ISSN 2518-1483 (Online),
ISSN 2224-5227 (Print)

ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES

№4
2025

ISSN 2518-1483 (Online),
ISSN 2224-5227 (Print)

2025 • 4

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES

PUBLISHED SINCE JANUARY 1944

ALMATY, NAS RK

ACADEMIC JOURNALOF PHYSICAL AND
CHEMICAL SCIENCES

2025 • 4

Editor-in-Chief:

ZHURINOV Murat Zhurinovich, Doctor of Chemical Sciences, Professor, Academician of NAS RK, Acting President of RPA NAS RK, General Director of JSC "Institute of Fuel, Catalysis and Electrochemistry named after D.V. Sokolsky" (Almaty, Kazakhstan) https://www.scopus.com/authid/detail.uri?authorId=6602177960

Editorial Board:

KALIMOLDAYEV Maksat Nuradilovich, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=56153126500

ADEKENOV Sergazy Mynzhasarovich, Doctor of Chemical Sciences, Professor, Academician of NAS RK, Director of the International Science and Production Holding "Phytochemistry" (Karaganda, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=7006153118

RAMAZANOV Tlekkabul Sabitovich, (Deputy Editor-in-Chief), Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=6701328029

ABIEV Rufat, Doctor of Technical Sciences (Biochemistry), Professor, Head of the Department of Optimization of Chemical and Biotechnological Equipment, St. Petersburg State Technological Institute (St. Petersburg, Russia) https://www.scopus.com/authid/detail.uri?authorId=6602431781

OLIVIERO Rossi Cesare, PhD (Chemistry), Professor at the University of Calabria (Calabria, Italy), https://www.scopus.com/authid/detail.uri?authorId=57221375979

TIGINYANU Ion Mihailovich, Doctor of Physical and Mathematical Sciences, Academician, President of the Academy of Sciences of Moldova, Technical University of Moldova (Chisinau, Moldova), https :// www . scopus . com / authid / detail . uri ? authorId = 7006315935

SANG SU Kwak, PhD (Biochemistry, Agricultural Chemistry), Professor, Chief Scientist, Research Center for Plant Systems Engineering, Korea Research Institute of Bioscience and Biotechnology (KRIBB), (Daecheon, Korea), https://www.scopus.com/authid/detail.uri?authorId=59286321700

BERSIMBAYEV Rakhmetkazhi Iskenderovich, Doctor of Biological Sciences, Professor, Academician of NAS RK, L.N. Gumilyov Eurasian National University (Astana, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=7004012398

CALANDRA Pietro, PhD (Physics), Professor, Institute for the Study of Nanostructured Materials (Rome , Italy) , https : // www.scopus.com/authid/detail.uri?authorId=7004303066

BOSHKAEV Kuantai Avgazyevich, PhD, Associate Professor, Department of Theoretical and Nuclear Physics, Al-Farabi Kazakh National University (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=54883880400

BURKITBAEV Mukhambetkali, Doctor of Chemical Sciences, Professor, Academician of NAS RK, (Almaty, Kazakhstan) https://www.scopus.com/authid/detail.uri?authorId=8513885600

QUEVEDO Hernando, Professor, National Autonomous University of Mexico (UNAM), Institute of Nuclear Sciences (Mexico City, Mexico), https://www.scopus.com/authid/detail.uri?authorId=55989741100

ZHUSUPOV Marat Abzhanovich, Doctor of Physical and Mathematical Sciences, Professor of the Department of Theoretical and Nuclear Physics, Al-Farabi Kazakh National University (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=6602166928

KOVALEV Alexander Mikhailovich, Doctor of Physical and Mathematical Sciences, Academician of NAS of Ukraine, Institute of Applied Mathematics and Mechanics (Donetsk, Ukraine), https://www.scopus.com/authid/detail.uri?authorId=7202799321

TAKIBAEV Nurgali Zhabagaevich, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK, Al-Farabi Kazakh National University (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=24077239000

KHARIN Stanislav Nikolaevich, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK, Kazakh-British Technical University (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=6701353063

DAVLETOV Askar Erbulanovich, Candidate of Physical and Mathematical Sciences, Associate Professor, Branch of NRNU MEPhI Kazakh National University named after Al-Farabi (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=6602642543

ABISHEV Medeu Erzhanovich, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK, (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=26530759900

ABILMAGZHANOV Arlan Zainutallaevich, PhD in Chemistry, First Deputy Director General of JSC "Institute of Fuel, Catalysis and Electrochemistry named after D.V. Sokolsky", (Almaty, Kazakhstan), https://www.scopus.com/authid/detail.uri?authorId=57197468109

ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES.
ISSN 2518-1483 (Online), ISSN 2224-5227 (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 **№ KZ93VPY00121157** issued **05.06.2025**
Thematic scope: *physics and chemistry.*
Periodicity: 4 times a year.
http://reports-science.kz/index.php/en/archive

© «Central Asian Academic Research Center» LLP, 2025

ACADEMIC JOURNALOF PHYSICAL AND
CHEMICAL SCIENCES
2025 • 4

Бас редактор:

ЖҰРЫНОВ Мұрат Жұрынұлы, химия ғылымдарының докторы, профессор, ҚР ҰҒА академигі, ҚР ҰҒА РҚБ президенті м.а., АҚ «Д.В. Сокольский атындағы Отын, катализ және электрохимия институтының» бас директоры (Алматы, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=6602177960

Редакция ұжымы:

ҚАЛИМОЛДАЕВ Мақсат Нұрәділұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=56153126500

ӘДЕКЕНОВ Серғазы Мыңжасарұлы, химия ғылымдарының докторы, профессор, ҚР ҰҒА академигі, «Фитохимия» халықаралық ғылыми-өндірістік холдингінің директоры (Қарағанды, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=7006153118

РАМАЗАНОВ Тілекқабыл Сәбитұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, әл-Фараби атындағы Қазақ ұлттық университетінің ғылыми-инновациялық қызмет жөніндегі проректоры, (Алматы, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=6701328029

ӘБИЕВ Руфат, техника ғылымдарының докторы (биохимия), профессор, Санкт-Петербург мемлекеттік технологиялық институты «Химиялық және биотехнологиялық аппаратураны оңтайландыру» кафедрасының меңгерушісі, (Санкт-Петербург, Ресей) https://www.scopus.com/authid/detail.uri?authorId=6602431781

