ISSN: 2224-5286 (Print)
ISSN: 2518-1491 (Online)

ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY

№3
2025

ISSN 2518-1491 (Online),
ISSN 2224-5286 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY

3 (464)

July – September 2025

PUBLISHED SINCE JANUARY
1947 PUBLISHED 4 TIMES A YEAR

ALMATY, NAS RK

ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY
ISSN 2518-1491 (Online),
ISSN 2224-5286 (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 **№ KZ23VPY00121156,**
issued 05.06.2025
Thematic scope: *organic chemistry, inorganic chemistry, catalysis, electrochemistry and corrosion, pharmaceutical chemistry and technology.*
Periodicity: 4 times a year.
http://chemistry-technology.kz/index.php/en/arhiv

Editorial address: JSC «D.V. Sokolsky institute of fuel, catalysis and electrochemistry», 142, Kunayev str., of. 310, Almaty, 050100, tel. 291-62-80, fax 291-57-22, e-mail: orgcat@nursat.kz

---

«ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY»
ISSN 2518-1491 (Online),
ISSN 2224-5286 (Print)

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

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген **№ KZ23VPY00121156** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *органикалық химия, бейорганикалық химия, катализ, электрохимия және коррозия, фармацевтикалық химия және технологиялар.*

Мерзімділігі: жылына 4 рет.

http://chemistry-technology.kz/index.php/en/arhiv

Редакцияның мекенжайы: 050100, Алматы қ., Қонаев к-сі, 142, «Д.В. Сокольский атындағы отын, катализ және электрохимия институты» АҚ, каб. 310, тел. 291-62-80, факс 291-57-22, e-mail:orgcat@nursat.kz

---

«ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY».
ISSN 2518-1491 (Online),
ISSN 2224-5286 (Print)

Собственник: Республиканское общественное объединение 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 **№ KZ23VPY00121156,** выданное 05.06.2025 г.

Тематическая направленность: *органическая химия, неорганическая химия, катализ, электрохимия и коррозия, фармацевтическая химия и технологии.*

Периодичность: 4 раз в год.

http://chemistry-technology.kz/index.php/en/arhiv

Адрес редакции: 050100, г. Алматы, ул. Кунаева, 142, АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского», каб. 310, тел. 291-62-80, факс 291-57-22, e-mail:orgcat@nursat.kz

CONTENTS

МАЗМҰНЫ

СОДЕРЖАНИЕ

ACADEMIC SCIENTIFIC JOURNAL OF CHEMISTRY
ISSN 2224–5286
Volume 3. Number 464 (2025), 29–40

https://doi.org/10.32014/2025.2518-1491.298

IRSTI 53.39.19
UDC 661.63:628.52

© A.P. Auyeshov[1], K.T. Arynov[2], Ch.Z. Yeskibayeva[1], 2025.
[1]M. Auezov South Kazakhstan University, Shymkent, Kazakhstan;
[2]Institute of Innovative Research and Technology, Almaty, Kazakhstan.
E-mail: centersapa@mail.ru

RESOURCE AND ECONOMIC EFFICIENCY OF SERPENTINITE WASTE UTILIZATION FOR THE PRODUCTION OF INORGANIC MAGNESIUM COMPOUNDS

Auyeshov Abdrazakh Pernebayevich — Doctor of Technical Sciences, Professor, M. Auezov South Kazakhstan University, Shymkent, Kazakhstan,
E-mail: abdrazahauesov@gmail.com, ORCID ID: https://orcid.org/0000-0002-3504-9117;
Arynov Kazhmukhan Tohtiyarovich — Doctor of Technical Sciences, Professor, Institute of Innovative Research and Technology, Almaty, Kazakhstan,
E-mail: i_technology@mail.ru, ORCID ID: https://orcid.org/0000-0002-1440-8248;
Yeskibayeva Chaizada Zulpuharovna — Candidate of Technical Sciences, Associate professor of M. Auezov South Kazakhstan University, Shymkent, Kazakhstan,
E-mail: centersapa@mail.ru, ORCID ID: https://orcid.org/0009-0009-8440-1242.

Abstract. This article explores the current state and future directions in the processing and utilization of serpentinite waste generated during the mining and beneficiation of chrysotile-asbestos ores in Russia and Kazakhstan. Inefficient management of this waste leads to significant environmental impacts and deterioration of ecological conditions in industrial regions. A critical review of recent scientific publications and developments in the production of magnesium compounds from serpentinite is presented. It is demonstrated that with proper technological approaches, serpentinite waste from chrysotile-asbestos processing can become a source of economic benefit. Examples are given of industrial production of high-purity chemical products derived from serpentinite waste. The article discusses the resource and economic efficiency of such processes, including research results obtained at M. Auezov South Kazakhstan University on the integrated processing of serpentinite waste from the Zhitikara deposit. The proposed technology involves an innovative approach using thermally activated serpentinite for the purification and neutralization of magnesium extraction solutions, enabling the production of high-purity magnesium compounds from low-grade mineral feedstock. The novelty lies in the combination of acid leaching with solid-phase reagents derived from the same waste, making the process more sustainable and economically efficient. The developed technologies can be implemented at chrysotile-asbestos mining enterprises to reduce environmental burden and meet the increasing demand for magnesium compounds in Kazakhstan's industry. Utilization of serpentinite waste not only mitigates environmental impact but also supplies key industrial sectors with valuable magnesium-based products.

