The work is devoted to the study of the electric pulse disintegration of a natural mineral. The object of the study is the natural mineral quartzite of the Aktas deposit of the Republic of Kazakhstan.

For the destruction and grinding of quartzite, a working cell of an electric pulse unit was developed. Electric pulse crushing is a modern technique for grinding a variety of materials, which provides the desired degree of grinding with a certain granulometric composition of the product and has a high ability of selective crushing. With the help of this technology, quartzite grinding was carried out with an increase in the capacity of capacitor banks from 0.25 mF to 1 mF, the pulse discharge voltage changed from 20 kV to 30 kV, the number of pulse discharges from 500 to 1,000, the inner diameter of the working cell from 60 mm to 80 mm. The results of the disintegration of a natural mineral by the electric pulse method allowed us to determine the degree of grinding of the finished product.

The obtained results can be used in the study and optimization of the extraction of natural minerals, which is important for ensuring the sustainable use of natural resources and balanced economic development.

Crushed quartzite is used in various industries, including the production of optical fibers, electronics and photovoltaic devices. A material with a particle diameter of 0.1 to 0.4 millimeters is used to create glass, ceramic and porcelain products, as well as insulation materials. Due to its homogeneous composition containing up to 98 % silicon oxide (SiO_2) and excellent absorbent properties, quartz sand is also used as a filter material for water purification

Keywords: quartzite, electricpulse installation, grinding, cell, pulse discharge, rock-forming oxides, spectrophotometer

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IDENTIFICATION OF THE IMPACT OF ELECTRIC PULSE ACTION ON THE DISINTEGRATION OF A NATURAL MINERAL

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1. Introduction

In the modern world, where sustainability and production efficiency are key factors, the electric pulse disintegration of a natural mineral is becoming increasingly relevant. This method of processing natural minerals is a unique and innovative technology with great potential for a variety of applications.

Electric pulse disintegration can significantly reduce energy consumption and harmful emissions into the environment, which is important in the context of the fight for environmental sustainability and reducing the negative impact on nature. This method contributes to the creation of new materials with unique properties, which is of great importance for innovations in industries such as construction, electronics and medicine.

In recent years, the demand for high-quality quartz raw materials has been steadily increasing. This can be attributed to the expanding production of new materials and products derived from quartz, including fiber-optic communication systems and crystalline silicon for the electronics industry. Consequently, a pressing problem is the assessment of the quality and potential utilization of abundant quartz resources, such as quartzites and quartz sand, as affordable, high-purity industrial raw materials [1].

Currently, the global market for quartz raw materials is witnessing a growing interest in chemically pure forms of quartz.

Quartz sand finds application in various fundamental areas like filtration, absorption, casting, fillers, and abrasive materials. Meanwhile, ultra-pure quartzite plays a crucial role in household appliances, electronics, optical fibers, high-efficiency solar cells, thin-film technology, and integrated circuits for the computer industry [2].

Quartz, the primary mineral found in quartzites, most sandstones, and quartz veins, is predominantly silicon dioxide (SiO_2). The theoretical chemical composition of quartz is 46.7 % Si and 53.3 % O. In practice, quartz crystals often contain impurities like gas bubbles, liquid inclusions, tourmaline, rutile needles, and occasionally, mica inclusions. Existing requirements applied to a variety of natural sources of quartz raw materials always have a common feature – they relate to raw materials that have undergone certain beneficiation processes, including grinding, separation, flotation and heat treatment.

To assess the quality of quartz raw materials, which have undergone the necessary mechanical processing and magnetic separation, the presence of coloring impurity elements is analyzed using chemical-spectral methods and photocolorimetry. Quartz raw materials can be considered suitable for industrial use only after performing a series of complex procedures and obtaining positive results in assessing its quality.

The primary criterion for suitable quartzite for industrial purposes is a high silica content. Higher SiO_2 content and lower impurity levels are considered favorable indicators. The industrial value of quartzites, sandstones, and vein quartz is determined to a great extent by their purity and the absence of foreign substances.