ОЛИВЬЕРО Росси Сезаре, PhD (химия), Калабрия университетінің профессоры (Калабрия, Италия) https://www.scopus.com/authid/detail.uri?authorId=57221375979

ТИГИНЯНУ Ион Михайлович, физика-математика ғылымдарының докторы, академик, Молдова Ғылым Академиясының президенті, Молдова техникалық университеті (Кишинев, Молдова) https://www.scopus.com/authid/detail.uri?authorId=7006315935

САНГ-СУ Квак, PhD (биохимия, агрохимия), профессор, Корей Биоғылым және биотехнология ғылыми-зерттеу институты (KRIBB), өсімдіктердің инженерлік жүйелері ғылыми-зерттеу орталығының бас ғылыми қызметкері, (Дэчон, Корея) https://www.scopus.com/authid/detail.uri?authorId=59286321700

БЕРСІМБАЕВ Рахметқажы Ескендірұлы, биология ғылымдарының докторы, профессор, ҚР ҰҒА академигі, Л.Н. Гумилев атындағы Еуразия ұлттық университеті. (Астана, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=7004012398

КАЛАНДРА Пьетро, PhD (физика), наноқұрылымды материалдарды зерттеу институтының профессоры (Рим, Италия) https://www.scopus.com/authid/detail.uri?authorId=7004303066

БОШКАЕВ Қуантай Авғазыұлы, Ph.D. Теориялық және ядролық физика кафедрасының доценті, әл-Фарабиатындағы Қазақ ұлттық университеті (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=54883880400

Бүркітбаев Мұхамбетқали, химия ғылымдарының докторы, профессор, ҚР ҰҒА академигі, (Алматы, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=8513885600

QUEVEDO Hernando, профессор, Мексика ұлттық автономиялық университеті (UNAM), Ядролық ғылымдар институты (Мехико, Мексика), https://www.scopus.com/authid/detail.uri?authorId=55989741100

ЖҮСІПОВ Марат Абжанұлы, физика-математика ғылымдарының докторы, теориялық және ядролық физика кафедрасының профессоры, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=6602166928

КОВАЛЕВ Александр Михайлович, физика-математика ғылымдарының докторы, Украина ҰҒА академигі, Қолданбалы математика және механика институты (Донецк, Украина), https://www.scopus.com/authid/detail.uri?authorId=7202799321

ТАКИБАЕВ Нұрғали Жабағаұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=24077239000

ХАРИН Станислав Николаевич, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=6701353063

ДАВЛЕТОВ Асқар Ербуланович, физика-математика ғылымдарының кандидаты, доцент, ҰЯЗУ МИФИ әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=6602642543

ӘБІШЕВ Медеу Ержанұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, (Алматы, Қазақстан) https://www.scopus.com/authid/detail.uri?authorId=26530759900

ӘБІЛМАҒЖАНОВ Арлан Зайнуталлайұлы, химия ғылымдарының кандидаты, Д.В. Сокольский атындағы "Отын, катализ және электрохимия институты" АҚ Бас директорының бірінші орынбасары, (Алматы, Қазақстан), https://www.scopus.com/authid/detail.uri?authorId=57197468109

ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES
ISSN 2518-1483 (Online), ISSN 2224-5227 (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Ақпарат агенттігінің мерзімді баспасөз басылымын, ақпарат агенттігін және желілік басылымды қайта есепке қою туралы ҚР Мәдениет және Ақпарат министрлігі «Ақпарат комитеті» Республикалық мемлекеттік мекемесі **05.06.2025 ж.** берген **№ KZ93VPY00121157** Куәлік.
Тақырыптық бағыты: *физика, химия.*
Мерзімділігі: жылына 4 рет.
http://reports-science.kz/index.php/en/archive

© «Орталық Азия академиялық ғылыми орталығы» ЖШС, 2025

ACADEMIC JOURNALOF PHYSICAL AND
CHEMICAL SCIENCES
2025 • 4

Главный редактор:

ЖУРИНОВ Мурат Журинович, доктор химических наук, профессор, академик НАН РК, и.о. президента РОО НАН РК, Генеральный директор АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского» (Алматы, Казахстан) https://www.scopus.com/authid/detail.uri?authorId=6602177960

Редакционная коллегия:

КАЛИМОЛДАЕВ Максат Нурадилович, доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=56153126500

АДЕКЕНОВ Сергазы Мынжасарович, доктор химических наук, профессор, академик НАН РК, директор Международного научно-производственного холдинга «Фитохимия» (Караганда, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=7006153118

РАМАЗАНОВ Тлеккабул Сабитович, (заместитель главного редактора), доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=6701328029

АБИЕВ Руфат, доктор технических наук (биохимия), профессор, заведующий кафедрой «Оптимизация химической и биотехнологической аппаратуры», Санкт-Петербургский государственный технологический институт (Санкт-Петербург, Россия), https://www.scopus.com/authid/detail.uri?authorId=6602431781

ОЛИВЬЕРО Росси Чезаре, доктор философии (PhD, химия), профессор Университета Калабрии (Калабрия, Италия), https://www.scopus.com/authid/detail.uri?authorId=57221375979

ТИГИНЯНУ Ион Михайлович, доктор физико-математических наук, академик, президент Академии наук Молдовы, Технический университет Молдовы (Кишинев, Молдова), https://www.scopus.com/authid/detail.uri?authorId=7006315935

САНГ-СУ Квак, доктор философии (PhD, биохимия, агрохимия), профессор, главный научный сотрудник, Научно-исследовательский центр инженерных систем растений, Корейский научно-исследовательский институт бионауки и биотехнологии (KRIBB), (Дэчон, Корея), https://www.scopus.com/authid/detail.uri?authorId=59286321700

БЕРСИМБАЕВ Рахметкажи Искендирович, доктор биологических наук, профессор, академик НАН РК, Евразийский национальный университет им. Л.Н. Гумилева (Астана, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=7004012398

КАЛАНДРА Пьетро, доктор философии (PhD, физика), профессор Института по изучению наноструктурированных материалов (Рим, Италия), https://www.scopus.com/authid/detail.uri?authorId=7004303066

БОШКАЕВ Куантай Авгазыевич, PhD, преподаватель, доцент кафедры теоретической и ядерной физики, Казахский национальный университет им. аль-Фараби (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=54883880400

