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Sorption Treatment and Desalination of Mineralized Water Using Opoka to Reduce Hardness and Chloride Content

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ABSTRACT

The increasing pollution of water resources, essential for agriculture and other industries, necessitates the exploration of alternative water purification methods. The study aims to determine the possibilities of treating mineralized water using opoka, a siliceous rock. Opoka is an accessible and effective adsorbent widespread in West Kazakhstan. Water purification with opoka is performed using the sorption method in three different variants: with opoka in its natural state, opoka thermally modified at 400℃, and opoka after thermal modification at 800℃. Initial testing showed high levels of hardness (17 meq/l) and chloride content (1384.5 mg/l) in the water. The results demonstrated that natural opoka reduced water hardness to 10 meq/l and chloride content to 11.35 mg/l. The most effective treatment was achieved with opoka modified at 400℃, which reduced hardness to 8 meq/l and chloride content to 9.38 mg/l. These findings suggest that utilizing thermally modified opoka could be a cost-effective and sustainable solution for improving water quality in arid regions. This approach has the potential to enhance water resource management practices and inform policy decisions aimed at addressing water scarcity and pollution, particularly in regions like West Kazakhstan where access to clean water is critical for agriculture and livestock farming.

1. INTRODUCTION

Rangeland farming is practiced widely all over the world and is important for livestock production. Intensive use of pastures largely depends on water availability. In many transhumance regions, brackish or saline groundwater is the only source of water supply for rangelands, considering that the growing livestock population is mainly concentrated far away from settlements. This problem is most acute in arid regions, such as West Kazakhstan.

Kazakhstan ranks sixth in the world in rangeland resources, covering 187 million ha, of which 70% are in arid regions. Historically, they have been a driving force in the country's economy as a source of fodder, food, fuel, medicinal plants, etc. According to the World Resources Institute, 99.2% of the territory of Kazakhstan is occupied by land prone to desertification. The total area of degraded rangelands reaches over 48 million ha (26% of the total area of pastures).

Access to water on or near pastures is vital for livestock farming [1] and is key for livestock during the dry season in arid and semi-arid rangelands [2]. Thus, the development of arid pastures depends crucially on the degree of watering.

The effectiveness of water supply to natural pasture areas depends on the condition of watering systems and facilities and the quality of available water [3]. Groundwater accounts for 65.2% of domestic water consumption, and surface water makes up 34.8%. Kazakhstan uses 35 thousand mine wells and 38 thousand tube wells in livestock pastures for irrigation and animals. However, many peasant farms in West Kazakhstan complain about the quality of water in them.

Adequate water resources are imperative for industrial production, anthropogenic activities, and animal husbandry. However, pollutants, such as metal ions, organics, and industrial exhausts, have led to serious environmental pollution, including the salinization of water resources [4]. Salinization is a common form of pollution caused by numerous salt ions, including sodium, potassium, magnesium, and calcium ions [5, 6].

Industrial wastewater saturated with salt ions can enter the environment in several ways: through direct runoff, wastewater treatment plants, and sludge. It poses a significant threat to water and soil quality and the health of aquatic and terrestrial animals. Sodium (mainly sodium chloride) is a major cause of water and soil salinization. Although research gives evidence of the positive effects of low sodium chloride concentrations on human and animal health, higher levels of sodium chloride in water can cause multiple health problems [7].

In several cases, the consumption of water with high hardness and increased chloride content results in various disorders in animals, leading to reduced farm productivity and product quality.

Microbial and parasitic flora that enter the water used for livestock breeding through effluents can cause outbreaks of contagious diseases – infectious and invasive, most often intestinal diseases. These risks create an urgent need to purify water to a safe level suitable for farm animals.

There is a wide variety of water treatment technologies: mechanical, ion exchange, reverse osmosis, magnetic, ultrasonic, membrane, biological, etc. When water is treated for domestic and drinking purposes, several technologies are usually used depending on the water composition. Almost any combination of these technologies uses bulk filters, which remove various particles from the water and reduce the content of chlorine, iron manganese, and salts that add to water's hardness.