During the disintegration of rocks, it is important to ensure selective destruction, preserving the integrity of crystals and avoiding contamination of processing products with metal particles, which in turn cannot be done by traditional mechanical methods of destruction.

In this regard, electric pulse disintegration of a natural mineral turns out to be less profitable compared to existing crushing methods and, conversely, with an increase in the degree of crushing, electric pulse crushing becomes the most profitable method [3]. Therefore, the study of the electric pulse disintegration of a natural mineral is an urgent and promising topic of research and development, contributing to the sustainability of production, innovation and promotion of environmental protection. Its further study and application can lead to significant advantages both in scientific research and in industry.

2. Literature review and problem statement

The grinding of natural minerals is an important process in various industries such as mining, construction and chemicals. The efficiency of this grinding process directly affects the productivity and quality of the materials produced. For many years, traditional comminution methods have been applied, such as crushing and mechanical comminution, which utilizes comminution methods based on crushing, splitting, breaking, abrasion and impact. The paper [4] shows that they are widely used for this purpose. However, these methods may have disadvantages related to energy consumption, the quality of the final product, the material could be contaminated with metal, which ultimately does not allow obtaining a final clean product.

The paper [5] investigates the interrelation between the characteristics of grinding various minerals in a complex ore under the influence of mechanical abrasion. Research has shown that the presence of sphalerite in the ore contributes to an increase in the grinding effect, while the presence of pyrrhotite and quartz has the opposite effect, that is, they reduce the efficiency of grinding ore. These results can be useful for choosing the optimal operating modes of equipment used in a given grinding process and methods of processing raw materials; this, in turn, requires a significant amount of energy consumption and does not always ensure the extraction of pure quartz from ore.

In the paper [6], the content of impurity elements in the quartz of the Kuznechikhinsky deposit was studied, as well as their distribution in structural form and mineral inclusions. Using spectroscopic methods, it was possible to determine the location of impurities and develop an effective enrichment process. This process includes the steps of crushing quartz to a fraction size of 0.1–0.4 mm, using electromagnetic separation, agglomeration purification, microwave decripitation and acid treatment using a mixture of hydrofluoric and hydrochloric acids.

Also for the enrichment of quartz, the paper [7] examines the process of obtaining nanostructured silicon from quartzite ore using the method of low-energy wet mixing of reagents. The research results show that the combination of acid pretreatment of quartzite ore, controlled atmosphere synthesis, and a final special acid leaching step is an effective method for producing porous nanostructured elemental silicon particles with a uniform structure. These particles can find application in various areas of the energy industry, both with and without subsequent processing. The methods of quartz enrichment proposed by the authors lead to significant consumption of reagents.

The paper [8] describes the production of nanostructured silicon from quartzite ore by low-energy wet mixing of reagents. The results showed that the combination of primary acid treatment, synthesis during combustion in a controlled atmosphere and the final process of special acid leaching is an effective way to obtain porous nanostructured elementary silicon particles with a homogeneous structure that can be used in several applications in the energy sector with or without further processing. However, the methods of quartz enrichment proposed by the authors of the works lead to significant consumption of reagents.

The paper [9] investigates the impact of different levels of impurities in quartz particles on their behavior during the flotation process and the corresponding mechanisms of influence. Experimental results showed that purer particles were more easily flotated. XPS analysis confirmed that impurities are mainly concentrated on the surface of the particles. These studies led to the development of a model to classify crushing and a model to explain adsorption. It should also be noted that the flotation enrichment method requires careful grinding of the material, high water consumption and possible contamination with toxic flotation reagents.

The paper [10] studies the use of electrical crushing as a potentially new method for purifying quartz raw materials from trace element impurities. The work carried out a comparative research of the effects of electrical and mechanical crushing on almost mono-mineralogical quartz raw materials in order to eliminate even the smallest microelements, which constitute less than 1 % of the total composition of the raw material. The method of electrical crushing of quartz raw materials proposed by the authors shows a more effective result than mechanical crushing.

