cdot \ln \left(\ln \frac{R_I}{R_c} \right)}{331 \cdot f \cdot \rho_n \cdot C_s \cdot \xi (\xi + 1)^2}} \quad (11)$$

Where ξ – the ratio of the distance between rows to the distance between pumping wells in a row;

R_l – approximate cell radius, m;

f – W:T ratio;

ρ_n – density of rocks of the ore horizon;

C_s – daily operating costs for the mine;

C_{ckk} – cost of 1 linear meter of a technological well;

α – distance between pumped wells in a row, m.

$$\xi = \frac{b}{d}$$

b – distance between pumping and injection rows, m;

d – distance between pumping wells in a row, m.

Let us consider the arrangement of the sets of injection N_{bi} and extraction N_{bo} using the example of a network graph (Figure 1).

Considering that $\Delta P_i = P_{\text{bi}} - P_{\text{bo}}$ in accordance with the graph $G_o = (U, \Gamma)$ (Figure 1), we have expenses along the arcs [13]:

$$\begin{cases} q_{1-1} = \frac{1}{r_{11}} \Delta P_1 \\ q_{2-2} = \frac{1}{r_{22}} \Delta P_2 \\ \dots \dots \dots \\ q_{i-j} = \frac{1}{r_{ij}} \Delta P_{ij} \end{cases} \quad (12)$$

From equations (12) we obtain the flow rates of all N_{bi} and N_{bo} in the form of expenses along arcs $i - j$.

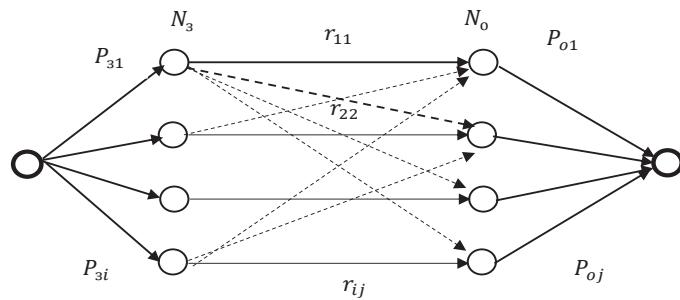


Figure 1-Graph G0 hydrodynamic system of underground leaching of uranium

For injection wells:

$$\begin{cases} Q_1 = \sum_{j=1}^{N_{oc}} q_{1-j} \\ Q_2 = \sum_{j=1}^{N_{oc}} q_{2-j} \\ \dots \dots \dots \\ Q_i = \sum_{j=1}^{N_{oc}} q_{i-j} \end{cases} \quad (13)$$

Similarly for pumping wells:

$$\begin{cases} Q_1^o = \sum_{j=1}^{N_{oc}} q_{j-1} \\ Q_2^o = \sum_{j=1}^{N_{oc}} q_{j-2} \\ \dots \dots \dots \\ Q_i^o = \sum_{j=1}^{N_{oc}} q_{j-i} \end{cases} \quad t \quad (14)$$

For an ideal network $G_o = (\mathcal{U}, \Gamma)$ the law of conservation of mass will always be observed in the form (Omelchenko A., 2018):

$$c_{sc} \sum_{i=1}^{N_{sc}} Q_i = c_{oc} \sum_{j=1}^{N_{oc}} Q_j^o \quad (15)$$

where c_{sc} – is the density of the solution at the input, t/m^3 ;

c_{oc} – solution density at the outlet, t/m^3

In the case where the productivity of injection wells is greater than the productivity of pumping wells, the solution spreads beyond the geometric contour of the geological block.

$$c_{sc} \sum_{i=1}^{N_{sc}} Q_i > c_{oc} \sum_{j=1}^{N_{oc}} Q_j^o \quad (16)$$

In cases where the productivity of injection wells is less than the productivity of pumping wells, the solution becomes diluted with water.

$$c_{\text{zc}} \sum_{i=1}^{N_{\text{zc}}} Q_i < c_{\text{oc}} \sum_{j=1}^{N_{\text{oc}}} Q_j^o \quad (17)$$

If the pressure at injection wells and the depression at pumping wells is a function of time $S_{\text{H}} = f(t)$ and $S_k = f(t)$, then, accordingly, $\Delta P_i = f(t), t \in (0, T), i = 1, N$.