Key words: serpentinite waste, Zhitikara deposit, utilization, magnesium compounds, resource efficiency

This research was funded by the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan (grant No. AP19676952).

© А.П. Ауешов[1], К.Т. Арынов[2], Ч.З. Ескибаева[1], 2025.
[1]М. Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан;
[2]Инновациялық зерттеулер және технология институты, Алматы, Қазақстан.
E-mail: centersapa@mail.ru

МАГНИЙДІҢ БЕЙОРГАНИКАЛЫҚ ҚОСЫЛЫСТАРЫН АЛУ МАҚСАТЫНДА СЕРПЕНТИНИТТІ ҚАЙТА ӨҢДЕУДІҢ РЕСУРСТЫҚ ЖӘНЕ ЭКОНОМИКАЛЫҚ ТИІМДІЛІГІ

Ауешов Абдразах Пернебаевич — техника ғылымдарының докторы, М. Ауезов атындағы Оңтүстік Қазақстан университетінің профессоры, Шымкент, Қазақстан,
E-mail: abdrazahauesov@gmail.com, ORCID ID: https://orcid.org/0000-0002-3504-9117;
Арынов Кажмухан Тохтиярович — техника ғылымдарының докторы, Инновациялық зерттеулер және технология институтының профессоры, Алматы, Қазақстан,
E-mail: i_technology@mail.ru, ORCID ID: https://orcid.org/0000-0002-1440-8248;
Ескибаева Чайзада Зулпухаровна — техника ғылымдарының кандидаты, М. Ауезов атындағы Оңтүстік Қазақстан университетінің доценті, Шымкент, Қазақстан,
E-mail: centersapa@mail.ru, ORCID ID: https://orcid.org/0009-0009-8440-1242.

Аннотация. Мақалада Ресей мен Қазақстан кен орындарында хризотил-асбест кенін өндіру және байыту барысында пайда болатын серпентинит қалдықтарын өңдеу және кәдеге жарату бойынша қазіргі жағдай мен перспективалық бағыттар қарастырылады. Мұндай қалдықтарды тиімді пайдаланбау өндірістік аймақтарда экологиялық жағдайдың нашарлауына және қоршаған ортаға айтарлықтай зиян келтіреді. Серпентиниттен магний қосылыстарын алу саласындағы соңғы ғылыми жарияланымдар мен әзірлемелерге сыни шолу ұсынылған. Хризотил-асбест қалдықтарын өңдеуге арналған дұрыс технологиялық тәсілдерді қолдану арқылы серпентинит қалдықтарының экономикалық әлеуеті бар екені дәлелденді. Серпентинит қалдықтарынан жоғары тазалықтағы химиялық өнімдер өндірісінің мысалдары келтірілген. Сонымен қатар, Жітіқара кен орны серпентинит қалдықтарын кешенді өңдеу бойынша М. Әуезов атындағы Оңтүстік Қазақстан университетінде алынған зерттеу нәтижелері негізінде ресурстық және экономикалық тиімділік мәселелері қарастырылды. Ұсынылған технологияда магнийді экстракциялау ерітінділерін тазарту және бейтараптандыру үшін термиялық активтендірілген серпентинитті қолдануға негізделген инновациялық тәсіл ұсынылады. Бұл төмен сапалы минералдық шикізаттан жоғары тазалықтағы магний қосылыстарын алуға мүмкіндік береді. Жаңашылдығы – қышқылмен сілтілеу үдерісін сол қалдықтардан алынған қатты фазалық реагенттермен біріктіруінде, бұл әдісті неғұрлым орнықты әрі экономикалық тұрғыда тиімді етеді. Дайындалған технологияларды хризотил-асбест өндіретін кәсіпорындарда енгізу арқылы экологиялық жүктемені азайтып, Қазақстан өнеркәсібіндегі магний қосылыстарына деген өсіп келе жатқан сұранысты қанағаттандыруға болады. Серпентинит қалдықтарын кәдеге жарату тек экологиялық әсерді төмендетіп қана қоймай, сонымен қатар елдің әртүрлі өнеркәсіп салаларын құнды магний өнімдерімен қамтамасыз етуге мүмкіндік береді.