In [11] research of rocks extracted at mining and processing plants of the Murmansk region was carried out using the method of electric pulse disintegration of materials. Analysis of the chemical composition of rocks before and after electric pulse disintegration confirmed the effectiveness of this method to increase the extraction of useful components from rock samples used at mining and processing plants. The results of this research became the starting point for deeper scientific research and development work aimed at assessing the possibility of using the electric pulse method on various rocks that are being enriched at mining and processing plants. These works confirm that electric pulse grinding of quartzite is the most effective method.

To use the electric pulse method of grinding quartzite, it is necessary to conduct studies depending on the electrical parameters of pulsed discharges. These studies are carried out by conducting research works devoted to experiments on the processing of raw materials depending on the voltage of electric pulse discharges and the number of discharges, the capacity of capacitor banks in the installation.

3. The aim and objectives of the study

The aim of the work is to study the impact of electric pulse discharges on the grinding of quartzite in laboratory conditions. The results of this research can contribute to the development of devices for disintegrating natural minerals.

To achieve this aim, we are addressing the following objectives:

– to investigate the effect of an underwater electric discharge on the selectivity of quartzitedestruction;

– to determine the rock-forming oxides in the composition of quartzite.

4. Materials and methods

The object of the study is quartzite from the Aktas deposit from the territory of the Karaganda region of the city of Zhezkazgan of the Republic of Kazakhstan (Fig. 1).

a *b*

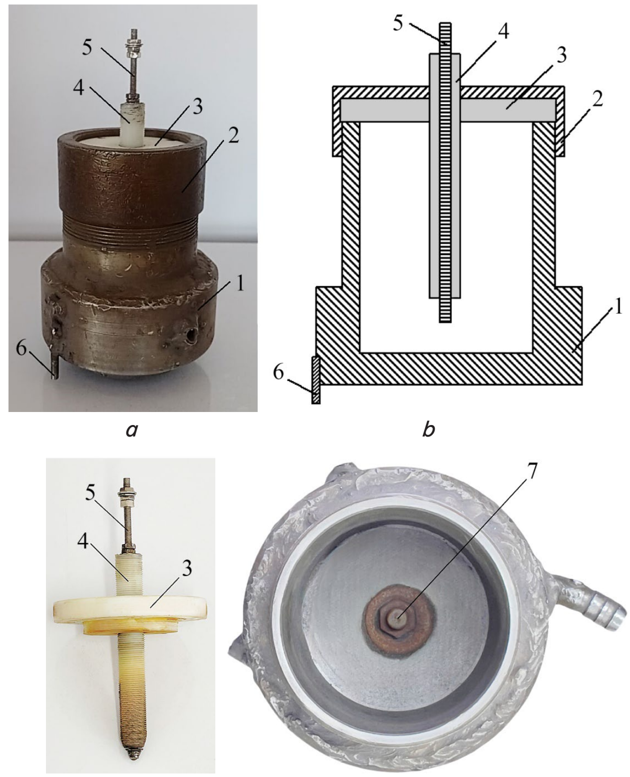
Fig. 1. Quartzite samples: *a* – quartz ore d=70.3 mm; *b* – crushed quartzite d=0.1÷0.4 mm

During the experimental work, a working cell of an electric pulse installation and a method for selective destruction of the quartzite mineral were developed. From the features of electric pulse crushing processes, it follows that the efficiency of the crusher itself will be higher, the smaller the material fractions [12]. This is explained by the fact that an underwater spark gives off energy with its surface, and therefore, the denser the material surrounding the discharge zone (the finer it is), the more rational the energy released by the discharge channel [13–15].

The basis of the proposed method is the electrohydraulic Yutkin effect. The electrohydraulic crushing method is an effective method of crushing various materials, which allows you to obtain a product with a given degree of grinding with a certain granulometric composition and has a high selectivity of crushing [16, 17].