Taking into account that the well parameters change depending on time, the system of equations (4) can be written in the form of partial differential equations:

$$\left\{ \begin{array}{l} r_{11} \frac{\partial Q_1(t)}{\partial t} + r_{12} \frac{\partial Q_2(t)}{\partial t} + \dots + r_{1N} \frac{\partial Q_N(t)}{\partial t} = \frac{\partial \Delta P_1(t)}{\partial t} \\ r_{21} \frac{\partial Q_1(t)}{\partial t} + r_{22} \frac{\partial Q_2(t)}{\partial t} + \dots + r_{2N} \frac{\partial Q_N(t)}{\partial t} = \frac{\partial \Delta P_2(t)}{\partial t} \\ \dots \dots \dots \dots \dots \dots \dots \\ r_{N1} \frac{\partial Q_1(t)}{\partial t} + r_{N2} \frac{\partial Q_2(t)}{\partial t} + \dots + r_{NN} \frac{\partial Q_N(t)}{\partial t} = \frac{\partial \Delta P_N(t)}{\partial t} \end{array} \right. \quad (18)$$

Using the finite difference method $\Delta t_1, \Delta t_2, \dots, \Delta t_N$ we find the solution to equations (18). In this case, the system of equations (4) is valid at each time interval Δt_i .

Discussion.

Analysis of modern methods of underground leaching of uranium shows that the efficiency of the leaching process depends most of all on the technological scheme of the well arrangement, the distance between rows, the distance between pumping wells in a row, the distance between injection wells in a row, i.e. on the hexagonal, triangular, square or linear scheme of the well arrangement (Alibaeva, 2013). Hydrodynamic flows in this case depend on the hydraulic resistance of filtration of the liquid solution in the porous medium, the filtration coefficient and the thickness of the ore-bearing filter layer (Galtsev et al., 2018). The flow rate of the pumping and injection well is directly proportional to the values of depressions and compressions in the pumping and injection wells and inversely proportional to the hydraulic resistances of the arcs of the graph between the pumping and injection wells (Terovskaya et al., 2021). For the most efficient metal recovery, the volume of the injected acid solution should be equal to the volume of the extracted productive solution. In this case, the balance of ore flows is regulated by pumping pumps. Selecting the optimal parameters of the well network allows for effective management of the process of underground leaching of uranium.

The main element of the control of the underground leaching process are mathematical models describing the processes occurring during uranium mining by the underground borehole leaching method. The mathematical model of the technological network allows determining the productivity of pumping and injection wells with known values of the network nodal pressures and the coefficient of hydraulic resistance of filtration. With known values of Q_i, Q_i^o and ΔP_{ij} , network models allow us to calculate the values of r_{ij} . Determining the values of r_{ij} of the

hydraulic resistance to filtration allows us to predict the costs along the network arcs, which allows us to effectively manage the process of underground leaching of uranium, adapt to changes in raw materials and optimally extract valuable components, which leads to increased productivity and reduced costs in the mining industry. Thus, the location of process wells along the geometric contour of a geological block with given network parameters is an important indicator of the process of underground borehole leaching of uranium.

Conclusions.

The results of the study confirm the high importance of the network approach in modeling and managing the process of underground leaching of uranium. The developed hydrodynamic model, based on graph theory and filtration equations, allows taking into account the spatial structure of the well system and predicting changes in flow parameters in real field conditions. Calculations of optimal cell radii for various well placement schemes (hexagonal, square, linear) allow a reasonable approach to the design of the production field. Measurements of reserves and nodal heads in the network allow for accurate determination of pressure differences between injection and pumping wells, as well as the hydraulic resistance of the ore body. This is critically important for maintaining flow balance, reducing solution losses and increasing the uranium recovery factor.