БУРКИТБАЕВ Мухамбеткали, доктор химических наук, профессор, академик НАН РК, (Алматы, Казахстан) https://www.scopus.com/authid/detail.uri?authorId=8513885600

QUEVEDO Hernando, профессор, Национальный автономный университет Мексики (UNAM), Институт ядерных наук (Мехико, Мексика), https://www.scopus.com/authid/detail.uri?authorId=55989741100

ЖУСУПОВ Марат Абжанович, доктор физико-математических наук, профессор кафедры теоретической и ядерной физики, Казахский национальный университет им. аль-Фараби (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=6602166928

КОВАЛЕВ Александр Михайлович, доктор физико-математических наук, академик НАН Украины, Институт прикладной математики и механики (Донецк, Украина), https://www.scopus.com/authid/detail.uri?authorId=7202799321

ТАКИБАЕВ Нургали Жабагаевич, доктор физико-математических наук, профессор, академик НАН РК, Казахский национальный университет им. аль-Фараби (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=24077239000

ХАРИН Станислав Николаевич, доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=6701353063

ДАВЛЕТОВ Аскар Ербуланович, кандидат физико-математических наук, доцент, Филиал НИЯУ МИФИ Казахский национальный университет им. аль-Фараби (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=6602642543

АБИШЕВ Медеу Ержанович, доктор физико-математических наук, профессор, академик НАН РК, (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=26530759900

АБИЛЬМАГЖАНОВ Арлан Зайнуталлаевич, кандидат химических наук, первый заместитель генерального директора АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского», (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=57197468109

ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES
ISSN 2518-1483 (Online), ISSN 2224-5227 (Print)
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство **№ KZ93VPY00121157** о повторной регистрации периодического печатного издания информационного агентства, информационного агентства и сетевого издания, выданное Республиканским государственным учреждением «Комитет информации» Министерства культуры и информации Республики Казахстан **05.06.2025**
Тематическая направленность: *физика, химия.*
Периодичность: 4 раза в год.
http://reports-science.kz/index.php/en/archive

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

CONTENTS

PHYSICS

CHEMISTRY

МАЗМҰНЫ

ФИЗИКА

ХИМИЯ

СОДЕРЖАНИЕ

ФИЗИКА

ХИМИЯ

ACADEMIC JOURNAL
OF PHYSICAL AND CHEMICAL SCIENCES
ISSN 2224-5227
Volume 4.
Number 356 (2025), 172–183

https://doi.org/10.32014/2025.2518-1483.392

ҒТАХР (МРНТИ) 61.29.39
ӘОЖ (УДК) 661.846:66.082

©A.P. Auyeshov, Ch.Z. Yeskibayeva*, A.K. Dikanbayeva*, 2025.
M. Auezov South Kazakhstan University, Shymkent, Kazakhstan.
E - mail**:** dikanbaeva86@mail.ru

RESOURCE-EFFICIENT UTILIZATION OF SERPENTINITE WASTE FOR MAGNESIUM SULFATE PRODUCTION

Auyeshov Abdrazakh — South Kazakhstan University named after M. Auezov, Head of the SRL "Applied Chemistry", Shymkent, Kazakhstan,
E-mail: centersapa@mail.ru; ORCID: https://orcid.org/0000 0002-3504-9117;
Yeskibayeva Chayzada — South Kazakhstan University named after M. Auezov, chief specialist of the SRL "Applied Chemistry", Shymkent, Kazakhstan,
E-mail: yeskibayeva@internet.ru; ORCID: https://orcid.org/0000-0002-8049-8851;
Dikanbayeva Aizhan — South Kazakhstan University named after M. Auezov, employee of the SRL "Applied Chemistry" Shymkent, Kazakhstan,
E-mail: dikanbaeva86@mail.ru; ORCID: https://orcid. org/0000-0003-4982-1566.

Abstract. This study presents a techno-economic assessment of technologies for producing magnesium sulfate from serpentinite waste generated during the mining and processing of chrysotile asbestos, which poses an environmental hazard. The investigation focuses on a new alternative method for processing powdered serpentinite waste (PTW), including stages of low-concentration sulfuric acid leaching and subsequent neutralization of the resulting sulfate solution using serpentinite waste thermally activated at 750 °C. The approach aims to evaluate the efficiency of magnesium sulfate production, the quality of the final product, and the potential profitability of the technology. It was demonstrated that the combined leaching and neutralization of serpentinite waste enables the production of magnesium sulfate with a total yield of 46%, yielding a high-quality commercial product — $MgSO_4 \cdot 7H_2O$. Preliminary techno-economic indicators, calculated based on material and energy inputs (excluding fixed costs) and average market prices of $MgSO_4 \cdot 7H_2O$, indicate the economic feasibility of the proposed technology. A comparative analysis with conventional magnesium sulfate production methods showed that the use of local serpentinite waste and its thermally activated form for neutralization significantly reduces raw material costs and enhances profitability. The study establishes that the proposed processing scheme has high technological efficiency and can be integrated into existing chrysotile waste processing facilities. Overall, the findings confirm the feasibility of industrial-scale magnesium sulfate production based on Kazakhstan's local mineral resources, offering an environmentally responsible and resource-efficient approach while generating a valuable chemical product for agricultural and industrial applications.

Keywords: magnesium sulfate, serpentinite waste, sulfuric acid leaching, thermally activated serpentinite

Financing. *This study was conducted with the financial support of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (BR21882242).*

©А.П. Ауешов, Ч.З. Ескибаева*, А.К. Диканбаева*, 2025.
М. Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан.
E-mail**:** dikanbaeva86@mail.ru

СЕРПЕНТИНИТ ҚАЛДЫҒЫНАН МАГНИЙ СУЛЬФАТЫН АЛУДЫҢ ТЕХНИКАЛЫҚ-ЭКОНОМИКАЛЫҚ ЗЕРТТЕУІ

Ауешов Абдразах — М. Әуезов атындағы Оңтүстік Қазақстан университеті, «Қолданбалы химия» ҒЗЗ меңгерушісі, Шымкент, Қазақстан,
E-mail: centersapa@mail.ru; ORCID: https:// orcid.org/0000-0002-3504-9117;
Ескибаева Чайзада — М. Әуезов атындағы Оңтүстік Қазақстан университеті, «Қолданбалы химия» ҒЗЗ бас маманы, Шымкент, Қазақстан,
E-mail: yeskibayeva@internet.ru; ORCID: https://orcid.org/0000-0002-8049-885;
Диканбаева Айжан — М. Әуезов атындағы Оңтүстік Қазақстан университеті, «Қолданбалы химия» ҒЗЗ қызметкері, Шымкент, Қазақстан,
E-mail: dikanbaeva86@mail.ru; ORCID: https:// orcid.org/0000-0003-4982-1566.