Bulk filters use both natural (quartz or garnet sand, zeolite, activated carbon) and artificial fillers (Manganese Greensand), Birm (artificial zeolite), MZhF (a product of processing rocks containing dolomite) as granular loading. The efficiency of adsorption purification reaches 80-95% and depends on the chemical nature of the adsorbent, the size of the adsorption surface and its availability, and the chemical structure of the substance and its state in the solution [8].

Proceeding from the focus of our research, particular attention was paid to the possibility of using sorption systems that utilize natural minerals of different origins and structures [9].

Researchers consider dispersed silica as sorbents and catalyst carriers for a wide range of applications. This is explained by natural sorbents' environmental and economic benefits in wastewater treatment [10, 11].

The arid West Kazakhstan region needs to find opportunities for the purification and desalination of mineralized water, including groundwater. The high content of Fe, Mn, and Ca in water makes it difficult to effectively remove them by traditional treatment methods, such as sedimentation or flotation. These methods often prove inadequate due to the high levels of mineralization, including excessive hardness and chloride content, which are common in the region's groundwater. Therefore, active research is underway to explore alternative methods of removing metals and excessive hardness from polluted water.

Among these methods, the adsorption process has proven highly effective due to its selectivity, low cost, and simplicity [12-14]. Recent studies are based on the use of activated carbon [15, 16], agricultural wastes [17], microorganisms, oxides [18], and natural clay [19]. Zeolites (natural and synthetic) have also been shown to remove iron and manganese from water [20, 21].

Zeolites are classified as aluminosilicate clay minerals with a microporous internal structure used as ion exchangers to improve water quality [22]. An additional negative charge appears on the zeolite surface, resulting from the partial substitution of silicon by aluminum atoms in the crystal lattice structure, balanced by the surrounding Na^+, Ca^{2+}, K^+, and Mg^{2+} cations. These cations can be replaced by other cations in the contact solution [23-25] to remove heavy metals from polluted water.

Opoka found in West Kazakhstan also belongs to the group of aluminosilicate materials characterized by a high content of amorphous silica, high porosity, and wide availability in the region. It is advantageous to apply this rock as a suitable sorbent. Opoka possesses biological activity, which partially relates the rock to biosorbents and gives it significant advantages over analogs. An important advantage of this class of sorbents is their availability and low cost, which is 10-15 times lower than synthetic sorbents' cost [24].

Opoka is a natural polymineral formation, which determines its chemical and geometric heterogeneity and the presence of grains of different sizes and areas with different densities in their structure.

Opoka belongs to the group of silica-calcites of marine origin, consisting of the remains of the smallest marine organisms from the late Cretaceous period with a mesoporous structure (about 50% of the volume). Its composition includes SiO_2 and Al_2O_3, as well as calcium, iron, and magnesium oxides. Opoka is free of toxic impurities, which makes it suitable for water treatment.

Porous materials, including Opoka, have specific physical properties. They are distinguished by high diffusion permeability, low hydrodynamic resistance, high filtering capacity, high adsorption properties, low sound and thermal conductivity, and the ability to integrate with biological tissues. With respect to their geometric features, porous bodies are distinguished into regular porous structures with a regular alternation in the volume of the body of individual pores or cavities and the channels connecting them, connected, in turn, into clusters and stochastic structures, in which form, size, orientation, mutual arrangement, and the connections of pores are random. The stochastic structure is more common [25].

A sorbent's efficiency depends on its surface area and the presence of active sites. The adsorption process is determined by the properties and amount of sorbent and the chemical nature and concentration of the components to be adsorbed. The amount of substance taken in depends on the free surface area and its properties. The material's surface area can be increased using methods of pulverization, granulation, and porosity increase.

Natural sorbents, including opokas and modified sorbents, are complex polymineral formations with various particle and surface structures. Natural silica, aluminum, and aluminosilicate gels are the dominant components of natural sorbents.

The surface and structure of obtained components determine their sorption qualities. A porous structure has a major influence in this respect, more significant than the effect of the surface. The porosity is determined by the presence of pores with varying radii. The overall evaluation of porosity is based on their total volume.

Micro- and transient pores play a major role in sorption, determining sorbents' technical value and applicability. The nature of the porous structure of adsorbents determines their specific surface area, which determines the amount of substance adsorbed and is also used in calculating adsorption and the work and heat of adsorption and wetting per surface unit [11].

