https://doi.org/10.18321/ectj955

New Sorption Properties of Diatomaceous Earth for Water Desalination and Reducing Salt Stress of Plants

Zh. Alsar[1], B. Duskinova[2], Z. Insepov[1,3,4]*

[1]Nazarbayev University, 53 Kabanbay Batyr Ave., 010000, Nur-Sultan, Republic of Kazakhstan
[2]Everest Consulting, 6/1-Uly Dala Ave., off. 57, 010000 Nur-Sultan, Republic of Kazakhstan
[3]National Nuclear Research University (MEPhI), Kashirskoe hwy, 31, 115409, Moscow, Russian Federation
[4]Purdue University, 500 Central Drive, West, Lafayette, IN 47907, United States

Article info

Received:
20 October 2019

Received in revised form:
16 December 2019

Accepted:
27 February 2020

Keywords:
Diatomaceous earth
Deionization
Sorption
Desalination
Sodium chloride
Ion exchange
Salt stress of plants

Abstract

A new practical application of the unique sorption abilities of Diatomaceous Earth (DE) or diatomite, a widely accessible and promising natural mineral, has been studied. By analyzing aqueous extracts of natural diatomite, it was shown that DE probably contains various inorganic salts, which are released into the solution in the form of ions, such as Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, K^+ and, apparently, others. Diatomite was able to exchange these ions with the environment, exhibiting the properties of a natural ion exchanger. Studying the kinetics of ion release from diatomite showed that the ion desorption process continues for 4–5 h until the surrounding solution is saturated with ions, after which it is dynamically balanced by the sorption process. In order to significantly reduce the ionic content of diatomite, DE samples were processed in a technologically simple and environmentally friendly way. Thus, as a result of deionization, the content of ions released from diatomite significantly decreases. Deionized diatomite was applied to study the adsorption of sodium and chloride ions from aqueous solutions. The maximum adsorption was 50.2 mg/g, and the maximum degree of extraction, corresponding to the concentration range of 5–100 mg/l, was 53.9%. The observed effect was also applicable for increasing the resistance of plants to salt stress, improving the germination and growth of wheat samples. The developed method can be used in the manufacturing of filters for water desalination, both drinking and technological; in ecology; in agriculture to reduce salt stress of plants, as well as for the restoration of lands contaminated by salt.

1. Introduction

The main task of developing future energy-efficient technologies for water desalination and cleaning soil from pollutants is the search for new sorbent materials that do not require complex and expensive sample preparation on the one hand, and which are biocompatible and non-polluting, on the other hand. Natural sorbents, and diatomite in particular, meet the requirements of environmental friendliness and safety, are widely available, and much cheaper than synthetic sorbents, so they do not need to be regenerated.

Diatomaceous earth (DE) or diatomite is of significant interest among natural sorption materials.

This mineral has a regular structure consisting of siliceous micro shells of unicellular algae – diatoms, the main component of which is amorphous silica – opal (SiO_2-nH_2O), that has a large inner surface, contains up to 80–90% of voids, and is characterized by significant chemical inertness, refractoriness, low density, thermal and electrical conductivities and some other valuable properties [1–3]. Diatomite deposits are found in almost all parts of the World. However, it is especially true for Kazakhstan, which according to preliminary estimates, possesses the largest reserves of this valuable mineral raw material [4–6].

Regardless of its significant adsorption, hygroscopic and abrasive properties, diatomite is harmless to the human body, due to which it is used in filtering in the production of drinks, toothpastes, skincare products, and in medical preparations [7].

*Corresponding author. E-mail: zinsepov@purdue.edu

© 2020 Eurasian Chemico-Technological Journal.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Plausible sorption properties of diatomite, due to its extremely large surface to volume ratio; makes it possible to trap various organic substances. So, diatomite is used in the fight against harmful insects: dry diatomite is able to absorb oils and fats from the cuticle of the exoskeleton of the insect, causing the insects to dry out and die. Sharp abrasive edges of diatomite speed up this process [7].

Several scientific papers have shown the ability of diatomite to bind organic substances [8–10] and immobilize microorganisms [11].

Over the past decade, scientific publications have tended to study the adsorption of various substances and ions on natural and modified diatomite. The studies cover a wide range of issues, including carbon adsorption with the possibility of forming carbon nanotubes on a surface of diatomite [12], the extraction of arsenates by diatomite modified with iron [13], the binding of lead [14, 15], copper [16], chromium [17], cobalt [18], and uranium ions [19].

Numerous studies have observed that the addition of diatomite to the soil improves the physical properties of soil, such as aggregate stability, bulk density, soil moisture, soil compaction, penetration resistance, and mechanical stress [20, 21].

Diatomite can serve as a source of silicon needed by plants. Recent studies have shown that diatomite additives improve rice productivity and growth in contrasting soils of South India [22]. Kazakh scientists have also found that addition of different amounts of diatomite in the soil improved the degree of microtrophy of barley [23].