Түйін сөздер: серпентинит қалдықтары, Жітіқара кен орны, кәдеге жарату, магний қосылыстары, ресурстық тиімділік

© А.П. Ауешов[1], К.Т. Арынов[2], Ч.З. Ескибаева[1], 2025.
[1]Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан;
[2]Институт инновационных исследований и технологий, Алматы, Казахстан.
E-mail: centersapa@mail.ru

РЕСУРСНАЯ И ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ УТИЛИЗАЦИИ СЕРПЕНТИНИТА С ПОЛУЧЕНИЕМ НЕОРГАНИЧЕСКИХ СОЕДИНЕНИЙ МАГНИЯ

Ауешов Абдразах Пернебаевич — доктор технических наук, профессор Южно-Казахстанского университета им. М. Ауэзова, Шымкент, Казахстан,
E-mail: abdrazahauesov@gmail.com, ORCID ID: https://orcid.org/0000-0002-3504-9117;
Арынов Кажмухан Тохтиярович — доктор технических наук, профессор Института инновационных исследований и технологий, Алматы, Казахстан,
E-mail: i_technology@mail.ru, ORCID ID: https://orcid.org/0000-0002-1440-8248;
Ескибаева Чайзада Зулпухаровна — кандидат технических наук, доцент Южно-Казахстанского университета им. М. Ауэзова, Шымкент, Казахстан,
E-mail: centersapa@mail.ru, ORCID ID: https://orcid.org/0009-0009-8440-1242.

Аннотация. В статье рассматриваются современное состояние и перспективные направления В статье рассматриваются современное состояние и перспективные направления переработки и утилизации серпентинитовых отходов, образующихся при добыче и обогащении хризотил-асбестовых руд на месторождениях России и Казахстана. Отмечается, что неэффективное обращение с такими отходами приводит к негативному воздействию на окружающую среду и ухудшению экологической обстановки в районах размещения производств. Представлен критический обзор научных публикаций и разработок последних лет в области получения магниевых соединений из серпентинитов. Показано, что при правильном подборе технологии серпентинитовые отходы переработки хризотил-асбестового сырья могут стать источником дохода. Приведены примеры организации производств химических продуктов высокой степени чистоты, полученных из серпентинитовых отходов. Рассматриваются аспекты ресурсной и экономической эффективности. Приведены результаты исследований, направленных на комплексную переработку серпентинитовых отходов Житикаринского месторождения, полученных в Южно-Казахстанском университете им. М. Ауэзова. Предложенная технология включает инновационный подход с использованием термически активированного серпентинита для очистки и нейтрализации растворов при извлечении магния. Это позволяет получать магниевые соединения высокой чистоты из низкосортного минерального сырья. Новизна заключается в сочетании кислотного выщелачивания с твердофазными реагентами, полученными из тех же отходов, что делает процесс более устойчивым и экономически выгодным. Разработанные технологии могут быть внедрены на предприятиях по добыче хризотил-асбеста для снижения экологической нагрузки и удовлетворения растущего спроса на магниевые соединения в промышленности Казахстана. Показано, что использование и утилизация серпентинитовых отходов позволит не только снизить экологическую нагрузку, но и обеспечить потребность различных отраслей промышленности Казахстана соединениями магния.

Ключевые слова: серпентинитовые отходы, Житикаринское месторождение, утилизация, соединения магния, ресурсосбережение

Introduction. Serpentinite rocks constitute one of the major types of anthropogenic waste generated during the processing of ultrabasic ores. The accumulated volume of such waste amounts to hundreds of millions of tons, posing a significant environmental burden. According to the Ministry of Natural Resources and geological services, over 500 million tons of serpentinite waste have been accumulated across the countries of the Commonwealth of Independent States (CIS), primarily Russia and Kazakhstan. At the same time, the rich chemical composition of serpentinite—including magnesium, silicon, and iron—makes it a valuable secondary raw material. These wastes typically contain 25–43% MgO, 35–45% SiO_2, 7–8% FeO, along with trace amounts of Ni, Cr, and Al. Their proximity to mining and processing facilities provides logistical advantages for utilization. It is estimated that 2 to 3 million tons of serpentinite waste could potentially be processed annually. However, at present, serpentinite waste resulting from the beneficiation of ultrabasic rocks, such as chrysotile-asbestos ore, remains largely unutilized. In this context, the development of innovative technologies aimed at converting serpentinite into value-added products has become a pressing and relevant objective.

Materials and methods. The research methodology included a comprehensive analysis and critical review of existing scientific literature, patents, and dissertations related to the processing and utilization of serpentinite and associated industrial waste. The review focused on identifying key technological directions, typical solutions, and limitations of current approaches, incorporating both domestic and international experience. Particular attention was paid to the work of international research groups and Kazakhstani scientists involved in the development of strategies for serpentinite valorization.

To evaluate the most promising processing pathways, benchmarking was applied to compare existing technologies in terms of efficiency, scalability, and environmental indicators. Additionally, foresight analysis was conducted to assess the long-term prospects for serpentinite utilization, considering the properties of the raw material, potential end products, and relevant market demand. This integrated methodological framework enabled the identification of the most efficient solutions for the sustainable conversion of serpentinite waste into high-value magnesium compounds.

Results and discussion. *Current status of serpentinite waste utilization.* The utilization of serpentinite waste generated during the processing of chrysotile-asbestos ores remains insufficiently developed, despite its significant volume and environmental hazard. At present, one of the most widespread approaches is its use in road construction as a filler or reinforcing component in road base layers. This practice not only enhances the mechanical strength of the road foundation, but also helps reduce waste accumulation at industrial sites (Tarasov et al., 2021).