In the research of quantitative analysis of rock-forming oxides in quartzite, titrimetric and photometric methods were used. The working cell used for grinding quartzite using the electric pulse method is shown in Fig. 2.

The electric pulse unit for grinding quartzite works as follows. A natural mineral is immersed in the unit housing 1 and filled with process water. The positive electrode is located vertically inside the nylon sleeve, and the bottom of the chamber serves as a negative electrode. An electric discharge occurs between the two electrodes 5 and 7, the shock wave from which spreads in the process water from the breakdown points in all directions and begins to crush the natural mineral.



a *b* *c* *d*

Fig. 2. Working cell of an electric pulse unit for grinding quartzite: *a, b* – main body and cell drawing; *c, d* – working electrode with insulation; 1 – cylindrical body (outer diameter 85 mm, inner diameter 80 mm); 2 – lid; 3 – nylon washer (85 mm); 4 – nylon sleeve (15 mm); 5 – working electrode; 6 – outlet for connection to ground; 7 – negative electrode

The grinding of quartzite in an electric pulse unit was carried out at constant values of the capacitance of the capacitor bank and the number of pulse discharges (C=0.75 μF, N=800 discharges). The voltage of the pulse discharges (U) varied from 20 kV to 30 kV. The experiments were carried out depending on the inner diameter (D) of the working cell.

5. Results of research and analysis of the effect of electric pulse discharges on the grinding of a natural mineral

5. 1. Main results of the effect of an underwater electric discharge on the selectivity of quartzite destruction

Tables 1–3 show the results of experiments on the grinding of quartzite by the electric pulse method. The mass of the feedstock was m_0=50 g, and the size of the pieces was about 10 mm. The minimum size of the resulting product was 0.1–0.4 mm.

From the data of experimental studies, it has been found that by increasing the voltage of pulse discharges, it is possible to increase the mass of finished products in size from 0.1 to 0.4 mm. Butit was noticed that these indicators can be achieved depending on the internal diameter of the metal housing, which performs the function of the negative electrode of the working cell.

Table 1

Dependence of the values of the quartzite grinding mass *m* (g) on the diameter of the working cell of the electric pulse unit (C=0.75 μF, U=20 kV, N=800, m_0=50 g)

d, mm	*D*=60 mm	*D*=70 mm	*D*=80 mm
	m, g	*m*, g	*m*, g
0.1–0.4	–	0.4	1.1
0.4–0.8	1.5	8.2	4.5
0.8–1	27.4	30.5	25.9
1–5	16.8	5.2	14.7

Table 2

Dependence of the values of the quartzite grinding mass *m* (g) on the diameter of the working cell of the electric pulse unit (C=0.75 μF, U=25 kV, N=800, m_0=50 g)

d, mm	*D*=60 mm	*D*=70 mm	*D*=80 mm
	m, g	*m*, g	*m*, g
0.1–0.4	0.9	8.4	3.5
0.4–0.8	6.3	11.5	13.1
0.8–1	19.2	9.7	14.8
1–5	15.6	12.3	11.5

Table 3

Dependence of the values of the quartzite grinding mass *m* (g) on the diameter of the working cell of the electric pulse unit (C=0.75 μF, U=30 kV, N=800, m_0=50 g)

d, mm	*D*=60 mm	*D*=70 mm	*D*=80 mm
	m, g	*m*, g	*m*, g
0.1–0.4	1.3	14.3	5.6
0.4–0.8	5.9	16.5	8.5
0.8–1	14.3	5.7	11.7
1–5	22.4	14.3	17.1

In subsequent studies (Fig. 3), quartzite was ground at different values of the capacitance of the capacitor bank of the installation (0.25–1 μF).