DE filters are simple to operate and are effective in removing cysts, algae, and asbestos from water. DE has been employed in many food and beverage applications for more than 70 years and was used specifically to filter potable water during WWII [24].

Despite the unique properties of diatomite, the extent of its use has not been exhausted to date. Specifically, the sorption properties of various substances (ions, organic molecules etc.) still require extensive studies.

Thus, in the literature there is practically no information on binding of sodium chloride by diatomite, which is one of the main components of sea water and saline soils. The ability of diatomite to adsorb sodium chloride opens up prospects for development of filters for water desalination, as well as in using diatomite in agriculture in order to reduce salt stress of plants and in the restoration of polluted lands.

Although there are numerous facts of using diatomite for cleaning water from different contaminants, it has not been systematically studied previously for an increase of its capacity as an ion exchanger.

To solve the above problems, a new way for expanding the ion-exchange capacity of diatomite has been developed in this work. It is as simple and affordable as washing out diatomite samples, thus removing the ions from it with clean water. In addition, a method was also proposed to quickly obtain information on the ion content in natural diatomite exposed to clean water. Ion chromatography with conductometric detection was also employed as an express method.

The aim of this work is to thoroughly study the potential of modifying of natural diatomite, an accessible natural mineral with good sorption properties, by expanding its sorption abilities and activating new sorption centers, application of the proposed method for the practical use of diatomite for water desalination and moderation of the plants' salt stress.

2. Materials and Methods

2.1. Source material

In 2015, the research team of Nazarbayev University [5, 25] evaluated diatomite deposits in one of the areas of the deposit in the Mugodzharsky district of the Aktobe region. The fieldwork has been carried out using satellite navigation while the obtained data were processed using the Garmin Base Camp program. The boundaries of the natural outcrops of diatomite were contoured on the "Zhalpak" square, the richest cluster of deposits of this rock. The thickness of the strata was established and the resources were estimated, which in category P amounted to at least two billion tons. By a well-known analogy, the authors called the diatomite deposits in the studied area – "Diatomite Valley". It was from this area that we took diatomite for this study.

2.2. Chemical composition of raw diatomite

The chemical composition of diatomite ore samples of the studied area was determined in [25] (Table 1).

It was shown that along with the main components (Table 1), various impurities are present in the samples in the form of montmorillonite, kaolinite, albite, and mica. The works of other Kazakh

Table 1
The composition of diatomite of «Zhalpak» square

Diatomite composition	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	TiO_2	CaO	MnO	P_2O_5	SO_3
Content, %	67.34	15.51	2.90	1.52	2.22	1.43	0.69	0.79	0.02	0.16	0.48

research groups show similar results in the composition of the Aktobe diatomite [26].

In this study, samples of natural diatomite from the Zhalpak area were used to study its sorption and ion-exchange properties.

2.3. Preparation of raw diatomite for experiments

Diatomaceous rock was crushed and sieved using Retsch laboratory sample preparation equipment. Diatomite pieces about 10–12 cm in size were first crushed using the TM 300 drum mill to a size of 20–50 mm, and then were subjected to a further grinding using the BB 250 jaw crusher till fineness of 4 mm. A finely dispersed fraction of the desired size was obtained by sieving through the AS 200 laboratory sieving machine, with pore diameter from 100 to 800 μ. Ion-exchange properties of diatomite were studied for a fraction with a dispersion of 800 μ.

2.4. Preparation of aqueous extracts of natural diatomite

To prepare aqueous extracts of natural diatomite certain weight samples were placed in conical flasks. Deionized water was poured on the samples in the ratio diatomite:water equal to 1:5. Samples with water were mixed and left to stand for 5 min [State standard 26423-85 Soil. Methods for determination of specific electric conductivity, pH and solid residue of water extract, 1986-01-01]. After that, a solution was taken over the precipitate for analysis of anions and cations.

2.5. Method of studying the kinetics of ion release from purified diatomite

Method of studying the kinetics of ion release from purified diatomite.

Crushed and sieved natural diatomite was first washed with flowing water and then with purified water and dried in air. Then 14 identical weighed portions of diatomite were prepared and placed in 14 identical flasks with deionized water. The ratio of diatomite:water in all flasks was kept equal to 1:5. The contents of all flasks were mixed and left for a certain time. The concentration of ions in the solutions of flasks was monitored over time during 13 h. The content of the first flask were aged for 5 min, the second – for 60 min (1 h), subsequent flasks – for 2, 3, 4, 5, 6, 7, 8, 9,10, 11, 12 and 13 h, respectively. After the lapse of each time instants, the solution above the precipitate in each flask was taken for analysis for the content of cations and anions.