Magnesium-containing waste, including serpentinite, is also used in the production of construction materials. Crushed serpentinite improves the strength, water resistance, and sulfate resistance of cement and concrete composites. The use of such waste as an aggregate reduces production costs and represents an environmentally safe method of resource conservation (Khudyakova, 2018). However, many of the proposed serpentinite utilization options have not yet been implemented on an industrial scale.

An analysis of the current situation at chrysotile-asbestos mining enterprises in Kazakhstan and Russia highlights the need to introduce more effective and diversified utilization strategies. Improving competitiveness and tightening environmental requirements necessitate the development of practical and economically viable technologies for serpentinite waste processing. Researchers emphasize that the rational and integrated use of mineral resources is regarded as a strategic priority for the sustainable development of the chrysotile-asbestos industry (Punenkov & Kozlov, 2022).

In addition to traditional applications in construction and cement production, serpentinite waste is increasingly considered a multifunctional raw material for obtaining high-tech products. Studies have confirmed the suitability of industrial serpentinite for use in heterogeneous catalysis (Teixeira et al., 2012), in the sorption of heavy metals from wastewater (Huang et al., 2017), and as a component of electrodes in electrochemical processes (Randelović et al., 2017). Although these applications are still at the laboratory stage, they demonstrate the multifunctionality of serpentinite and its potential in advanced technologies.

Technological and kinetic aspects of acid leaching of magnesium from serpentinite. Serpentinite is a valuable secondary raw material due to its high magnesium content (25–43% MgO). As a result, intensive research is being conducted to develop technologies for producing magnesium salts and oxides. Since serpentinite exhibits low reactivity with alkalis, most studies focus on acid leaching using mineral acids such as sulfuric (H_2SO_4), hydrochloric (HCl), nitric (HNO_3), and phosphoric (H_3PO_4) acids.

One of the approaches for obtaining magnesium sulfate ($MgSO_4$) involves leaching thermally activated serpentinite with sulfuric acid at temperatures ranging from

500–600°C (Becciano et al., 2024). This method has demonstrated high efficiency in extracting magnesium for agricultural and industrial applications. A similar scheme was described in a patent (Grigorovich et al., 2006), where the main product is magnesium oxide. However, that method is characterized by high energy consumption and technological complexity. An optimized process includes pre-calcination of serpentinite at 680–750°C, followed by leaching with 4–8% hydrochloric acid at a solid-to-liquid ratio of 1:15–40 (Zulumyan et al., 2010). The resulting slurry is filtered, and cyclic processing is often applied in laboratory-scale studies. Despite improved performance, the need for high-temperature activation remains a key limitation of the technology.

Another approach involves the use of nitric acid: the non-magnetic fraction of serpentinite is leached with the formation of magnesium nitrate, which is then purified, evaporated, and subjected to thermohydrolysis to produce magnesium oxide and regenerate nitric acid (Kalichenko & Gabdullin, 2007). Despite its high efficiency, the method requires complex equipment and implementation.

Other acid leaching technologies using various acids have also been proposed (Aueshov et al., 2017); however, they are limited by long process durations, high reagent and energy consumption, and the formation of a gelatinous silica dioxide precipitate. These limitations hinder widespread implementation of the technologies and emphasize the need for further optimization.

The kinetics of serpentinite dissolution in various acids plays a critical role in the efficiency of magnesium extraction and has been the subject of numerous studies. When treated with sulfuric acid, both magnesium sulfate and silica gel are formed. The leaching rate depends on the acid concentration, temperature, and reaction time. However, the formation of a passivating gel of silicic acid hinders further dissolution and phase separation (Yeskibayeva et al., 2024).

When hydrochloric acid is used, magnesium chloride and silica gel are formed, with the reaction kinetics also influenced by acid concentration and temperature (Khartukova, 2005). In the case of nitric acid, magnesium nitrate and a SiO_2 precipitate are formed. Interaction with phosphoric acid may result in the formation of various magnesium phosphates, such as $Mg(HPO_4)_2$, MgH_2PO_4, and $Mg_3(PO_4)_2$, depending on the pH and reaction conditions (Arynov et al., 2017).

Comparative studies show that the type of acid and process parameters significantly affect both the leaching kinetics and the degree of silica gel precipitation (Teir et al., 2007; Yoo et al., 2009). Silica gels still represent a major technological challenge, as they clog filters and reduce the efficiency of phase separation.

Recent studies have explored the use of organic acids, such as citric acid, as milder and more effective solvents. According to data from the Russian Science Foundation (grant No. 22-27-00035, 2022–2024), citric acid significantly accelerates serpentinite dissolution under flow conditions and reduces the formation of silica gels.

At the 2024 scientific and practical conference in Yekaterinburg, it was emphasized that acid concentration, particle size, temperature, and thermal activation are key factors influencing the leaching kinetics (Aueshov et al., 2024c).

The general mechanism of acid leaching involves the protonation of hydroxyl groups in the serpentinite structure [$Mg_3Si_2O_5(OH)_4$], leading to the release of Mg^{2+} ions and the formation of colloidal silica. To intensify the process, methods such as increasing acid concentration, reducing particle size, raising the temperature, and pre-calcination are employed. Nevertheless, the development of scalable and economically viable acid leaching technologies remains an urgent task.