Аннотация. Бұл мақалада хризотил асбестті өндіру және байыту кезінде пайда болатын серпентинит қалдықтарынан магний сульфатын алу технологиясының технико-экономикалық зерттеулері ұсынылған. Зерттеу барысында ұнтақталған технологиялық қалдықтарды төмен концентрациялы күкірт қышқылы ерітіндісімен өңдеу және алынған сульфат ерітіндісін 750 °C-та термоактивтенген серпентинит қалдығымен бейтараптау және тазарту кезеңдері жан-жақты қарастырылған. Бұл тәсіл магнийдің тиімді шығуын қамтамасыз етіп, қосымша иондармен ластануды азайтуға мүмкіндік береді. Бұл тәсіл магний сульфатын $MgSO_4 \cdot 7H_2O$ 46% өнімділікпен және тазалығы жоғары сапада алуға мүмкіндік береді. Элементтік талдау барысында магний сульфатының құрамында кальций мен темірдің мөлшері өте аз екені анықталды, бұл өнімнің коммерциялық тұрғыдан тартымдылығын арттырады. Материалдық және энергетикалық шығындар, сондай-ақ өнімнің орташа нарықтық бағалары негізінде, магний сульфатын өндірудің технико-экономикалық көрсеткіштері анықталып, технологияның экономикалық тиімділігін бағалауға мүмкіндік берді. Салыстырмалы талдау көрсеткендей, жергілікті серпентинит қалдықтарын магний сульфатын алу өндірісінде пайдалану және оның термоактивтенген формаларын қышқыл ерітіндісін бейтараптауда қолдану шығындарды айтарлықтай азайтып, өндірістің рентабельділігін арттырады. Сонымен қатар, ұсынылған технология экологиялық тұрғыдан қауіпсіз, тұрақты өндіріс процессін қамтамасыз етеді және ресурстарды тиімді пайдалануға мүмкіндік береді. Бұл технология қайта өңдеу арқылы техногендік қалдықтардың қоршаған ортаға тигізетін зиянды әсерін азайтады. Жаңа өңдеу технологиялық сұлбасы жоғары тиімділікке ие болып, хризотил қалдықтарын қайта өңдейтін кәсіпорындарға енгізілуі мүмкін. Зерттеу нәтижелері Қазақстандағы жергілікті минералдық-шикізат базасына сүйене отырып, магний сульфатының өнеркәсіптік өндірісін ұйымдастырудың перспективтілігін нақты дәлелдейді.

Түйін сөздер: магний сульфаты, серпентинит қалдықтары, күкіртқышқылды сілтісіздендіру, термобелсендірілген серпентинит

©А.П. Ауешов, Ч.З. Ескибаева*, А.К. Диканбаева*, 2025.
Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан.
E - mail: dikanbaeva86@mail.ru

ТЕХНИКО-ЭКОНОМИЧЕСКОЕ ИССЛЕДОВАНИЕ ПОЛУЧЕНИЯ СУЛЬФАТА МАГНИЯ ИЗ СЕРПЕНТИНИТОВОГО ОТХОДА

Ауешов Абдразах — Заведующий НИЛ «Прикладная химия», Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан,
E-mail: centersapa@mail.ru; ORCID: https://orcid.org/0000 0002-3504-9117;
Ескибаева Чайзада — Главный специалист НИЛ «Прикладная химия», Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан,
E-mail: yeskibayeva@internet.ru; ORCID: https:// orcid.org/0000-0002-8049-8851;
Диканбаева Айжан — Сотрудник НИЛ «Прикладная химия», Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан,
E-mail: dikanbaeva86@mail.ru; ORCID: https://orcid. org/0000-0002-9859-5545.

Аннотация. В статье представлено технико-экономическое исследование технологии получения сульфата магния из серпентинитового отхода, образующегося при добыче и обогащении хризотил-асбеста и представляющего экологическую опасность. Рассмотрены основные аспекты новой альтернативной технологии переработки порошкообразного отхода хризотилового сырья, включающей стадии сернокислотного выщелачивания растворами серной кислоты низкой концентрации и последующей нейтрализации продуктивного сульфатного раствора с использованием термоактивированного при 750 °С серпентинита. Проведена оценка эффективности получения сульфата магния, качества конечного продукта и потенциальной рентабельности предложенной технологии. Показано, что сочетание процессов выщелачивания и нейтрализации позволяет получить сульфат магния с общим выходом 46% и высокими качественными характеристиками товарного продукта $MgSO_4 \cdot 7H_2O$. На основе расчетов материальных и энергетических затрат (без учета постоянных расходов) и средней рыночной стоимости $MgSO_4 \cdot 7H_2O$ определены предварительные технико-экономические показатели, позволяющие прогнозировать экономическую эффективность технологии. Проведен сравнительный анализ с известными методами получения сульфата магния. Установлено, что использование местных серпентинитовых отходов и их термоактивированных форм для нейтрализации кислых растворов выщелачивания позволяет существенно снизить затраты на сырьё и повысить рентабельность производства. Показано, что новая технологическая схема обладает высокой эффективностью и может быть интегрирована в действующие предприятия по переработке хризотиловых отходов. Результаты исследования подтверждают перспективность организации промышленного производства сульфата магния на основе минерально-сырьевой базы Казахстана.

Ключевые слова: сульфат магния, серпентинитовые отходы, сернокислотное выщелачивание, термоактивированный серпентинит

Introduction. Serpentinites are magnesium-rich silicate rocks containing significant amounts of silica and have been widely investigated as raw materials for producing magnesium and its compounds. These rocks, including industrial waste generated during the processing of chrysotile-asbestos ores, represent a valuable source of magnesium (Kalichenko et al. 2007; Sagarunyan et al. 2014; Shevko et al. 2022; Kozlov et. al. 2015; Gabdullin et al. 2012; Fedorôcková et al. 2016; Sierra et al. 2018). Various processing methods for serpentinites have been proposed, each with specific technological and economic limitations (Auyeshov et al. 2024).

