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OBTAINING AND APPLICATION OF MAGNESIUM COMPOUNDS FROM RAW MATERIALS

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Magnesium, the eighth most abundant element in the Earth's crust and the second most abundant in the world's oceans after potassium, possesses unique properties that find wide application in various industries. Commercial magnesium compounds are extensively used in chemical processing, whether in the production of paper or viscose fiber, or as catalysts, fillers, flame retardants, alkaline materials, stable coatings for magnetic recording media, or wastewater and flue gas purifiers. Magnesium hydroxide is a common over-the-counter antacid and laxative. Additionally, a branch of synthetic organic chemistry known as Grignard reactions is based on magnesium compounds. Magnesium forms stable salts with the most common anions such as acetate, carbonate, halides, hydroxide, oxide, and sulfide, as well as with some less common ones such as vanadates. Many magnesium alkyls are also known. Its low density, high tensile strength, good thermal and electrical conductivity, and ability to absorb vibration make magnesium and its compounds valuable in aviation, automotive industry, medicine, agriculture, and other fields [1-2].

In 2010, the US accounted for approximately 53% of the demand for magnesium powders used in refractory materials, with the remaining 47% utilized in agriculture, chemical industry, construction, and environmental applications. While the USA and Canada dominated magnesium production in 1990, by the end of the 1990s, China had taken the leading position in this industry [3].

The extraction of magnesium from natural sources such as seawater, brines, and mineral ores plays a strategic role. Seawater is the source of 15% of the world's total magnesium production and contains a potential 1,900 million tons of magnesium compounds. Therefore, the economic evaluation of ore partially depends on the concentration of magnesium oxide and technological methods. The profitability of ore processing depends on the magnesium oxide concentration, which requires careful analysis and selection of optimal technologies. The efficiency of processes such as solar evaporation of brines makes them relevant for large-scale magnesium production [4].

In this work, the dissolution kinetics of natural magnesite is studied using formic acid as a leaching agent. The influence of various reaction parameters, such as temperature, acid solution concentration, particle size, and the liquid-to-solid ratio, was examined in relation to the leaching kinetics of natural magnesite [5].

The key importance in the production of magnesium powders lies in manufacturing a high-quality product with an MgO content of 96 to 99%, high density, and fine grain size (40-80 µm), which is necessary for the production of refractory materials. The powder is extracted from brine by precipitating it using calcined dolomite, and brucite is formed by the following reaction:

$$CaO\ (MgO) + MgCl_2 + 2H_2O \rightarrow 2Mg(OH)_2\downarrow + CaCl_2 \quad (1)$$

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This technology has found wide application in Western European countries and the USA, as well as in Israel, China, Japan, Mexico, and Jordan [6; 200 p.]. Today, the manufacturers using the electrolytic method in the West have been replaced by Chinese pyrometallurgical production facilities using Pidgeon technology. The method is based on the thermal reduction of magnesium oxide (MgO) from dolomite ($MgCO_3 \cdot CaCO_3$) using silicon as a reducing agent. This process occurs in a vacuum or at low pressure, which facilitates the evaporation of magnesium at a relatively low temperature. China has become the main user of Pidgeon technology due to the availability of cheap coal, large amounts of dolomite and ferrosilicon, and inexpensive labor. As a result, China became the world leader in magnesium production, significantly reducing its production costs. Thus, in 2008, an Australian company estimated the cost of magnesium produced using this innovative technology at 3,000 dollars per ton [7; p.63-69].

These methods primarily involve the use of dolomite and magnesite, employing thermal calcination (700-800°C) and electrolysis, as well as magnesium leaching and its precipitation with lime or caustic magnesite, and alloying with ferrosilicate [8; p. 1197].

There are also methods of reducing magnesium with metallic aluminum (aluminothermic method) [9; p. 65-70] at 1700°C:

$$MgO + Al \rightarrow Mg + MgAl_2O_4 \quad (1.2)$$

The carbothermic method involves the reduction of magnesium at a temperature of 1500°C [10; p. 463-473, 11; p. 51-55]:

$$MgO + C \rightarrow Mg + CO \quad (1.3)$$

Magnesium electrolysis is a method of obtaining magnesium from magnesium chloride ($MgCl_2$) extracted from seawater or salt brines. The process takes place at a temperature of about 700°C, where $MgCl_2$ decomposes into magnesium and chlorine under the influence of electric current:

$$MgCl \xrightarrow{electrolysis} Mg^{2+}\uparrow + Cl_2^{-}\uparrow$$

The main advantages are high magnesium purity, automation, and lower CO_2 emissions compared to thermal methods. However, the technology requires high capital investments and cheap electricity, so it is used in countries with accessible renewable energy, such as Canada, Iceland, and Norway.