Economic efficiency and industrial potential. One of the most important tasks in serpentinite waste utilization is achieving not only environmental, but also economic benefits. The results of systematic studies (Aueshov et al., 2024a; Yeskibayeva et al., 2024) aimed at developing efficient processing routes for serpentinite waste from the Zhitikara deposit, conducted at South Kazakhstan University named after M. Auezov, confirm the practical relevance and industrial potential of further research in this area. Figure 1 presents a generalized process flow diagram for the stepwise production of magnesium compounds from serpentinite waste. It outlines the main stages of magnesium sulfate, magnesium hydroxide, and magnesium oxide production, including acid leaching, purification, precipitation, and final calcination to obtain high-purity magnesium oxide.

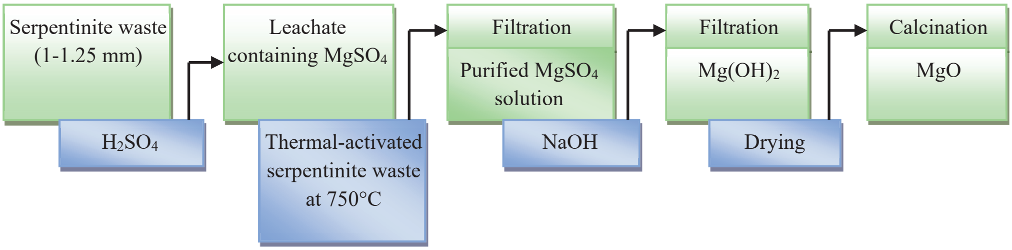

Figure 1 - Process flow diagram for the production of high-purity magnesium oxide (MgO) from serpentinite waste

Table 1 presents the key technical and economic indicators for producing magnesium sulfate ($MgSO_4 \cdot 7H_2O$), magnesium hydroxide ($Mg(OH)_2$), and magnesium oxide (MgO) from serpentinite waste of the Zhitikara deposit, based on systematic experimental studies (Auyeshov et al., 2024b; Yeskibayeva et al., 2024).

Table 1 - Resource and energy efficiency of $MgSO_4 \cdot 7H_2O$, $Mg(OH)_2$, and MgO production from serpentinite waste of the Zhitikara deposit

Item	Unit of Measure	Quantity	Unit Cost (USD)	Total Cost (USD)
a) $MgSO_4 \cdot 7H_2O$				
Revenue				$175.00
$MgSO_4 \cdot 7H_2O$	tons	1.00	$175.00	$175.00
Costs				$60.00
Industrial waste (ITW)	tons	0.46	$3.00	$1.40
Thermally activated ITW	tons	0.40	$3.00	$1.20

Sulfuric acid (H_2SO_4, density=1.824 g/cm^3)	tons	0.44	$100.00	$44.40
Water (technical)	tons	2.80	$1.00	$2.80
Electricity (drying or calcination)	kWh	92.40	$0.07	$6.00
Miscellaneous costs				$4.20
Profit				$115.00

b) Mg(OH)₂

Item	Unit of Measure	Quantity	Unit Cost (USD)	Total Cost (USD)
Revenue				$1445.00
$Mg(OH)_2$	tons	1.00	$1200.00	$1200.00
Na_2SO_4	tons	2.45	$100.00	$245.00
Costs				$950.00
$MgSO_4·7H_2O$	tons	4.25	$60.00	$255.80
NaOH	tons	1.38	$500.00	$690.00
Water (technical)	tons	4.20	$1.00	$4.20
Profit				+$495.00

c) MgO

Item	Unit of Measure	Quantity	Unit Cost (USD)	Total Cost (USD)
Revenue				$5000.00
MgO	tons	1.00	$5000.00	$5000.00
Costs				1444.30
$Mg(OH)_2$	tons	1.47	$950.00	1397.00
Electricity	kWh	731.30	$32.64	47.80
Profit				+$3555.70

Note: Calculations are based on the production of 1 metric ton of product using serpentinite waste from the Zhitikara deposit. Cost estimates include raw materials, reagents, electricity, water, and miscellaneous operational expenses. Source: experimental data obtained by the authors (Ch.Z. Yeskibayeva et al.)

As shown in Table 1, the stepwise conversion of serpentinite waste into magnesium compounds demonstrates consistent improvement in economic attractiveness. The production of magnesium sulfate heptahydrate ($MgSO_4·7H_2O$) yields a moderate profit of $115 per ton, primarily due to the high cost of reagents. In contrast, the subsequent conversion to magnesium hydroxide ($Mg(OH)_2$) significantly increases profitability to $495 per ton due to the market value of sodium sulfate as a by-product. The final stage — calcination to obtain high-purity MgO — provides the highest economic return, with a net profit of $3555.70 per ton.

These economic indicators are further illustrated in Figure 2, which shows the gross profit for the three target magnesium compounds — sulfate, hydroxide, and oxide.