2.6. Deionization of diatomite

For deionization, natural diatomite was first washed with flowing water and then with purified water and dried in air. Weighed portions of diatomite were placed in water purified from ions in a mass ratio of 1:10 and washing was carried out for 12 h. The solution with desorbed ions was replaced with fresh portions of water every hour. The first 15 min of each hour, the diatomite/water system was stirred using ultrasonic treatment as well. Diatomite deionized for 12 h was separated from the solution, dried in air, and then in an oven at a temperature of 105 °C to remove adsorption water.

2.7. Adsorption experiments

Weighed portions of the deionized diatomite were placed in aqueous solutions of sodium chloride of various concentrations in the ratio of sorbent/solution equal to 1:100 and kept for 4 h, after which the sorbent was separated from the solution. The solutions were then analyzed for sodium and chloride ions.

2.8. Analysis of ion content

The ion content in various solutions of diatomite was determined using the method of ion chromatography on the analytical ion-chromatographic system with conductometric detection Dionex ICS-6000. HPIC grade Standards and Reagents were used for analysis.

All the experiments were carried out at the temperature of 22 ± 1 °C.

2.9. Experiments on reducing the salt stress of plants

The effect of diatomite on salt stress was studied by growing wheat grains in the soil with different compositions. Before planting wheat grains were previously tested by treatment with a weak $KMnO_4$ solution. Samples with planted grains were placed for 24 h in a cold, dark room (+ 4 °C) to ensure hardening and uniform germination of seeds, after which the samples were placed in a climatic room with a lighting mode of 14/10 and a temperature of 22.5 °C. Plant growth was observed for 15 days.

Four types of wheat growing experiments were performed with combinations of salt and diatomite. In the first experiment, soil with a known mineral composition was irrigated with a solution of sodium chloride salt. The content of sodium and chloride ions in the solution was 7.5 mEq/l. In the second experiment the same soil with the addition of deionized diatomite in a mass ratio of sorbent:-soil equal to 1:100 and 1:1000 was also irrigated with the same solution of sodium chloride. The third experiment was carried out without addition of salt. In the control experiment, neither salt nor diatomite was added to the soil.

3. Results

3.1. The content of ions in natural diatomite

Diatomite is a sedimentary rock of organic origin. Due to its high hygroscopicity and porosity, it has shown the ability to capture and accumulate various ions from the surrounding water or gas environment. These ions are most likely adsorbed due to weak dispersion forces such as Van der Waals and therefore can easily be washed out with clean deionized water. Ion exchange of diatomite with the environment is also eased by the ability of diatomite to wash out foreign ions and molecules.

To develop the new sorption feature of diatomite as a natural ion exchanger, one should examine which ions can be absorbed by diatomite in its natural environment.

The proposed technology is based on the observation that when soaking natural diatomite in pure deionized water (obtaining an aqueous extract), ions are released into the solution. Implementation of this technology at a laboratory scale showed that chloride (Cl^-) and sulfate (SO_4^{2-}) ions, as well as sodium (Na^+), calcium (Ca^{2+}), and, in a smaller amount, magnesium (Mg^{2+}) and potassium (K^+) ions are present in aqueous extracts in significant amounts.

The experimental data on the averaged content of ions in natural diatomite obtained in this work using aqueous extract method are given in Table 2.

The data in Table 2 show that the average total content of anions (Cl^-, SO_4^{2-}) prevails over the average total content of cations (Na^+, Ca^{2+}, Mg^{2+}, K^+). Since the whole system should be electrically neutral, we suppose that other cations uncontrolled in these experiments can contribute to the total ion content. The pH of the aqueous extracts of natural diatomite obtained in this experiment varies between 4.46–4.55.

The data obtained show that natural diatomite, probably, contains various mineral salts, which, when dissolved in pure deionized water, pass into the solution in the form of ions. The slightly acidic reaction of aqueous extracts of natural diatomite shows that diatomite, apparently, contains chlorides and sulfates of various metals, both detected in this experiment and shown in Table 2, and those that were not controlled during this experiment (iron ions, aluminum ions, etc.). Study of the ion content in purified diatomite, as well as the kinetics of ion release from purified diatomite, will be aimed in our further research.

3.2. Kinetics of the release of ions from diatomite

In order to determine the possibility of washing out of ions from diatomite, it was interesting to study how ions are released over time. The kinetics of release and the amount of released ions will allow us to judge how diatomite can be activated and how much it is possible to free the adsorption centers on its surface. When diatomite is immersed in deionized water, obviously, water molecules diffuse into the pores of diatomite, where the dissolution of salts in water happens and then the release of dissolved salts into the solution should take place.