Significant reserves of magnesium salts have been discovered in the CIS countries, occurring in natural brines, potassium-magnesium basins, salt lakes, and marine deposits. In Russia, major deposits are located in the Caspian Lowland (Astrakhan region), Irkutsk and Orenburg regions, as well as in the Perm region (Solikamsk), where bischofite and carnallite are extracted. In Kazakhstan, magnesium salts are found in the Zhanatas deposit and the Balkhash basin. In Belarus, the Starobin deposit (Soligorsk) contains magnesium alongside potassium salts. In Ukraine, sources of magnesium compounds include the Crimean salt lakes (Sasyk-Sivash, Sivash) and some deposits in Donbas. In Uzbekistan, substantial amounts of magnesium salts are present in Lakes Tuzkan and Karakalpak, while in Turkmenistan, they are found in the Garlyk deposit. The extraction of magnesium salts in the CIS is conducted both as an independent operation and as a by-product of potassium and sodium salt production. The obtained raw materials are utilized in metallurgy, the chemical industry, and agriculture. Studies indicate that the largest reserves of magnesium salts are in Russia (approximately 2/3), while Turkmenistan holds 20%, Ukraine 18.4%, and Kazakhstan only 0.2% [12; 200 p., 117].

In Uzbekistan, there are large reserves of brines, for example, in the Aral Sea region and other salt marshes. These brines, containing magnesium, sodium, and other elements, can be processed to obtain various useful substances.

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In Uzbekistan, the raw materials for the production of MgO and Mg $(OH)_2$ can be brine and mixed salts from Lakes Karaumbet and Barsakelmes (Karakalpakstan). The Geological Committee of Uzbekistan estimates the reserves of Lake Karaumbet to be more than 700 thousand tons of magnesium chloride (295 thousand tons of MgO), of which 74 thousand tons are in brine. The brine of Barsa-Kelmes contains 2,470 thousand tons of magnesium chloride (1,040 thousand tons of MgO) [12; 200 p.]. Overall, the total magnesium chloride reserves in the brine of these lakes exceed 3.5 million tons, equivalent to 1.1 million tons of MgO in Barsa-Kelmes and over 300,000 tons of MgO in Karaumbet. These resources are valuable, but the processing involves several complex stages.

An additional product of the technology is table salt (NaCl), which increases the economic efficiency of the process. However, it is worth noting that the development remains at the laboratory research stage and requires further improvement and scaling for industrial application. In the works of scientists [13-16], a two-stage method for evaporating filtered brine from the Barsakelmes and Karaumbet lakes of Karakalpakstan was developed.

Crystalline magnesite (MgCO3) forms as a result of chemical processes occurring in natural conditions, such as precipitation from solutions and high-temperature evaporation of water. Typically, magnesite crystallizes in alkaline waters saturated with magnesium, or in salt lakes, particularly in areas with high concentrations of magnesium salts. During the precipitation process, magnesite can form through water evaporation or through biochemical reactions involving microorganisms.

$$CaCO_3 + MgCl_2 \rightarrow MgCO_3 + CaCl_2 \quad (1.4)$$

Magnesite crystals can also form during metasomatic processes when magnesium replaces calcium in carbonate minerals such as calcite. These processes can occur in geothermal waters when conditions change, for example, during shifts in temperature or the chemical composition of the water.

$$2CaCO_3 + MgCl_2 \rightarrow CaMg(CO_3)_2 + CaCl_2 \quad (1.5)$$

Magnesite is also found in geological formations, such as limestone deposits, where exchange reactions between calcium and magnesium have taken place.

$$CaMg(CO_3)_2 + MgCl_2 \rightarrow 2MgCO_3 + CaCl_2 \quad (1.6)$$

Additionally, dolomites can be used as local raw materials for magnesium production, with reserves in Uzbekistan considered practically inexhaustible. Dolomite (CaMg (CO3) 2) is an important source of magnesium and is widespread in the republic, especially in carbonate rocks, sedimentary and metamorphic formations. The main dolomite deposits are concentrated in mountainous regions, such as the Tian Shan and Pamir-Alai, where thick layers of these rocks are found. In industry, dolomite is used not only for obtaining metallic magnesium but also in metallurgy, construction, and chemical production. Dolomites of industrial importance in terms of reserves are found in the following deposits: "Sherabad" deposit with CaO content: 30.0-31.5%, MgO: 21.0-22.5%; "Navbahor" with CaO 28.0% and MgO 25.0%; "Akhangaran" with CaO: 30.2-31.0%, MgO: 21.2-22.0%; "Karnak" with CaO 30.02% and MgO 19.36%; "Ketmonchi" with CaO 30.32% and MgO 19.56%; "Dzhahanabad" with CaO 30.56% and MgO 20.41% [17; 123 p.].