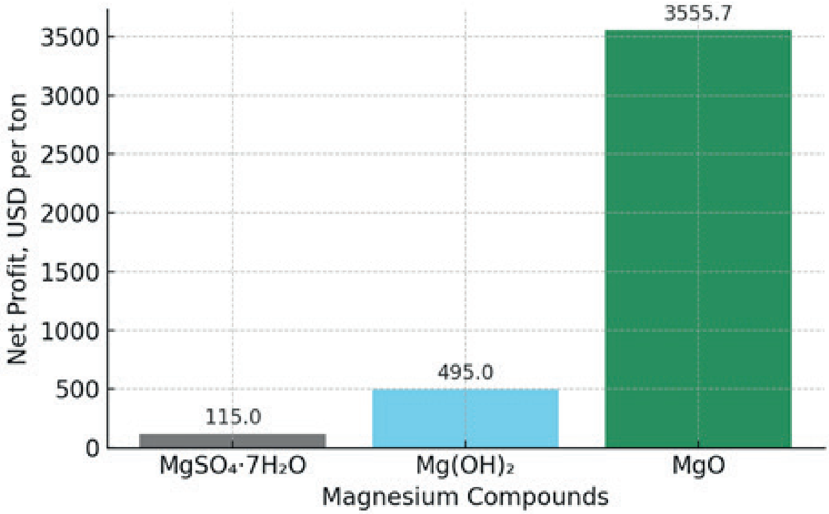

Figure 2 - Gross profit (per ton) of magnesium compounds obtained from serpentinite waste

As seen in Figure 2, the transition from magnesium sulfate to magnesium hydroxide and subsequently to magnesium oxide is accompanied by a significant increase in gross profit. While the production of $MgSO_4 \cdot 7H_2O$ ensures only a modest profit due to high reagent costs, $Mg(OH)_2$ provides a higher economic return, largely owing to the by-product formation of sodium sulfate. The final stage—MgO production—offers the highest profit, approximately $3555.7 per ton. This confirms the high commercial significance of the proposed stepwise processing scheme and its potential for industrial implementation. The results confirm that the proposed technological scheme is not only resource-efficient but also economically viable at every stage of the production cycle.

The first practical steps in implementing such a technological scheme (Figure 1) are already underway in Russia. For example, the Russian company Ultra S has launched a modular pilot plant for the production of high-purity magnesium oxide, amorphous silica, and magnesium sulfate. The flexibility of the process allows for adaptation to market demands (Ultra "S" Ltd., 2024). Currently, production capacities enable pilot-scale output of up to 200 tons/year of high-purity magnesium oxide (purity above 99.0%), 400 tons/year of amorphous silica (as an analog of synthetic silicates), and 600 tons/year of magnesium sulfate. The modular organization of Ultra S technology allows adjustment of the product balance depending on market conditions.

The Zhitikara deposit, which has been operating since the mid-20th century, contains millions of tons of serpentinite tailings. According to geological characteristics, it is similar to the Russian Kiyembay and Bazhenov deposits (Punenkov & Kozlov, 2022), which makes the application of similar technologies in Kazakhstan feasible.

The obtained results may serve as a reliable scientific and technical basis for scalable and sustainable industrial solutions.

Conclusion. The Zhitikara chrysotile-asbestos deposit in the Kostanay region of Kazakhstan has been in operation since the mid of the last century and is considered one of the largest in the world. However, along with valuable fiber, its extraction has resulted in the accumulation of millions of tons of serpentinite tailings. Today, these wastes are being considered as a strategic source of magnesium—an element essential for dozens of industrial sectors.

The use of serpentinite waste from chrysotile-asbestos ore of the Zhitikara deposit as a source of magnesium for the production of industrially significant inorganic magnesium compounds is a promising direction that combines economic benefits with environmental sustainability. The presented data and rationale confirm the feasibility of continuing research in this area to develop effective approaches for utilizing serpentinite waste to obtain magnesium and other valuable products.

Литература

Ауешов А.П., Арынов К.Т., Ескибаева Ч.З. Реагентные технологии переработки отходов производства асбеста. – Saarbrücken: LAP LAMBERT Academic Publishing, 2017. — 113 с.

Бекчанов Б.Б., Джандуллаева М.С., Эркаев А.У., Кошанова Б.Т. Разработка технологии получения солей магния расщеплением серпентинита серной кислотой. Universum: технич. науки: электрон. научный журнал – 2024, 10-5(127). — С. 58-61. DOI: 10.32743/UniTech.2024.127.10.18416

Патент 2285666 Российская Федерация, МПК C 01 F 5/06, C 01 B 33/142. Способ комплексной переработки магний-силикатосодержащего сырья. М.М. Григорович, Л.И. Мельник, Р.М. Кузьмина; заявл. 20.07.2005; опубл. 20.10.2006.

Патент 2407704 РФ, МПК С 01 В33/12. Способ комплексной обработки серпентинита. Н.О. Зулумян, А.Р. Исаакян, Т.А. Овсепян. – № 2008113333/05; заявл. 09.04.2008; опубл. 27.12.2010. — 6 с.