Table 2

The average content of adsorbed ions in the natural DE of the Zhalpak area

Ions in natural diatomite	Cl^-	SO_4^{2-}	Na^+	Ca^{2+}	Mg^{2+}	K^+
The content in the aqueous extract, mg/l	80–100	60–80	80–100	25–30	15–20	up to 10

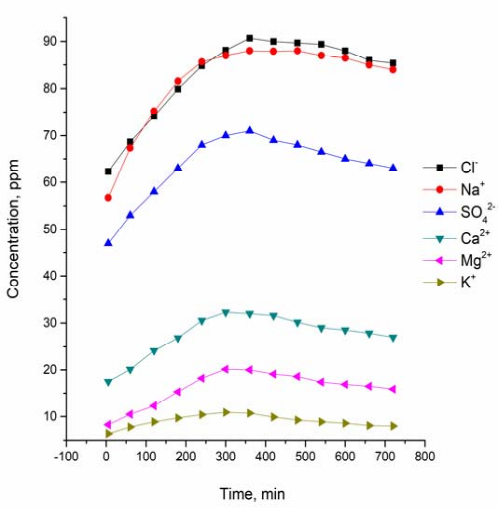

Fig. 1. Release of ions from diatomite.

Since this process takes time, kinetic curves should show how much time the most complete release of ions takes place. As these experimental data show, diatomite predominantly releases sodium and calcium cations as well as chloride and sulfate anions.

As our data indicates the concentration of ions in the diatomite solution increases during the first 4–5 h, as a result of desorption (release), reaches a certain maximum, and then starts to decrease (Fig. 1).

The results of the ion release experiments show that the ion desorption process proceeds until the surrounding solution is saturated with ions, after which desorption is dynamically balanced by the sorption process. By removing the desorption products, it is hoped that this procedure would deionize diatomite to a maximum, thereby increasing its sorption capacity and increase the attractiveness of its application as a sorbent. This can be achieved by a periodic renewing the solution saturated with desorbed ions with fresh portions of water.

3.3. Diatomite deionization

In previous experiments, diatomite showed an ability to exchange ions with the environment. This ability of diatomite can be used to develop a technologically simple way to increase its sorption properties with respect to ions. This method should be environmentally friendly and should not violate the initial structure of the sorbent. As such method, the authors proposed a deionization of diatomite.

Deionization in this case is the release of ions from diatomite during a washing out with purified water due to desorption processes caused by a significant weakening of the electrostatic forces acting on the ions, due to a high dielectric constant of water, $\varepsilon_0 = 81$. The periodic change of washing aqueous solution over diatomite, which resulted in the removal of desorption products, contributed to the release process and prevented sorption – the process reverse to desorption. The use of mechanical mixing made it possible to accelerate the desorption process without affecting the structure and properties of diatomite.

An operational analysis of the drained portions of water using ion chromatography showed that the content of released ions is constantly decreasing during the washing process. The Mg^{2+} and K^+ ions were not taken into account, due to their low concentration in the solution.

As shown in Fig. 2, the content of all the studied ions decreases within 12 h and reaches a minimum of 2.23 mg/l for Cl^- ions, 2.26 mg/l for Na^+, 1.18 mg/l for SO_4^{2-} and Ca^{2+} – 1.85 mg/l, which is about 30 times less than the initial value for sodium and chloride ions, more than 40 times for sulfates, and more than 10 times for calcium ions. The release of ions is accompanied by a change in the pH of the solution, as shown in Fig. 3.

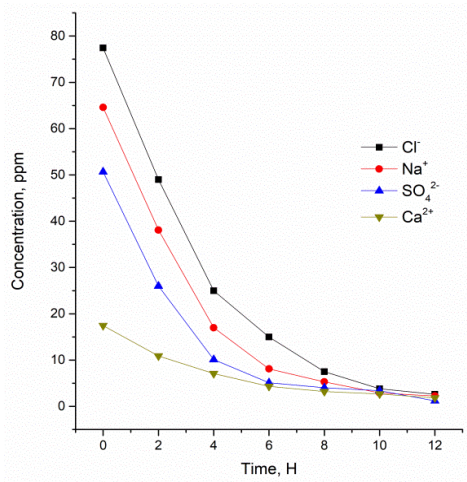

Fig. 2. Deionization of diatomite.

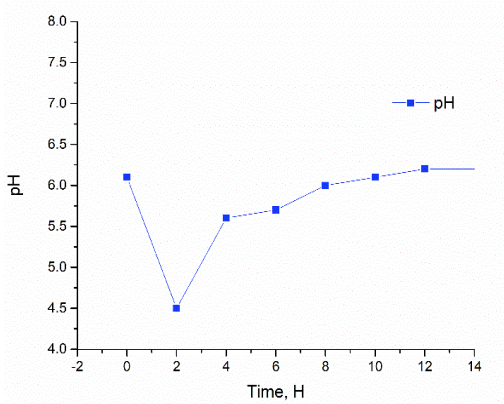

Fig. 3. Change in pH of a diatomite solution in the process of deionization.