References

- Alibaeva K.A. (2013) Chislennoye issledovaniye putey povysheniya vyrobotki mestorozhdeniya pri dobyche mineralov metodom podzemnogo vyschelachivaniya [Numerical study of ways to increase the production of a deposit during the extraction of minerals by underground leaching] (Doctoral dissertation, Al-Farabi Kazakh National University). Republic of Kazakhstan, Almaty. (in Russian)
- Altayev Sh.A., et al., (2003) Tekhnologiya razrabotki gidrogennykh uranovykh mestorozhdeniy Kazakhstan [Technology of development of hydrogenic uranium deposits in Kazakhstan]. Almaty: IGD im. D.A. Kunayeva. (in Russian)
- Beletsky V.I., et al. (1997) Spravochnik po geotekhnologii urana [Handbook on geotechnology of uranium] (D.I. Skorovarov, Ed.). Moscow: Energoatomizdat. (in Russian)
- Bugenov E.S., & Vasilevskiy O.V. (2006) Fiziko-khimicheskie osnovy i tekhnologiya polucheniya khimicheskikh kontsentratov prirodnogo urana [Physicochemical fundamentals and technology of obtaining chemical concentrates of natural uranium]. Almaty: KazNTU. (in Russian)
- Dzhakupov D.A. (2019) Povyshenie effektivnosti razlichnykh skhem skvazhinogo podzemnogo vyschelachivaniya pri razrabotke slozhnykh hidrogennykh mestorozhdeniy [Improving the efficiency of various well-to-well underground leaching schemes in the development of complex hydrogenic deposits] (Doctoral dissertation, Kazakh National Research Technical University named after K. I. Satpayev). Almaty, Kazakhstan. (in Russian)
- Galtsev O.V., & Galtseva O.A. (2018) Matematicheskoe modelirovanie protsessa podzemnogo vyschelachivaniya na makroskopicheskom urovne [Mathematical modeling of in-situ leaching at the macroscopic level]. Nauchnye Vedomosti. Seriya: Matematika. Fizika, 50(4). — P. 478–486. <https://doi.org/10.18413/2075-4639-2018-50-4-478-486> (in Russian)
- Ismanova K.D., et al., (2021) Sistemnyi analiz protsessa podzemnogo vyschelachivaniya v kachestve obekta issledovaniya [System analysis of the underground leaching process as an object of research]. Ekonomika i Sotsium, (6–1(85)). Retrieved July 24, 2025, from <https://cyberleninka.ru/article/n/sistemnyy-analiz-protsessa-podzemnogo-vyschelachivaniya-v-kachestve-obekta-issledovaniya> (in Russian)

Istomin A.D., et al., (2013) Primenenie gorno-geologicheskoi informatsionnoi sistemy pri geologicheskem izuchenii i podgotovke gidrogennykh mestorozhdenii urana k osvoeniyu metodom podzemnogo vyschelachivaniya [Application of the mining and geological information system in geological exploration and preparation of hydrogenic uranium deposits for development by underground leaching method]. Izvestiya Rossiyskoy akademii yestestvennykh nauk, (7). — P. 19–24. (in Russian)

Laverov N.P., et al., (1998) Podzemnoe vyschelachivanie polielementnykh rud [Underground leaching of poly-element ores]. Moscow: Akademiya gornykh nauk. (in Russian)

Mukhanov B.K., Omirbekova Zh.Zh., & Orakbaev E.Zh. (2016) Research and development of an optimal control system for underground leaching. Bulletin of the National Academy of Sciences of the Republic of Kazakhstan, 5. — P. 178–185. (in English)

Muzaparov M.Zh. (2011) Napravlennoe burenie. Tom 5. Determinirovannaya tekhnologiya. Podzemnoe skvazhynnoe vyschelachivanie [Directional drilling. Volume 5. Deterministic technology. Underground well-to-well leaching]. Almaty: KazNTU. ISBN 978-601-278-493-0. (in Russian)