However, the use of opoka as a sorbent faces several challenges, including the need to understand its adsorption properties, its effectiveness in various forms (natural and thermally modified), and the potential for large-scale application. The study of the surface morphology and porous sorbent structure of opoka is relevant for predicting the effectiveness of its practical use. Previous studies have explored various natural sorbents for water purification, but there is limited research specifically on the use of opoka, particularly in its thermally modified forms, for treating highly mineralized water.

The high adsorption, ion exchange, and filtration properties of opoka, the emergence of methods to regulate its geometric structure and chemical nature of the surface, and large industrial deposits in West Kazakhstan explain the feasibility of using this mineral in water treatment [22].

The purpose of this study was to determine the possibilities of reducing the hardness and chloride content of mineralized water using opoka.

The novelty of this research lies in its comprehensive approach to assessing opoka's potential as a low-cost and accessible sorbent, particularly its performance after thermal modification.

2. MATERIALS AND METHODS

We performed tests on opoka samples and water subjected to purification. Opoka was analyzed using electron microscopy and mercury porometry methods, which allowed us to determine the morphological features of the samples.

The organoleptic and physicochemical properties of groundwater samples were determined by the titrimetric method for measuring hardness, Mohr's method for determining chloride content, and repeated measurements of salt content using a conductometer.

Three batches of opoka samples were prepared for water treatment by the sorption method: 1 – opoka in its natural state; 2 – opoka subjected to thermal modification at 400℃; 3 – opoka subjected to thermal modification at 800℃. The decision to include thermal modifications at 400℃ and 800℃ was based on the need to explore how different levels of thermal treatment impact the sorption capacity of opoka. Thermal modification is known to alter the physical structure and chemical properties of materials, potentially enhancing their adsorption capabilities. Specifically, the temperatures of 400℃ and 800℃ were selected to represent moderate and high levels of thermal modification, respectively, allowing for the assessment of how increasing thermal energy influences opoka's effectiveness in reducing water hardness and chloride content.

The groundwater was run through an adsorption column with different batches of sorbent with a total mass of 30 g and a particle size of 1-3 mm. The water that passed the purification process was subjected to repeated control tests.

Opoka from the Taskalinskoye deposit in West Kazakhstan was chosen as the subject of study.

The Taskala District is an administrative unit located in the northwest of West Kazakhstan and covers 8.1 ths. km^2. Located on a relatively elevated plain in the north and northwest of the Taskala District, the steppe landscapes of the structural dissected Obshchy Syrt plateau pass in the south into the steppe landscapes of a relatively lowered plain of the dissected Predsyrt escarpment. In the south, there are steppe landscapes of a relatively lowered undivided flat marine (Rannehvalyn) plain, whose main portion is taken up by the tectonic depressions of the Durinsky and Chizhinsky spills.

The region comprises deposits of writing chalk, marl, and opoka of the Cretaceous period overlain by clay, sandy loam, and sand and by clay, loam, and sand in the Caspian Lowland.

In the north, the hilly-valleyed landscape of Syrt with wide valleys of dead and existing hydrosystems forms two large massifs, dissected by scour holes, ravines, and gullies – the eastern part of Kamenny Syrt and Derkulsky uval. In the northwest of the Taskala District, there are the eastern spurs of the Syrt and the hilly and dense massif of the Sinie Gory massif.

The area has substantial reserves of siliceous rocks in the form of opoka.

Figure 1 shows the general view of opoka samples from the Taskalinskoye deposit and its macrostructure.

Opoka is a light gray rock with a yellowish shade and porous structure. Its average density is 1.32 g/cm^3; the rock has a natural porosity (43.8%) and sorption activity.