In the first 2 h, the solution shows a slightly acidic medium with a pH value in the region of 4.5, apparently due to the release of a large amount of chlorides and sulfates, but in the next 10 h the reaction of the medium shifts to neutral and at the end of the process leaves 6.15, which is apparently due to the release of sodium, calcium and other cations along with chlorides and sulfates.

Diatomite deionized for 12 h was separated from the solution, dried in air, and then in an oven at a temperature of 105 °C to remove adsorption water.

As a result of the treatment described above, the porous sorbent diatomite did not change its structure, but significantly deionized and freed from adsorption water, as a result of which vacant centers for adsorption of new ions were released (activated), due to which deionized diatomite has a much larger sorption capacity compared to natural diatomite.

3.4. NaCl salt adsorption on deionized diatomite

To date, there is no unified theory that correctly describes all types of adsorption on different interfaces. In this work, when studying adsorption, the authors were guided by generally accepted approaches for describing the adsorption of ions from a solution on the surface of a solid adsorbent. For the practical application of the obtained sorbent for reducing the content of sodium chloride in aqueous solutions, the adsorption of NaCl on the surface of deionized diatomite was studied. The obtained NaCl adsorption isotherm, which is the total adsorption of Na^+ and Cl^- ions, is shown in Fig. 4a.

The appearance of the isotherm in Fig. 4a resembles the picture of localized adsorption occurring at the adsorption centers of the sorbent. With increasing concentration of a substance in a solution, the mass of adsorbed salt also increases. At concentrations <100 mg/l, the dependence increases proportionally, which apparently indicates the filling of the active sites of the sorbent and the formation of a monomolecular layer of the substance.

The calculation of the degree of salt extraction by deionized diatomite according to the formula R% = 100 (C/C_0) shows that in this range the degree of salt extraction is maximum and reaches 53.9%. In the concentration range 100–250 mg/l, the isotherm is gently sloping which corresponds to intermediate degrees of surface filling. This behavior can be described by the Freundlich equation. In this range, the degree of salt recovery is also quite high, up to 50%, although slightly lower than in the region of lower concentrations.

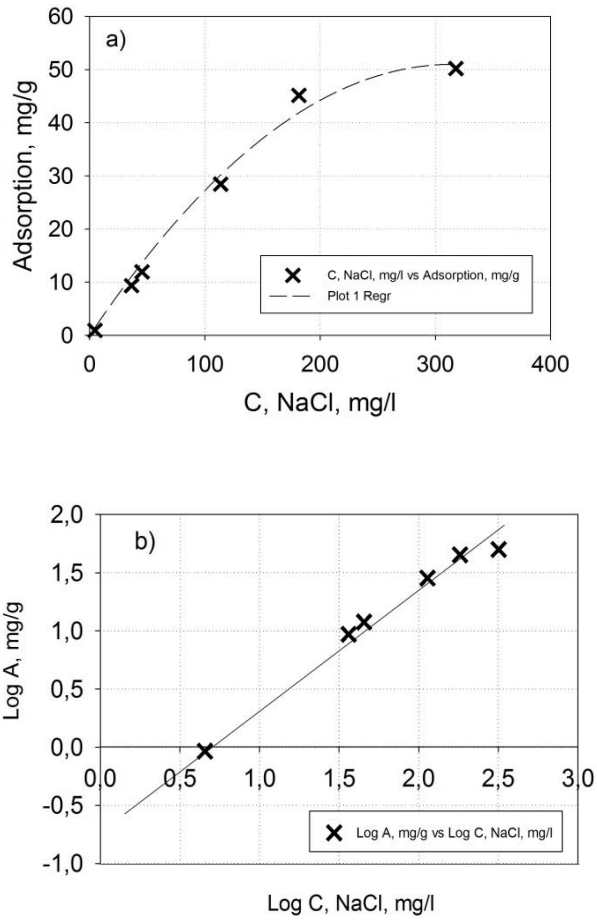

Fig. 4. Isotherm of NaCl adsorption on deionized diatomite; (a) is the equilibrium adsorption value (mg/g), C-equilibrium concentration (a) mg/l, (b) double-logarithmic (log-log) scale. The mass ratio of adsorbent/solution is 1/100; A concentration range of sodium chloride C_0 = 3–350 mg/l.

At higher concentrations adsorption centers are filled and adsorption reaches maximum under these experimental conditions, and the degree of extraction decreases.

Table 3 shows the parameters of the adsorption isotherm of sodium chloride by deionized diatomite, calculated according to the Langmuir and Freundlich models. The Langmuir model was described by the equation:

$$A = (A_{max} \cdot K_L\, C)/(1 + K_L\, C), \text{ [27]}$$

where A – equilibrium adsorption value (mg/g), C – equilibrium concentration (mg/l), K_L – empirical Langmuir constant in units of inverse concentration (l/mg), A_{max} – maximum adsorption value (mg/g).