The serpentinite ores from the Zhitikara deposit, located on the eastern slope of the Southern Urals in Kazakhstan, belong to the Bazhenov geological-industrial type and consist primarily of serpentinized peridotites, dunites, and serpentinites (Dzhafarov 2013).

The average chrysotile content in these ores is approximately 4.5–5.5%. The mineralogical composition includes chrysotile, lizardite, and antigorite ($Mg_3Si_2O_5(OH)_4$), along with brucite ($Mg(OH)_2$) and magnetite (Fe_3O_4). The processing plant, JSC "Kostanay Minerals," has an annual production capacity of approximately 500,000 tons of chrysotile, and over 65 years of operation, it has generated substantial volumes of waste. This waste, which may still contain residual chrysotile fibers, poses environmental and health risks due to airborne dispersion (Punenkov et al. 2022).

To mitigate these issues, several approaches for valorizing the tailings have been proposed, with particular attention to extracting magnesium from serpentinite waste. Compared to dolomite, which contains 20–22 wt.% Mg, serpentinite can have a higher magnesium content of 25–26 wt.%, making it a promising alternative raw material. Previous studies have investigated its leaching behavior using various acids, including sulfuric (Błońska et al. 2016) and hydrochloric acid (Mpouras et al. 2017; Fouda et al. 1996; Shaban et al. 2018; Huang et al. 2017; Teixeira et al. 2012). However, despite extensive research, there is still limited practical implementation of technologies for producing specific industrial-grade magnesium compounds from serpentinite, especially those supported by techno-economic analyses.

In response to this gap, the present study proposes a novel process scheme for the production of magnesium sulfate ($MgSO_4 \cdot 7H_2O$) from serpentinite waste generated during chrysotile processing at the Zhitikara deposit. The process involves sulfuric acid leaching followed by neutralization using thermally activated serpentinite, combined with a preliminary economic evaluation of the key process stages. The aim is to assess the resource and economic efficiency of this technology and the feasibility of utilizing industrial waste for the production of high-purity magnesium compounds.

Materials and Methods. *Sample preparation.* Powdered process waste (PTW) from the chrysotile beneficiation plant at JSC "Kostanay Minerals" was used as the main raw material. The chemical and mineralogical composition of this waste closely resembles that of the original chrysotile ore. The material appears as a bluish-gray fibrous powder without lumps or solid inclusions, collected using bag-type dust collection systems used during the crushing and fractionation of chrysotile raw materials. The elemental composition of the PTW is presented in Table 1.

Table 1. Elemental composition of PTW

Element	C	O	Mg	Al	Si	S	Ca	Fe	Total
Elemental composition of PTW, wt.%	2.58	51.00	25.00	0.54	17.45	–	0.50	2.93	100.00

Thermal activation. Thermal treatment of the PTW was carried out at 750°C for one hour in order to prepare it for use as a neutralizing and purifying reagent for the sulfate solution. The treatment significantly altered the particle size distribution, eliminating fractions smaller than 0.9mm. The dominant particle size fraction after calcination was in the range of 0.14—0.08—0.07mm, representing approximately 94% of the material. The thermally activated PTW was used without any further grinding.

Analytical instrumentation. Analytical measurements were performed using a JSM-6490LV scanning electron microscope (JEOL, Japan) equipped with an INCA Energy 350 EDS system, and an iCAP-Q mass spectrometer (Thermo Scientific, Germany). All analyses were conducted in accordance with established laboratory protocols to ensure the accuracy and reproducibility of results.

Results and discussion. *Leaching of process tailings (PTW) with sulfuric acid*

Leaching of powdered PTW with sulfuric acid was carried out according to the following stoichiometric reaction:

$$Mg_3Si_2O_5(OH)_4 + 3H_2SO_4 \rightarrow 3MgSO_4 + 2SiO_2 + 5H_2O \qquad (1)$$

To ensure complete reaction of magnesium with sulfuric acid and account for the presence of trace metal impurities, a slight excess of acid was introduced. The leaching process also follows the simplified ionic reaction:

$$Mg^{2+} + H_2SO_4 \rightarrow MgSO_4 + 2H^+ \qquad (2)$$

A molar ratio of 1.0:1.046 (Mg^{2+}: H_2SO_4) was selected. The stoichiometric amount of sulfuric acid was calculated based on the total magnesium content in PTW.

Leaching was performed in a round-bottom flask equipped with a thermometer, reflux condenser, sampler, and a propeller stirrer. A mixture of 500 g of PTW and 1000 cm^3 of distilled water was placed into the flask. Under continuous stirring at 200—300 rpm, 415 cm^3 of 92% sulfuric acid (density = 1.824 g/cm^3) was added dropwise in three portions of 150—200 cm^3 using a dropping funnel. The total mass of the reaction mixture was 2256 g, resulting in a liquid-to-solid (L:S) ratio of 4.51.

Upon acid addition, the suspension rapidly heated to 100—105°C within 2—3 minutes, accompanied by intense foaming and boiling. To avoid overheating, acid was added in intervals. After the final portion, gentle boiling was maintained throughout the remainder of the 3-hour leaching period.

The resulting mixture appeared as a dense bluish-gray suspension with a measured pH of 0.57. Aliquots (10 mL) were taken at 30, 60, 120, and 180 minutes. Samples were filtered, and the residues were washed, dried at 105°C, and analyzed chemically. Magnesium concentration was determined both instrumentally and by classical chemical titration, with a relative error not exceeding 2—3%, confirming the consistency of results. The elemental compositions of both filtrates and residues for the different leaching durations are summarized in Table 2.

Table 2. Elemental composition of the filtrate and insoluble residue at different leaching durations (30, 60, 120, and 180 min, t = 100—105°C)

Element	Leaching time, min							
	30	60	120	180	30	60	120	180
	Filtrate, wt.%				Residue, wt.%			
C	—	—	—	—	4.85	4.36	5.19	4.43
O	5.09	57.10	53.65	57.41	54.17	53.53	53.79	53.98
Mg	10.36	10.71	11.11	11.69	3.31	2.99	2.42	2.39
Al	0.48	0.42	0.37	0.30	0.33	—	—	—
Si	4.10	3.82	4.25	3.86	34.53	36.06	36.36	36.45
S	28.99	28.02	28.46	28.42	1.50	1.31	1.19	1.56
Ca	—	0.27	—	—	0.22	0.28	—	—
Fe	1.98	2.66	2.16	2.32	1.10	1.46	1.06	1.19
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
m, g ($MgSO_4$)	168.65	168.90	171.60	167.68	—	—	—	—
Note: “—” indicates values below the detection limit or not determined.								