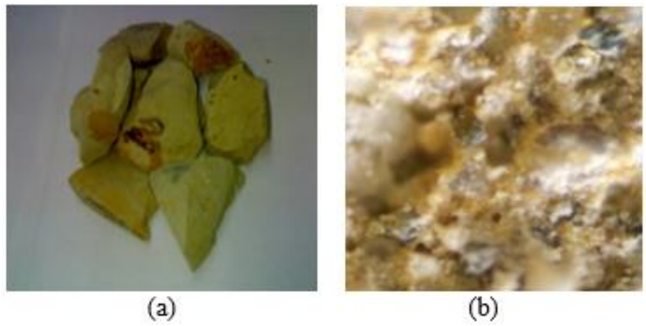


Figure 1. (a) General appearance of opoka, and (b) its macrostructure (Levenhuk 320 series microscope, magnification ×100)

The morphology of the sorbent's surface was estimated from microphotographs obtained with a scanning electron microscope JSM-IT 200. A petrographic polarization microscope POLAM P-211M was used to identify minerals. The qualitative mineralogical composition of opoka was determined with a scanning electron microscope TESCAN TIMA. Quantitative (qualitative) energy dispersion microanalysis to determine the chemical element composition was carried out on a scanning electron microscope JSM-6390LV with the energy dispersion microanalysis system INCA Energy.

The priority application of electron microscopy is explained by the fact that it can analyze macroporous rock structures in the pore size range inaccessible for investigation by other methods. Electron microscopy is indispensable in the study of macropores to show their general character, reasonably model their structure, and interpret the results of other porosimetry methods.

A PoreMaster 60 mercury porosimeter was used to characterize the porous structure of the samples. A mercury porosimeter determines macropores, micropores, mesopores, total pore volume, and specific surface area as a function of applied pressure from mercury intrusion/extrusion measurements. The pore size range spans from 0.0064 to 950 μm.

Mercury porosimetry, based on capillary phenomena, was employed to study the size distribution of opoka pores by pressing mercury into the pores. Liquid mercury does not wet the material and hardly interacts with it. Each pressure corresponds to a certain volume of mercury pressed into pores of a certain radius. By increasing the pressure and simultaneously measuring the volume of mercury pressed into the pores, it is possible to build an integral curve of the distribution of the specific volume of pores by their diameters, determining the porosity and specific surface area of the rock.

The next stage in the study was to investigate the organoleptic and physicochemical properties of groundwater. For initial testing of water quality, a sample was taken from a mine well of the Akkurai deposit in the Taskala District, situated more than 200 km away from the center of Uralsk. Since there are no other nearby water sources for livestock breeding, the study of the composition of this source gave us a general idea of water quality in places with low water availability.

Overall water hardness was determined using the titrimetric method. 100 cm^3 of filtered test water or a smaller volume diluted to 100 cm^3 with distilled water was introduced into a conical flask. The total amount of the substance equivalent to calcium and magnesium ions in the volume taken should not exceed 0.5 mol. Then, we added 5 cm^3 of buffer solution, 5-7 drops of the indicator, or approximately 0.1 g of dry mixture of the indicator, and chromogen black with dry sodium and immediately titrated with strong shaking with a 0.05 n. Trilon B solution until color change at the equivalent point (color should be blue with a greenish tint).

If more than 10 cm^3 of the 0.05 n. Trilon B solution was consumed for titration, it indicated that the total amount of calcium and magnesium ions equivalent in the measured volume of water was more than 0.5 mol. In such cases, the test had to be repeated, taking a smaller volume of water and diluting it to 100 cm^3 with distilled water.

A fuzzy color change in the equivalent point indicates the presence of copper and zinc. To eliminate the influence of interfering substances, 1-2 cm^3 of a sodium sulfide solution was added to the water sample measured for titration, after which the test was repeated.

The chloride content in the sample was determined by silver nitrate titration with a chromate indicator (Mohr's method). This method was used to directly determine dissolved chloride at concentrations from 5 to 150 mg/l. The working range can be extended to 400 mg/l by using a larger burette or by diluting the sample. The chloride reacts with the added silver ions to form insoluble silver chloride, which forms a quantifiable precipitate. A small excess amount of silver ions was added as an indicator to form red-brown silver chromate with chromate ions. This reaction is used to mark the end point of titration. The pH level was maintained between 5 and 9.5 throughout the titration process to allow for precipitation.

During this study, only reagents of established analytical purity and exclusively distilled water were used. Two types of distilled water, distilled water and water for injection, were obtained using a biodistiller Livam BE-4 (4.3 l/h).

To confirm the reliability of the results, salt content was determined using a MARK-603 conductometer.