Table 3
NaCl adsorption isotherm parameters

Langmuir model		Freundlich model		R_{max}, % (at C = 5–100 mg/l)	S, at P = 0.95
K_L, l/mg	A_{max}, mg/g	K_f, l/g	1/n		
1.2×10^{-3}	50.2	0.1819	0.94	53.9	4.0404

The empirical Freundlich model for adsorption on heterogeneous surfaces was described by the following equation:

$$A = K_f C^{1/n},^{*} \text{ [28]}$$

where K_f and 1/n – characteristic constants of the studied adsorption system, 1/n – characterizes the degree of adsorption. (*Some authors [19] mark the constant 1/n as n).

The calculation of the adsorption parameters (Table 3) shows that the obtained experimental isotherm of the studied sorption process is rather well described both by the Langmuir model, in the region of low concentrations of the adsorbed substance, and by the Freundlich equation, in the region of higher concentrations. The fact that the Freundlich constant (K_f), calculated from the logarithmic form of the isotherm (Fig. 4b), is larger than the Langmuir constant (K_L), indicates that during the adsorption of sodium chloride on the surface of deionized diatomite along with monomolecular adsorption more complex processes of interaction between active centers and ions of matter also occur, caused by the development and heterogeneity of the surface of the sorbent. The constant 1/n characterizes the intensity of the adsorption process. So, for 0.1 <1/n <0.5, adsorption is maximal, for 0.5 <1/n <1, the adsorption process proceeds quite easily, and for 1/n> 1 adsorption is difficult [9]. The 1/n value obtained in this work is 0.94, which indicates that the adsorption of both sodium and chlorine ions on diatomite proceeds quite easily.

The deionization, to which diatomite was subjected, allowed the release of additional active centers on the surface of the nanochannels, thereby activating diatomite to adsorb Na^+ and Cl^- ions. The maximum adsorption under these experimental conditions was 50.2 mg/g, and the maximum degree of extraction corresponding to the concentration range of 5–100 mg/l was 53.9%.

The parameters of the adsorption isotherm of sodium chloride on deionized diatomite and the standard deviation of the experimental results (S = 4.0404 with a confidence level of 95%) show that the adsorption process proceeds quite efficiently, which makes it possible to use the obtained sorbent to extract the sodium chloride salt from various solutions.

Thus, the positive results on the adsorption of sodium chloride by deionized diatomite facilitate the use of this method to reduce soil salinity.

3.5. Experiment to reduce salt stress in plants

Salinization of the soil is one of the extreme factors common in very large areas both in our country and around the world. According to the land management committee of the Republic of Kazakhstan (2007), saline soils, solonetzes and salt marshes cover 41% of the total land area in Kazakhstan [29]. The restoration of saline lands to agricultural land is one of the global urgent tasks. Salt tolerance is the ability of a plant under salinization conditions to carry out growth, development and reproduction with the least damage. The effect of deionized diatomite on salt tolerance, i.e. salt stress of wheat, was the aim of the study in this section.

The experimental results obtained in this work are shown in Fig. 5 and in Table 4.

The experiments on growing wheat samples under various conditions were performed in 10 replicates. The average error of the experimental results did not exceed 13%.

As can be seen from Fig. 5, deionized diatomite reduces the salt stress of plants. Samples in salt soil without sorbent additives (bottom row, samples 7, 8, 9) show significantly lower growth rates than samples under salt stress, but with sorbent additives. These wheat sprouts under salt stress conditions without sorbent additives not only lagged in growth but also turned out to be thinner and paler. At the same time, the effect of the sorbent is observed both at a mass ratio to the soil of 1:100, and at a much lower ratio – 1:1000. In control experiments, the addition of a sorbent to the initial soil without salt also clearly contributes to the improvement of plant growth and an increase in their biomass. The effect of sorbent additives on plant growth rates and germination data under salt stress conditions found in this work are shown in Table 4.

Table 4
The effect of additives of deionized diatomite in the soil on the germination and growth of plants under conditions of salt stress

Soil sample composition	Soil+NaCl	Soil+NaCl+DEd	Soil w/o salt + DEd	Control soil
Germination of wheat seeds, %	43	90	93	93
The average length of wheat sprouts, mm:				
Day 5	91	115	131	128
Day 10	176	217	245	241
Day 15	250	319	347	342
Total growth, mm	159	204	216	214
The mineral composition of the initial soil, mEq/l	-	-	-	Na^+ 0.004 Cl^- 0.002 NO_3^- 0.07 PO_4^{3-} 0.02 Ca^{2+} 0.09 Mg^{2+} 0.01