Analysis of the data in Table 2 shows that within 30 minutes from the start of PTW leaching with sulfuric acid, nearly all elements present in the waste are transferred into the sulfate solution, with the exception of calcium, which appears in the solution only after 60 minutes. However, a significant change in the concentrations of the main elements in the sulfate solution and insoluble residue is not observed in the time interval from 30 to 180 minutes. Specifically, the magnesium content in the solution increases by only 12.8%, iron by 17%, and silicon decreases by 5.8%. In the insoluble residue, the concentrations of these elements also change accordingly: magnesium decreases by 27%, silicon increases by 5.5%, and iron by 17%. These results confirm that the maximum rate of PTW dissolution during acid leaching occurs within the first 30 minutes of contact with sulfuric acid.

The mass of magnesium sulfate formed during the leaching of 100 g of PTW with sulfuric acid at 98 °C after 30 minutes was 168.65 g (containing 10.36% Mg, equivalent to 16.90 g), which corresponds to 70% of the theoretical yield. It is also notable that the yield of magnesium sulfate in the solution does not increase significantly beyond the 30—180-minute range (168.65, 168.90, 171.60, and 167.68 g).

Neutralization and purification of the productive sulfate solution using thermally activated PTW at 750°C. Under the same conditions, the leaching of PTW with sulfuric acid was conducted, but the leaching time was limited to 30 minutes. Upon completion of this step, 1.0 dm³ of distilled water was added to the acidic suspension. Thermally activated PTW (TA-PTW), previously heated at 750°C for one hour, was used as the neutralizing agent. At this temperature, the alkaline reactivity of the material is significantly enhanced due to internal structural transformations of the serpentinite, including the formation of periclase (Dikanbayeva et al. 2021; Yeskibayeva et al. 2024). Neutralization was carried out until the suspension reached a pH of 8.3. The resulting mixture was then filtered, and the solid residue was washed twice with 0.5 L of distilled water. It is noteworthy that at pH = 8.3, both filtration and washing were completed efficiently. The obtained filtrate was almost completely free of impurity metal ions, with the exception of trace amounts of calcium.

Table 3 presents the results of elemental analysis of both the filtrate and the solid residue after neutralization of the acidic suspension using thermally activated PTW (TA-PTW). The data reflect the composition of the purified productive magnesium sulfate solution and the remaining solid phase.

Table 3. Elemental analysis of the neutralized sulfate suspension at pH = 8.3: initial materials, filtrates after phase separation, and solid residue (OS)

	Initial materials		Neutral suspension		
Element	PTW	TA-PTW	Filtrate I	Filtrate II	Residue (OS)
C	2.58	2.54	—	—	9.35
O	51.00	45.22	59.90	61.90	48.55
Mg	25.00	27.89	16.60	15.64	11.91
Al	0.54	0.46	—	—	0.56
Si	17.45	19.17	—	—	23.60
S	—	—	23.50	22.21	0.43
Ca	0.50	0.53	—	0.25	0.30
Fe	2.93	4.19	—	–	5.30
Total	100.00	100.00	100.00	100.00	100.00
Note: “—” indicates values below the detection limit or not determined.					

The yield of magnesium sulfate during the neutralization of the acidic PTW suspension using TA-750 reaches 46% of the total magnesium content in the initial materials (PTW and TA-PTW), while magnesium recovery relative to the amount of sulfuric acid used was approximately 100%.

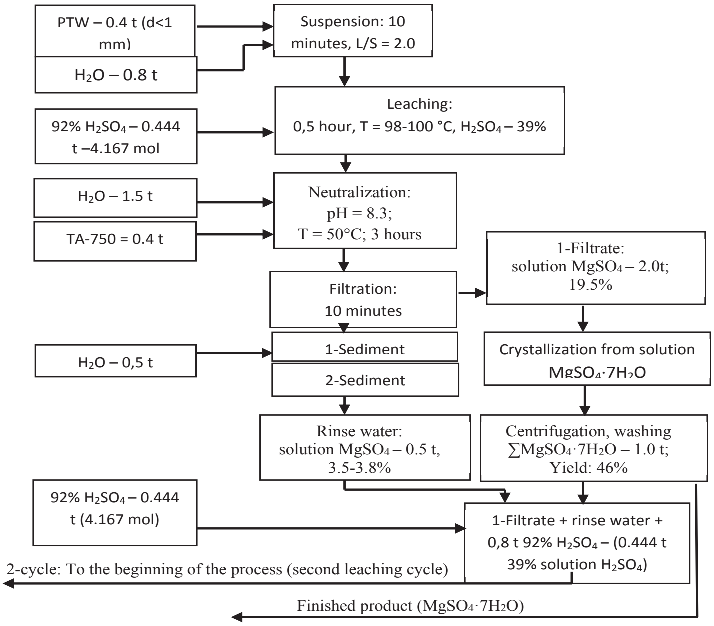
The concentration of magnesium sulfate in the filtrate obtained after leaching the first portion of PTW (Filtrate I) was 243 g/L (24.3%). When a second, fresh portion of PTW was leached using this magnesium sulfate solution (with sulfuric acid concentration adjusted for repeated leaching), the concentration of magnesium sulfate in Filtrate II increases to 47—48%. Calcium remained in the final product at a concentration of 0.014—0.016% (see Table 3, residue—OS).

The solid residue obtained after neutralization of the acidic PTW suspension using TA-PTW contained the following elements: Mg = 11.91%, Al = 0.56%, Si = 23.56%, S = 0.43%, Ca = 0.30%, and Fe = 5.30%. These values suggest the potential reuse of the residue as a magnesium- and silicon-containing fertilizer for agricultural applications.

The use of TA-PTW as a neutralizing reagent offers several advantages over conventional reagents such as NaOH:

1. It additionally enriches the productive sulfate solution with magnesium due to acid—base interactions between TA-PTW and the acidic suspension;
2. It does not introduce any foreign elements into the sulfate system from external sources;
3. Owing to its specific structural and adsorptive properties, it ensures more efficient purification of the magnesium sulfate solution from impurity metal ions, except for a minor amount of calcium.