Before water purification, opoka was thermally modified to establish the regularity of changes in its properties depending on the temperature reached. The rock samples were pre-dried in a laboratory drying cabinet at 65-70°C to a residual moisture content of 6-7%. Then, the dried opoka was crushed using a laboratory jaw crusher to get 1-3 mm fractions. The obtained fractions were fired in an electric muffle furnace for thermal modification at 400 and 800°C with temperature increasing at 150°C/hour. The sample was then fired at the final temperature for 1 hour. After this, the samples of thermally modified opoka were cooled in the switched-off furnace to room temperature.

The sorption properties of the obtained opoka with respect to chlorides and water hardness were determined using the dynamic method. The ratios chosen for the study were: 30 g of natural opoka/100 ml of water, 30 g of thermally modified opoka (at 800°C)/100 ml of water, and 30 g of thermally modified opoka (at 400°C)/100 ml of water.

The results of water tests were processed using Microsoft Excel with the calculation of the arithmetic mean (x), its deviation ($d=x-\overline{x}$), standard deviation, and confidence interval. The given confidence probability is a=0.95. The total number of determinations n=4; the number of degrees of freedom K=n-1=3. Student's t-test, K=3.18.

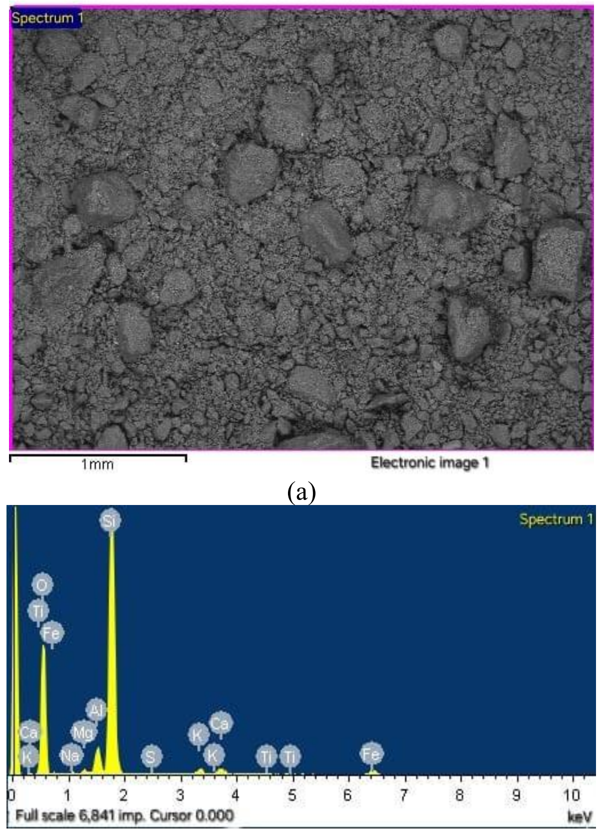
3. RESULTS AND DISCUSSION

Macrostructure analysis showed that the studied opoka is composed of predominantly amorphous quartz particles cemented by finely dispersed porous particles. Clay particles and organic residues are present in opoka structure. Under the microscope, they appear as dark-colored particles.

Data on the chemical elemental composition, microstructure, and spectrum of opoka are presented in Table 1 and Figure 2.

Table 1. Element weight ratio

Element	Weight	Atomic	Element	Weight	Atomic
O	53.68	67.97	S	0.19	0.12
Na	0.21	0.18	K	1.18	0.61
Mg	0.55	0.46	Ca	1.33	0.67
Al	3.40	2.55	Ti	0.18	0.08
Si	36.53	26.35	Fe	2.75	1.00



(a)

(b)

Figure 2. Chemical element composition, microstructure, and spectrum of opoka: (a) surface morphology, (b) element composition

Our analysis of opoka sample allows us to state that it has an amorphous structure. Peaks of a mineral – SiO_2 (quartz) are visible in the X-ray spectra.

Opal is represented by a structureless microglobular mass, in some places it turns into chalcedony.

An admixture of clayey material, sandy grains of quartz, feldspars, mica, and glauconite is also observed. Table 2 shows the mineralogical composition of the rock.