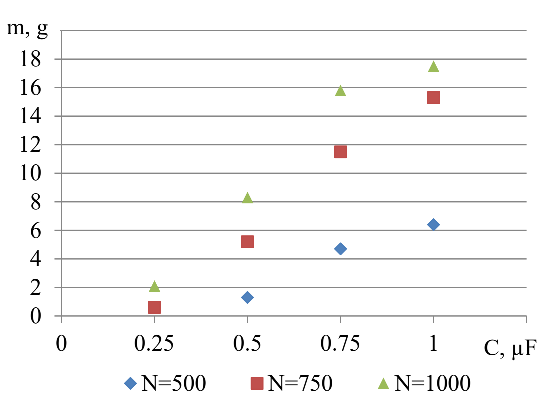


Fig. 3. Results of obtaining quartzite powder depending on the numberof pulse discharges and capacitance of the capacitor bank

Experimental work was carried out at a discharge voltage of 30 kV and the number of pulse discharges of 500–1,000 discharges. The inner diameter of the working cell was 70 mm. The mass of the feedstock was m_0=50 g, the diameter of large pieces was 12–14 mm.

The diameter of the finished product was 0.2 mm. According to the results of the experiment, it was noticed that by increasing the capacitance of the capacitor bank and the number of pulse discharges, it is possible to increase the yield of the finished product.

5. 2. Results of quantitative analysis of rock-forming oxides in quartzite

The content of impurity elements in quartz is one of the most important characteristics of the quality of quartz raw materials. In the experiments, the main fraction of quartzite was used, groundto a size of less than 0.1 mm.

Quantitative determination of rock-forming oxides in quartzite before and after electric pulse treatment was carried out on a LAMBDA 25 spectrophotometer (Table 4).

Table 4

Elemental composition of quartzites before and after electric pulse treatment

Oxides	Before electric pulse treatment, %	After electric pulse treatment, %
SiO_2	98.96	99.68
Fe_2SO_4	0.28	0.08
TiO_2	0.16	0.06
MnO	0.1	0.03
Al_2O_3	0.28	0.05
Otheradmixtures	0.2	–

One of the requirements for the finished product made of quartz material is its chemical purity, i.e. the minimum amount of metal impurities, in particular iron, since it can be present in the form of oxides in the feedstock. In accordance with the quantitative determination of rock-forming oxides obtained after electric pulse processing of the feedstock, the final sample contains 0.08 % in terms of the total Fe content. This effect is associated with the selectivity of destruction, when grains and minerals are separated from each other by microcracks during electric pulse destruction. In the process, both minerals containing iron and microcracks containing iron oxides are exposed. The resulting new surfaces due to turbulent fluid flows in the working chamber are freed from oxides that pass into the surrounding liquid and are removed with it during the washing of the sample.

6. Discussion of the results of the investigation of the effect of an underwater electric explosion on the destruction of quartz ore

From Table 1, we see that with a pulse voltage U=20 kV with a working cell diameter of 70 mm, the grinding mass (d=0.1–0.4 mm) is 0.4 g. Based on Table 2, we see that at a pulse voltage U=25 kV and a working cell diameter of 70 mm, the grinding mass (d=0.1–0.4 mm) increases to 8.4 g. At the same time, the results of Table 3 show that at a pulse voltage U=30 kV, with a working cell diameter of 70 mm, the grinding mass (d=0.1–0.4 mm) was 14.3 g.

It can be seen from Tables 1, 2that with an increase in the pulse voltage, small quartz particles with a diameter of 0.1–0.4 mm are crushed most intensively. At the same time, the diameter of the working cell also affects the reduction of the ore dispersion. In our case, the optimal diameter of the working cell was D=70 mm. Based on the results obtained, it can be seen that with an increase in voltage in the discharge channel, the intensity of crushing and grinding of quartzite increases.

According to the results of obtaining quartzite powder, depending on the number of pulse discharges and the capacitance of the capacitor bank (Fig. 3), it was found that the capacitance of the capacitor should be at least 0.5 μF to obtain raw materials with a diameter of 0.2 mm. From the analysis of the results of obtaining powder raw materials, depending on the number of pulse discharges, it is noted that quartzite is intensively crushed in the range of 750–1,000 discharges.