DEd – deionized DE; Control soil – initial soil; The ratio of sorbent (DEd)/soil = 1/100

As can be seen from the data given in Table 4, the highest percentage of seed germination observed in the control soil and the control soil with the sorbent. In both types of experiments, this value was 93%. In soil with deionized diatomite under salt stress, this indicator is lower and amounts to 90%. Under conditions of salt stress and without sorbent, the germination rate of wheat seeds is the smallest and equal to 43%. The effect of additives of deionized diatomite also affects the length of wheat sprouts. In all four types of experiments, sprouts show positive growth dynamics, however, the growth rate is different in each case. The maximum total growth of sprouts for 15 days is observed in the control soil and the soil with diatomite. Moreover, in the soil with diatomite, the final length of sprouts is maximal. The average length of wheat sprouts in saline soil without sorbent was almost 1.3 times less than in saline soil with deionized diatomite, and more than 1.3 times less than in soil with the sorbent and control soil.

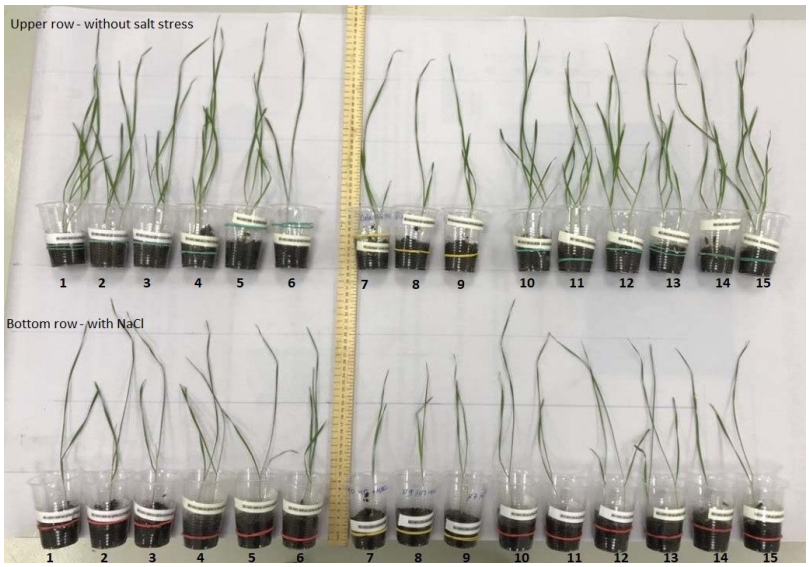

Fig. 5. The effect of deionized DE on reducing salt stress of plants. The bottom row – samples grown in soil with the addition of NaCl, from left to right: Samples 1-6 – Ded:soil ratio 1:100; Samples 7-9 – soil without DEd; samples 10-15 – the ratio DEd:soil 1:1000. The upper row – samples grown without salt stress, from left to right: Samples 1-6 – Ded:soil ratio 1:100; samples 7-9 – soil without DEd; Samples 10-15 – the ratio DEd:soil 1:1000; (Here DEd means DE deionized).

4. Conclusions

Deionized DE shows good results in the adsorption of sodium chloride with a maximum degree of extraction equal to 53.9% in the range of concentrations of 5–100 mg/l and 50% in the range of higher concentrations. The maximum of adsorption under the experimental conditions was 50.2 mg/g. Calculation of the adsorption isotherm according to the Freundlich equation shows that the sorption process is more complicated than just a simple monomolecular Langmuir adsorption.

When added to salt soil, deionized DE also exhibits a clear effect of reducing the salt stress of plants, allowing plants to show germination and growth rates comparable to samples grown in the absence of salt stress.

Acknowledgments

This work was in part funded by the "World Science Stars" program of Nazarbayev University.

References

[1]. H.E. Bakr, *Asian Journal of Materials Science* 2 (2010) 121–136. DOI: 10.3923/ajmskr.2010.121.136

[2]. V.A. Zhuzhikov. Filtration: Theory and practice of suspension separation. Chemistry, Moscow, 1980, 400 p.

[3]. T.A. Malinovskaya, I.A. Kobrinsky, O.S. Kirsanov, V.V. Reinfart. Suspension separation in the chemical industry. Chemistry, Moscow, 1983. 264 p.

[4]. R.D. Crangle, Jr., Mineral commodity summaries 2013: U.S. Geological Survey (2013) 198 p.

[5]. Z.A. Insepov, K.Sh. Shunkeyev, V.V. Yurish, M. Grinberg, S.Y. Maksimova, Z.K. Aimaganbetova, A.A. Temirbayeva, *Vestnik KazNRTU* [Bull. KazNRTU] 2 (2016) 215–221.

[6]. T.Ya. Dacko, V.I. Zelentsov, E.E. Dvornikova. *Elektronnaya obrabotka materialov* [Electronic Material Processing] 47 (2011) 59–68 (in Russ).