The porous structure of opoka at 500- and 2,000x magnification is shown in Figure 3.

Table 2. Mineralogical composition of the siliceous rock of opoka

No.	Visible	Ref. Code	Compound Name	Chemical Formula	Score	Scale Factor	SemiQuant [%]
1	True	01-070-2517	Quartz low – theoretical	SiO_2	62	0.978	-
2	True	01-073-0603	iron(III) oxide	Fe_2O_3	35	0.047	-
3	True	00-048-0476	Octadecasil	SiO_2	12	0.147	-
4	True	00-009-0478	Anorthoclase, disordred	$(Na, K) (Si_3 Al) O_8$	30	0.169	-

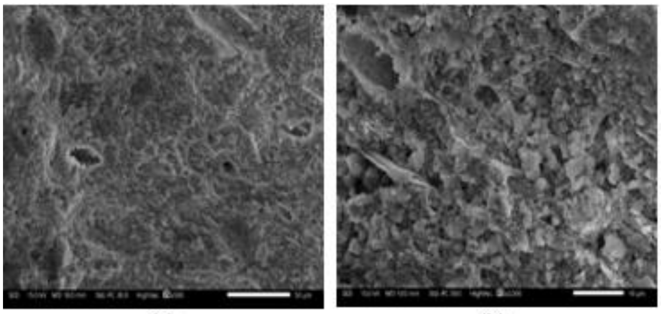

(a) (b)

Figure 3. Porous structure of opoka: (a) magnification x500, (b) magnification x2,000 (scanning electron microscope JSM-IT 200)

Microscopic observations show that the main mass of the rock is formed by globular opal with a low refractive index with clay matter and a small amount of terrigenous impurities evenly distributed within its mass. The clay component constitutes 20-50%.

Opoka is rich in organic silica. Organogenic inclusions are observed in the opal mass, represented mainly by the remains of spicules of sponges and diatom algae. Some diatom shells are well preserved, their cellular-net structure being visible. Thus, the studied opoka consists not only of minerals but also of biological components (Table 3).

Other primary components include calcite, quartz, and amorphous SiO_2. Aleuritic material is represented mainly by quartz grains (up to 15%) and glauconite grains (about 5%) of a bright green color. Relatively large (up to 0.5 mm) mica flakes are often present. The concentration of iron hydroxides is visible along the microcracks.

Table 3. Adsorption-structural characteristics of opoka

	Properties			
Sample	Average Density, g/cm^3	Specific Surface Area, m^2/g	Micropore Volume, cm^3/g	Macropore Volume, cm^3/g
Opoka	0.65-0.72	107-109	0.01-0.02	0.3-0.4

Table 4. Physicochemical composition of water from a mine well in the Akkurai deposit

No.	Physicochemical Properties of Water	Norm	Water Before Purification	Notes
1	Temperature	7-11°C	11°C	Measured under laboratory conditions at room temperature
2	Temperatures and color	No more than 20-30°C	30°C Greenish tint	Normal
3	Turbidity	No more than 1.5 mg/l	1.5 mg/l	Normal
4	Taste	Can be salty, bitter, sweet, and sour	Salty flavor	Salty flavor
5	Smells	No more than 2 points	3 points, noticeable odor or aftertaste that is easily detectable	Normal
6	pH	Within 6.0-9.0	pH = 6.8	Normal
7	Hardness	Should not exceed 7 (10) meq/l	17 meq/l	Water hardness is 10-15 meq/l above normal (hard water)
8	Chloride content	Threshold limit value is 300-350 mg/l	1,384.5 mg/l	Chloride content is 1,000 mg/l above the norm

The data indicate that the original natural sorbent has a sufficiently large specific surface area with the presence of micro- and macropores, making it suitable for the purification of water from the Akkurai deposit.

Before the purification process, the organoleptic and physicochemical properties of water samples were also examined. The results of water sample quality tests are presented in Table 4.

The analysis indicates that the assessed mine well groundwater does not meet the norm in hardness and chloride content. Water hardness is higher than the standard by 10-15 meq/l (the water is hard), and chloride content is 1,000 mg/l above the normal level.