In previous studies, quartzite powder with a diameter of $d<0.4$ mm was obtained by changing the discharge voltage in the range of 18–24 kV and the number of discharges in the range of 300–1,500 with a capacitor capacity of 0.4 μF [13]. In the proposed work, a product with a diameter of 0.1–0.4 mm was obtained at C=0.25 μF and C=0.75 μF, N=800 discharge, U=30 kV. At the same time, the peculiarity of the experimental results is that the studies were carried out depending on the diameter of the inner surface of the working channel, which performs the function of a negative electrode.

Table 4 shows the elemental composition of quartzites before and after electric pulse treatment. The results of the quantitative determination of rock-forming oxides in quartz using a LAMBDA 25 spectrophotometer showed that they are predominantly composed of silicon dioxide. In general, the studied quartzites are highly siliceous quartzites, with very few impurities.

The results of the research showed that, after electric pulse treatment, the SiO_2 content in quartzite is 99.68 %. Also, quartz raw materials of the Aktas deposit from the territory of the Karaganda region of Dzhezkazgan of the Republic of Kazakhstan are the most economically feasible due to the purity of the ore. Therefore, it can be used in any production without additional cleaning.

The main difficulties lie in the development and manufacture of the necessary element, that is, a high-voltage generator that ensures the necessary operation of the entire installation. In addition, difficulties arise when purchasing a pulse capacitor of the required capacity.

The results of the research showed that the electric pulse grinding method allows you to adjust the granulometric composition of the finished product with increased selectivity. The proposed method and the energy parameters of the installation are the most acceptable in production conditions, provides intensive grinding of quartzite. Conducting these researches and introducing their results to enterprises will contribute to technological progress in industry.

The technological process of electric pulse crushing is easy to automate. Maintenance of electric pulse crushers does not require a large number of highly skilled workers. In electric pulse crushers, almost any solid materials can be crushed and ground. In addition, electric pulse crushing devices, unlike mechanical crushers, have no moving parts, are made of ordinary structural steel, their body practically does not wear out during operation. During operation, these devices do not form dust, occupy relatively small production areas and allow them to combine the processes of crushing, mixing and flotation of materials. Any liquid, mainly industrial water, can serve as a working medium in electrohydraulic crushers. The installation is designed to operate in the following conditions: air temperature from 278 to 313 K (from +5 to +40 °C); relative humidity of the ambient air no more than 80 % at a temperature of 293 K (+30 °C); absence of conductive dust and vapors of chemically active substances that destroy insulation of conductive wires of devices.

The research results can be used to obtain 0.1–0.4 mm powder raw materials by the electric pulse method. Obtaining products below the specified granulometric composition requires additional research. In addition, for the use of the electric pulse method in the destruction of solid dielectric materials, it is necessary to take into account the size of the initial fraction of the processed raw materials.

In the future, it is planned to obtain a product with a size of less than 0.1 mm and increase its quantity by the proposed method. For this purpose, it is planned to conduct special investigations depending on the electrical parameters of the electric pulse installation and pulse discharges formed in the working channel for grinding the material.

7. Conclusions

1. The dependences of quartzite grinding on the capacitance of the capacitor bank, on the number and voltage of pulse discharges, and on the diameter of the working cell are obtained. From the experimental results, U=30 kV was taken as the optimal parameter of the discharge voltage, and D=70 mm was taken as the optimal parameter of the diameter of the working cell. With an increase in the value of the discharge voltage from the specified interval, the mass of the finished product with a powder size in the range of 0.1–0.4 mm did not change significantly.

2. Studies of quantitative determination of rock-forming oxides in quartzite have shown that after electric pulse treatment of quartzite from the Aktas deposit, the percentage of SiO_2 increased from 98.96 % to 99.68 %, the percentage of the element $FeSO_4$decreased from 0.28 % to 0.08 %, TiO_2 from 0.16 % to 0.06 %, and Al_2O_3 from 0.28 % to 0.05 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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