[7]. T.R. Bunch, C. Bond, K. Buhl, D. Stone, 2013. Diatomaceous Earth General Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services. http://npic.orst.edu/factsheets/degen.html

[8]. H. Nefzi, L.L. El Atrache, *J. Mater. Environ. Sci.* 9 (2018) 1614–1621.

[9]. L. Tian, J. Zhang, H. Shi, N. Li, Q. Ping, *J. Disper. Sci. Technol.* 37 (2016) 1059–1066. DOI: 10.1080/01932691.2015.1080610

[10]. O. Demirbas, M.H. Calimli, E. Kuyuldar, M.H. Alma, M.S. Nas, F. Sen, *BioNanoSci.* 9 (2019) 474–482. DOI: 10.1007/s12668-019-00615-1

[11]. H. Chu, Y. Zhang, B. Dong, X. Zhou, D. Cao, Zh. Qiang, Zh. Yu, H. Wang, *Desalination and Water Treatment* 40 (2012) 84–91. DOI: 10.5004/dwt.2012.2602

[12]. E.M. Duraia, M. Burkitbaev, H. Mohamedbakr, Z. Mansurov, S. Tokmoldin, *Vacuum* 84 (2009) 464–468. DOI: 10.1016/j.vacuum.2009.09.012

[13]. M.L. Pantoja, H. Jones, H. Garelick, H.G. Mohamedbakr, M. Burkitbayev, *Environ. Sci. Pollut. Res.* 21 (2014) 495–506. DOI: 10.1007/s11356-013-1891-7

[14]. H. Mohamedbakr, M. Burkitbaev, *Oecologia Aegyptiaca* 1 (2008) 21–29.

[15]. G. Sheng, S. Wang, J. Hu, Y. Lu, J. Li, Y. Dong, X. Wang, *Colloid. Surface. A* 339 (2009) 159–166. DOI: 10.1016/j.colsurfa.2009.02.016

[16]. K.B. Korzhynbayeva, S.M. Tazhibayeva, A.B. Orazymbetova, K.B. Musabekov, M.M. Burkitbayev, A.A. Turgynbayeva, *Vestnik KazNU. Serija himicheskaja* [Chem. Bull. Kaz. Nat. Univ.] 2 (2011) 47–51.

[17]. P. Yuan, D. Liu, M. Fan, D. Yang, R. Zhu, F. Ge, J. Zhu, H. He, *J. Hazard. Mater.* 173 (2010) 614–621. DOI: 10.1016/j.jhazmat.2009.08.129

[18]. O. Hernandez-Ramırez, P.I. Hill, D.J. Doocey, S.M. Holmes, *J. Mater. Chem.* 17 (2007) 1804–1808. DOI: 10.1039/B700048K

[19]. M. Sprynskyy, T. Kowalkowski, H. Tutu, E.M. Cukrowska, B. Buszewski, *Colloid. Surface. A* 465 (2015) 159–167. DOI: 10.1016/j.colsurfa.2014.10.042

[20]. E.L. Aksakal, I. Angin, T. Öztaş, *Catena* 88 (2012) 1–5. DOI: 10.1016/j.catena.2011.08.004

[21]. E.L. Aksakal, I. Angin, T. Öztaş, *Catena* 101 (2013) 157–163. DOI: 10.1016/j.catena.2012.09.001

[22]. K. Sandhya, N. B. Prakash, J. D. Meunier, *J. Soil Sci. Plant Nut.* 18 (2018) 344–360.

[23]. K.K. Boguspaev, D.G. Faleev, Zh.Zh. Myrzagaliev, S.K. Nayekova, K.M. Aubakirova, M.T. Myrzabaeva, Z.A. Insepov, Z. Alikulov, Zh.Sh. Urgaliyev, Sh.E. Arystanova, *Vestnik ENU im. L. N. Gumileva. Serija Biologicheskie nauki* [Bull. ENU. Ser. Biol. Sci.] 4 (2018) 26–32.

[24]. A National Drinking Water Clearinghouse Fact Sheet, Tech Brief, 2001.

[25]. Report on research work, state registration number 0115RK02472, Nazarbayev University, 2015.

[26]. H. Mohamedbakr, M. Burkitbayev, *The Open Mineralogy Journal* 3 (2009) 12–16.

[27]. Irving Langmuir. Adsorption of gases on glass, mica and platinum, 1918.

[28]. H. Freundlih, *Trans. Faraday Soc.* 28 (1932) 195–201. DOI: 10.1039/tf9322800195

[29]. G.T. Issanova, J. Abuduwaili, Zh.U. Mamutov, A.A. Kaldybaev, G.A. Saparov, T.A. Bazarbaeva, *Arid Ecosystems* 7 (2017) 243–250. DOI: 10.1134/S2079096117040035