Groundwater is a vital source of drinking water and a resource for agriculture and industry, and its physical and chemical properties are affected by any pollutants interacting with it. The presence of chloride in groundwater can be caused by a wide range of factors such as soil decomposition, saline geologic formations, salt spray deposition, the use of salt for road de-icing, the influence of sewage, and the intrusion of saline ocean water into fresh groundwater sources in coastal areas. In most cases, chloride is found in water in combination with potassium or calcium or as part of salt (sodium chloride).

A valuable method of chloride reduction in water is desalination, performed, among other options, using sorption. Of particular interest in various studies is using biosorbents to solve the problem of alkalinity and chloride removal from water, which applies to the variants of natural and thermally modified opoka used in our study.

The role of biosorbents is played by a wide range of naturally occurring substances capable of binding metal ions through physical or chemical binding, chelation, reduction, precipitation, and complexation. The findings of this study align with previous research that has emphasized the importance of chemical and functional groups in the ability of biosorbents to bind metal ions. For instance, the studies [17, 20] have shown that the presence of these groups is essential for the ion-binding capabilities of biosorbents. However, while those studies focused on a broad range of biosorbents, including those derived from plant, animal, and microbial biomass, as well as industrial and agricultural wastes, our research specifically highlights the effectiveness of opoka, a naturally occurring siliceous rock.

Biosorbents can be produced from any plant, animal, or microbial biomass and its derivatives or plant, industrial, and agricultural wastes [5, 10].

There are also factors affecting adsorption involving a biosorbent. Adsorption capacity is observed to decrease with increasing temperature. There are scientifically proven patterns of the pH of the medium affecting adsorption. Adsorption is impaired when pH decreases, although the retention capacity of the adsorbing surface improves, particularly in cases where pH increases from 7.0 to 7.5.

With increasing pressure, the degree of adsorption increases until the saturation level is reached. Once this point is reached, adsorption can no longer proceed no matter how high the pressure is.

A promising technique for increasing the sorption capacity is adsorbent activation. Through activation, the number of vacant sites on the adsorbent surface is increased by breaking the crystal into small pieces, heating it to a high temperature, grinding the solid clumps into powder, or using one of many other acceptable methods [16, 24].

The thermal modification of opoka at 400 and 800°C is associated with ensuring more efficient sorption.

Thus, the thermal modification of opoka samples conducted prior to purification changed the properties of the rock depending on the temperature (Table 5).

Table 5. Changes in the properties of opoka depending on thermal modification

Properties	Natural Opoka	Temperature, °C	
		400	800
Weight loss due to ignition, %	-	3.2	10.4
Density, g/cm^3	2.51	2.52	2.78
Bulk density, g/cm^3	1.32	1.22	0.89
Porosity, %	43.8	51.2	65.2

The thermal modification of opoka not only activated the sorption abilities of the raw material by removing moisture from its internal pores but also burned out the organics and all contaminants, changing its physical and chemical properties.

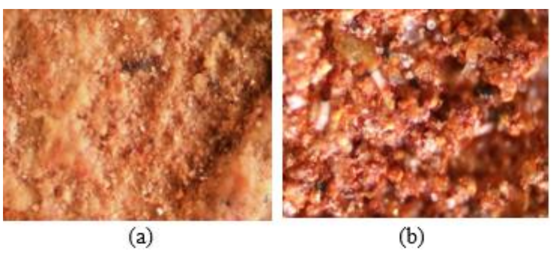


Figure 4. Macrostructures of thermally modified opoka, a) at 400°C, b) at 800°C (Levenhuk 320 series microscope, ×100 magnification)

The high-temperature treatment changed the color, while its bulk density decreased from 1.32 to 0.89 g/cm^3. The overall porosity of opoka grew proportionately to the temperature of thermal treatment: the porosity achieved with the thermal modification of opoka at 800°C was 65.2%. Given these changes, modified opoka is a promising industrial mineral and a material for purifying natural waters. Figure 4 shows the macrostructure of thermally modified opoka.

Opoka modified at 400°C presents pink particles comprised of amorphous quartz particulate sintered together by fine particles. There are no organic residues under the microscope, indicating a complete burnout. A similar picture can be observed with thermal modification at 800°C. In this variant, the color changes from pink to red. There is an increase in the porosity of the components, which is probably associated with a complete removal of chemically bound water from the sample.