Omelchenko A. (2018) Teoriya grafov [Graph theory] (416 p.). Moscow: MCNMO. ISBN 978-5-4439-1247-9. (in Russian)

Podrezov D.R. (2021) Razrabotka i identifikatsiya modeley otsenki zapasov rudnika podzemnogo skvazhinnogo vyschelachivaniya urana [Development and identification of models for estimating the reserves of an underground uranium leaching mine] (Doctoral dissertation). Moscow. (in Russian)

Ravshanov N.P., & Usmonov L. (2025) Review of research on mathematical modeling of the process of underground leaching of minerals. International Journal of Theoretical and Applied Issues in Digital Technologies, 8(1). — P. 22–36. <https://doi.org/10.62132/ijdt.v8i1.230> (in English)

Rogov E.I., et al., (2000) Gidrodinamicheskaya model' podzemnogo vyschelachivaniya urana [Hydrodynamic model of underground uranium leaching]. Gornyi informatsionno-analiticheskii byulleten' (GIAB), (5). Retrieved July 24, 2025, from <https://cyberleninka.ru/article/n/gidrodinamicheskaya-model-podzemnogo-vyschelachivaniya-urana> (in Russian)

Terovskaya T.S., et al., (2021) Matematicheskaya model' izmeneniya sostoyaniya produktivnogo gorizonta pri serno-kislotnom skvazhinnom vyschelachivaniyu urana [Mathematical model of the productive horizon state change during sulfuric acid well leaching of uranium]. Izvestiya vysshikh uchebnykh zavedeniy. Fizika, 64(2/2). — P. 119–124. Retrieved July 24, 2025, from <http://vital.lib.tsu.ru/vital/access/manager/Repository/koha:000719540> (in Russian)

Tsoy S.V., & Zhusupbekov S.S. (2016) Osnovy razrabotki gidrogennykh mestorozhdeniy urana [Fundamentals of hydrogenic uranium deposit development]. Almaty: [Publisher not specified]. (in Russian)

Yazikov V.G. (2014) Osobennosti izucheniya geotekhnologicheskikh svoystv rud i geotekhnologicheskikh usloviy gidrogenного tipa [Features of studying geotechnological properties of ores and geotechnological conditions of the hydrogenic type]. Tomsk: TPU. (in Russian)

Yazikov V.G., & Belykh A.V. (2005) Problemy sozdaniya adaptivnoy k usloviyam okruzhayushchey sredy avtomatizirovannoy informatsionnoy sistemy upravleniya izvlecheniem metallov pri podzemnom skvazhinnom vyschelachivaniyu [Problems of creating an automated information system for managing metal extraction during underground well leaching that is adaptive to environmental conditions]. In Materialy III Mezhdunarodnoy nauchno-prakticheskoy konferentsii «Aktualnye problemy uranovoy promyshlennosti». — P. 138. Almaty. (in Russian)

Zhiganov A.N., et al., (2001) Postroenie geotekhnologicheskoy informatsionno-modeliruyushchey sistemy dlya upravleniya razrabotkoy mestorozhdeniya metodom podzemnogo vyschelachivaniya [Construction of a geotechnological information and modeling system for managing the development of a deposit by underground leaching]. In Materialy III Mezhdunarodnoy konferentsii «Problemy upravleniya i modelirovaniya v slozhnykh sistemakh». — P. 588–593. Samara: Samarskiy nauchnyy tsentr RAN. (in Russian)

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see <http://www.elsevier.com/publishingethics> and <http://www.elsevier.com/journal-authors/ethics>.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see <http://www.elsevier.com/postingpolicy>), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service <http://www.elsevier.com/editors/plagdetect>.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:

www:nauka-nanrk.kz
<http://www.geolog-technical.kz/index.php/en/>
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*

Редакторы: *Д.С. Аленов, Ж.Ш.Әден*

Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.08.2025.

Формат 70x90¹/₁₆. Бумага офсетная. Печать – ризограф.
20,5 п.л. Заказ 4.