Патент 2292300 РФ, МПК C01F5/02. Способ переработки серпентинита. Каличенко И.И., Габдуллин А.Н.; заявл. 13.07.2005; опубл. 27.01.2007.

Патент на изобретение РК №32561. Способ получения комплексного магний-фосфатного удобрения. Арынов К.Т., Ауешов А.П., Ескибаева Ч.З., Алжанов К.Б., Ибраева А.М. и др. – заявл. 20.06.2016; опубл. 27.11.2017.

Пуненков С.Е., Козлов Ю.С. Хризотил-асбест и ресурсосбережение в хризотил-асбестовой отрасли. Горный журнал Казахстана, 2022. — № 1. — С. 5-10. https://10.0.189.114/minmag.2022.204.4.001

Тарасов П.И., Хазин М.Л., Апакашев Р.А. Использование отходов горнодобывающей промышленности Урала. Горный информационно-аналитический бюллетень, 2021. — №1. — С. 21-31. https://doi.org/10.25018/0236-1493-2021-1-0-21-31

Хартукова А.А. Химико-технологические основы утилизации магнийсиликатных отходов, образующихся при добыче минерального сырья: автореф. дис. ... канд. техн. наук, 2005.

Худякова Л.И. Научные и практические основы утилизации магнийсиликатных отходов горнодобывающей промышленности: автореф. дис. ... докт. наук, 2018.

Auyeshov A., Arynov K., Yeskibayeva Ch., Alzhanov K., Raiymbekov Y. (2024a) Thermoacid behavior of serpentinite of the Zhitikarinsky deposit (Kazakhstan). Molecules, 29(16), 3965. https://doi.org/10.3390/molecules29163965

Auyeshov A., Arynov K., Yeskibayeva Ch., Satimbekova A., Alzhanov K. (2024b) Thermal activation of serpentinite from the Zhitikarinsky deposit (Kazakhstan). Molecules, 29(18), 4455. https://doi.org/10.3390/molecules29184455

Auyeshov A., Yeskibayeva Ch., Arynov K., Kolesnikov A. (2024c) Aspects of waste recycling problems in chrysotile asbestos industry. Mining Informational and Analytical Bulletin, 9, 88–98. https://doi.org/10.25018/0236_1493_2024_9_0_88

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. Applied Clay Science, 149, 1–7. https://doi.org/10.1016/j.clay.2017.08.030

Randelovic M.S., Momcilovic M.Z., Nikolic G., Dordevic J.S. (2017). Electrocatalytic behaviour of serpentinite modified carbon paste electrode. Journal of Electroanalytical Chemistry, 801, 338–344. https://doi.org/10.1016/j.jelechem.2017.08.011

Teir S., Revitzer H., Eloneva S., Fogelholm C.J., Zevenhoven R. (2007). Dissolution of natural serpentinite in mineral and organic acids. International Journal of Mineral Processing, 83, 36–46. https://doi.org/10.1016/j.minpro.2007.04.001

Teixeira A.P.C., Purceno A.D., Barros A.S. et al. (2012) Amphiphilic magnetic composites based on layered vermiculite and fibrous chrysotile with carbon nanostructures: Application in catalysis. Catalysis Today, 190. — P. 133–143. https://doi.org/10.1016/j.jelechem.2017.08.011

Yeskibayeva Ch., Auyeshov A., Arynov K., Dikanbayeva A., Satimbekova A. (2024) Nature of serpentinite interactions with low-concentration sulfuric acid solutions. Green Processing and Synthesis, 13, Article ID 20240034. https://doi.org/10.1515/gps-2024-0034

Yoo K., Kim B.-S., Kim M.-S., Lee J., Jeong J. (2009). Dissolution of magnesium from serpentine mineral in sulfuric acid solution. Materials Transactions, 50. — P. 1225–1230. https://doi.org/10.2320/matertrans.M2009019

Arynov K.T., Auyeshov A.P., Eskibaeva Ch.Z., Alzhanov K.B., Ibraeva A.M. et al. (2017) Patent RK No. 32561. Sposob polucheniya kompleksnogo magniy-fosfatnogo udobreniya [Method for producing complex magnesium-phosphate fertilizer]. Filed. 20.06.2016; published. 27.11.2017.

References

Aueshov A.P., Arynov K.T., Eskibaeva Ch.Z. (2017) Reagentnye tekhnologii pererabotki otkhodov proizvodstva asbesta [Reagent technologies for processing asbestos production waste]. Saarbrücken: LAP LAMBERT Academic Publishing. — P. 113 (in Russian)

Auyeshov A., Arynov K., Yeskibayeva Ch., Alzhanov K., Raiymbekov Y. (2024a) Thermoacid behavior of serpentinite of the Zhitikarinsky deposit (Kazakhstan). Molecules, 29(16). — P. 3965. https://doi.org/10.3390/molecules29163965. (in English)

Auyeshov A., Arynov K., Yeskibayeva Ch., Satimbekova A., Alzhanov K. (2024b) Thermal activation of serpentinite from the Zhitikarinsky deposit (Kazakhstan). Molecules, 29(18), 4455. https://doi.org/10.3390/molecules29184455 (in English)