The thermal modification also achieves partial sintering, allowing to strengthen the macrostructure of the rock, which ensures the required resistance of particles to water of up to 98%. The macro-structure strength of opoka increases by 35-40%, and its porosity grows by 12-15%.

The results of studies on the sorption and desalination of mineralized water using three variants of opoka are presented in Figure 5.

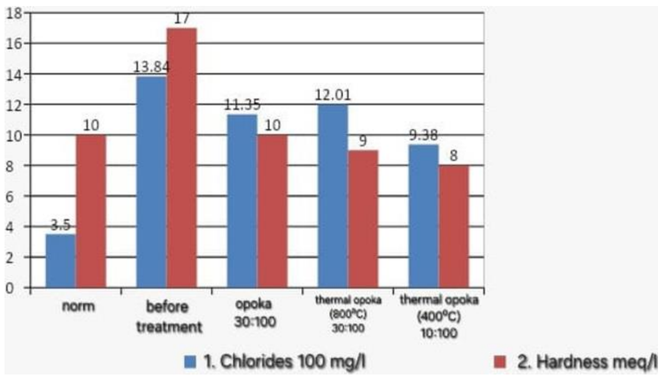


Figure 5. Results of studies on the sorption treatment and desalination of mineralized water using opoka

The sorption treatment of mineralized water with unmodified opoka (in its natural condition) resulted in a reduction of water hardness from 17 meq/l to 10 meq/l and chloride content from 13.84 to 11.35 mg/l.

Sorption with opoka subjected to thermal modification at 800°C also achieved a decrease in water hardness and chloride content (down to 9 meq/l and 12.01 mg/l). Notably, thermally modified opoka showed a more significant effect on hardness than on chloride content.

The greatest decline in the hardness and chloride content was observed in the variant using opoka modified at 400°C. The reduction in hardness reached 9 meq/l (17 to 8) and chloride content dropped by 4.46 mg/l (13.84 to 9.38).

Thus, water purification using biosorbents, namely natural and thermally modified opoka, proves highly effective. The application of opoka is consistent with scientific research on other biosorbents.

The findings of this study demonstrate that opoka, particularly when thermally modified at 400°C, is a highly effective sorbent for reducing water hardness and chloride content in mineralized groundwater.

The use of opoka as a low-cost and locally available sorbent can be readily integrated into existing water treatment systems in rural and remote areas. Implementing opoka-based filtration systems could improve water quality, thereby enhancing agricultural productivity and supporting the health of livestock.

Also, the development of guidelines and regulations to standardize the use of thermally modified opoka in water purification could help ensure consistent water quality across different regions. Additionally, the cost-effectiveness of opoka as a sorbent could lead to significant savings in water treatment, making it a viable option for large-scale deployment.

However, there are potential challenges to consider. The effectiveness of opoka may vary depending on the specific characteristics of the water being treated, such as the presence of other contaminants. Additionally, the long-term performance and maintenance of opoka-based filtration systems need to be evaluated to ensure their durability and reliability in different environmental conditions.

4. CONCLUSIONS

The research achieved the objectives set for the study of the possibilities of purifying mineralized water with opoka:

•The porous structure and chemical-mineralogical properties of opoka were studied with to use it as a sorbent for the purification and desalination of highly mineralized groundwater;

•The parameters of changes in the sorption properties of opoka were established using thermal modification 400 and 800°C. The best reduction in hardness and chloride content in mineralized water was achieved with using opoka thermally modified at 400°C.

The conducted studies allow us to recommend opoka from the Taskalinskoye field as a raw material for an effective sorbent for the desalination and purification of highly mineralized groundwater.

While this study demonstrates the effectiveness of opoka, particularly when thermally modified, in reducing water hardness and chloride content, further research is needed to explore its long-term performance in various environmental conditions and its scalability for widespread use. Future studies could focus on optimizing the thermal modification process, evaluating the cost-effectiveness of large-scale opoka-based filtration systems, and assessing the environmental impact of opoka extraction and use. Additionally, exploring the combination of opoka with other biosorbents could enhance its effectiveness in removing a broader range of contaminants.

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