The production of magnesium sulfate heptahydrate using the described leaching (Figure 1), neutralization, and purification processes with TA-PTW enables the formation of high-purity $MgSO_4 \cdot 7H_2O$.



2-cycle: To the beginning of the process (second leaching cycle)

Finished product ($MgSO_4 \cdot 7H_2O$)

Figure 1 - Technological scheme for the production of magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) from chrysotile processing waste (PTW)

Comparative analysis (Table 4) demonstrates that the purity characteristics of the synthesized magnesium sulfate comply with the requirements of GOST 4523-77, confirming its classification as a marketable product with established commercial value.

Table 4. Comparison of magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) quality indicators with GOST 4523-77

No	Indicator	Norm		Experimentally obtained $MgSO_4 \cdot 7H_2O$*
		Chemically pure	Pure for analysis (h.d.a.)	
1	$MgSO_4 \cdot 7H_2O$ (magnesium sulfate heptahydrate), %	99.5	99.5	99.5
2	Water-insoluble substances, %	0.00200	0.00200	0.00100
3	H_2SO_4 (acidity), %	0.00200	0.00200	–
4	MgO (alkalinity), %	0.00100	0.00100	0.00100
5	Cl (chlorides), %	0.00050	0.00200	–
6	NH_4 (ammonium salts), %	0.00100	0.00200	–
7	Fe (iron), %	0.00020	0.00030	0,00024
8	Ca (calcium), %	0.01000	0.02000	0.01400-0.01600
9	Mn (manganese), %	0.00050	0.00100	0.00070
10	As (arsenic), %	0.00004	0.00004	–
11	Pb (heavy metals), %	0.00010	0.00010	–
12	Zn (zinc), %	0.00100	0.00500	0.00020
Note: * — Analysis performed using Thermo Scientific iCAP-Q Mass Spectrometer. "–" indicates values below the detection limit or not determined. h.d.a., highly defined analytical.				

Based on the scaled data from Table 3, the resource and energy efficiency of the proposed technology for producing 1.0 t of $MgSO_4 \cdot 7H_2O$ from PTW was assessed, considering only material and energy inputs and excluding capital and operational costs. The calculations were performed using average market prices for sulfuric acid and electricity tariffs in Kazakhstan in 2024 (0.065 $/kWh) (Table 5).

Table 5. Resource and energy efficiency of the technology for producing commercial-grade magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) from PTW (serpentinite waste)

1) Specific consumption of raw materials and energy required to produce 1 ton of $MgSO_4 \cdot 7H_2O$			
Resource type	Unit	Consumption per product	Role
PTW	tons	0.40	Raw material
TA-PTW		0.40	Raw material
Sulfuric acid (density = 1.824 g/cm^3)	tons	0.44	Reagent 1
Technical water	tons	2.80	Reagent 2
2) Specific consumption of raw materials and energy resources to produce 0.400 tons of TA- PTW			
Resource type	Unit	Consumption per product	Role
PTW	tons	0.46	Raw material
Electricity	kWh	92.40	Energy input
3) Resource and energy efficiency $MgSO_4 \cdot 7H_2O$			

Articles	Unit	Quantity	Price, \$/t	Price, \$
Income part				175.00
$MgSO_4·7H_2O$	tons	1.00	175.00	175.00
Expenditure part				60.00
PTW	tons	0.46	3.00	1.40
TA- PTW	tons	0.40	3.00	1.20
Sulfuric acid (density=1.824 g/cm^3	tons	0.44	100.00	44.40
Water (technical)	tons	2.80	1.00	2.80
Electricity (firing)	kWh	92.40	0.07	6.00
Note: Estimated based on average market prices for 2024 in Kazakhstan: sulfuric acid — \$100/t; technical water — \$1/t; electricity — \$0.07/kWh. Labor, depreciation, and overhead costs are not included.				

Thus, the gross profit, excluding fixed costs, for the production of magnesium sulfate ($MgSO_4·7H_2O$) is \$115/t. The break-even price (P_{min}) is \$60/t, and since $P_{min} <$ \$175/t, this indicates that magnesium sulfate production by this method is economically viable. From an economic perspective, the process demonstrates a sufficiently positive balance. Industrial production of magnesium sulfate heptahydrate ($MgSO_4·7H_2O$) is carried out using several technological routes, which differ both in terms of the raw materials employed and the associated cost structures. The most common approaches include: 1) extraction from natural kieserite/epsomite; 2) processing of magnesite/dolomite using sulfuric acid. Under typical prices for industrial H_2SO_4 and energy resources, the production costs via these conventional routes generally exceed those of direct processing of serpentinite waste, reaching approximately from 150 to 220 USD/t. Therefore, reducing the costs of raw materials (PTW) and the neutralizing agent (TA-PTW) represents a critical factor in enhancing the economic efficiency of the proposed technology.

Conclusions. The techno-economic study of the processes of sulfuric acid leaching of PTW using low-concentration sulfuric acid solutions and the neutralization of the resulting sulfate solution with thermally activated serpentinite waste (TA-PTW) demonstrates that this technology can achieve a total magnesium sulfate yield of 46% relative to the theoretical magnesium content in the raw serpentinite involved in the extraction processes, producing a commercial-quality product — $MgSO_4·7H_2O$.

The techno-economic indicators, determined based on calculations of material and energy consumption and the average market price of the product, show promisingly high values, confirming the resource and economic efficiency of the proposed magnesium sulfate production technology from PTW, as well as the feasibility of the repeated utilization of chrysotile-based technogenic waste.

Simple calculations show that 1.0 ton of PTW can yield magnesium sulfate ($MgSO_4·7H_2O$) products valued at \$175-200. At the same time, success from both technological and economic standpoints is ensured by the use of thermally activated PTW for the neutralizing and purifying the sulfate leaching solution. The rational use of sulfuric acid, which is the only consumable reagent, is an additional advantage in the process of producing magnesium sulfate from serpentinite waste.

References

Auyeshov A, Yeskibayeva Ch, Arynov K, Kolesnikov A (2024) Aspects of waste recycling problems in the chrysotile asbestos industry. Scientific and Technical Journal Mining Informational and Analytical Bulletin 9:88–98. (in English)

Błońska E, Januszek K, Małek S, Wanic T (2016) Effects of serpentinite fertilizer on the chemical properties and enzyme activity of young spruce soils. International Agrophysics 30(4):401–414. https://doi.org/10.1515/intag-2016-0015 (in English).