Auyeshov A., Yeskibayeva Ch., Arynov K., Kolesnikov A. (2024c) Aspects of waste recycling problems in chrysotile asbestos industry. Mining Informational and Analytical Bulletin, 9. — P. 88–98. https://doi.org/10.25018/0236_1493_2024_9_0_88. (in English)

Bekchanov B.B., Dzhandullaeva M.S., Erkaev A.U., Koshanova B.T. (2024) Razrabotka tekhnologii polucheniya soley magniya rasshchepleniem serpentinita sernoy kislotoi [Development of magnesium salts production technology by serpentinite decomposition with sulfuric acid]. Universum: Technical Sciences, 10(127). — P. 58–61. https://doi.org/10.32743/UniTech.2024.127.10.18416. (in Russian)

Grigorovich M.M., Mel'nik L.I., Kuz'mina R.M. (2006) Patent RU No. 2285666. Sposob kompleksnoy pererabotki magnisilikatsoderzhashchego syr'ya [Method for complex processing of magnesium silicate-containing raw materials]. Filed 20.07.2005; published 20.10.2006. (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. Applied Clay Science, 149, 1–7. https://doi.org/10.1016/j.clay.2017.08.030. (in English)

Kalichenko I.I., Gabdullin A.N. (2007). Patent RU No. 2292300. Sposob pererabotki serpentinita [Method for processing of serpentinite]. Filed 13.07.2005; published 27.01.2007. (in Russian)

Khartukova A.A. (2005) Khimiko-tekhnologicheskie osnovy utilizatsii magnisilikatnykh otkhodov, obrazuyushchikhsya pri dobyche mineral'nogo syr'ya [Chemical-technological foundations of utilization of magnesiosilicate waste generated during mineral extraction]: Abstract of Cand. Tech. Sci. Dissertation. (in Russian)

Khudyakova L.I. (2018) Nauchno-prakticheskie osnovy utilizatsii magnisilikatnykh otkhodov gornodobyvayushchey promyshlennosti [Scientific and practical foundations for the utilization of magnesiosilicate waste from the mining industry]: Abstract of Doctoral Dissertation (Tech. Sci.). (in Russian)

Punenkov S.E., Kozlov Yu.S. (2022) Khrizotil-asbest i resursosberezhenie v khrizotil-asbestovoy otrasli [Chrysotile asbestos and resource conservation in the chrysotile asbestos industry]. Mining Journal of Kazakhstan, 1. — P. 5–10. (in Russian)

Randelovic M.S., Momcilovic M.Z., Nikolic G., Dordevic J.S. (2017) Electrocatalytic behaviour of serpentinite modified carbon paste electrode. Journal of Electroanalytical Chemistry, 801. — P. 338–344. https://doi.org/10.1016/j.jelechem.2017.08.011. (in English)

Tarasov P.I., Khazin M.L., Apakashev R.A. (2021). Ispol'zovanie otkhodov gornodobyvayushchey promyshlennosti Urala [Utilization of mining industry waste in the Urals]. Mining Journal of Kazakhstan, 1. — P. 21–31. https://doi.org/10.25018/0236-1493-2021-1-0-21-31. (in Russian)

Teir S., Revitzer H., Eloneva S., Fogelholm C.J., Zevenhoven R. (2007). Dissolution of natural serpentinite in mineral and organic acids. International Journal of Mineral Processing, 83, 36–46. https://doi.org/10.1016/j.minpro.2007.04.001 (in English)

Teixeira A.P.C., Purceno A.D., Barros A.S. et al. (2012). Amphiphilic magnetic composites based on layered vermiculite and fibrous chrysotile with carbon nanostructures: Application in catalysis. Catalysis Today, 190. — P. 133–143. https://doi.org/10.1016/j.chemSphere.2016.06.022. (in English)

Yeskibayeva Ch., Auyeshov A., Arynov K., Dikanbayeva A., Satimbekova A. (2024). Nature of serpentinite interactions with low-concentration sulfuric acid solutions. Green Processing and Synthesis, 13, Article ID 20240034. https://doi.org/10.1515/gps-2024-0034. (in English)

Yoo K., Kim B.-S., Kim M.-S., Lee J., Jeong J. (2009). Dissolution of magnesium from serpentine mineral in sulfuric acid solution. Materials Transactions, 50. — P. 1225–1230. https://doi.org/10.2320/matertrans.M2009019. (in English)

Zulumyan N.O., Isaakyan A.R., Ovsepyan T.A. (2010). Patent RU No. 2407704. Sposob kompleksnoy obrabotki serpentinita [Method for complex processing of serpentinite]. Filed 09.04.2008; published 27.12.2010. (in Russian)

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 сайтах:
www:nauka-nanrk.kz
http://chemistry-technology.kz/index.php/en/arhiv
ISSN 2518-1491 (Online), ISSN 2224-5286 (Print)

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

Подписано в печать 29.09.2025.
Формат $60x88^1/_8$. 18,0 п.л.
Заказ 3.

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