Processing methods face the challenge of forming mixtures of magnesium and calcium compounds, which makes it difficult to obtain a high-purity product, as decomposition and extraction reactions often result in the formation of such mixtures. For example, calcination of dolomite at high temperatures leads to the formation of oxides (MgO and CaO), after which their separation is carried out (for instance, hydration of MgO to Mg (OH) 2). The drawback of this method is that it requires high temperatures (around 900-1000°C). During acid leaching, both

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magnesium and calcium carbonates dissolve, resulting in a solution containing Mg2+ and Ca2+ ions. The process requires several stages with additional purification and separation operations.
A review of the magnesium nitrate market in recent years shows stable growth both globally and locally, including in Russia and CIS countries. In 2023, the global magnesium nitrate market volume was estimated at $770.8 million, with projected increases to $1.152 billion by 2030 at an average annual growth rate of 4.1%. The main drivers of growth are the increasing demand for nitrogen fertilizers and the expansion of their use in agriculture.
Magnesium nitrate is widely used in agriculture and industry in the Uzbek market, although data on production and consumption volumes are limited. In 2023, the total production of mineral fertilizers, including magnesium nitrate, increased by 17% and exceeded 1.4 million tons, due to the launch of new production facilities and improved manufacturing efficiency.
The import of magnesium nitrate and other magnesium compounds into Uzbekistan is necessitated by limited local processing and production capacities. The main suppliers continue to be CIS and East Asian countries. At the same time, exports from Uzbekistan are minimal, indicating a domestic market orientation [https://review.uz/post/obzor-rnka-mineralnx-udobreniy-v-period-pandemii].
In 2023, the import volume of magnesium nitrate and other magnesium compounds to Uzbekistan amounted to approximately $3.99 million, which is 8.55% less compared to 2022. The share of these goods in the country's total imports is only 0.01%, indicating their relatively low proportion in the overall trade structure. The export of magnesium-based fertilizers, including magnesium nitrate, is growing. The main export destinations from Uzbekistan include Turkmenistan (20%), Tajikistan (14.4%), and Romania (9.44%).
Import prices for magnesium nitrate and similar compounds varied depending on the supplier and volume; however, the average increase in import cost was 48% year-on-year in 2023. The average prices for exported magnesium compounds remain competitive in the Central Asian market, which contributes to their active sales in the region. Uzbekistan is focused on developing domestic production of magnesium compounds; however, it continues to depend on imports to meet its full range of needs. The main consumers of magnesium nitrate remain the agricultural sector, where it is used as a component of fertilizers, as well as the chemical and construction industries.
The main areas of application for magnesium oxide (MgO) are metallurgy and construction. Of all magnesia, 65% is used for steel production, 15% for the cement industry, 7% for refractory production, and 13% in other areas. Practice shows that pure MgO refractories increase the effectiveness of binders, and the reliability and productivity of steelmaking furnaces and refractories. Additionally, MgO and Mg (OH) 2 are used for the production of liquid and solid magnesium fertilizers, as well as an additive to saltpeter. MgO in the form of magnesium chloride - bischofite, is used as a raw material for the production of defoliants.
Efficient and cost-effective extraction of magnesium from natural sources and its subsequent conversion into useful compounds is key to expanding the application of this valuable metal. Ongoing research and development in this field contribute to optimizing magnesium production processes and increasing its utilization efficiency across various industries.

The developed technology for processing serpentinite from the Karakalpak deposit has been successfully tested at the pilot-industrial scale. It enables magnesium extraction with an efficiency of 75-86%, reducing technological waste by 25% [18-19].

The basic technological scheme of processing includes stages of heat treatment, nitric acid decomposition, ammonization, and subsequent isolation of magnesium compounds. These processes have proven their effectiveness in industrial applications.

Economic analysis has shown that the proposed technology ensures a reduction in production costs, creation of added value through obtaining multifunctional products (magnesium nitrate, iron- and aluminum-containing concentrate, liquid fertilizers), and increased sustainability of enterprises focused on fertilizer production.

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