Dikanbayeva AK, Auyeshov AP, Satayev MS, Arynov KT, Yeskibayeva ChZ (2021) Researching of sulfuric acid leaching of magnesium from serpentines. News of the academy of sciences of the republic of Kazakhstan Satbayev university, series of geology and technical sciences 5(449):32–38 https://doi.org/10.32014/2021.2518-17OX.95 9 (in English)

Dzhafarov N.N. Nektorye osobennosti ocenki hrizotil-asbestovyh mestorozhdenij [Some features of the assessment of chrysotile-asbestos deposits]. Gorno-geologicheskij zhurnal. — Zhitikara, 2013. — № 3-4 (35-36). — S. 8-10. (in Russian)

Fedorôcková A, Raschman P, Sučik G, Ivanova D, Kavuličová J (2016) Utilization of Chrysotile-Type Tailings for Synthesis of High-Grade Silica by Controlled Precipitation. Mineral Processing and Extractive Metallurgy Review 37:287—294 https://doi.org/10.1080/08827508.2016.1167173 (in English)

Fouda MFR, Amin RE-S, Abd-Elzaher MM (1996) Extraction of magnesia from Egyptian serpentine ore via reaction with different acids I Reaction with sulfuric acid. Bull Chem Soc Jpn 69(7):1907–1912 https://doi.org/10.1246/bcsj.69.1907 (in English).

Gabdullin A.N. Bezothodnaya azotnokislotnaya pererabotka serpentinita — othoda asbestoobogatitelnoj promyshlennosti [Waste-free nitric acid processing of serpentinite — waste of asbestos beneficiation industry]// Gabdullin A.N., Kalinichenko I.I., Pecherskih E.G., Semenishev V.S. Sbornik dokladov. II Mezhdunarodnaya nauchno-prakticheskaya konferenciya «Sovremennye resursosberegayushie tehnologii: problemy i perspektivy». — Odessa: ONU imeni I. I. Mechnikova. — 2012. — S. 50-52. (in Russian)

Huang P, Li Z, Chen M, Hu H, Lei Z, Zhang Q, Yuan W (2017) Mechanochemical activation of serpentine for recovering Cu (II) from wastewater. Appl Clay Sci 149:1–7. https://doi.org/10.1016/j.clay.2017.08.030 (in English).

Mpouras T, Chrysochoou M, Dermatas D (2017) Investigation of hexavalent chromium sorption in serpentine sediments. J Contam Hydrol 197:29–38. https://doi.org/10.1016/j.jconhyd.2016.12.009 (in English)

Patent 2292300 Rossijskaya Federaciya, MPK S01F5/02. Sposob pererabotki serpentinita [Method for processing serpentinite]. Kalichenko I.I., Gabdullin A.N.; zayavl. 13.07.2005; opubl. 27.01.2007. (in Russian)

Patent 2953 A Respublika Armeniya, MPK S 01 V33/00, S 09 S1/00. Sposob kompleksnoj pererabotki serpentinitov [Chrysotile asbestos and resource conservation in the chrysotile asbestos industry]. Sagarunyan S.A., Arustamyan A.G., Agamyan E.S., Arakelyan A.M., Sagarunyan A.S.; opubl. 2014. (in Russian)

Patent 29779 Respublika Kazahstan. Sposob kompleksnoj pererabotki othodov hrizotil-asbestovogo proizvodstva [Method for integrated processing of chrysotile asbestos production waste]. V.A. Kozlov, O.S. Bajgenzhenov, K.K. Zhusupov, V.V. Shevelev; zayavitel i patentoobladatel RGP na PHV «Nacionalnyj centr po kompleksnoj pererabotke mineralnogo syrya Respubliki Kazahstan»; zayavl. 14.03.2014; opubl. 15.04.2015, byul. — №4. (in Russian).

Punenkov S.E., Kozlov Yu.S. Hrizotil-asbest i resursosberezhenie v hrizotil-asbestovoj otrasli [Chrysotile asbestos and resource conservation in the chrysotile asbestos industry]. Gornyj zhurnal Kazahstana. — 2022. — № 1. — S. 5-10. (in Russian)

Shaban M, Abukhadra MR, Khan AAP, Jibali BM (2018) Removal of Congo red, methylene blue and Cr (VI) ions from water using natural serpentine. Journal of the Taiwan Institute of Chemical Engineers 82:102–113 https://doi.org/10.1016/j.jtice.2017.10.023 (in English)

Shevko V, Akylbekov E, Karataeva G, Badikova A (2022) Processing of chrysotile asbestos production waste. Metallurgical research and technology 119(4):410 https://doi.org/10.1051/metal/2022050 (in English)

Sierra C, Chouinard S, Pasquier LC, Mercier G, Blais JF (2018) Feasibility Study on the Utilization of Serpentine Residues for $Mg(OH)_2$ Production. Waste Biomass Valorization 9:1921–1933. https://doi.org/10.1007/s12649-017-9926-9 (in English)

Teixeira APC, Purceno AD, Barros AS, Lemos BRS, Ardisson JD, Macedo WAA et al (2012) Amphiphilic magnetic composites based on layered vermiculite and fibrous chrysotile with carbon na nostructures: Application in catalysis. Catalysis Today 190:133–143. https://doi.org/10.1016/j.cattod.2012.02.062 (in English)

Yeskibayeva Ch, Auyeshov A, Arynov K, Dikanbayeva A, Satimbekova (2024) Nature of serpentinite interactions with low-concentration sulfuric acid solutions. Green Processing and Synthesis 13(9). https://doi.org/10.1515/gps-2024-0034 (in English)

Publication Ethics and Publication Malpractice in the journals of the Central Asian Academic Research Center LLP

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 journals of the Central Asian Academic Research Center LLP 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 Central Asian Academic Research Center LLP 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 Central Asian Academic Research Center LLP.

The Editorial Board of the Central Asian Academic Research Center LLP will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайте:
www:nauka-nanrk.kz
ISSN 2518-1483 (Online), ISSN 2224-5227 (Print)
http://reports-science.kz/index.php/en/archive

Ответственный редактор *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Т. Апендиев*
Верстка на компьютере *Г.Д. Жадырановой*

Подписано в печать 29.12.2025.
Формат 60x88$^{1}/_{8}$.
18,0 п.л. Заказ 4.

«Central Asian Academic Research Center» LLP
Алматы, Қонаев к-сі, 142